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Research Article

Determinants of Caregiver Awareness and Uptake of the R21 Malaria Vaccine Among Under Five Children in Aweil South and West Counties, Northern Bahr el-Ghazal, South Sudan

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Abstract

Introduction: *Malaria is one of the leading causes of morbidity and mortality among children under five in South Sudan. In 2024, the South Sudan Ministry of Health introduced the R21/Matrix-M malaria vaccine as part of an integrated malaria control strategy. This study examines caregivers' awareness of the malaria vaccine, vaccine uptake among eligible children, and their associated determinants.*

Methods: *This is a secondary analysis of data collected during a routine monitoring survey to assess seasonal malaria chemoprevention (SMC) coverage in Aweil West and Aweil South counties, South Sudan. The survey was conducted in November 2024, five months after the vaccine rollout. Multistage random sampling was utilized to select 1,500 child-caregiver pairs across 75 survey clusters: 40 in Aweil West and 35 in Aweil South. All 1,500 participants were considered in the analysis for assessing level of awareness and associated factors, but only 533 children who met the malaria vaccine age eligibility criteria at rollout – aged between 5 and 23 months at the time of the survey – were included in the analysis for malaria vaccine coverage and factors affecting its uptake. The data were collected using a structured questionnaire using SurveyCTO. Logistic regression was used to determine factors associated with vaccine awareness and uptake, with a level of significance of $\alpha=0.05$.*

Findings: *Only 15.9% (95% CI: 14.1-17.9) of caregivers had heard of the malaria vaccine, with awareness considerably higher in Aweil South (18.4%, 95% CI: 19.7-26.2) than in Aweil West (7.6%, 95% CI: 7.9-12.1) ($p<0.001$). Awareness was higher among caregivers with higher education compared to those with no education (aOR = 2.01 ($p < 0.05$), 3.44 ($p < 0.05$), and ($p < 0.05$) for primary, secondary, and tertiary education levels, respectively). Coverage of the first dose of malaria vaccine among eligible children was 9.0%, with higher rates in Aweil South (13.9%) than Aweil West (4.9%) ($p < 0.001$). Coverage was significantly associated with caregiver education, agricultural employment, nomadic lifestyle, and the child's age group.*

Conclusion: *The study revealed low levels of malaria vaccine awareness and uptake in both counties. However, there were notable disparities in both outcomes influenced by location, caregiver demographics, and the child's age. Strengthening vaccination messaging and social and behaviour change efforts, particularly targeting key sociodemographic drivers, may improve knowledge of malaria vaccines and vaccine uptake.*

Keywords: *Malaria vaccination, R21/Matrix-M malaria vaccine, Seasonal Malaria Chemoprevention*

1. Introduction

Malaria continues to be a leading cause of illness and death among children under five in sub-Saharan Africa. In South Sudan alone, the Ministry of Health reported approximately 2.8 million malaria cases and 6,680 deaths in 2022, an average of 7,630 cases and 18 deaths per day, making it one of the highestburden countries globally [1,2]. According to DHIS2 data, malaria cases reported were 3.8 million in 2024. The country's weak health system, violence, displacement, and logistical challenges all complicate effective malaria control [3]. Until the recent rollout of the R21 malaria vaccine, malaria prevention in South Sudan primarily relied on indoor residual spraying, seasonal malaria chemoprevention (SMC), a combination of sulphadoxine-pyrimethamine with amodiaquine (SPAQ), insecticide-treated nets, and other behavioural methods. The malaria vaccine was introduced to reduce malaria-related deaths, especially among children under five and complement existing interventions [4]. Immunization campaigns have successfully reduced child morbidity and mortality from a range of infectious diseases [5]. Until recently, vaccines for malaria (not just R21) had been challenging to develop. However, two vaccines, RTS, S and R21, have been approved by WHO in 2021 and 2023, respectively for preventing malaria in children [6]. In July 2024, the government of South Sudan, in partnership with WHO, UNICEF, and Gavi, launched a nationwide rollout of the R21/Matrix-M malaria vaccine to supplement existing preventive strategies [6]. The rollout targeted 265,897 children in, in 28 counties across six states - Central, Equatoria, Eastern Equatoria, Jonglei, Northern Bahr el Ghazal, Western Bahr el Ghazal, and Warrap [3]. The states were identified as having the highest cases of malaria and, therefore, a broader strategy to reduce malaria-related illnesses and deaths in the country. Over 645,000 vaccine doses were allocated for the initial phase. With the help of John Snow Inc (JSI), 1,934 health workers, including 1,102 vaccinationists and 551 social mobilizers, were trained.

In South Sudan, the R21/Matrix-M vaccine is administered in four doses: the first at around five months of age, followed by two monthly doses and a fourth at 18 months. In high-risk areas, a fifth booster dose may be given after one year [7]. WHO recommends vaccination schedules be adapted based on age, seasonality, and transmission intensity [8]. The vaccination targets children aged 6 to 18 months, as this age group is particularly vulnerable to Complications from malaria or severe forms of the disease [9]. The success of vaccination campaigns, especially in remote or fragile settings, depends heavily on community awareness, trust, accessibility, and logistical efficiency [10]. Previous studies from subSaharan Africa suggest that caregiver awareness, trust in health workers, and perceived benefits of vaccination significantly influence uptake [12,13]. However, South Sudan's vaccination efforts are frequently hindered by poor infrastructure, a limited healthcare workforce, high operational costs, and weak data systems [11]. Successful vaccination campaigns rely on awareness, trust, and accessibility. In South Sudan, however, these pillars are challenged by a history of conflict, vaccine hesitancy, and systemic weaknesses in the health system [12]. These factors may significantly influence awareness, uptake, and coverage of new vaccines. While substantial information exists on the challenges surrounding mosquito nets and seasonal malaria chemoprevention (SMC), little is known about the malaria vaccine, which was only recently added to South Sudan's childhood immunization programme in 2024. Given its recent introduction, there is a dearth of evidence on the factors influencing malaria vaccine uptake in the country. Therefore, we conducted a study to assess caregivers' awareness of the malaria vaccine, determine vaccination coverage among eligible children, and identify key determinants affecting awareness and uptake in Aweil, a rural high-burden area.

2. Methods

2.1. R21 Malaria Vaccine Implementation Approach

The rollout of the R21 malaria vaccine in Aweil South and Aweil West counties followed a phased, multisectoral implementation strategy, aligned with national malaria control priorities and adapted to the local context of Northern Bahr el Ghazal State. These two counties were among the six high-burden areas selected for the initial phase of the vaccine introduction in 2024, based on malaria prevalence, population vulnerability, and readiness of local health systems. Other targeted states were in Central Equatoria, Eastern Equatoria, Jonglei, Warrap, and Western Bahr el Ghazal. The strategy emphasized strengthening health systems, enhancing cold chain infrastructure, and training over 1,900 health workers, including vaccinators and social mobilizers. Community engagement was central to the rollout, with targeted awareness campaigns and interpersonal communication designed to increase vaccine uptake and reduce dropout rates. Vaccines were offered at static health facilities, which could have affected access. Despite initial community eagerness, coverage and other challenges emerged. These gaps were attributed to systemic bottlenecks, funding shortfalls, and environmental disruptions such as flooding and displacement. Implementation of the malaria vaccine campaign highlighted the need for resilient health systems, sustained funding, and

adaptive strategies to ensure equitable access and long-term impact. This locally adapted approach ensured that the vaccine rollout in Aweil South and Aweil West was both technically sound and socially responsive, contributing to improved malaria prevention outcomes among children under five in these high-risk communities.

2.2. Study Design and Setting

This study is a secondary analysis of data collected through a crosssectional household survey conducted to assess Seasonal Malaria Chemoprevention (SMC) coverage and quality, as well as awareness and uptake of the R21 malaria vaccine. The survey involved structured interviews with caregivers of 1,500 children aged 3 to 59 months, carried out between 12 November and 1 December 2024 - approximately five months after the R21 vaccine rollout in the study area. The study was conducted in Aweil South and Aweil West, two predominantly rural counties within Northern Bahr el Ghazal State, located in the northwestern region of South Sudan. These counties were selected due to their inclusion in both the 2024 SMC campaign and the initial rollout of the R21 malaria vaccine targeting children under five years of age.

Aweil West County had an estimated population of 236,402, while Aweil South County had approximately 104,385 residents. Approximately 19% of the population is under the age of five, underscoring the relevance of these counties for malaria prevention interventions [14]. In addition to evaluating coverage, the analysis explored key determinants of vaccine uptake, including caregiver awareness, access to vaccination services, and perceived benefits of the R21 vaccine. The findings aim to inform future strategies for integrated malaria prevention in similar rural settings.

2.3. Study Variables

The primary outcome variables in this study were caregiver awareness and malaria vaccine uptake among children under five years. Awareness was defined as the caregiver's knowledge of the vaccine's availability and the eligibility criteria for vaccination. Caregivers were asked whether they were aware of the malaria vaccine since its introduction in July 2024. Uptake was defined as a child having received at least one dose of the malaria vaccine. Caregivers were asked to report whether their child had been vaccinated and, if so, how many doses had been received. Where available, vaccination cards were used to verify this information. Independent variables in the study focused on both caregiver-level and child-level characteristics. Caregiver-level variables included sociodemographic factors that may influence awareness and uptake, such as age, educational level, occupation, engagement in nomadic practices, duration of residence in the area, and awareness and uptake of other malaria prevention interventions. Child-level variables included age and sex, history of fever in the month preceding data collection (used as a proxy for recent malaria exposure), and possession of a child health card. Although data related to Seasonal Malaria Chemoprevention (SMC) were collected, these were analysed primarily to explore potential associations with malaria vaccine uptake, given the concurrent implementation of both interventions in the study counties. Additionally, the proximity of the caregiver's household to the nearest health facility was considered a key health system factor that could influence access to malaria vaccination services.

2.4. Sample Size Calculation

This secondary analysis utilized data originally collected through a crosssectional household survey conducted in Aweil South and Aweil West counties. The survey employed a multi-stage cluster sampling technique to ensure representativeness of the target population - caregivers of children aged 3 to 59 months who were eligible for SMC and the R21 malaria vaccine [15]. Cochran's sample size formula was used and this adjusted for design effect and anticipated non-response. While the broader SMC survey reached a total of 1,500 children aged 3 to 59 months, only 533 children were eligible and considered for the vaccination coverage assessment. This subsample is statistically sufficient to yield reliable estimates of caregiver awareness and vaccine coverage. The age-specific targeting and the timing of the survey conducted five months after the vaccine rollout enhance the relevance and accuracy of the findings. Moreover, the sample size allows for meaningful disaggregation by age group, geographic location, and other key variables, thereby enabling a nuanced understanding of the vaccine campaign's reach, equity, and impact. These methodological strengths support confident conclusions and provide a solid foundation for programmatic decision-making and future planning. The inclusion criteria were based on the MR21 implementation protocol used in South Sudan, which specified that children eligible for initial enrolment had to be between 5 and 23 months old at the time of the vaccine rollout [28].

2.5. Dataset Description and Data Extraction

This secondary analysis utilized data from a crosssectional household survey conducted between 12 November and 1 December 2024 in Aweil South and Aweil West counties, Northern Bahr el Ghazal State, South Sudan. The dataset was collected to assess Seasonal Malaria Chemoprevention (SMC) coverage and quality, as well as R21 malaria vaccine awareness and coverage. The dataset comprised structured responses from 1,500 caregivers of children aged 3 to 59 months, collected using digital tools (Survey CTO) during household interviews. The survey included variables on sociodemographic characteristics, SMC participation, malaria vaccine awareness, vaccine uptake, and verification of vaccination status through child health cards. For this analysis, a subset of the original dataset was extracted to focus specifically on R21 malaria vaccine coverage. The following inclusion criteria were applied: Children aged 5 to 23 months at the time of the vaccine rollout, in accordance with the R21 implementation protocol in South Sudan; availability of caregiver interview data and vaccination card verification; and residence in either Aweil South or Aweil West counties. Children who did not meet the age eligibility criteria or whose vaccination status could not be verified were excluded from the vaccine coverage analysis.

2.6. Final Analytical Sample

After applying the inclusion criteria, a total of 533 children were retained for analysis. This subsample was deemed statistically sufficient to generate reliable estimates of caregiver awareness, vaccine uptake, and dose completion, and allowed for disaggregation by age group, geographic location, and other key variables. This rigorous data extraction process ensured that the analysis was both methodologically sound and aligned with programmatic objectives, providing actionable insights for malaria vaccine implementation and planning.

2.7. Statistical analysis

Data were initially exported and cleaned in Microsoft Excel 365, where basic data validation and imputation were applied to address missing values. The cleaned dataset was then imported into Stata version 14 for statistical analysis. For descriptive analysis, summary statistics were computed for all relevant variables. Categorical variables were summarized using frequencies and percentages. The prevalence of malaria vaccine awareness and vaccination coverage per dose were presented as percentages with corresponding 95% confidence intervals (CIs). Inferential analysis was done to assess factors associated with vaccine uptake, a logistic regression model was initially employed to estimate the influence of independent variables on the binary outcome: whether a child had received at least one dose of the R21 malaria vaccine. Given the hierarchical structure of the data resulting from cluster sampling, a multilevel logistic regression model (mixed effects) was used to account for intra-cluster correlation. The model included random intercepts at both the county and cluster levels. Fixed effects were estimated for all individual-level covariates. A multivariable logistic regression model was subsequently fitted, including only variables with a pvalue ≤ 0.2 from bivariate analysis to adjust for potential confounding. Crude and adjusted odds ratios (ORs) were reported, with statistical significance set at $p < 0.05$. The model is therefore specified as follows: Let Y be the binary Yijk: Binary outcome for individual i in cluster j and county k, where Yijk=1 if the caregiver is aware of the malaria vaccine, 0 otherwise, or the child received at least one dose of malaria vaccine, 0 otherwise. Xijk: Vector of individual-level covariates (e.g., gender, age, education, etc.). uk: Random effect at the county level (county-specific intercept). vjk: Random effect at the cluster level within county k (cluster-specific intercept). εijk: Individual-level error.

- β_0: Fixed intercept
- β: Vector of fixed-effect coefficients
- u_k N(0, σ2u): Random intercept for county k
- v_{jk} N(0,σ2v): Random intercept for cluster j within county k

The model assumes that random effects uk and vjk are independent of each other and of the individual-level covariates. To assess the validity and robustness of the multilevel logistic regression model a Goodness-of-Fit was evaluated using Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) to compare nested models and assess model parsimony and Likelihood Ratio Tests (LRTs) to determine the significance of random effects and improvements over simpler models. Multicollinearity was assessed by reviewing correlation matrices to identify highly correlated predictors between malaria vaccine uptake and caregiver characteristics.

3. Results

Characteristics of the caregivers: A total of 1,500 caregivers were interviewed, 800 in Aweil West and 700 in Aweil South. Most of the caregivers are female (83.1%), are engaged in agricultural work (65.5%), have no formal education (69.6%), and are aged 20-39 years (72.2%). Caregivers who practiced seasonal nomadism were 33.3%. Nearly all (95.9%) of the households were residents in the community since July 2024, when the malaria vaccination campaign started. Almost all (94.4%) of the caregivers were also the household heads. Child characteristics: Most children (59.9%) were in the 12-36-month age group. There were more female children (53.3%) than males (46.7%). Table 1 presents the characteristics of the caregivers and the children.

Characteristic		n	%	95% CI
Occupation of caregiver	Not employed	344	22.9	20.8-25.1
	Agriculture (paid/unpaid)	983	65.5	63.1-67.9
	Unskilled manual work (unpaid/paid)	100	6.7	5.5-8.0
	Skilled manual work (e.g., builder, electrician)	14	0.9	0.5-1.6
	Sales and services work (e.g., shopkeeper)	35	2.3	1.6-3.2
	Clerical, technical, professional, or managerial	24	1.6	1.0-2.3
Level of education of the caregiver	None	1044	69.6	67.2-71.9
	Primary school	363	24.2	22.1-26.5
	Secondary school	88	5.9	4.7-7.2
	Higher education (post-secondary, including vocational college, teacher training college, university, etc.)	5	0.3	0.1-0.8

Child's gender	Male	702	46.8	44.2-49.4
	Female	798	53.2	50.6-55.7
Gender of primary caregiver	Male	253	16.9	15.1-18.9
	Female	1247	83.1	81.1-85.0
Age of caregiver	Under 20 years	196	13.1	11.4-14.9
	20-29 years	580	38.7	36.2-41.1
	30-39 years	503	33.5	31.1-36.0
	40-49 years	145	9.7	8.2-11.3
	50-59 years	62	4.1	3.2-5.3
	60 or more years	14	0.9	0.5-1.6
Seasonal nomadism	Yes	499	33.3	30.9-35.7
	No	1,001	66.7	64.3-69.1
The household has been in this location since 1st July 2024	Yes	1,439	95.9	94.8-96.9
	No	61	4.1	3.1-5.2
The caregiver is the household head	Yes	1,241	94.4	93.0-95.6
	No	74	5.6	4.4-7.0

Table 1: Background Characteristics of Children and Caregivers, Aweil West and Aweil South, Northern Bahr el Ghazal, 2025

Awareness about Malaria Vaccines

Among 1,500 caregivers, 239 (15.9%, 95% CI: 14.1-17.9%) reported being aware of malaria vaccinations. There was a significant difference between Aweil South and Aweil West in the percentage of informed caregivers, 22.9% (160/700, 95% CI: 19.7-26.2) vs 9.9% (79/800, 95% CI: 7.9-12.1).

SMC drug characteristics	Response	Aweil West (n=800) f	(%)	95% CI	Aweil South (n=700) f	(%)	95% CI	Overall (N=1500) F	(%)	95% CI	χ2 (p-values)
Heard about Malaria vaccination	Yes	79	9.9	7.9-12.1	160	22.9	19.7-26.2	239	15.9	14.1-17.9	46.974
	No	721	90.1	87.8-92.1	540	77.1	73.8-80.2	1261	84.1	82.1-85.9	(0.000)

Table 2: Proportions of Households with Children Who Had Heard about and Received Malaria Vaccines

3.1. Factors Associated with CAREGIVERS' Awareness about Malaria Vaccination

The mixed-effects logistic regression model presented in Table 3 was used to assess the factors associated with caregivers' awareness of malaria vaccination, accounting for the hierarchical structure of the data resulting from the cluster sampling design. The model included random intercepts at both the county (LGA) and cluster levels to control for intra-class correlation and unobserved heterogeneity at these levels. However, it is important to note that a multivariable mixed-effects logistic regression model could not be run. This is because, in the bivariate analysis, only one variable, the education level of the caregiver, had a p-value less than or equal to 0.2, which was the predefined threshold for inclusion in the multivariable model. As such, the results presented are from unadjusted mixed-effects logistic regression models. The findings indicate that caregiver gender was not significantly associated with awareness of the malaria vaccine. Although male caregivers had slightly higher odds (OR = 1.288) of being aware compared to females, the association was not statistically significant (p = 0.342) at the bivariate level. Similarly, age did not show a significant influence on awareness; none of the age categories from 20 to 59 years differed meaningfully in awareness compared to caregivers under 20 years, with all p-. Caregivers with primary, secondary, or higher education were significantly more likely to know about the malaria vaccine. Compared with those without education, the odds of awareness increase with increasing education (uOR=1.65 (p=0.027) for primary school, 3.22 for secondary education, and 11.29 for tertiary education level).

The association remained significantly higher after adjusting for other variables (aOR = 2.01 (p= 0.008), 3.44 (p= 0.003), 21.18 (p=0.036)), suggesting that vaccination awareness is associated with higher education levels. However, the findings for higher education are affected by the small sample in the specific subgroup,) leading to a wider confidence interval. These findings emphasize the importance of education as a driver of health awareness, indicating that improving literacy and access to formal education may contribute significantly to increasing public understanding of the malaria vaccine. Other factors, including occupation, distance to the health facility, household headship status, nomadism, and recent residency, were not significantly associated with awareness. For instance, caregivers involved in agricultural or manual

labour had similar odds of awareness compared to those not working or not seeking work, with no statistically significant differences. Likewise, caregivers living more than 70 minutes away from a health facility had odds of awareness comparable to those living closer (OR = 1.028, p = 0.920). Household dynamics, including whether the caregiver's partner was the household head (OR = 0.801, p = 0.589), and being a nomadic caregiver (OR = 1.223, p = 0.388), also showed no significant association. Additionally, caregivers who had resided in the area since June 2024 had higher odds of awareness (OR = 1.844), but the association was not statistically significant (p = 0.210). The random effects output from the model reveals substantial variability at the cluster level, with a variance estimate of 3.733 (95% CI: 2.235–6.237), compared to a smaller and less precise variance at the county level (0.278; 95% CI: 0.031–1.851). This shows that caregivers' awareness varies more between clusters than between counties, thereby revealing the influence of localized community-level factors such as local health communication efforts or leadership on awareness outcomes.

	Variables of interest	Aware of the malaria vaccine		Unadjusted OR (uOR) (95% CI)	p-value	Adjusted OR (aOR) (95% CI)	p-value
		Yes	No				
Caregiver's Gender	Female	204 (85.36)	1043 (82.7)	1			
	Male	35 (14.6)	218 (17.3)	1.288 (0.764-2.169)	0.342	1.125 (0.606-2.092)	0.707
Age of the caretaker	Under 20 years	26 (10.9)	170 (13.5)	1			
	20-29 years	93 (38.9)	487 (38.6)	1.127 (0.627-2.056)	0.690	1.037 (0.499-2.155)	0.922
	30-39 years	92 (38.5)	411 (32.6)	1.401 (0.773-2.541)	0.267	1.658 (0.777-3.536)	0.191
	40-49 years	20 (8.4)	125 (9.9)	0.894 (0.395-2.025)	0.789	1.145 (0.427-3.064)	0.788
	50-59 years	8 3.4)	54 (4.3)	0.840 (0.276-2.557)	0.759	0.574) 0.134-2.463)	0.455
Education level of the caretaker	None	145 (60.7)	899 (71.3)	1			
	Primary school	71 (29.7)	292 (23.2)	1.650 (1.057-2.575)	0.027*	2.013 (1.203-3.366)	0.008**
	Secondary school	22 (9.2)	66 (5.2)	3.223 (1.640-6.336)	0.001**	3.443 (1.531-7.741)	0.003**
	Higher education	1 (0.4)	4 (0.3)	11.287 (0.719-177.2)	0.085	21.184 (1.228-365.5	0.036*
Occupation of a caretaker	Not employed, not looking for paid work	34 (14.2)	310 (24.6)	1			
	Agriculture (paid/unpaid)	192 (80.3)	791 (62.7)	1.367 (0.713-2.625)	0.346	1.670 (0.805-3.462)	0.168
	Unskilled manual work (unpaid/paid)	3 (1.3)	97 (7.7)	0.549 (0.119-2.535)	0.442	0.721 (0.154-3.365)	0.677
	Skilled manual work	10 (4.2)	63 (5.0)	1.228 (0.502-3.006)	0.652	0.750 (0.272-2.068)	0.578
Distance to health facility	70 minutes or less	176 (73.6)	818 (64.9)	1			
	More than 70 minutes	63 (26.4)	443 (34.1)	1.028 (0.600-1.761)	0.920	1.014 (0.576-1.787)	0.961
The caregiver partner is the household head	No	17 (7.9)	57 (5.2)	1			
	Yes	199 (92.1)	1042 (94.8)	0.801 (0.352-1.825)	0.589	0.760 (0.323-1.788)	0.530
Nomadism	No	113 (47.3)	888 (70.4)	1			
	Yes	126 (52.7)	373 (29.6)	1.223 (0.775-1.930)	0.388	1.514 (0.915-2.505)	0.107
Resident since June 2024	No	11 (4.6)	50 (4.0)	1			
	Yes	228 (95.4)	1211 (96.0)	1.844 (0.709-4.793)	0.210	2.969 (0.936-9.413)	0.065

Table 3: Factors Associated with Caregivers' Awareness about Malaria Vaccination

3.2. Malaria Vaccination Coverage

Characteristics of children eligible for the malaria vaccine and their caregivers: In total, 533 caregivers of the children eligible r the malaria vaccine were interviewed, 288 in Aweil West and 245 in Aweil South. Most (80.7%) of the caregivers are female, are engaged in agricultural work (64.9%), have no formal education (67.7%), and are aged 20-39 years (72.2%). Caregivers who practiced seasonal nomadism were 31.0%. Nearly all (96.1%) of the households were residents in the community since July 2024, when the malaria vaccination campaign started. Almost all (94.0%) of the caregivers' partners were the household head. Most children were in the 13-23-month age group (64.9%). There were more male children (52.5%) than females (47.5%). The characteristics of the caregivers and the children are presented in Table 4.

Characteristic		n	%	95% CI
Sex of the child	Female	253	47.5	43.2-51.8
	Male	280	52.5	48.2-56.8
Selected child age	05-12 months	187	35.1	31.0-39.3
	13-23 months	346	64.9	60.7-69.0
Caregiver Gender	Female	430	80.7	77.1-83.9
	Male	103	19.3	16.1-22.9
Caregiver Age	Under 30 years	296	55.5	51.2-59.8
	30-49 years	211	39.6	35.4-43.9
	Over 50 years	26	4.9	3.2-7.1

Caregiver Occupation	Not employed, not looking for paid work	123	23.1	19.6-26.9
	Agriculture (paid/unpaid)	346	64.9	60.7-69.0
	Unskilled manual work (unpaid/paid)	40	7.5	5.4-10.1
	Skilled manual work (e.g., builder, electrician)	24	4.5	2.9-6.6
Level of education of the caregiver	None	361	67.7	63.6-71.7
	Primary school	127	23.8	20.3-27.7
	Secondary school or post-secondary (higher education)	45	8.4	6.2-11.1
Distance to health facility	70 minutes or less	351	65.9	61.6-69.9
	More than 70 minutes	182	34.1	30.1-38.3
The caregiver partner is the HH head	Yes	442	94.0	7.9-8.6
	No	28	6.0	3.5-7.5
Nomadism	Yes	165	31.0	27.1-35.1
	No	368	69.0	64.9-72.9
Resident since June 24	Yes	512	96.1	94.0-97.5
	No	21	3.9	2.4-6.0
Heard about SMC	Yes	483	90.6	87.8-93.0
	No	50	9.4	7.0-12.2
Heard about the malaria vaccine	Yes	67	12.6	9.9-15.7
	No	466	87.4	84.3-90.1
The child had an SMC card	Yes	457	85.7	82.5-88.6
	No	76	14.3	11.4-17.5
History of fever in the past four months	Yes	97	18.2	15.0-21.7
	No	436	81.8	78.2-85.0
Received all SMC cycles	Yes	82	15.4	12.4-18.7
	No	451	84.6	81.3-87.6

Table 4: Background Characteristics of Children Aged 5-23 Months and Their Caregivers, Aweil West and Aweil South, Northern Bahr-el-Ghazel State, 2025

In terms of malaria vaccine uptake, 48 of the 533 children (9.0%, 95% CI: 6.7-11.8) had received at least one dose in the first five months of the malaria vaccine rollout. The uptake for the first dose was significantly higher in Aweil South at 13.9% (34/245, 95% CI: 8.3-16.1), compared to Aweil West's 4.9% (14/288, 95% CI: 2.7-8.0) (p<0.001). The percentage of children receiving subsequent doses of the malaria vaccine declined markedly. Out of the 533 eligible children at the beginning of the vaccination campaign, only 48 received the first dose, 14 in Aweil West and 34 in Aweil South. Of the 48 children who had received the first malaria vaccine dose, 29 (60.4%, 95% CI: 45.3-74.2) had received the second dose. Of those 29, only 22 (75.9%, 95% CI: 56.4-89.4) had received the third dose. Finally, of the 22 children who received the third dose, only 5 (22.7%, 95% CI: 7.8-45.3) had received the fourth dose. Aweil South experienced the largest decrease in malaria vaccine reception from dose 1 to dose 4, showing a significant decline of 94.1% between these doses, compared to a 78.6% drop observed in Aweil West (p<0.001).

Malaria vaccine characteristics	Response	Aweil West (n=288) F	(%)	95% CI	Aweil South (n=245) f	(%)	95% CI	Overall (N=533) F	(%)	95% CI	χ2 (p-values)
		Aweil West (n=288)			**Aweil South (n=245)**			**Overall (N=533)**			
Children who received each of the malaria vaccines	Malaria 1	14	4.9	2.7-8.0	34	13.9	8.3-16.1	48	9.0	6.7-11.8	13.133 (0.000)
		Aweil West (n=14)			**Aweil South (n=34)**			**Overall (N=48)**			

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Children who received the 2nd dose	Malaria 2	9	64.3	35.1-87.2	20	58.8	40.7-75.4	29	60.4	45.3-74.2	0.124 (0.725)
Children who received the 3rd dose	Malaria 3	**Aweil West (n=14)** 6	66.7	29.9-92.5	**Aweil South (n=34)** 16	80.0	56.3-94.2	**Overall (N=48)** 22	75.9	56.4-89.7	0.603 (0.438)
Children who received the 4th dose	Malaria 4	**Aweil West (n=6)** 3	50.0	11.8-88.1	**Aweil South (n=16)** 2	12.5	1.5-38.3	**Overall (N=22)** 5	22.7	7.8-45.3	3.494 (0.062)

Table 5: Proportions of Households with Children Who Had Heard About and Received Malaria Vaccines (N=533)

Aweil West (n=14) Aweil South (n=34) Overall (N=48)

Association between the reception of at least one dose of a malaria vaccine in the first five months of the vaccine rollout among eligible children with child and caregivers' characteristics in the study sites

The results presented in Table 4 show the findings from both unadjusted and multivariable mixedeffects logistic regression models assessing the association between various caregiver and child characteristics and the likelihood of a child aged 5 to 23 months having received at least one dose of the malaria vaccine. The analysis accounts for the hierarchical nature of the data by incorporating random intercepts at both the county (LGA) and cluster levels.

Variables of interest		Received the malaria vaccine Yes	No	uOR (95% CI)	p-value	aOR (95% CI)	p-value
Sex of the child	Female	26 (54.2)	227 (46.8)	1			
	Male	22 (45.8)	258 (53.2)	1.257 (0.547-2.888)	0.331		
Age of the child	5-12 months	27 (56.3)	160 (33.0)	1			
	13-23 months	21 (43.7)	325 (67.0)	0.245 (0.102-0.588)	0.002**	0.272 (0.102-0.729)	0.010*
Gender of caregiver	Female	40 (83.3)	390 (80.4)	1			
	Male	8 (16.7)	95 (19.60	0.552 (0.372-1.811)	0.321		
Age of the caregiver	Under 30 years	27 (56.3)	269 (55.5)	1			
	30-49 years	19 (39.6)	192 (39.6)	1.944 (0.634-3.523)	0.359		
	50 years or more	2 (4.2)	24 (5.0)	2.114 (0.328-13.626)	0.431		
Education level of the caregiver	None	25 (52.1)	336 (69.3)	1			
	Primary school	14 (29.2)	113 (23.3)	2.331 (0.840-6.466)	0.104	1.698 (0.559-5.159)	0.351
	Secondary school or tertiary	9 (18.7)	36 (7.4)	6.920 (1.878-25.495)	0.004*	5.917 (1.362-25.705)	0.018*
Occupation of a caregiver	Not employed	3 (6.3)	120 (24.7)	1			
	Agriculture (paid/unpaid)	42 (87.5)	304 (62.7)	6.498 (1.151-36.675)	0.034*	9.179 (1.448-58.186)	0.019*
	Unskilled manual work	1 (2.1)	39 (8.0)	4.164 (0.186-93.036)	0.368	6.601 (0.235-185.320)	0.267
	Skilled manual work	2 (4.2)	22 (4.5)	7.417 (0.728-75.592)	0.091	3.536 (0.259-48.168)	0.342
Distance to health facility	70 minutes or less	39 (81.3)	312 (64.3)	1			
	More than 70 minutes	9 (18.7)	173 (35.7)	1.220 (0.366-4.068)	0.746		

The caregiver partner is the household head	No	3 (7.0)	25 (5.8)	1			
	Yes	40 (93.0)	402 (94.2)	0.436 (0.070-2.699)	0.372		
Nomadism	No	20 (41.7)	348 (71.3)	1			
	Yes	28 (58.3)	137 (28.3)	1.557 (0.537-4.517)	0.414		
Resident since June 2024	No	2 (4.2)	19 (3.9)	1			
	Yes	46 (95.8)	466 (96.1)	2.489 (0.276-22.444)	0.416		
Heard about SMC	No	1 (2.1)	49 (10.1)	1			
	Yes	47 (97.2)	436 (89.9)	4.601 (0.503-42.111)	0.177	3.892 (0.340-44.541)	0.275
The child had an SMC card	No	3 (6.3)	73 (15.1)	1			
	Yes	45 (93.7)	412 (84.9)	2.658 (0.804-8.779)		2.029 (0.275-14.991)	0.488
The child had a fever	No	42 (87.5)	394 (81.2)	1			
	Yes	6 (12.5)	91 (18.8)	0.618 (0.255-1.499)		0.406 (0.096-1.712)	0.219
Received all SMC cycles	No	78 (95.1)	407 (90.2)	1			
	Yes	4 (4.9)	44 (9.8)	0.474 (0.166-1.358)		0.823 (0.112-6.067)	0.849

*p< 0.05, OR Odds Ratio

Table 6: Association Between Reception of the Malaria Vaccine by Children Aged 5-23 Months and Caregivers' Characteristics in the Study Sites

3.3. Child Characteristics Influencing Malaria Vaccine Uptake

The age of the child was a significant factor associated with malaria vaccination uptake in the adjusted model. Children aged 13 to 23 months were significantly less likely to have received the vaccine compared to those aged 05 to 12 months. Specifically, the adjusted odds ratio (aOR) was 0.272 (95% CI: 0.102–0.729; p = 0.010), suggesting a 73% reduction in the odds of vaccination among older children.

3.4. Caregiver Characteristics Influencing Malaria Vaccine Uptake

The caregiver's education level was a strong predictor of vaccine uptake. Children whose caregivers had secondary or tertiary education were nearly six times more likely to be vaccinated compared to those whose caregivers had no education (aOR = 5.917; 95% CI: 1.362–25.705; p = 0.018). Although caregivers with only primary education also had higher odds of vaccinating their children, this result was not statistically significant after adjustment (aOR = 1.698; p = 0.351), indicating that it is higher levels of education that are more strongly associated with positive vaccine behaviours. The occupation of the caregiver was another significant factor in the adjusted model. Caregivers engaged in agriculture, whether paid or unpaid, had significantly higher odds of ensuring their children received the vaccine compared to those not employed (aOR = 9.179; 95% CI: 1.448–58.186; p = 0.019). Other occupational categories, including skilled and unskilled manual labour, were not significantly associated with vaccine uptake after adjusting for other factors.

Other sociodemographic factors such as caregiver gender, age, distance to the nearest health facility, nomadic status, and recent residency in the area were not significantly associated with whether a child had received the vaccine. The lack of association with distance to health facilities (aOR = 1.220; p = 0.746) is particularly noteworthy, as it suggests that physical access, at least as measured by travel time, may not have been a major barrier in this context. Similarly, variables related to household decisionmaking, such as whether the caregiver's partner was the household head, also showed no significant influence on vaccination outcomes. Several variables related to SMC were included in the model to explore potential cross-programme influences. For example, caregivers who reported hearing about SMC or having children with SMC cards had higher odds of vaccinating their children, but these associations were not statistically significant in the multivariable model. This may suggest some degree of overlapping influence from broader malaria prevention programmes, although the evidence was not strong enough to confirm this relationship within the sample. The variance components from the mixed-effects model indicate significant clustering at the community level. The cluster-level random intercept had a substantial variance estimate in both unadjusted (7.185; 95% CI: 2.736–18.868) and adjusted (6.101; 95% CI: 2.333–15.955) models, which

explains the importance of some possible contextual factors at the cluster level such as community leadership, outreach intensity, and local norms influencing vaccine uptake. In contrast, the countylevel variance was much smaller and statistically uncertain (aOR = 1.027; 95% CI: 0.077–13.722), which possibly shows that variation between counties had less impact on vaccine uptake than variation within them.

4. Discussion

These findings present several insights into awareness and uptake of the R21 vaccine in Aweil South and Aweil West counties in South Sudan. First, malaria vaccine awareness gaps persist in both counties, with only 9.9% (79/800) of the caregivers aware of the vaccine in Aweil West compared to 22.9% (160/700) in Aweil South. Nevertheless, malaria vaccine awareness among caregivers of children was significantly higher in Aweil South County than in Aweil West County. This study found that awareness of the malaria vaccine five months after roll-out was relatively low when compared to other sub-Saharan African countries, where awareness was recorded at 58.3% in Nigeria and 42.2% in a study conducted in Ghana [10,11]. Vaccine awareness at the time of the study was low, possibly because the vaccine had just been introduced less than six months before, and awareness at evaluation was still developing Low community awareness levels may also be due to inadequate communication outreach, low literacy, and low education levels, as observed in this study. Other possible causes of limitations in awareness could further be explored while planning strategies for improving malaria vaccine awareness. Furthermore, the low levels of awareness may suggest that existing health education and communication strategies around the malaria vaccine were not sufficiently impactful to drive widespread understanding and acceptance. This calls for a reassessment and strengthening of current approaches, including expanding community mobilization efforts through local leaders and health workers, utilizing culturally appropriate messaging and media channels and integrating malaria vaccine education into routine health services and outreach programs.

No significant association was observed between caregivers' gender and awareness of the malaria vaccine. These findings contrast with other findings in northern Nigeria, where women exhibited higher malaria vaccine awareness [16]. In addition, previous studies in South Sudan have shown that women are more likely to utilize health services (though not malaria vaccinations) compared to men [17,18]. The findings imply that awareness campaigns concerning the malaria vaccine have not been disproportionately directed at or received by either men or women, hence creating an informational gap regarding the malaria vaccine among both female and male populations. Consequently, there might be no immediate necessity to tailor messaging by gender for the purpose of malaria vaccine awareness campaigns. Therefore, this underscores the need for more comprehensive and widespread health education about the malaria vaccine to all caregivers uniformly to boost malaria vaccine decision-making, acceptance, and eventual uptake.

The uptake of the first dose of the malaria vaccine in the first five months of roll out was low, with only 9% of eligible children receiving the vaccine. While vaccine uptake in other states is unknown, Northern Bahr el Ghazal has historically had low vaccination rates, mainly due to geographic and system-level barriers such as distance, insecurity, and weak health facility functionality [27]. For example, caregivers on average must travel 45 minutes to reach a health facility for vaccines [28]. Therefore, the challenges affecting routine immunization may also affect malaria vaccine uptake [17]. The uptake of the R21 malaria vaccine was inadequate across both counties, characterized by a high initial dose uptake but a subsequent decline to low levels for the fourth dose in Aweil South. This observation aligns with previous research findings, where, despite challenges faced in both counties, Aweil West had lower access and utilisation of immunisation services which may suggest there were more challenges. For example, Aweil West County has been identified as having a higher proportion of children who did not receive measles and PENTA vaccines compared to other counties within the Northern Bahar al Ghazal state [17]. Moreover, Aweil West has been recognized as an area with a greater number of children requiring humanitarian assistance, including health and nutrition support, which may indirectly impede immunization access if resources are overstretched [18]. Conversely, Aweil South has demonstrated success in specific immunization campaigns, such as those for polio and COVID-19 vaccines [19,20]. Nevertheless, the observed low fourth dose, despite a high first dose uptake, could also be attributable to severe flooding experienced during the 2024 rainy season, more remarkable in Aweil South, which disrupted access to healthcare facilities and displaced numerous families [21].

Compared to children aged 05-12 months, children aged 13-23 months were less likely to receive the malaria vaccine. Some, if not most, of the children aged 05-12 months also needed other routine vaccinations against preventable diseases at the time the vaccine was introduced. Therefore, it is indicative that each time a caregiver took a child for routine vaccinations, they also received the malaria vaccine, unlike older children who usually complete their routine immunizations earlier and are less likely to be brought to the health facility for additional vaccines. Given that the first three doses of the vaccine are administered four weeks apart starting at five months of age, and the fourth dose is scheduled at 18 months, it is likely that many children were approaching or due for their fourth dose at the time of the survey. Considering this, it can be inferred that children had not yet received their fourth dose because of the programme design. The findings highlight two caregiver-related determinants of malaria vaccine uptake in children in the study area. Caregiver education and employment in agriculture were the significant factors associated with malaria vaccine uptake and awareness. This finding corroborates with other studies that have indicated that higher education leads to a better understanding of vaccine benefits [10]. The finding further reinforces the critical role of caregiver education in health decision-making and uptake

of new interventions. Higher education also influences vaccine acceptance, leading to higher coverage [22]. The high uptake among caregivers engaged in agriculture may reflect effective outreach and mobilization efforts in rural farming communities, where malaria burden is high and community based health interventions are more accessible and trusted. This study also revealed that previous malaria exposure or preventive treatment does not strongly influence vaccination decisions, as exhibited by a non-significant relationship between SMC and vaccine uptake. These findings mirror findings in Malawi, Ghana, and Burkina Faso, where vaccine uptake was not found to be influenced by malaria exposure or preventive treatment, including prior SMC uptake [23-25]. This underscores the need to put much emphasis on systemic and individual factors influencing uptake, such as education and awareness about the vaccine, to create trust and to put much emphasis on targeted interventions for increasing coverage rather than relying on prior malaria prevention measures. This may also be a result of non-integration or inadequate integration of other malaria prevention interventions with those of malaria vaccination. In addition, distance to health facilities and prior malaria prevention efforts did not significantly impact vaccine uptake, suggesting that accessibility is not the primary barrier. This finding contradicts the findings in Malawi, where distance was found to deter vaccine uptake [23,24]. However, studies in Uganda and Ghana have revealed that despite distance being a hindrance to vaccine uptake, caregivers often prioritized vaccine trust, efficacy, and effectiveness to ensure that their children got treated, which could be the case in the vaccination [26,27]. Future interventions should focus on addressing sociocultural factors, caregiver engagement, and awareness campaigns to ensure all eligible children receive the malaria vaccine [28].

4.1. Study limitations

The study was conducted only five months after the malaria vaccine rollout, which may not have captured the full trajectory of vaccine awareness and coverage. As such, the findings may disproportionately reflect early adopters and exclude populations who were reached later in the campaign. Also, given the vaccine schedule, many children were likely due for their fourth dose around the time of the survey. However, the study may not have adequately captured this cohort, potentially underestimating full-dose completion rates. Ongoing health education and communication efforts during the study period may have influenced caregiver awareness and attitudes. This evolving context introduces variability that may not be fully captured in a cross-sectional design, limiting the ability to attribute findings solely to the vaccine rollout. The exclusive use of quantitative methods limits the depth of understanding regarding caregiver perceptions, motivations, and barriers to vaccine uptake. A mixed-methods approach incorporating qualitative interviews or focus groups could have enriched the findings and provided more nuanced insights. The study did not explore sociocultural beliefs, trust in health systems, or community-level dynamics that may significantly influence vaccine acceptance. These factors are critical in shaping health behaviors and should be considered in future research.

4.2. Recommendations

These findings have important policy and programmatic implications. Efforts should focus on increasing initial vaccine uptake in Aweil West and Aweil South to enhance overall malaria prevention outcomes. The strong influence of caregiver education underscores the need for health education programmes targeting caregivers with low literacy levels. There is a need for a tailored malaria vaccine uptake campaign and social behaviour change efforts, as it was currently rolled out with routine immunization. Community engagement and health education initiatives should be enhanced in both counties to create community awareness about malaria vaccines. The lack of association between other malaria prevention interventions, such as SMC and vaccination, underpins the need for integrating malaria prevention efforts. Further malaria vaccination campaigns will benefit from understanding the behavioural, logistical, or structural factors supporting dose completion to inform best practices for improving vaccine retention.

5. Conclusion

Findings indicate low levels of malaria vaccine awareness and uptake across both counties, with notable disparities linked to caregiver demographics and the age of the child. Strengthening vaccination messaging and social and behaviour change efforts, particularly those tailored to address key sociodemographic drivers such as education level, gender, income, and geographic location, may significantly enhance vaccine acceptance and uptake.

Declarations

Consent for publication

All authors have reviewed and approved the final manuscript and consent to its publication.

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Competing interests

The authors declare that they have no competing interests related to this study.

Data availability

All data and materials supporting the findings of this study are included within the article. Additional information can be made available from the corresponding author upon reasonable request.

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