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Impact of malaria on family rice farm management in Gaya, Niger

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Abstract

Malaria remains a major public health challenge in sub-Saharan Africa, affecting household labor and economic productivity. In agricultural communities, the disease can disrupt farm management and reduce profitability, particularly for labor-intensive crops such as rice. This study investigates the effects of malaria on the management of family rice farms in the urban commune of Gaya. The methodological framework combined descriptive statistics, comparative analyses across rainy and dry seasons, and econometric modeling. Data were collected from 104 rice-farming households. Results demonstrate that both the average number of individuals affected by malaria and the associated healthcare expenditures are substantially higher during the rainy season. In the rainy season, health-related costs markedly increase total production expenses, causing value added and the profitability index to decline sharply (from 0.423 to 0.095). In contrast, during the dry season, despite higher revenues, the impact of health expenditures remains marginal, with only a slight reduction in the profitability index (from 3.26 to 3.22). Econometric analysis further reveals that, in the rainy season, rice farm profitability is significantly and negatively influenced by the number of lost workdays, malaria prevalence, and cultivated area ($p<0.05$). Each additional workday lost due to malaria reduces farm profitability by approximately USD 93, corresponding to a 3.6% decline relative to baseline profitability. These findings underscore malaria's dual burden on rice-farming households: it reduces labor availability while increasing financial costs, particularly during the rainy season when labor demands peak. Strategies to mitigate malaria could therefore improve both health and economic outcomes for smallholder rice farmers.

Keywords: Malaria; Rice; Farms; Management; Gaya; Niger

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1. Introduction

Agriculture continues to be the cornerstone of income and employment for the majority of rural populations in sub-Saharan Africa. In Niger, it employs nearly 80% of the active workforce and contributes substantially to the national gross domestic product (INS, 2022). Within the Niger River Valley, irrigated rice cultivation has emerged as a strategic activity for ensuring food security and generating household income. However, rice productivity is constrained by multiple factors, among which health-related risks are frequently underestimated. Human health represents a critical dimension of human capital, enabling individuals to perform their economic activities at full capacity (Véronique, 2016). Consequently, the quality of population health exerts a significant influence on economic performance at both microeconomic and macroeconomic levels. Among health risks, malaria constitutes a major constraint, with profound health, economic, and social implications. The disease remains one of the leading causes of morbidity and mortality in sub-Saharan Africa, accounting for approximately 94% of global cases and 95% of malaria-related deaths worldwide (WHO, 2022). Malaria imposes high economic costs on agricultural households by reducing labor productivity, increasing healthcare expenditures, and constraining rural development (WHO, 2023). At the macroeconomic level, recurrent malaria episodes undermine food security and agricultural growth, thereby reinforcing poverty traps in endemic regions (FAO, 2023a). The nexus between malaria and agriculture is particularly pronounced in irrigated rice systems. Recent studies confirm that rice-growing environments, especially those with persistent irrigation, create ideal breeding conditions for malaria vectors due to stagnant water and microclimatic factors (Chan *et al.*, 2023; Hardy *et al.*, 2025). Consequently, rice-farming households experience heightened exposure to malaria, particularly during the rainy season, which coincides with labor-intensive agricultural operations such as land preparation, transplanting, weeding, and harvesting (Chan *et al.*, 2022). This temporal overlap between peak malaria transmission and peak labor demand increases household vulnerability, resulting in lost workdays, diminished productivity, and heightened household expenditure on healthcare. Despite recognition of malaria prevalence in rural Niger (Ministry of Health, 2021; Mouchet *et al.*, 2004), few studies have explicitly examined its direct impact on agricultural management, particularly within irrigated rice systems. Most research has primarily concentrated on epidemiological and clinical dimensions, leaving a significant gap in understanding the interactions between health status and agricultural productivity. Addressing this gap is critical for designing integrated strategies aimed at poverty reduction and strengthening the resilience of farming households to health shocks. Recent initiatives across the Sahel and West Africa confirm that combining agricultural support with health interventions can significantly improve household welfare and reduce vulnerability (African Development Bank, 2024; FAO, 2023b; WFP, 2024). Within this context, the study aims to (i) quantify the economic effects of malaria on rice-farming households in Gaya, (ii) identify the mechanisms through which health shocks affect agricultural productivity and household welfare, and (iii) propose policy-relevant interventions to mitigate these impacts. For this purpose, five basic hypotheses were formulated: (H1) Malaria prevalence is positively associated with the number of lost agricultural workdays; (H2) Lost workdays due to malaria are negatively associated with rice farm yields; (H3) Malaria-related healthcare expenditures significantly increase total production costs; (H4) Higher malaria prevalence reduces farm profitability indices; and (H5) Reduced farm profitability contributes to household vulnerability and perpetuates the rural poverty cycle.

2. Literature review

Malaria remains one of the most widespread parasitic diseases in the world, constituting a major public health and development challenge, particularly in sub-Saharan Africa, which accounts for more than 90% of global malaria cases (WHO, 2022). Beyond its health burden, malaria represents a socioeconomic constraint that hinders agricultural productivity, weakens rural household livelihoods, and exacerbates food insecurity. Malaria and other infectious diseases directly reduce agricultural productivity by lowering labor availability and increasing household health expenditures. This loss of productive capacity constrains farm income, which in turn limits households' ability to invest in preventive health measures and agricultural inputs, creating a vicious cycle of vulnerability. Several recent studies confirm that malaria imposes significant negative externalities on labor supply, agricultural productivity, and rural household income. Andrade *et al.* (2022) demonstrate in their systematic review that malaria reduces individuals' capacity to work, leads to losses in agricultural output, and constrains household earnings in rural communities. Similarly, Adewale *et al.* (2016) highlights that malaria episodes among farmers directly and indirectly reduce agricultural output, resulting in lower rural household income. While Fink & Masiye (2015) emphasize the macroeconomic burden of malaria, more recent studies (Lamesgen *et al.*, 2025; Snyman *et al.*, 2025) highlight household-level heterogeneity in coping strategies. This divergence underscores the need for localized analyses that capture both economic and health dimensions. Edith *et al.* (2023), in their study on the macroeconomic impact of increasing investments in malaria control in 26 high malaria burden countries, revealed that scaling-up malaria control could produce an economic dividend of USD 152 billion across the modeled countries, equivalent to 0.17% of total gross domestic product (GDP) projected over the study period across the 26 countries. Assuming a larger share of malaria investments is financed from domestic savings, the dividend would be smaller but still significant, ranging between 0.10% and 0.14% of total projected GDP. Annual GDP gains are estimated to increase over time, with larger benefits accruing to lower-income and higher-burden countries. Within this context, the relationship between malaria and agriculture is inherently bidirectional. On the one hand, malaria reduces the labor force and agricultural productivity; on the other hand, agricultural practices, particularly irrigation and rice cultivation, create ecological conditions conducive to the proliferation of *Anopheles* mosquitoes, vectors of malaria transmission. Keiser, Castro, *et al.* (2005) emphasize that irrigation schemes and rice fields expand mosquito breeding sites, thereby increasing malaria transmission risk in rural communities. Similarly, Tusting *et al.* (2019) demonstrate that agricultural development, especially irrigation projects, can inadvertently enhance vector habitats. Monroe, Olapeju, *et al.* (2021) argue that malaria control strategies must therefore account for agricultural practices, as farming activities simultaneously sustain livelihoods and intensify vector habitats. The epidemiological literature emphasizes the specific risks associated with irrigated rice-growing areas. These agroecosystems are often characterized by permanent or semi-permanent water bodies, which constitute highly favorable breeding sites for malaria vectors (Keiser, Singer, *et al.*, 2005; Mouchet *et al.*, 2004). The "paddies paradox," identified in several African contexts, highlights a contradictory situation in which irrigated rice-growing areas tend to have higher entomological indices (vector density and transmission), yet malaria prevalence is not always proportionally higher, due in part to greater access to health care, preventive measures, and improved socio-economic conditions (Ijumba & Lindsay, 2001). However, in many rural areas of West Africa, and particularly in Niger, limited access to health services and preventive tools often neutralizes this paradox, resulting in high malaria prevalence in rice-growing areas (INS, 2022). At the household level, malaria generates both direct and indirect costs. Direct costs include health expenditures for treatment and prevention, while indirect costs arise from loss of working days, decline in labor productivity, and reduced agricultural yields (Malaney, 2002). These effects are especially severe for smallholder family farms, which depend heavily on family labor and face financial constraints that limit their ability to hire additional workers. In Niger, where agriculture represents nearly 40% of GDP and employs over 80% of the population, the effects of malaria on agricultural management are particularly critical (INS, 2022). Rice cultivation in Niger, mainly concentrated in irrigated perimeters along the Niger River, is both a strategic economic activity and a highly vulnerable sector due to its dependence on water management and labor availability. In this context, malaria exacerbates production risks, especially during peak agricultural periods such as transplanting, weeding, and harvesting (Mouchet *et al.*, 2004). Several studies in Africa have demonstrated that malaria-induced morbidity and mortality in agricultural households lead to reallocation of labor, reduction in cultivated areas, abandonment of certain plots, and lower investment capacity. For family rice farms, these effects are particularly pronounced, as malaria frequently affects active members of the household, especially men and women responsible for the most labor-intensive agricultural tasks (Sauerborn *et al.*, 1996). In addition, the economic burden of malaria treatment can divert financial resources from agricultural investment, thereby reducing productivity and compromising household resilience (Sachs & Malaney, 2002; WHO, 2022). In Niger, the Gaya region illustrates this dual vulnerability of rice-growing households to malaria. Located in the south-west of the country, along the Niger River, the Gaya-Amont perimeter constitutes one of the main irrigated rice-growing areas, yet it is also among the most malaria-affected zones due to ecological conditions favorable to vector proliferation and the persistence of endemic transmission (INS, 2022). Rice-growing households in this area face the ongoing challenge of managing production under constant pressure from health shocks, which not only reduce available labor but also impose financial costs that weaken the sustainability of farming systems. This duality highlights the importance of integrating health considerations into agricultural policies and development interventions aimed at improving productivity and resilience in Nigerien rice-growing systems (Malaney, 2002; Mouchet *et al.*, 2004). Overall, the literature converges on the idea that malaria is not only a public health issue but also a critical determinant of agricultural performance and rural household welfare. For family rice farms in endemic areas such as Gaya-Amont, malaria exerts both direct effects, through reduction of labor and yields, and indirect effects, through increased financial burden and diminished resilience. Understanding these interactions is essential for designing integrated strategies that combine health interventions with agricultural development policies to break the vicious cycle of malaria and rural poverty in Niger and beyond.

2.1. Conceptual framework

Malaria represents a major health shock whose repercussions extend beyond the medical sphere to shape structural economic and agricultural vulnerability. High disease prevalence reduces household labor availability through increased morbidity and lost workdays. This decline in labor productivity directly constrains farm operations, leading to lower yields and diminished profitability. At the same time, malaria-related healthcare expenditures impose an additional financial burden that weakens household resilience and perpetuates the rural poverty cycle. Malaria thus generates a multidimensional burden on farming households, initiating a cascade of health, economic, and agricultural disruptions. Malaria-induced morbidity increases household health expenditures and psychological stress, crowding out operating capital and reducing the capacity to invest in agricultural inputs and labor. This forced reallocation of resources results in a contraction of cultivated land and declining yields, producing significant losses in farm income. The reduction in labor availability, exacerbated by illness and rural workforce migration, further compromises productivity during critical agronomic periods. These constraints prolong the lean season and intensify household food insecurity, while cumulative stress and nutritional deprivation contribute to child malnutrition. The economic consequences of malaria reinforce a health–poverty trap, in which vulnerable households face recurrent shocks that erode resilience and perpetuate structural poverty. Moreover, the weakening of local commercial activity and the migration of labor disrupt market dynamics, reducing access to agricultural inputs and further depressing farm performance. In response, households adopt coping and adaptation strategies such as crop diversification, reliance on informal credit mechanisms, or adjustments in labor allocation. However, these measures often provide only partial mitigation and may involve trade-offs that compromise long-term sustainability (Figure 1).

3. Methodology

3.1. Study area

The study was conducted in the department of Gaya, located in the southwestern region of Niger. This agroecological zone is characterized by the Niger River and intensive irrigated and rainfed rice farming. The urban commune of Gaya lies approximately 150 km from the regional capital, Dosso, and is situated between longitudes 3°10'35" and 3°37'48" east, and latitudes 11°41'24" and 12°11'32" north. The commune is bordered to the southeast by the rural commune of Tounouga, to the northwest by the

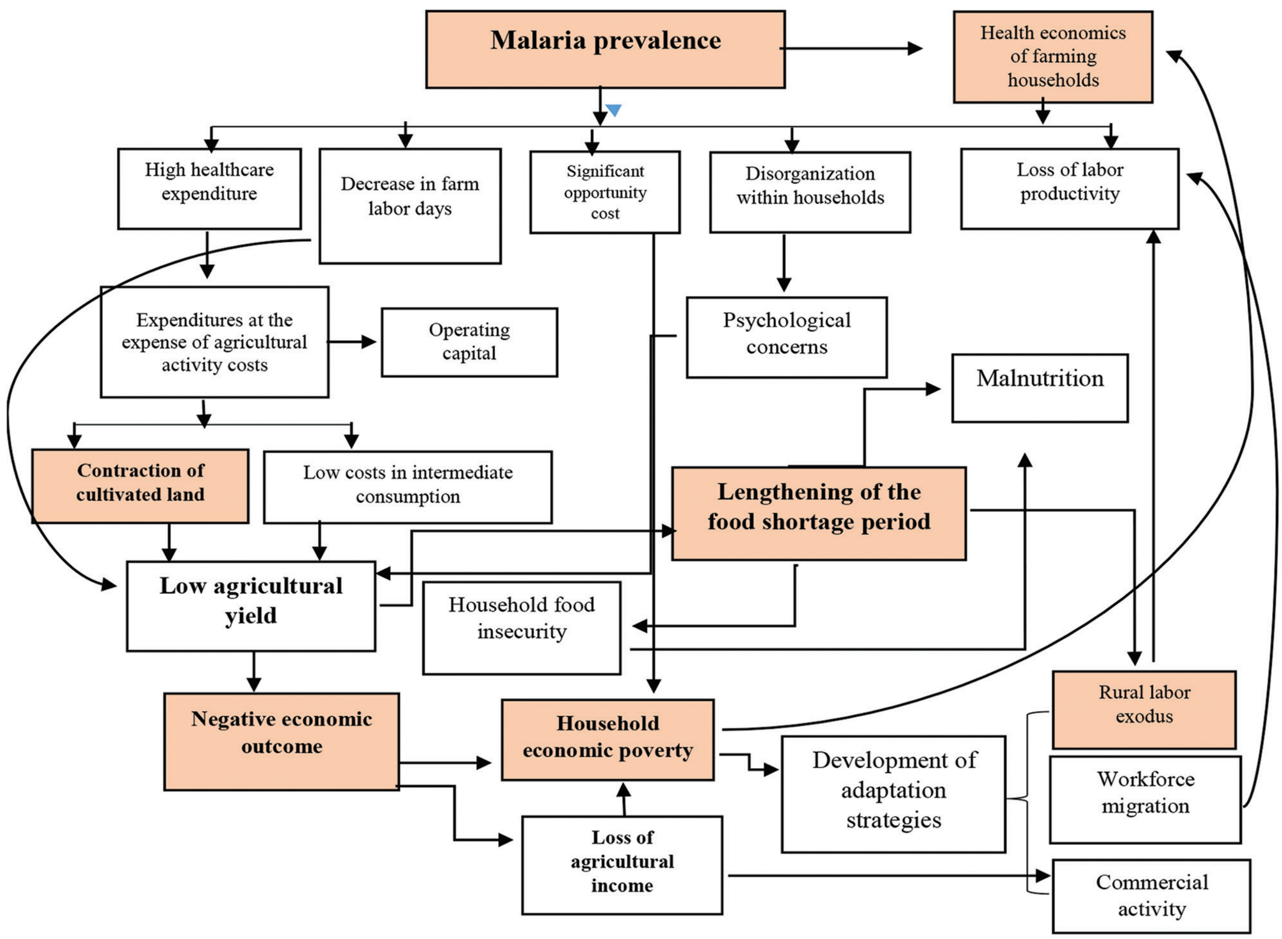

Figure 1. Conceptual model of the health–poverty trap in farming households

commune of Tanda, to the south by the Niger River, and to the north by the rural communes of Bengou and Bana. The region experiences a high prevalence of malaria, particularly during the rainy season, which coincides with peak agricultural labor demand. This overlap makes the area highly relevant for analyzing the interactions between health shocks and agricultural performance. In the urban commune of Gaya, universal access to healthcare is supported by an established health system. The healthcare workforce comprises 220 personnel across all categories, including 24 in the private sector (PDC, Gaya, 2024).

3.2. Population and sampling

The target population of this study comprised rice farming households located in the Department of Gaya. The total number of these farms was established using an official registry, which identified 731 rice-producing units. To determine the appropriate sample size for the survey, Cochran's (1977) formula was applied, using both of its methodological variants (Equations [1] and [2]). Based on this approach, the estimated sample size was approximately 104 rice farms.

Survey data were collected in 2024 during the main rice production season in the Department of Gaya. Malaria cases were identified through household reports of illness episodes, and these reports were systematically cross-checked against household medical records. This verification procedure ensured that the health indicators used in the study were not based solely on self-reported symptoms but were supported by documented treatment records. Data for both agricultural seasons (rainy and dry seasons) were obtained from the same 104 rice-farming households, which were followed consistently throughout the study period. Of these, 102 households participated in the survey, yielding a response rate of 98%. Non-response was primarily due to the temporary absence of household heads during the survey period. All participants provided verbal informed consent, which was considered appropriate given the literacy levels and local research practices. Participation was entirely voluntary, and respondents were informed of their right to withdraw at any time. No monetary compensation was provided. The sample size was calculated as follows:

$$N_i = \frac{Z^2 * P * (1-p)}{e^2} \tag{1}$$

$$N_f = \frac{N_i}{1 + \frac{N_i}{N}} \tag{2}$$

- Target population (N): 731 rice farming households
- Confidence level (Z): 1.96 (corresponding to 95%)
- Estimated proportion (p): 0.5 (to maximize variance)
- Margin of error (E): 9% (0.09).

3.3. Analytical methods

The statistical analysis employed a mixed-methods approach, integrating both descriptive and inferential techniques to comprehensively examine the effects of malaria on rice-farming households (Nguyen *et al.*, 2021; Thiam *et al.*, 2024 and Ozodiegwu *et al.*, 2025). Descriptive statistics were first applied to characterize households according to socioeconomic attributes, demographic profiles, and health-related variables, thereby providing an overview of the study population. Key economic and financial indicators of rice farm performance, such as gross margin, labor productivity, and input–output ratios, were computed using standard arithmetic formulas, as summarized in Table 1 (Mahamadou *et al.*, 2025). All analyses explicitly accounted for seasonality by distinguishing between two rice-growing periods: The rainy season and the dry season. This approach enabled the assessment of temporal variations in labor allocation, productivity, and the economic impact of malaria-related morbidity.

Finally, to quantify the effect of malaria on the economic performance of rice farming households, a multiple linear regression model was employed in the following general form:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \ldots + \varepsilon_i \tag{3}$$

Where

Y_i =Net margin of rice farm i

X_{3i}, X_{3i},X_{3i} = Denote explanatory variables, including malaria prevalence indicators and farm-specific characteristics such as land size, labor availability, input use, and household socio-economic attributes (Gujarati & Porter, 2021).

β_0 = Is the model intercept.

β_j=Represents the marginal effect of each explanatory variable on farm net margin.

ε_i=Is the stochastic error term, capturing unobserved factors influencing farm performance.

3.4. Model variables

Table 2 presents the variables included in the multiple linear regression model, detailing their type, description, coding in the equations, and expected effects on the net margin and rice farming yield.

The indicators employed in this study were selected to capture both the economic performance of rice farms and the multidimensional impacts of malaria on household management. Net margin per hectare

Table 1. Economic and financial indicators (adapted from Mahamadou *et al.* [2025])

Indicator	Description	Arithmetic Formula
Gross rice production (GRP)	It refers to the total value of rice production achieved over a given period, before any deductions (expenses, costs, depreciation, losses).	GRP=Quantity produced×unit selling price
Variable costs (VC)	These are the costs that increase or decrease in proportion to the quantity produced.	VC=Costs of inputs+casual labor+water fees and other variable expenses
Fixed costs (FC)	These are the costs that do not vary with the quantity produced: whether production is high or low, they remain constant.	FC=Depreciation costs+other fixed expenses
Production cost (PC)	The total expenses incurred in the process of producing.	PC=FC+VC
Intermediate consumption (IC)	It corresponds to the value of goods and services used up during the rice production cycle, excluding durable investments (such as machinery and buildings).	IC=Quantity of consumables×unit selling price
Gross margin on variable costs (GMVC)	It is the portion of revenue that remains available to cover fixed costs and generate profit.	GMVC=GRP – agricultural variable costs
Gross added value (GAV)	The economic value that farmers create after subtracting the cost of inputs from the value of their harvest.	GAV=Production value – IC
Net added value (NAV)	The portion of wealth created by production that remains after subtracting depreciation (consumption of fixed capital) from the GAV.	NAV=GAV – depreciation
Net margin (including health costs)	Net margin is the profit remaining after subtracting health costs and labor replacement costs from the farm's gross added value.	Net margin=Gross added value – health costs – labor replacement costs
Profitability index (PI)	A financial metric used to evaluate the attractiveness of an investment or project. It shows the value created per unit of investment. • PI >1 → The farm is profitable (it generates more value than it costs). • PI = 1 → The farm breaks even. • PI <1 → The farm is not profitable (costs exceed benefits).	PI=Gross margin/PC
Opportunity cost of labor (OCL)	Refers to the income or value that farmers could have earned if they used their time in another activity	OCL=Number of lost workdays×replacement daily wage or value of family labor

Table 2. Description of variables used in the study

No.	Variable	Type	Description	Expected effects
1	Net margin per hectare	Continuous	Net economic return calculated based on positive margins per hectare.	
2	Household size	Discrete	Number of household members dependent on the farm.	+
3	Respondent's education level	Discrete	Coded from 0 (no formal education), 1 (primary), up to 4 (higher education).	+
4	Marital status	Binary	1 if married, 0 otherwise.	+
5	Age (years)	Continuous	Age of the household head.	+
6	Gender	Binary	1 if male, 0 if female.	+
7	Cultivated area (ha)	Continuous	Total area cultivated by the household, in hectares.	+
8	Lost workdays (individual)	Discrete	Number of workdays lost by the household head due to illness or other reasons.	–
9	Malaria prevalence	Continuous	Proportion of household members affected by malaria (%) during rainy or dry seasons.	–
10	Average treatment cost	Continuous	Average cost of malaria treatment per affected individual.	–
11	Number of income sources	Discrete	Total number of income-generating activities within the household.	+
12	Number of sick individuals	Discrete	Total number of household members who contracted malaria.	+
13	Number of treated individuals	Discrete	Number of malaria-affected individuals who received treatment.	–
14	Total treatment cost	Continuous	Total household expenditure on malaria treatment	+
15	Lost workdays (household)	Discrete	Total number of workdays lost across the household due to illness.	–
16	Distance to health center (km)	Continuous	Distance from the household to the nearest health facility, in kilometers.	–

was used as the primary measure of farm profitability, reflecting the balance between revenues and production costs. Household size, education level, marital status, age, and gender of the household head were included as socio-demographic variables that influence labor allocation, decision-making, and resilience capacity. Cultivated area was included as a proxy for production potential, while the number of income sources reflects diversification strategies. Health-related indicators such as malaria prevalence, number of sick individuals, treatment costs, and lost workdays were integrated to assess both the direct and indirect economic burden of the disease. As documented by Lamesgen *et al.* (2025), malaria imposes substantial direct and indirect costs on African households through treatment expenditures and productivity losses. Similarly, Udoh & Ubong Abasi (2025) emphasize that farming households often face significant economic trade-offs when allocating resources toward malaria treatment. Evidence from Lukwa *et al.* (2019) demonstrates that malaria-related absenteeism reduces agricultural productivity in plantation settings, while Adekanye *et al.* (2020) show that malaria-induced workday losses contribute directly to household poverty among food crop farmers in Nigeria. Finally, Snyman *et al.* (2025) underline the importance of treatment costs and health service accessibility, noting that distance to health facilities strongly influences household vulnerability. Together, these indicators provide a comprehensive framework for analyzing how malaria prevalence shapes household health economics, agricultural productivity, and food security outcomes.

3.5. Model selection and specification

To identify the explanatory variables with statistically significant effects on the net margin of rice farms, we employed a stepwise model selection approach based on the Akaike Information Criterion (AIC). The procedure was implemented using the stepAIC() function from the modern applied statistics with S (MASS) package in R 4.4.1 (Venables & Ripley, 2002). An initial full model was specified, incorporating 12 candidate variables representing both economic performance (net margin) and agronomic factors (yield), as specified in Equations (4) and (5). The stepwise procedure iteratively removed variables to identify the most parsimonious model that minimized the AIC value while maximizing explanatory power. This method reduces model complexity, mitigates the risk of overfitting, and ensures that retained variables are robust predictors of rice farm economic performance (Burnham & Anderson, 2002; Hair *et al.*, 2021). To ensure the reliability of the regression estimates, several diagnostic tests were performed. Breusch & Pagan (1979) proposed the widely used Breusch–Pagan test for heteroskedasticity, which was applied to confirm variance stability in the models. Salmerón-Gómez *et al.* (2025) emphasize the importance of variance inflation factors in detecting multicollinearity, and this method was used to verify that no explanatory variable exceeded the critical threshold. Outlier detection was conducted following the procedures described by Midi & Ariffin (2013), which recommend the use of standardized residuals and leverage statistics to identify influential observations. Missing observations were excluded from regression analyses to avoid estimation bias.

$$Y(\text{net margin}) = \beta_0 + \beta_1 (\text{“household size”}) + \beta_2 (\text{“educational level”}) + \beta_3 (\text{“marital status”}) + \beta_4 (\text{Age}) + \beta_5 (\text{“Gender”}) + \beta_6 (\text{cultivated area}) + \beta_7 (\text{Number of lost days}) + \beta_8 (\text{agricultural workforce size}) + \beta_9 (\text{malaria prevalence}) + \beta_{10} (\text{treatment cost}) + \beta_{11} (\text{Number of income sources.}) + \beta_{12} (\text{Number of dependents.}) + \beta_{13} (\text{Number of sick persons}) + \beta_{14} (\text{malaria incidence}) + \beta_{15} (\text{malaria severity}) + \beta_{16} (\text{Distance to Health Center}) + \varepsilon_i \quad (4)$$

$$Y(\text{yield}) = \beta_0 + \beta_1 (\text{“household size”}) + \beta_2 (\text{“educational level”}) + \beta_3 (\text{“marital status”}) + \beta_4 (\text{Age}) + \beta_5 (\text{“Gender”}) + \beta_6 (\text{cultivated area}) + \beta_7 (\text{Number of lost days}) + \beta_8 (\text{agricultural workforce size}) + \beta_9 (\text{malaria prevalence}) + \beta_{10} (\text{treatment cost}) + \beta_{11} (\text{Number of income sources}) + \beta_{12} (\text{Number of dependents}) + \beta_{13} (\text{Number of sick persons}) + \beta_{14} (\text{malaria incidence}) + \beta_{15} (\text{malaria severity}) + \beta_{16} (\text{Distance to Health Center}) + \varepsilon_i \quad (5)$$

The stepwise selection process (direction = “both”) involved iterative inclusion and exclusion of variables to identify the model configuration that minimized the AIC.

$$AIC = -2ln(\check{L}) + 2k \quad (6)$$

Where $\check{L}$ is the likelihood of the model, and k is the number of estimated parameters.

Ultimately, based on the lowest AIC values, two final models were retained, providing an optimal balance between goodness of fit and model parsimony, thereby reducing the risk of overfitting. These models include the following variables:

- For net margin: cultivated area, malaria-related healthcare costs for women and men, number of workdays lost during farming activities, and the gender of the household head.
- For yield: total healthcare costs, number of workdays lost during farming activities, and the gender of the household head.

The final models can be expressed as:

$$Y(\text{net margin}) = \beta_0 + \beta_4 (\text{cultivated area}) + \beta_7 (\text{Number of lost days}) + \beta_{10} (\text{malaria prevalence}) + \varepsilon_i \quad (7)$$

$$Y(\text{yield}) = \beta_0 + \beta_4 (\text{treatment cost}) + \beta_7 (\text{"Number of lost days"}) + \beta_{10} (\text{"Gender"}) + \varepsilon_i \quad (8)$$

Relative losses in profitability were calculated by dividing the estimated coefficients of significant variables by the baseline profitability level represented by the regression intercept (Equation [9]).

$$\text{Relative losses} = \frac{\text{The estimated coefficient}}{\text{Intercept of the regression model}} \quad (9)$$

4. Results

4.1. Sociodemographic and agricultural characteristics of rice-farming households

Analysis of the results presented in Table 3 indicates that the average age of farm household heads is 51 ± 12.55 years, reflecting an aging farming population with substantial experience in managing rice farms. Literacy levels among household heads are low: 50.5% are illiterate, 17.5% have received a Quranic education, and 24.3% have completed primary education. This high proportion of illiteracy has important implications for adaptive capacity as households with limited literacy may face constraints in accessing written agricultural extension materials, understanding health information, and adopting improved technologies. Consequently, illiteracy can exacerbate vulnerability to both economic and health shocks. On average, households comprise 11 ± 6.46 members, of whom 7 ± 3.28 are economically active. Among these, only five individuals typically participate in agricultural activities during the rainy season, while participation drops to two members during the dry season. Farm sizes are relatively small, averaging 0.38 ± 0.25 ha in the dry season and 0.38 ±0.28 ha during the rainy season.

4.2. Analysis of key malaria-related indicators

Table 4 highlights significant seasonal disparities in malaria-related impacts. During the rainy season, individuals affected by malaria lost an average of 7.05 ± 2.79 days of agricultural work, compared to 2.80 ± 1.71 days during the dry season. This productivity loss corresponds to an estimated opportunity cost of USD 113. On average, 6.58 ± 3.32 individuals per household contracted malaria in the rainy season, versus 2.25 ± 1.54 in the dry season. When multiple members are simultaneously incapacitated, households face compounded productivity shocks, which reduce resilience to external stressors. The average treatment cost per household (USD 38) was markedly higher during the rainy season than in the dry season (USD 12), suggesting that households may be forced to reallocate resources away from agricultural inputs to cover healthcare needs.

4.3. Impact of malaria-related workday losses on rice yield

Figure 2 illustrates the variation in average rice yield according to the number of agricultural workdays lost due

Table 3. Sociodemographic and agricultural characteristics of rice-farming households

Variables	Mean	Standard deviation	Shapiro test	
			W	*p*-value
Age of household head	51	12.56	0.99	0.30
Year of plot acquisition	26	8.02	0.87	8.13e-08
Number of household members	11	6.46	0.94	0.00
Number of economically active members	7	3.28	0.92	1.93e-05
Area cultivated (rainy season, ha)	0.38	0.29	0.71	9.50e-13
Number of participants in agricultural activity (rainy season)	5	2.53	0.92	1.12e-05
Area cultivated (dry season, ha)	0.38	0.25	0.70	3.21e-13
Number of participants in agricultural activity (dry season)	2	1.40	0.87	3.32e-08

Education level	Literacy levels	%
	Literate	1.0
	Illiterate	50.5
	Quranic education	17.5
	Primary education	24.3
	Secondary education	6.8

Note: The data are based on the authors' calculations from 102 households that participated in the 2024 survey.

Table 4. Key malaria-related indicators by season

Indicators	Rainy season		Dry season	
	Mean±SD	Opportunity cost	Mean±SD	Opportunity cost
Workdays lost due to malaria	7.05±2.791	USD 113	2.80±1.71	USD 20.5
Individuals affected by malaria	6.58±3.32		2.25±1.54	
Treatment cost for affected individuals	USD 38		USD 12	

Note: The data are based on the authors' calculations from 102 households that participated in the 2024 survey.
Abbreviation: SD: standard deviation.

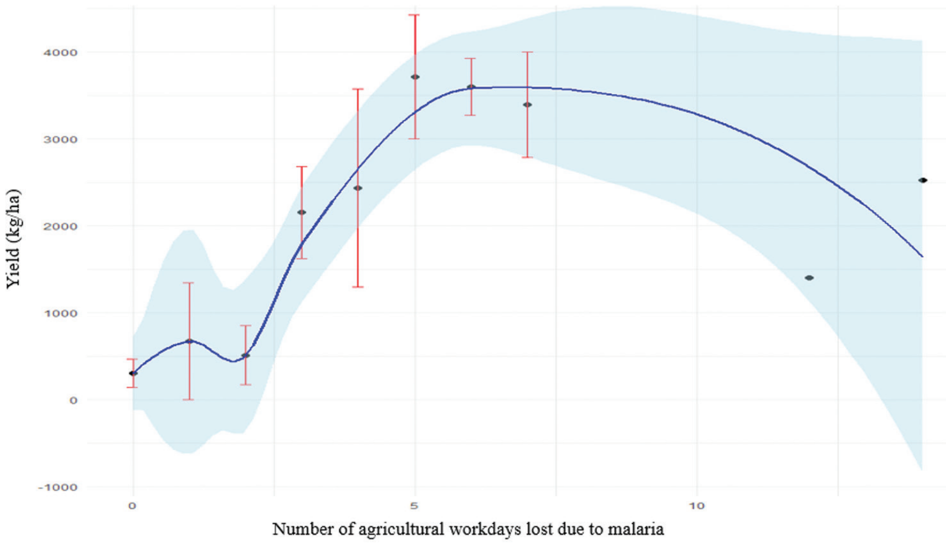

Figure 2. Variation in rice yield according to the number of agricultural workdays lost due to malaria. The blue line shows the fitted relationship; the shaded band indicates the 95% confidence interval.
Source: Authors' calculations based on household survey data analyzed in R.

to malaria. The analysis reveals a non-linear trend, with the light blue shaded area representing the 95% confidence interval around the fitted relationship, and red bars indicating observed yield variability. A temporary increase in yield is observed between 3 and 6 lost workdays, suggesting that households are able to maintain relatively high productivity within this range. However, beyond this threshold (from 6 to 7 days), further losses in labor time led to a rapid and sustained decline in rice yield. This pattern underscores the organizational and financial limitations faced by farming households in coping with recurrent malaria episodes.

4.4. Effects of malaria prevalence on the economic and financial performance of rice farms

Analysis of Table 5 reveals that during the rainy season, the inclusion of healthcare expenditures leads to a substantial increase in total production costs from USD 427 to USD 539, representing an additional burden of USD 112.6. This rise directly impacts both gross and net value added, which decline from USD 398 to USD 269 and from USD 181 to USD 51.3, respectively. The profitability index (PI) clearly reflects this deterioration, dropping from 0.423 without health-related costs to 0.095 (with costs), a reduction of 32.8 percentage points during the rainy season, reflecting a ~70% reduction in net margin compared to the dry season. In contrast, during the dry season, overall revenues are higher (gross output: USD 1,748), and the impact of healthcare costs is less pronounced, with the PI contracting only slightly from 3.26 to 3.22. The opportunity cost of malaria accounts for 21% and 3% of total production costs in the rainy and dry seasons, respectively.

4.5. Determinants of economic and financial profitability of rice farms in a socio-economic and malaria-endemic context

Analysis of Table 6 reveals that during the rainy season, rice farm profitability was significantly and negatively influenced by three key variables: cultivated area, number of workdays lost, and malaria prevalence within farming

Table 5. Economic outcomes of rice farms without and with healthcare costs, by season

Economic and financial indicators	Rainy season			Dry season		
	Without cost (USD)	With cost (USD)	Share of costs	Without cost (USD)	With cost (USD)	Share of costs
Gross rice production	490	-	-	**1,739**	-	
Variable costs	109.3	222	20%	170.3	191	29%
Opportunity cost	-	112.6	21%	-	20.4	3%
Fixed costs	317.5	-	59%	397	-	68%
Production cost	427	539	100%	567	588	100%
Total annual depreciation Cost	217.4	-	-	217.4	-	
Gross added value	398	269	-	1,569	1,548	
Net added value	181	51.3	-	1,351	1,331	
Profitability index	0.423	0.095	-	3.26	3.22	

Note: The data are based on the authors' calculations from 102 households that participated in the 2024 survey.

households. These factors were statistically significant at the 1% and 5% levels, respectively, and substantially increased the likelihood of a decline in profitability. Notably, the negative coefficient associated with cultivated area suggests that expanding land under cultivation does not necessarily lead to higher profitability. This counterintuitive result may reflect scale-management inefficiencies, labor bottlenecks, or increased exposure to health-related risks on larger plots, particularly during peak malaria transmission periods. The model's explanatory power during the rainy season was statistically robust, with an adjusted R^2 of 28.4 % (F-statistic = 7.905; p-value = 0.0002), indicating that nearly one-third of the variation in profitability can be explained by these health and structural factors. In contrast, the model for the dry season was not statistically significant and did not yield interpretable results.

Table 6. Key determinants of rice farm profitability

Explanatory variable	Estimate (USD)	Standard error	t-value	Pr(>|t|)
Intercept	2,570**	941.85	2.729	0.00879
Cultivated area	−1,144**	384.58	−2.980	0.00448
Number of workdays lost	−93.40*	44.50	−2.100	0.04092
Seasonal malaria prevalence	−2,405*	1030.03	−2.337	0.02355

Notes: The data are based on the authors' calculations from 102 households that participated in the 2024 survey. * denotes p<0.01; ** denotes p<0.001. Adjusted R^2: 0.284, p-value: 0.0002123, n=102.

4.6. Determinants of rice yield in a socioeconomic and malaria-endemic context

Analysis of Table 7 reveals that rice yield during the rainy season was negatively influenced by total healthcare costs and the number of workdays lost during farming activities. These effects were statistically significant at the 5% and 10%, levels, respectively. This suggests that resources diverted to healthcare limit the ability of households to invest in farm inputs or hire additional labor, thereby constraining productivity. In addition, additional workday lost to malaria was significantly associated with a decrease in yield, confirming that labor availability during peak agricultural periods is a critical determinant of farm performance. Yield was positively associated with the gender of the household head. Farms headed by men appear to achieve higher yields, possibly reflecting differences in access to land, credit, or labor mobilization compared to female-headed households. This highlights gender disparities in agricultural outcomes and suggests that targeted support for female-headed households could help mitigate productivity gaps. The model for the rainy season explained 34.8% of the variability in rice yield and was statistically significant at the 5% level (p-value = 0.04769).

Table 7. Determinants of agricultural yield

Explanatory variable	Estimate	Std. Error	t-value	Pr(>|t|)
Intercept	−891.22055	1,565.85768	−0.569	0.5763
Total Healthcare Cost	−0.05586	0.03204	−1.744	0.0983·
Number of Workdays Lost During Farming Activities	−402.86743	166.70525	2.417	0.0265*
Gender of the Household Head	2,693.06463	1,434.78554	1.877	0.0768.

Notes: The data are based on the authors' calculations from 102 households that participated in the 2024 survey. *Denotes p<0.01. Multiple R^2: 0.3487; adjusted R^2: 0.240; p-value: 0.04769; n=102. Abbreviation: std: standard.

4.7. Adoption of mosquito prevention methods

The most widely used malaria prevention strategy among respondents is sleeping under bed nets, reported by 67% of households, followed closely by the use of mosquito repellents (60.2%). These figures suggest a relatively high level of awareness regarding personal protection measures. In contrast, environmental prevention practices are much less common: only 20.4% of households engage in drainage of stagnant water, and a mere 15.5% use window screens (Figure 3). These low adoption rates may reflect limited access to infrastructure, low perceived efficacy, or lack of technical support at the community level.

5. Discussion

The average age of rice farm household heads was 51 years, reflecting an aging agricultural population with substantial experience in farm management. This observation aligns with several studies conducted in sub-Saharan Africa, which highlight the declining interest of rural youth in agricultural activities, often favoring migration to urban centers or abroad (Bélières *et al.*, 2015). However, advanced age may also be viewed positively, as it often correlates with accumulated experience in farming practices, risk management, and adaptation to multiple constraints (Adeoti *et al.*, 2011). A high proportion of illiteracy (50.5%), defined here as having no formal education, illustrates a structural reality of rural Sahelian communities where access to education remains limited (INS Niger, 2022). This educational gap continues to hinder the adoption of new agricultural technologies and the understanding of innovations related to farming practices and inputs (Mendola, 2007). On average, 7 ±3.28 individuals per household were considered active, yet only five participated in agricultural activities during the rainy season, and just 2 during the dry season. This limited labor availability outside the rainy season can be attributed to the presence of school-aged children, elderly or ill individuals, and seasonal migration, all of which could reduce the effective workforce. Cultivated areas remain modest, averaging 0.38 ha in both seasons. These findings are consistent with FAO (2017) and Seck *et al.* (2010), who report that rice farming in West Africa is predominantly carried out by small-scale family farms, often under 1 ha. Such land constraints limit household production, diversification, and investment capacity, thereby increasing socio-economic vulnerability to climatic and health-related shocks such as malaria, which directly affects labor availability (Sulemana & James, 2014). During the rainy season, an average of 7.05 ± 2.79 workdays were lost per malaria-affected individual, compared to 2.80 ± 1.71 days in the dry season, resulting in an estimated opportunity cost of USD 113. This seasonal disparity may be explained by climatic conditions favoring mosquito proliferation, including high humidity and stagnant water during the rainy season (WHO, 2021). In the same period, an average of 6.58 ± 3.32 individuals per household contracted malaria, compared to 2.25 ± 1.54 in the dry season. The reduction in labor availability during this critical phase, often corresponding to sowing and crop maintenance, directly compromises agricultural productivity (Sauerborn *et al.*, 1996). This observation aligns with findings by Fink & Masiye (2015), who emphasize that agricultural households in sub-Saharan Africa are frequently affected by seasonal malaria outbreaks, often impacting multiple members simultaneously. This dual burden, loss of active labor and increased healthcare expenditures, is particularly severe among households already characterized by low agricultural incomes and small cultivated areas (Seck *et al.*, 2010). The average healthcare cost during the rainy season was USD 37.8, compared to only USD 12.35 in the dry season. Direct costs include medical consultations, medications, and sometimes transportation to health centers. These are compounded by indirect or opportunity costs, estimated at USD 113, representing the value of agricultural workdays lost due to illness. Similar studies in West Africa (Onwujekwe *et al.*, 2000) have shown that the total cost of malaria, both direct and indirect, constitutes a significant share of annual household income. Even when affected individuals do not participate in family farming, they often contribute as hired labor elsewhere. The opportunity cost of malaria accounts for 21% and 3% of total production costs during the rainy and dry seasons, respectively. The observed reduction in PI (~32.8 percentage points) corresponds to ~70% of the margin, comparable to findings in Zambia (Fink & Masiye, 2015). Critical farming tasks, such as nursery preparation, sowing, transplanting, weeding, and harvesting, require a healthy and consistent labor force to ensure technical and economic efficiency. Worker absences compromise both the quality of operations and adherence to agricultural timelines. Overall, these results demonstrate a measurable negative impact of malaria on rice farm profitability,

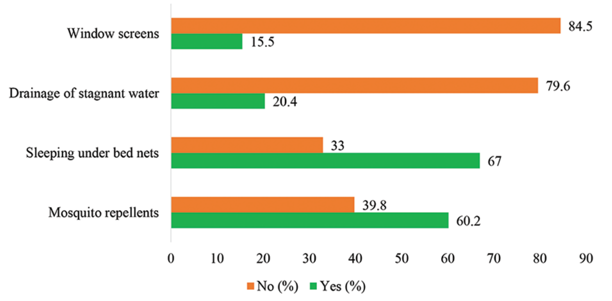

Figure 3. Adoption of mosquito prevention methods
Source: Authors' calculations based on household survey data analyzed using Microsoft Excel 2016.

particularly during the rainy season, where declines in net margins and PI are more pronounced during this period. This is largely due to the overlap between peak malaria transmission and labor-intensive agricultural activities, resulting in both increased healthcare costs and reduced labor productivity. These findings are consistent with Asenso-Okyere *et al.* (2011), who argue that malaria, by reducing labor availability and increasing medical expenses, poses a major constraint to agricultural growth and rural household welfare in sub-Saharan Africa. During the dry season, the impact of malaria on net margins and PI is relatively less pronounced. Two econometric models were developed to identify the key determinants of profitability, one for the rainy season and one for the dry season. Only the rainy season model was statistically significant (F-statistic = 7.905; p-value = 0.0002), with an explanatory power of 32.6%. Profitability was significantly influenced by three key variables: cultivated area, number of workdays lost, and malaria prevalence. These same variables were tested using the StepAIC method from the MASS package to identify determinants of rice yield during the rainy season. Only the total healthcare cost, the number of workdays lost during farming activities, and the gender of the household head were statistically significant. The regression results not only confirm the statistical significance of malaria-related variables but also allow a quantitative interpretation of their economic impact. For instance, each additional workday lost due to malaria could reduce farm profitability by approximately USD 93, which corresponds to a relative decline of 3.6% compared to the baseline profitability level. Similarly, expanding the cultivated area by one ha is associated with a probable 44.5% reduction in profitability, suggesting that larger plots may exacerbate management inefficiencies and labor bottlenecks, particularly during the rainy season. Survey results indicate higher adoption of personal protection measures, with sleeping under bed nets (67%) and mosquito repellents (60.2%) being the most common, compared to environmental or structural measures, such as low uptake of drainage of stagnant water (20.4%) and window screens (15.5%). This pattern suggests a reliance on household-level behaviors rather than community- or infrastructural-based interventions, which may limit the effectiveness of integrated vector control in irrigated rice systems. These findings are consistent with a 2023 qualitative study in Côte d'Ivoire by Chan *et al.* (2023), which found that farmers in irrigated schemes recognize their role in mosquito proliferation but rarely engage in coordinated environmental control due to a lack of support and resources. Pegalepo *et al.* (2025) emphasized that sustainable pest management in rice systems requires integrating farmer knowledge with technical assistance for drainage and habitat modification. The World Health Organization (2023) recommends combining personal protection with environmental management strategies such as larval source reduction and improved irrigation practices, particularly in agricultural zones with high malaria transmission. However, as noted by Otolorin *et al.* (2025), uptake of structural measures remains low in many rural contexts due to infrastructural limitations and weak cross-sectoral coordination.

5.1. Contribution beyond existing literature

This study extends prior research on the nexus between malaria and agriculture in several important ways. First, while earlier works have primarily emphasized the epidemiological burden of malaria or its macroeconomic effects (Gallup & Sachs, 2001; Sachs & Malaney, 2004), our analysis provides micro-level evidence of how malaria prevalence directly alters the economic management of family rice farms. By quantifying the dual impact of lost labor days and increased healthcare costs, the study demonstrates that malaria is not only a health constraint but also a determinant of farm-level profitability and resilience. Second, the methodological approach combines seasonal comparative analysis (rainy versus dry season) with econometric modeling, capturing temporal variations in both disease prevalence and agricultural labor demand. This dual perspective represents a unique methodological improvement over previous studies, which often treat health shocks as static or uniform across time. Third, the findings carry specific policy implications for integrated health–agriculture programs. The evidence shows that malaria-related costs account for up to 21% of total production costs during the rainy season, underscoring the need for policies that jointly address health and agricultural productivity. For instance, targeted interventions, such as subsidized healthcare for farming households, seasonal malaria prevention campaigns in rice-growing zones, and labor substitution schemes, could significantly mitigate the economic burden of malaria. These recommendations go beyond generic health policies by situating malaria control within the strategic framework of agricultural development and food security. Finally, by focusing on the Gaya-Upstream perimeter, the study highlights the representativeness of local realities in Niger, offering insights that are both context-specific and transferable to other malaria-endemic rice systems in West Africa. This localized evidence contributes to filling the gap in the literature that has often overlooked the microeconomic consequences of malaria within irrigated agroecosystems.

5.2. Representativeness and limitations of the study

The sample of 104 rice farming households was determined using Cochran's formula (1977), ensuring statistical validity relative to the target population of 731 rice-producing units in the department of Gaya. This sample size provides an adequate representation of the farming households, as it captures diverse sociodemographic and production characteristics within the study area. Nevertheless, several limitations should be acknowledged. First, the sample is geographically restricted to the urban commune of Gaya, which may limit the generalizability of the findings to other rice-producing regions of Niger. Second, the survey was conducted during a specific agricultural season, and seasonal variations in malaria prevalence and farm management practices may not be fully captured. Third, while the sample size is sufficient for statistical analysis, it may not reflect all heterogeneities in household structures and coping strategies. Fourth, while malaria was the primary focus of this study, other health conditions, such as diarrheal and respiratory diseases, may also contribute to labor losses among farming households. These conditions were not systematically controlled for in the econometric models, and their potential influence on productivity outcomes is therefore recognized as a limitation.

Despite these limitations, the results can reasonably be expected to be similar in other rice-producing zones that share comparable socioeconomic, ecological, and health characteristics with Gaya, including areas with high malaria prevalence, similar farm structures, and equivalent access to health services. Thus, while the findings are context-specific, they provide insights that may be cautiously extended to regions with analogous conditions.

6. Conclusion and recommendations

This study assessed the impact of malaria on the economic performance of rice farming households in the Tillabéri region. The findings reveal that the agricultural population is relatively aging, with low levels of formal education and a strong reliance on family labor. Cultivated areas remain modest, limiting the potential for production intensification. Malaria emerges as a key vulnerability factor: It causes significant losses in labor days, affects multiple household members simultaneously, and generates substantial healthcare costs. Among these impacts, the opportunity cost of labor is particularly notable, representing the value of productive activities foregone when sick workers must be replaced. Econometric analysis confirmed that, especially during the rainy season, farm profitability is negatively influenced by malaria prevalence, the number of workdays lost, and, paradoxically, the size of the cultivated area. These results underscore the direct link between household health and agricultural productivity and income, highlighting how health shocks can severely constrain the economic resilience of family farms. While the findings are context-specific, they provide insights into the broader nexus between health and agricultural productivity. Future studies should employ panel data and integrate climatic and entomological variables to model spatio-temporal malaria–agriculture interactions, thereby strengthening the predictive power and generalizability of results.

Based on the findings, the following recommendations are proposed:

(a) For rice farmers

- Promote the use of insecticide-treated mosquito nets, regular drainage of stagnant water around rice fields, and community awareness campaigns on malaria prevention, particularly during the rainy season.
- Establish labor-sharing strategies, for instance, village-based mutual aid systems or labor tontines, to mitigate the impact of illness-related absences.
- Encourage rational intensification of production rather than expanding cultivated areas that may be difficult to manage effectively.

(b) For the government

- Deploy mobile health clinics and establish village-level pharmaceutical depots during the rainy season to improve access to healthcare.
- Continue efforts to reduce the direct cost of malaria treatment to ease the financial burden on farming households.
- Implement seasonal malaria prevention campaigns aligned with the agricultural calendar, particularly in June–July, when the rainy season begins. Measures may include indoor residual spraying, distribution of mosquito nets, and seasonal chemoprevention.

(c) For agricultural policy, research, and rural development

- Integrate the health-agriculture nexus into farm support policies and research agendas.
- Support farmer organizations in developing mutual health coverage systems and labor management schemes.
- Promote light mechanization, such as power tillers, seeders, and manual weeders, to reduce dependence on human labor, especially during the rainy season when morbidity is high.

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Conflict of interest

The authors declare that they have no competing interests.

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Writing – review & editing: Idrissa Saidou Mahamadou

Ethics approval and consent to participate

This study was conducted in accordance with ethical standards for research involving human participants. Informed consent was obtained from all respondents before data collection, following a clear explanation of the study's purpose, procedures, and voluntary nature of their participation.

Consent for publication

Not applicable.

Availability of data

The data supporting the findings of this study, including household survey responses, agricultural performance indicators, and malaria prevalence records, are available from the corresponding author on reasonable request.

Further disclosure

Part of the findings were presented at academic meetings (At the African University of Social Sciences, Technology and Medical, Janvier, June 28, 2025, Impact of Malaria on Agricultural Productivity in Niger: cas of Gaya at Institute of Higher Health Studies? Academic Seminars, Niamey, Niger) and (At the African University of Social Sciences, Technology and Medical, Academic Seminars, Niamey, Niger, January 12, 2026, Health Shocks and Economic Resilience: A Bayesian Mediation Analysis of Malaria in Rainfed Rice Systems in Niger).

References

Adekanye, J.O., Adeoti, A.I., Adepoju, A.O., & Awoyemi, T.T. (2020). Effect of workdays lost to presumptive malaria on households' poverty status among food crop farming households in rural South West, Nigeria. *Uniosun Journal of Agriculture and Renewable Resources*, 4(1):1-26.

https://doi.org/10.5281/zenodo.3821234

Adeoti, A., Barry, B., Namara, R., Kamara, A., & Titiati, A. (2011). Water management practices and irrigation performance in Nigeria: Farmers' perceptions and policy implications. *Agricultural Water Management*, 98(5):733-741.

https://doi.org/10.1016/j.agwat.2010.12.004

Adewale, T.A., Adebosin, W.G., & Oladoja, S.O. (2016). Impact of Malaria on Agricultural Productivity. *International Journal of Advanced Research in Social Engineering and Development Strategies,* 4(1):1–12.

African Development Bank (AfDB). (2024). Improving Resilience and Food Security - ADER; 2024. Available from: https://www.afdb.org/sites/default/files/news_documents/ader_2024_-_chapter_2_en.pdf [Last accessed on 2025 Dec 10].

Andrade, M.V., Noronha, K., Diniz, B.P.C., Guedes, G, Carvalho, LR., Silva, V.A., *et al*. (2022). The economic burden of malaria: A systematic review. *Malar Journal*, 21(1):283.

https://doi.org/10.1186/s12936-022-04303-6

Asenso-Okyere, K., Asante, F.A., Tarekegn, J., & Andam, K.S. (2011). A review of the economic impact of malaria in agricultural development. *Agricultural Economics*, 42(3):293-304.

https://doi.org/10.1111/j.1574-0862.2011.00584.x

Bélières, J.F., Bourgeois, R., Marzin, J., Ton-Nu, C., & Triomphe, B. (2015). Les *Agricultures Familiales* du Monde: Définitions, Contributions et Politiques Publiques. AFD, CIRAD.

Breusch, T.S., & Pagan, A.R. (1979). A simple test for heteroscedasticity and random coefficient variation. *Econometrica*, 47(5):1287-1294.

https://doi.org/10.2307/1911963

Burnham, K.P., & Anderson, D.R. (2002). Model Selection and *Multimodel Inference*: A Practical Information-Theoretic Approach. 2nd ed. Berlin: Springer.

Chan, K., Konan, K.AC., Doudou, D.T., Kouadio, G.B., Lines, J., Aunger, R., *et al*. (2023). Rice farmers' knowledge, attitudes and practices towards mosquitoes in irrigation schemes in Côte d'Ivoire: A qualitative study. *Malar Journal,* 22(1):352.

https://doi.org/10.1186/s12936-023-04785-y

Chan, K., Tusting, L.S., Bottomley, C., Saito, K., Djouaka, R., & Lines, J. (2022). Malaria transmission and prevalence in rice-growing versus non-rice-growing villages in Africa: A systematic review and meta-analysis. *Lancet Planet*

Health, 6(3):e257-e269.

https://doi.org/10.1016/S2542-5196(21)00349-1

Cochran, W.G. (1977). Sampling Techniques. 3rd ed. New York, NY: John Wiley and Sons.

Edith, P., Han, S., Lauer, J., Barschkett, M., & Arcand, J.L. (2023). The macroeconomic impact of increasing investments in Malaria control in 26 high Malaria burden Countries: An application of the Updated EPIC model. *International Journal of Health Policy and Management*, 12:7132.

https://doi.org/10.34172/ijhpm.2023.7132

FAO. (2017). The Future of Food and Agriculture. Trends and Challenges. Rome: FAO. Available from: https://openknowledge.fao.org/handle/20.500.14283/i6583e [Last accessed on 2026 Jan 28].

FAO. (2023b). The State of Food Security and Nutrition in the World 2023. Rome: Food and Agriculture Organization of the United Nations. Available from: https://openknowledge.fao.org/items/445c9d27-b396-4126-96c9-50b335364d01 [Last accessed on 2026 Jan 28].

Fink, G., & Masiye, F. (2015). Health and agricultural productivity: Evidence from Zambia. *Journal of Health Economics*, 42:151-164.

https://doi.org/10.1016/j.jhealeco.2015.04.004

Food and Agriculture Organization (FAO). (2023a). Building Resilience through Agrifood Systems Transformation. Available from: https://openknowledge.fao.org/server/api/core/bitstreams/fb1b1163/e017/4b20/b932/06f2629e993c/content

Gallup, J.L., & Sachs, J.D. (2001). The economic burden of malaria. *American Journal of Tropical Medicine and Hygiene*, 64(1-2 Suppl):85-96.

https://doi.org/10.4269/ajtmh.2001.64.85

Gujarati, D.N., & Porter, D.C. (2021). Basic Econometrics. 6th ed. United States: McGraw-Hill Education.

Hair, J.F., Black, W.C., Babin, B.J., & Anderson, R.E. (2021). Multivariate Data Analysis. 8th ed. United States: Cengage Learning. ISBN: 9781473756540.

Hardy, H., Hopkins, R.J., Mnyone, L., & Hawkes, FM. (2025). Climate change adapted rice production: Does the system of rice intensification impact malaria vector ecology?. *Parasites Vectors,* 18(1):427.

https://doi.org/10.1186/s13071-025-06973-y

Ijumba, J.N., & Lindsay, S.W. (2001). Impact of irrigation on malaria in Africa: Paddies paradox. *Medical and Veterinary Entomology,* 15(1):1-11.

https://doi.org/10.1046/j.1365-2915.2001.00279.x

INS. (2022). Enquête Nationale Sur Les Conditions de Vie Des Ménages et l'Agriculture au Niger (ECVMA). Niamey: *Institut National de la Statistique*. Available from: https://www.stat-niger.org/anado/index.php/catalog/173/related-materials [Last accessed on 2026 Jan 28].

Institut National de la Statistique (INS). (2022). Annuaire Statistique du Niger. Niamey: INS.

Institut National de la Statistique (INS). (2022). Tableau de Bord Social 2022. Niamey: Ministère du Plan, République du Niger. INS Niger Official Site. Available from: https://stat-niger.org [Last accessed on 2026 Jan 28].

Keiser, J, Singer, B.H., & Utzinger, J. (2005a). Reducing the burden of malaria in different eco-epidemiological settings with environmental management: A systematic review. *Lancet Infect Dis*, 5(11):695-708.

https://doi.org/10.1016/S1473-3099(05)70268-1

Keiser, J., Castro, M.C., Maltese, M.F., Bos, R., Tanner, M., Singer, B.H., *et al.* (2005b). Effect of irrigation and large dams on the burden of malaria on a global and regional scale. *American Journal of Tropical Medicine and Hygiene*, 72(4):392-406.

https://doi.org/10.4269/ajtmh.2005.72.392

Lamesgen, A., Engidaw, M., Gedif, G., Gete, M., & Belay, Y.A. (2025). The economic burden of malaria in Africa: A systematic review of cost of illness studies. *Malar Journal*, 24(1):223.

https://doi.org/10.1186/s12936-025-05390-x

Lukwa, A.T., Mawoyo, R., Zablon, K.N., Siya, A., & Alaba, O. (2019). Effect of malaria on productivity in a workplace: The case of a banana plantation in Zimbabwe. *Malar Journal*, 18(1):390.

https://doi.org/10.1186/s12936-019-3021-6

Mahamadou, I.S., Boubacar, S., & Ouedraogo, A. (2025). Farm management practices and health outcomes in kourtheye District, Niger: A focus on climate variability impacts. *Agricultural Sciences*, 16(1):68-88.

https://doi.org/10.4236/as.2025.161005

Malaney, P. (2002). Microeconomic approaches to studying the effects of malaria on education. *American Journal of Tropical Medicine and Hygiene*, 71(2 Suppl):161-166.

https://doi.org/10.4269/ajtmh.2004.71.161

Malaney, P., Spielman, A., & Sachs, J. (2004). The malaria gap. The American Journal of *Tropical Medicine and Hygiene*, 71(2 Suppl):141-146.

Mendola, M. (2007). Agricultural technology adoption and poverty reduction: A propensity-score matching analysis for rural Bangladesh. *Food Policy*, 32(3):372-393.

https://doi.org/10.1016/j.foodpol.2006.07.003

Midi, H., & Ariffin, S.B. (2013). Modified standardized Pearson residual for the identification of outliers in logistic regression model. *Journal of Applied Sciences*, 13(6):828-836.

https://doi.org/10.3923/jas.2013.828.836

Ministry of Health, Niger. (2021). *Enquête Nationale Sur Les Facteurs de Risque Des Maladies Transmissibles et Non Transmissibles (STEPS Niger 2021)*. Ministère de la Santé Publique, de la Population et des Affaires Sociales, Niamey, Niger. WHO STEPS Niger 2021 Report.

Monroe, A., Olapeju, B., Moore, S., Hunter, G., Merritt, A.P., Okumu, F., *et al*. (2021). Improving malaria control by understanding human behaviour. *Bulletin of the World Health Organization*, 99(11):837-839.

https://doi.org/10.2471/BLT.20.285369

Mouchet, J., Carnevale, P., Coosemans, M., Julvez, J., Manguin, S., Richard-Lenoble, D., *et al*. (2004). Biodiversité du Paludisme Dans le Monde. Paris: J. Libbey Eurotext.

Mouchet, J., Manguin, S., Sircoulon, J., Laventure, S., Faye, O., Onapa, A., *et al*. (2004). Agriculture and malaria in Africa: Eco-epidemiological determinants. *Acta Tropica*, 89(2):99-117.

https://doi.org/10.1016/j.actatropica.2003.10.012

Nguyen, T.T., Gryseels, C., Tran, D.T., Smekens, T., Gerrets, R., Nguyen, X.X., *et al*. (2021). Understanding malaria persistence: A mixed-methods study on the effectiveness of malaria elimination strategies in South-Central Vietnam. *Frontiers in Public Health*, 9:742378.

https://doi.org/10.3389/fpubh.2021.742378

Onwujekwe, O., Chima, R., & Okonkwo, P. (2000). Economic burden of malaria illness on households versus that of all other illness episodes: A study in five malaria holo-endemic Nigerian communities. *Health Policy*, 54(2):143-159.

https://doi.org/10.1016/S0168-8510(00)00105-6

Otolorin, G.R, María, E.C., Oyelola, A.A., & Emma, S. (2025). Integrated vector management for malaria control: A review of approaches and effectiveness. *Transactions of The Royal Society of Tropical Medicine and Hygiene*, 119(11):1223-1232.

https://doi.org/10.1093/trstmh/traf084

Ozodiegwu, I.D., Legris, G., Chiziba, C., & Mhlanga, L. (2025). Agricultural Work, Malaria Prevalence, and Mediating Factors: A Cross-Sectional Analysis of Data from 15 Sub-Saharan African Countries. [medRxiv Preprint].

https://doi.org/10.1101/2025.07.21.25331926

PDC, Gaya. (2024). *Plan de Développement Communal de Gaya: Rapport de Validation*.

Pegalepo, E., Bocco, R., Onaga, G., Nwilene, F., Tamò, M., Togola, A., *et al*. (2025). Sustainable insect pest management options for rice production in Sub-Saharan Africa. *Insects*, 16(11):1175.

https://doi.org/10.3390/insects16111175

Sachs, J., & Malaney, P. (2002). The economic and social burden of malaria. *Nature*, 415(6872):680-685.

https://doi.org/10.1038/415680a

Salmerón-Gómez, R., García-García, C.B., & García-Pérez, J.A. (2025). A redefined variance inflation factor: Overcoming the limitations of the variance inflation factor. *Computational Economics*, 65:337-363.

https://doi.org/10.1007/s10614-024-10575-8

Sauerborn, R., Adams, A., & Hien, M. (1996). Household strategies to cope with the economic costs of illness. *Social Science and Medicine*, 43(3):291-301.

https://doi.org/10.1016/0277-9536(95)00375-4

Seck, P.A., Tollens, E., Wopereis, M.C.S., Diagne, A., & Bamba, I. (2010). Rising trends and variability of rice prices: Threats and opportunities for Sub-Saharan Africa. *Food Policy*, 35(5):403-411.

https://doi.org/10.1016/j.foodpol.2010.05.003

Snyman, K., Pitt, C., Aturia, A., Aber, J., Gonahasa, S., Namuganga, J.F., *et al*. (2025). Who pays to treat malaria and how much? Analysis of the cost of illness, equity and economic burden of malaria in Uganda. *Health Policy and Planning*, 40(1):52-65.

https://doi.org/10.1093/heapol/czae093

Sulemana, I., & James, H.S. Jr. (2014). Farmer identity, ethical attitudes and environmental practices. *Ecological Economics*, 98:49-61.

https://doi.org/10.1016/j.ecolecon.2013.12.011

Thiam, T., Kande, D., Ntuku, H., Guinovart, C., Galles, N., Merriman, L., *et al*. (2024). Identifying populations at high risk of malaria: A mixed-methods case-control study to inform targeted interventions in Senegal. *Malaria Journal*, 23(1):373.

https://doi.org/10.1186/s12936-024-05219-z

Tusting, L.S., Bisanzio, D., Alabaster, G., Cameron, E., Cibulskis, R., Davies, M., *et al*. (2019). Mapping changes in housing in Sub-Saharan Africa from 2000 to 2015. *Nature,* 568(7752):391-394.

https://doi.org/10.1038/s41586-019-1050-5

Udoh, E.J., & Ubong Abasi, R. (2025). The economic costs of malaria and behaviour of farming households towards treatment care in Ibesikpo Asutan Local Government Area, Akwa Ibom State, Nigeria. *International Journal of Organic Agriculture Research and Development*, 20(1):55-70.

https://doi.org/10.5281/zenodo.10876543

Venables, W.N., & Ripley, B.D. (2002). Modern Applied Statistics with S. 4th ed. Berlin: Springer. Available from: https://link.springer.com/book/10.1007/978-0-387-21706-2 [Last accessed on 2025 Dec 04].

Véronique, T. (2016). Politiques de Santé et Théories Economiques. hal-01311494. Ver. 1. Available from: https://hal.science/

hal-01311494 [Last accessed on 2025 Dec 04].

WHO. (2023). World Malaria Report 2023. Geneva: World Health Organization. Available from: https://cdn.who.int/media/docs/default-source/malaria/world-malaria-reports/world-malaria-report-2023.pdf [Last accessed on 2026 Jan 28].

World Food Programme (WFP). (2024). Integrated Resilience in the Sahel. Available from: https://www.wfp.org/publications/integrated-resilience-sahel [Last accessed on 2025 Dec 10].

World Health Organization (WHO). (2021). World Malaria Report 2021. Geneva: WHO.

World Health Organization. (WHO). (2022). World *Malaria Report* 2022. Geneva: WHO. Available from: https://www.who.int/publications/i/item/9789240064898 [Last accessed on 2025 Dec 10].