International Journal of Environmental Chemistry
2025, Vol. 9, No. 2, pp. 90-98
https://doi.org/10.11648/j.ijec.20250902.16

Research Article

Assessment of the Impact of Pesticides on Soil Quality in Rice-Growing Areas of Baguineda, Mali

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Abstract

The intensive use of pesticides in the rice-growing areas of the Baguineda Irrigated Perimeter Office (OPIB), as in several other rice-growing regions of Mali, is raising growing concerns about the environment and public health. This study was conducted to examine the impact of pesticide use on the quality of rice-producing soils, through an assessment of farmers' knowledge and practices and the detection and quantification of pesticide residues in soil samples. Preliminary surveys were conducted in four villages of Baguineda (Dougourakoro, Kognimba, Sebela, and Mofa) to identify the pesticides currently used by the farmers. These surveys involved 50 respondents with 15 farmers from Kognimba and Dougourakoro villages and 10 farmers from Mofa and Sebela. Subsequently, a sampling campaign collected 40 soil samples, which were analyzed at the Central Veterinary Laboratory in Bamako using an Agilent 7890 gas chromatograph. The surveys identified a list of 19 active pesticide substances currently used in the OPIB production area, including three herbicides, two fungicides, and fourteen insecticides. Four methods of managing empty pesticide packaging used by producers were also identified. Pesticide application practices, such as over- and under-dosing, were also observed. Among farmers, 33.5% follow the advice of OPIB supervisors on pesticide use, 44.5% rely on local distributors, while 12.25% follow the advice of their neighbors and 9.75% rely on their own experience, with none of them admitting to following the recommendations of pesticide manufacturers. These varied practices, including failure to comply with recommended dosages and lack of expert advice, contribute directly to soil contamination, as evidenced by the presence of three organochlorine pesticides (endosulfan α, endosulfan β, and lindane) and two organophosphates (dichlorvos and chlorpyrifos) in the samples analyzed. The concentrations measured, ranging from 0.008 to 0.28 $mg.kg^{-1}$, indicate that the soil is contaminated with pesticide residues, some of which are classified as persistent organic pollutants. This study highlights the need to continue adopting sustainable agricultural practices and raising farmers' awareness of the risks associated with the safe use of pesticides in order to preserve soil quality and public health in OPIB rice growing areas.

Keywords

Pesticide Residues, Rice Growing, Soil, Contamination, Baguineda, Mali

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Received: 11 September 2025; **Accepted:** 20 September 2025; **Published:** 9 October 2025

1. Introduction

Mali is a Sahelian country in West Africa, agriculture remains the pillar of the national economy, accounting for around 40% of gross domestic product (GDP) and constituting the main source of incomes for the majority of the rural population [1]. Among the strategic sectors, rice cultivation occupies a prominent place, with an estimated contribution of 8.3% of agricultural GDP [2]. The country is now one of the top four rice producers in Africa, with annual production exceeding two million tons [3].

The Baguinéda Irrigated Perimeter Office (OPIB) was set up in this context to play a crucial role in national food security policy through the promotion of rice cultivation. However, phytosanitary constraints, particularly insect attacks, fungal diseases, and weeds, are pushing producers to resort to the massive use of pesticides. Although these products improve yields, their excessive and often uncontrolled use poses a serious threat to human health, the environment, and soil quality [4, 5].

Since the 1990s, Africa has seen an exponential increase in pesticide use, with a 261% increase between 1990 and 2010. Mali is no exception to this trend, consuming more than 5,400 tons of pesticides each year, 90% of which are used in the agricultural sector [6]. This growing use of plant protection products, which are often poorly stored and misused, leads to frequent cases of poisoning. In Mali, pesticides are the third leading cause of accidental poisoning deaths [7].

The use of pesticides in agriculture is a common practice intended to protect crops from pests and diseases. However, this practice can have adverse effects on soil quality, particularly in areas of intensive cultivation such as Baguineda, where rice farming is predominant. Field research has revealed elevated levels of pesticide residues in rice field soils, raising concerns about the sustainability of agricultural systems [8].

Several studies have shown that pesticides can cause significant soil contamination. Pesticide residues can persist in the soil, affecting not only groundwater quality but also soil biodiversity [9]. Pesticides, particularly insecticides and fungicides, disrupt soil microbiology, leading to a decrease in microbial diversity, which can affect decomposition processes and soil fertility [10].

Although specific research on the impact of pesticides on soil quality in rice-growing areas in Baguineda is limited, some regional studies provide valuable information. The work of some authors shows that repeated pesticide application can alter the physical and chemical properties of soil, including its pH, cation exchange capacity (CEC), and organic matter [11]. These changes can have long-term consequences for fertility and agricultural productivity.

2. Materials and Methods

2.1. Study Area

Baguineda is a rural commune in the Cercle of Kati and the Koulikoro region, located 30 km east of the city of Bamako on the banks of the Niger River. This rural commune covers an area of 987.04 km^2 and comprises 32 villages. The climate is Sudano-Sahelian, with a rainy season from June to October and annual rainfall of between 900 and 1,000 millimeters (mm). Agriculture, consisting mainly of rice cultivation with the facilities of the Baguneda Irrigated Perimeter Office (OPIB) and market gardening, is the main economic activity of the population.

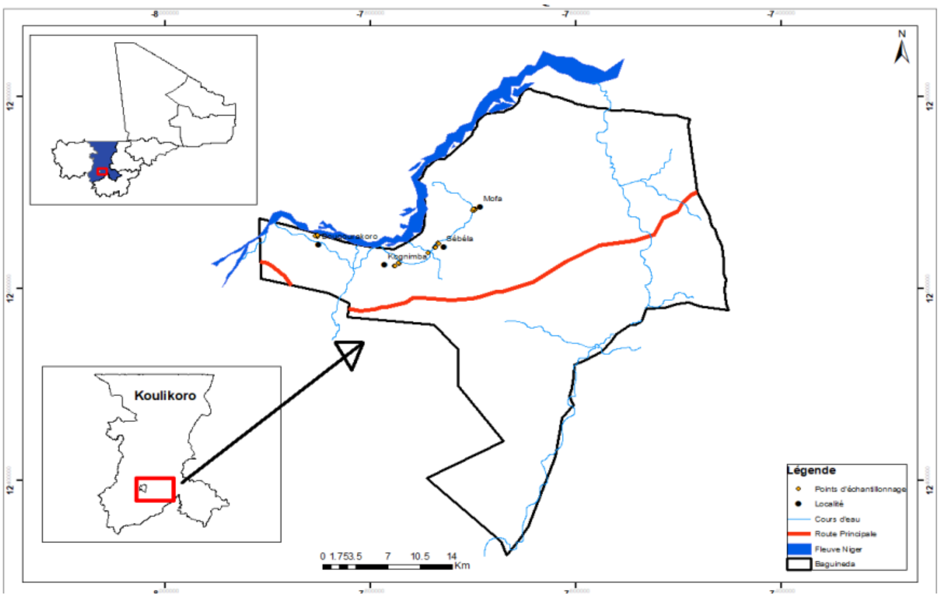

Figure 1. *Study area showing sampling locations.*

2.2. Survey and Collection of Pesticide Data Used by Rice Productors

Surveys were conducted to identify recent and older pesticides used by farmers in the four OPIB sectors during the 2021-2022 harvest season. The surveys were conducted according to the following plan:

1) Development of the questionnaire: A questionnaire was designed to collect information on pesticides used or currently in use in rice cultivation,
2) Organization of meetings: To facilitate the collection of information, meetings were held in the field with rice farmers in each sector visited.
3) Distribution of the questionnaire: The questionnaire was distributed to all participants present at these meetings.
4) Presentation and explanation: Before proceeding with data collection, we introduced our scientific team and the purpose of our visit, taking care to explain the content of the questionnaire in detail in order to obtain accurate responses. This approach was systematically applied in the four OPIB sectors in order to achieve our objectives.

Before the main survey was conducted, the questionnaire was tested on a small group of farmers to assess its clarity and relevance. This pilot phase identified any ambiguities and gathered constructive feedback on the wording of the questions. Based on this feedback, adjustments were made to refine the questionnaire, ensuring that it adequately met the study objectives and was appropriate for the context of the target farmers. This approach helped to improve the quality of the data collected during the main survey.

The survey was conducted among producers belonging to four major rice production sectors supervised by OPIB, namely Dougourakoro, Kognimba, Mofa, and Sebela. Its purpose was to document the use of pesticides on rice and vegetables produced in the study area. The four sectors were divided into two distinct subgroups based on the size of the areas cultivated per sector. The size of the samples to be surveyed per sector was set in proportion to the size of the production sector. Thus, fifteen producers per sector for Kognimba and Mofa and ten per sector for Dougourakoro and Sebela, bringing the total number of respondents to fifty for the four sectors. These producers were interviewed at random between November 23 and December 8, 2022, using a revised questionnaire focused on predefined objectives to document the main pests that attack rice and selected vegetables, pesticide use habits (type of pesticides, sources of supply, dosages, method of selecting the timing of spraying and interval of insecticide application, interval before harvest, etc.). In order to obtain valid and reliable data, the information was verified, corrected, and streamlined by repeating questions, interviewing neighboring farmers, and using the interviewer's personal judgment to ensure the accuracy of the respondent's answers.

2.3. Pesticide Residue Analysis

2.3.1. Sample Collection

All rice fields located within the Baguineda Irrigated Perimeter Office were first georeferenced using RTREX GPS, enabling each sampling point to be precisely located [12]. Between November and December 2022, fourteen soil samples were collected from four OPIB sectors (Dougourakoro, Kognimba, Mofa and Sebela) and then placed in polyethylene bags. Each sample was labeled with a unique code comprising the producer's initials, the name of the village, and the month and year of collection. The samples were then transported in a cooler to the Central Veterinary Laboratory in Bamako.

2.3.2. Samples Preparation and Extraction

In the laboratory, each soil sample was dried at room temperature, then crushed, ground, and sieved to 1 mm. Solid-liquid extraction was performed according to EPA method 1699 [13]: 5 g of each sample was weighed, then 15 mL of a 50:50 v/v mixture of acetone and hexane was added. The sample was then vortexed and centrifuged at 2,500 rpm for 5 minutes. This operation was repeated twice, with the third extraction requiring only 5 mL of hexane. The combined extracts were concentrated to 0.5 mL using a rotary evaporator [14].

2.3.3. Preparation of Standards Solution

An accurately weighed 10mg of an individual analytical grade pesticide was dissolved in 10 ml volumetric flask using n-hexane to prepare the standard stock solution to 1000 $mg.kg^{-1}$. Standard stock solution of each pesticide was serially diluted to obtain immediate lower concentration of 100 $mg.kg^{-1}$. A mixture of standard stock pesticide solution (analyte MIX solution) was prepared by taking 0.1ml solution of compatible (deltametrin, dichlorvos, endosulfan A, endosulfan B, chlorpyrifos, Lamda Cyhalothrin, Lindane and Permethrin) pesticide in a 10ml volumetric flask and making the volume up to the mark with n-hexane. Standard mixture contained 10 $mg.kg^{-1}$ of solution to determine the time of detection of the instrument. Then concentration standards 5 $\mu g.mL^{-1}$ was prepared by dilution in hexane. Then an assay range of five different levels at concentrations (0.0625, 0.125, 0.25, 0.5 and 1 $\mu g.mL^{-1}$) was prepared and used for GC calibration.

3. Results

3.1. Commonly Used Pesticides Against Different Pest of Rice and Vegetables in Survey Area

Based on the responses provided by the 50 farmers surveyed in the four sectors regarding the different types of pesticides used, such as insecticides, fungicides, and herbicides to control pests, a list of nineteen (19) pesticides was compiled. The data collected was compared with the local pesticide distributors in these four sectors then the suggestions and recommendations of agricultural advisors from the Baguineda Irrigation Office (OPIB). The compiled and summarized results are presented in the Table 1.

Table 1. Commonly used pesticides in the OPIB-Baguineda area.

Local name	Active Ingredient (Pesticide)	Use as
Lambda	Lambda-Cyhalothrin	Insecticide
Beret Rouge	Glyphosate	Herbicide
Caima rouge	Deltamethrin	Insecticide
Solevo	Permethrin	Insecticide
Tangana	Cypermethrin	Insecticide
Fanga	Profenofos	Insecticide
Aligator	Pendimethalin	Herbicide
Glyphader	Glyphosate	Herbicide
Pacha	Acetamiprid + L. Cyhalothrin	Insecticide
Synpirifox	Chlorpyrifos	Insecticide
Farima	Profenofos	Insecticide
Champion	Chlorpyrifos	Insecticide
Calfos	Profenofos	Insecticide
Dursban	Chlorpyriphos-ethyl	Insecticide
Magnum	Lambda	Insecticide
Duron	Pirimiphos-ethyl	Insecticide
Samory Toure	Bensulfuron-methyl	Insecticide
Tihan	Spirotetramate	Insecticide
Belt	Flubendiamide	Fungicide
Rapax	Azoxystrobine	Fungicide

*Source: Field surveys conducted in 2022 with OPIB by LCV.

The survey results were compiled based on the responses provided by producers. They classify pesticides according to their use. Of the nineteen molecules identified, two (2) are fungicides, three (3) are herbicides, and fourteen (14) are insecticides.

3.2. Pesticide Dosage Practices Among Farmers

Producers were surveyed to gather information on their pesticide use practices. The summary of responses to the various questions on this topic is presented in the Table 2 below.

Table 2. Percentage of producers using pesticides according to instructions received from various advisors.

Sectors	Pesticide Use following Instructions			
	OPIB's advisors	Local Distributor	Neighboring Producers	Farmers own experience
Kognimba	31	47	12	10
Mofa	28	41	17	14
Sebela	35	43	12	10
Dougourakoro	40	47	8	5
Average	33,5	44,5	12,25	9,75

*Source: Field surveys conducted in 2022 with OPIB by LCV.

In the four selected sectors of the Baguineda Irrigated Perimeter Office (OPIB), 33.5% of farmers used pesticides in accordance with the instructions and advice given by OPIB supervisors, and 44.5% followed the advice of the local pesticide distributor. New producers follow the advice of their neighbors (12,25%) and 9,75% of producers use their own experience. No producers admitted to following the instructions provided by the pesticide manufacturer. In the study villages, 17.15% of producers acknowledge having used higher application than those recommended by the various advisors operating in the area while 11.26% used lower application.

3.3. Management of Empty Pesticide Containers

The results of surveys on the management of empty pesticide packaging by rice producers in the four (4) sectors of OPIB Mali identified four (4) current practices as methods of managing this packaging. The table summarizes the main information collected:

Table 3. Percentage of producers using pesticides according to instructions received from various advisors.

Management Practices	Practice Rate	Description	Disadvantages
Recovery and storage	55	Storage of empty pesticide containers in specific locations on farms	Storage is not carried out under safe conditions, which may pose contamination risks.
Burning	15	Burning empty packaging on farms	Quick solution that can release toxic substances into the environment and is not a recommended method
Informal recycling	20	Giving certain packaging a second life by reusing it for other purposes, such as storing water or grain	This practice poses enormous health risks, especially since it is very difficult to ensure that these packages are properly cleaned.
Landfilling	10	Packaging buried in the soil on farms	This method can contaminate soil and groundwater in the long term.

*Source: Field surveys conducted in 2022 with OPIB by LCV.

The practice rates were used to rank each management practice. The analysis shows that "recovery and storage" ranks first, followed by "informal recycling" in second place. Burning packaging ranks third, while landfilling is the least used practice.

3.4. Pesticide Residues in Soil Samples

This study involved taking forty (40) soil samples from twenty locations spread across four rice-growing areas designated as "sectors" by the Baguinéda Irrigated Perimeter Office (OPIB). Analysis of the samples detected residues of nine (9) pesticides on the list of pesticides used (Table 1): Endosulfan α, Endosulfan β, Lambda-cyhalothrin, Deltamethrin, Permethrin, Dichlorvos, Chlorpyrifos, Lindane, and Profenofos. Table 4 shows the concentrations (in $mg.kg^{-1}$) found in the various soil samples. The majority of the results were below the analytical detection limit (<LOD), indicating low or non-existent residual levels in many cases, although traces of certain pesticides were occasionally observed at some sampling points.

Table 4. Quantity of residue of different pesticides quantified from soil samples collected from 4 OPIB's sectors.

Samples Code	Quantity of detected residue ($mg.kg^{-1}$)								
	Endosulfan A	Endosulfan B	Lambda-Cyhalothrin	Deltamethrin	Permethrin	Diclorvos	Chlorpyri fos	Lindane	Profenofos
KS2E6	ND	ND	ND	ND	ND	ND	ND	0,055	ND
SS3E11	0,074	0,103	ND	ND	ND	ND	ND	ND	ND
SS3E14	ND	ND	ND	ND	ND	0,008	ND	ND	ND
MS4E18	ND	ND	ND	ND	ND	ND	0,289	ND	ND

ND: Not Detected $1mg.kg^{-1}$: 1 milligram of pesticide per kilogram of soil

The results of the soil sample analysis reveal a diversity in the presence of pesticide residues. These residues belong to two main groups of pesticides: Organophosphates (Chlorpyrifos and Profenofos) and Organochlorines (Endosulfan A, Endosulfan B and Lindane). In the four sectors studied, chlorpyrifos residues were detected at a concentration of 0.008 $mg.kg^{-1}$, indicating a very low presence. This low concentration could suggest limited use or rapid degradation of this pesticide in the environment. In contrast, Profenofos residues were quantified at 0.055 $mg.kg^{-1}$. This concentration could indicate exposure to or specific use of this pesticide, which warrants further investigation to understand current agricultural practices. In addition, levels of Endosulfan A (0.074 $mg.kg^{-1}$), Endosulfan B (0.103 $mg.kg^{-1}$), and Lindane (0.289 $mg.kg^{-1}$) were also detected in the samples. The presence of these organochlorine pesticides at high levels suggests two to three possible scenarios:

1) Previous use of these products, which could still be affecting the soil.
2) Recent use, which could indicate continued application in agricultural practices.
3) It is also possible that both cases coexist, raising questions about the potential impact of these residues on the environment and public health.

4. Discussion

The results obtained regarding pesticide use by farmers in the sectors of the Baguinéda Irrigated Perimeter Office (OPIB) showed that only 33.5% of farmers use pesticides in accordance with the instructions and advice of OPIB supervisors. This indicates a certain level of compliance with professional recommendations, but there is still a significant percentage of farmers (66.25%) who do not follow this advice. This could be due to several factors, such as a lack of awareness of the importance of following these guidelines or insufficient confidence in the recommendations provided. According to a FAO study, following expert recommendations is crucial to minimizing the environmental and health impacts of pesticides [15].

The fact that 44.5% of farmers follow the advice of local pesticide distributors raises concerns. Pesticide distributors may be motivated by commercial interests, which can influence the quality of the advice they provide. Research by the Pesticide Action Network during 2018 highlights that distributors may sometimes promote products that are not the most appropriate for farmers, leading to excessive or inappropriate pesticide use [16].

It is also interesting to note that only 12.25% of new producers follow the advice of their neighbors. This could indicate a lack of support networks or information sharing among farmers, which is essential for newcomers to the sector. Another study by showed that knowledge sharing among peers is essential for the effective adoption of good agricultural practices [17].

The fact that 9.75% of producers rely on their own experience highlights the need for ongoing training and education on pesticide use. The total absence of producers reporting that they follow pesticide manufacturers' instructions is particularly concerning. This could indicate mistrust of the information provided by manufacturers or a lack of access to these instructions. The work of another similar study emphasized the importance of communication between pesticide manufacturers and farmers to ensure the safe and effective use of chemicals [18].

The results of the survey on empty packaging management indicate that the practice of "collection and storage" is the most common among farmers, followed by "informal recycling." This suggests that farmers are aware of the need to properly manage empty packaging and are seeking solutions to minimize environmental impacts. The practice of recovery and storage is often considered an essential first step in waste management, reducing the risk of contamination and promoting recycling [19].

On the other hand, "informal recycling" as a second practice can pose safety and efficiency issues. Authors who have worked on empty packaging management have reported that informal recycling can be associated with unregulated methods that do not guarantee worker safety or environmental protection [20]. This practice can also lead to the spread of toxic substances if packaging is not properly treated. The ranking of incineration in third place and landfill in last place also merits consideration. Incinerating packaging may seem like a quick solution, but it poses significant environmental risks, including the release of harmful air pollutants [21]. In light of a study on the same subject, it was concluded that the incineration of plastic waste, including pesticide packaging, can generate dioxins and furans, which are known to be carcinogenic substances [22].

Finally, the fact that landfilling is the least used practice may indicate farmers' awareness of the harmful effects of this method on the environment. The storage and landfilling of waste can lead to soil and groundwater contamination [23].

Farmers reported using higher doses of pesticides than those recommended by advisors and distributors due to the apparent ineffectiveness of the pesticides. In some cases, they reported using lower doses due to the high price of certain pesticides. Farmers' statements regarding the use of pesticide doses higher than those recommended highlight a critical issue in the management of plant protection products in agriculture. Several studies have shown that the perceived effectiveness of pesticides can influence farmers' decisions. For example, research conducted by the Pesticide Action Network (PAN) revealed that farmers, faced with resistant pests, are often tempted to increase doses to achieve the desired results [24].

In addition, the use of excessive doses can have serious environmental and health consequences. According to a study concluted, applying higher than recommended doses can lead to increased soil and water contamination, affecting biodiversity and human health [25]. This also raises concerns about pest resistance, which can be exacerbated by excessive pesticide use [26].

On the other hand, farmers' decision to use lower doses due to the high cost of certain pesticides highlights the economic impact on agricultural practices. A study conducted by the World Bank during 2017 found that input costs, including pesticides, can influence farmers' management strategies [27]. Farmers often choose to reduce doses to minimize expenses, which could ultimately compromise their ability to manage pests effectively.

In 80% of the sites studied, no detectable residues were observed, suggesting that contamination was not widespread [28, 29]. However, four samples revealed the presence of persistent organochlorines: Endosulfan α (0.074 $mg.kg^{-1}$) Endosulfan β (0.103 $mg.kg^{-1}$) in Sébela, and Lindane (0.055 $mg.kg^{-1}$) in Kognimba, reflecting historical contamination in Sahelian soils consistent with a similar studies conducted during 2020 and confirmed in 2024 [30, 31].

Chlorpyrifos (0.289 $mg.kg^{-1}$) detected in Mofa and Dichlorvos (0.008 $mg.kg^{-1}$) in Sébela indicate recent use of organophosphate insecticides, probably in violation of current regulations [32]. The copresence of old and new molecules highlights a gradual transition in phytosanitary practices [33].

The distribution of residues, mainly concentrated in Sebela and Mofa, reflects irregular management (informal supply, non-compliant formats), as well as mobility influenced by soil characteristics and the effects of leaching linked to seasonal rains [28, 29].

5. Conclusions

The results of the study provided a better understanding of the role played by the Baguineda Irrigated Perimeter Office in rice production, while highlighting the challenges associated with the increasing use of pesticides and the consequences for soil quality, the environment, and human health. A majority of producers do not follow professional recommendations, revealing a lack of awareness and perception of the risks associated with pesticide use. Dependence on local pesticide dealers, often motivated by commercial interests, increases the risk of excessive use of plant protection products. Soil contamination in rice-growing areas can be attributed to inappropriate agricultural practices by producers. Poor management of pesticide packaging, characterized by disposal techniques that do not meet the required standards, is a major problem. This poor management leads to leaks or direct spills of pesticides onto the soil, causing immediate contamination. Failure to comply with recommended dosages when applying pesticides is also a significant cause of soil contamination. Farmers who resort to overdosing, often in the hope of achieving better results against pests, contribute to increasing the concentration of pesticides in the soil beyond safe levels. In addition, the unsafe use of pesticides, applied under inappropriate conditions, also increases the risk of soil contamination. In addition, there are significant shortcomings in the management of empty packaging. Although pesticide residues are often below detection limits, their presence raises concerns about persistent contamination risks. Therefore, it is essential to implement training programs to promote sustainable agricultural practices and the safe use of pesticides in the area.

Abbreviations

CEC	Cation Exchange Capacity
CSP	Comité Sahelien des Pesticides
IER	Institut d'Economie Rurale
EPA	Environmental Protection Agency
ETQCL	Environmental Toxicology and Quality Control Laboratory
FAO	Food and Agriculture Organization
LCV	Laboratoire Central Veterinaire
GDP	Gross Domestic Product
LOD	Limit Of Detection
ND	Not Detected
OPIB	Office du Périmètre irrigué de Baguinéda
PAN	Pesticides Action Network

Acknowledgments

The authors are thankful to the Environmental Toxicology and Quality Control Laboratory (ETQCL) of the Central Veterinary Laboratory (LCV) to conduct the research successfully. We acknowledge our sincere thanks to all those from OPIB (Office du Périmètre Irrigué de Bamako) who extended their kind help and support. We would also like to thank the local authorities and producers in the villages for their availability and cooperation in gathering information.

Author Contributions

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Funding

Funding for this investigation was provided by the Central Veterinary Laboratory.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors hereby declare no conflicts of interest.

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