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Evaluation of carcass condemnation and economic losses resulting from bovine tuberculosis infection in a dairy farm in Manica Province, Mozambique

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ABSTRACT

Bovine tuberculosis is a chronic infectious disease that has a considerable impact on livestock production by reducing milk and meat output, impairing animal performance, and increasing the risk of premature culling and mortality. Beyond its economic consequences, the disease represents an important public health issue because of its zoonotic nature. This study evaluated the economic impact of bovine tuberculosis by estimating carcass condemnation at slaughter and the associated production losses in a dairy farm located in Manica Province, Mozambique. Data were obtained from 100 cattle that tested positive in the tuberculin skin test. Carcass weights were recorded at the Machava Slaughterhouse, and the economic value of both approved and condemned carcass portions was calculated using the prevailing market price of beef per kilogram. Carcass sections presenting gross lesions consistent with bovine tuberculosis were classified as condemned, allowing the estimation of financial losses. The overall carcass condemnation rate attributable to bovine tuberculosis was 17.24%, corresponding to an estimated economic loss of US$11,464.32. These findings demonstrate that bovine tuberculosis imposes a substantial economic burden on dairy production, emphasizing the importance of effective disease control and eradication strategies to minimize financial losses and protect public health.

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1. Introduction

Bovine tuberculosis (bTB) is a chronic granulomatous disease caused predominantly by Mycobacterium bovis, a member of the genus Mycobacterium (1).

The infection is characterized by the formation of tubercles in affected organs and tissues.

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Besides compromising animal health, bTB leads to substantial reductions in livestock productivity and represents an important zoonosis, with economic consequences for the livestock industry and restrictions on the trade of animals and animal products (1).

The economic burden of bovine tuberculosis extends across all sectors of cattle production. The disease adversely affects herd productivity through lower milk yield, reduced growth rates, reproductive losses, increased culling, and higher mortality. Moreover, bovine tuberculosis limits access to domestic and export markets because of animal health regulations, diminishing the commercial value and sanitary certification of infected herds and reducing the profitability of livestock enterprises (1–3).

In Africa, bovine tuberculosis remains an important transboundary animal disease that constrains the development of the livestock sector. Its persistence limits the continent's participation in international markets due to sanitary trade barriers and results in considerable economic losses through reduced productivity, increased mortality, and the partial or total condemnation of carcasses and affected organs during meat inspection (4).

In Mozambique, bovine tuberculosis is endemic and has been reported in all provinces of the country, where it continues to represent a major constraint to livestock production and animal health (5). Despite ongoing efforts, bovine tuberculosis remains a major animal health concern in the country, generating substantial economic losses. This situation is largely related to the absence of an effective national programme for disease surveillance and control (5).

According to different studies (6,7), bovine tuberculosis lesions identified during routine post-mortem inspection at Mozambican abattoirs have rarely been subjected to confirmatory laboratory diagnosis. This limited diagnostic follow-up has hindered accurate epidemiological surveillance and disease monitoring, thereby facilitating the persistence and dissemination of M. bovis within cattle populations. Consequently, the continued circulation of the pathogen has contributed to an increasing disease burden and has resulted in the following consequences (6):

- Lack of data on the performance of routine post-mortem meat inspection in slaughterhouses;
- Absence of confirmatory diagnosis for bovine tuberculosis cases;
- Potential occurrence of false-positive and false-negative diagnostic results;
- Limited information regarding the prevalence of bovine tuberculosis detected during slaughter;
- The absence of comprehensive documentation of bovine tuberculosis cases identified through meat inspection limits the effectiveness of surveillance programmes and disease monitoring. In addition, the zoonotic nature of Mycobacterium bovis makes bovine tuberculosis a major public health issue. Individuals living or working in close contact with cattle, as well as those consuming raw milk or unpasteurized dairy products, are at increased risk of infection, particularly in endemic regions (5).
- The clinical management of tuberculosis caused by Mycobacterium bovis is particularly challenging because this pathogen is intrinsically resistant to pyrazinamide, one of the core drugs in first-line tuberculosis treatment. The impact of the disease is even more pronounced among people living with HIV, whose compromised immune systems increase the likelihood of developing mycobacterial infections. Consequently, zoonotic tuberculosis remains an important opportunistic disease in HIV-positive populations, contributing to a considerable burden of illness and death in regions where both infections are endemic (5,8).

bTB imposes a considerable economic burden on livestock production systems by reducing animal productivity and leading to the partial or complete condemnation of carcasses and edible offal during post-mortem meat inspection. In addition to these direct financial losses, infected animals may exhibit a 10–25% decline in productive performance and act as a persistent source of infection for both susceptible animals and humans (9) (Fig. 1).

Information on the economic impact of bovine tuberculosis in Mozambique is limited, especially with respect to production losses and the financial implications of carcass condemnation. A bovine tuberculosis outbreak was identified on a dairy farm in Gondola District, Manica Province, where the tuberculin skin test revealed an apparent prevalence of 69% (138/200). Following diagnosis, 100 reactor cattle were sent for slaughter at the Machava Municipal Slaughterhouse and underwent routine post-mortem inspection. The findings were used to estimate the economic losses resulting from the partial or complete condemnation of carcasses and affected organs associated with bovine tuberculosis.

Accordingly, this study aimed to estimate the economic impact of bovine tuberculosis in a dairy herd located in Manica Province, Mozambique, using carcass and edible organ condemnation at slaughter as indicators of financial loss. The findings are expected to provide evidence to inform veterinary authorities, decision-makers, and other stakeholders, thereby supporting the development and enhancement of surveillance, prevention, and control strategies.

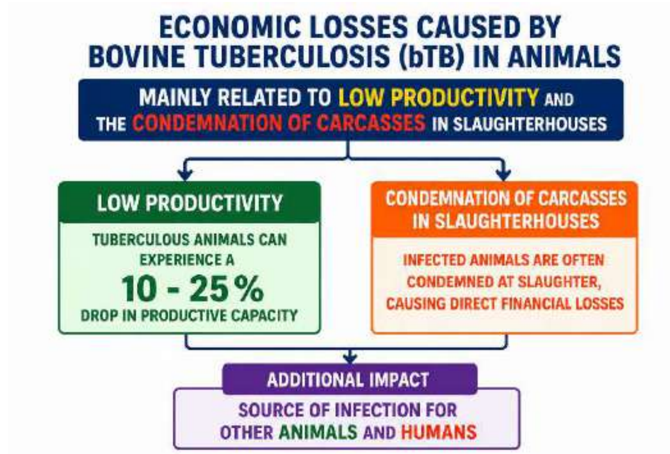

Figure 1. Main economic impacts of bovine tuberculosis (bTB) in cattle, including reduced productivity, carcass condemnation at slaughter, and the risk of transmission to other animals and humans.

2. Materials and Methods

2.1. Study area

This study was carried out at the Machava Municipal Slaughterhouse, located in Maputo Province, Mozambique (Fig. 2), where routine ante-mortem and post-mortem meat inspections are conducted by official veterinary inspectors from the Ministry of Agriculture, Environment and Fisheries. The investigation was conducted over a period of seven months. Information on post-mortem findings and carcass evaluations was retrieved from slaughterhouse inspection records maintained by the Faculty of Veterinary Medicine, Eduardo Mondlane University, located on Avenida de Moçambique (Mozambique Avenue), Km 1.5, Maputo, Mozambique. During routine meat inspection, data were collected on the occurrence, anatomical distribution, and gross characteristics of lesions suggestive of bovine tuberculosis, together with records of carcass and organ condemnation. These data were systematically compiled and organized for subsequent analysis.

Figure 2. Location of the Machava Slaughterhouse

2.2. Ante-mortem and post-mortem inspection

During ante-mortem inspection, cattle presenting progressive weight loss, anorexia, or a history suggestive of chronic wasting disease were considered suspected cases of bTB. Additional clinical signs that may raise suspicion include poor body condition, a rough or dull hair coat, lethargy, reduced activity, and docile behaviour despite remaining alert. In lactating cows, particularly during the postpartum period, these clinical manifestations may become more pronounced due to physiological stress and immunosuppression (10,11).

The general examination included the assessment of body condition score using a five-point scale (scores 1–5) (12), body symmetry, evidence of illness or distress, and overall behaviour. In addition, the hygienic conditions of the lairage facilities, including holding pens and flooring, were evaluated. The systematic clinical examination consisted of assessing the integumentary system (skin and associated structures), digestive, respiratory, cardiovascular, musculoskeletal, nervous, reproductive, and urinary systems for abnormalities compatible with disease. Based on the findings of the ante-mortem inspection, each animal was classified as either fit or unfit for slaughter for human consumption, in accordance with established meat inspection guidelines (13).

During post-mortem inspection, particular attention was given to lesions consistent with bovine tuberculosis. In cases of advanced pulmonary involvement, affected animals may exhibit chronic bronchopneumonia characterized by a persistent productive cough. As the disease progresses and extensive pulmonary tissue is destroyed, severe respiratory compromise may occur, manifested by dyspnoea, tachypnoea, and increased respiratory effort. In addition, systemic clinical signs commonly associated, in animals with advanced bovine tuberculosis, the most common clinical manifestations include progressive weight loss, reduced body condition, intermittent fever, anorexia, and general debility (10,11).

2.3. Study animals

The study included 100 cattle that tested positive in the tuberculin skin test and were subsequently slaughtered at the Machava Municipal Slaughterhouse, Maputo Province, Mozambique. The animals originated from a dairy farm located in Gondola District, Manica Province, and consisted of Jersey and Holstein–Friesian breeds. Each animal was identified using a permanent brand before slaughter. The study population comprised 84 lactating cows, 9 heifers, 5 steers, and 2 bulls.

Following the suspicion of bovine tuberculosis on the farm, the entire herd was screened using the intradermal tuberculin skin test. Despite the absence of obvious clinical manifestations in several animals, all 100 cattle tested positive for bovine tuberculosis. Consequently, in compliance with the established veterinary sanitary regulations for disease control, the infected animals were sent for slaughter and post-mortem examination.

2.4. Carcass inspection

Post-mortem inspection was performed following standard meat inspection procedures and included a comprehensive visual examination of the carcass and internal organs, complemented by palpation and, where required, systematic incision of selected organs and lymph nodes. The examination aimed to identify gross pathological lesions, including abnormalities in size, shape, colour, consistency, and odour that were suggestive of disease.

Post-mortem inspection focused on the detection of gross lesions consistent with bovine tuberculosis. The examination included the lungs, liver, spleen, tongue, diaphragm, and their associated lymph nodes using standard meat inspection procedures, including visual inspection, palpation, and selective incision. Particular emphasis was placed on lymph nodes frequently affected by Mycobacterium bovis, namely the mandibular, retropharyngeal, parotid, prescapular, mediastinal, bronchial, precrural, mesenteric, and popliteal lymph nodes, in addition to the tonsils (14). The location, extent, and distribution of all tuberculosis-compatible lesions were systematically documented for each carcass.

2.5. Data collection and analysis

Data on animal origin, including the production unit, district, and locality, as well as animal characteristics (age, breed, and sex), were extracted from the slaughterhouse inspection records. Information obtained from both ante-mortem and post-mortem inspections, including the condemnation of carcasses and edible organs, was also recorded for subsequent analysis.

For each slaughtered animal, the weight of condemned organs and carcass portions (one-quarter, one-half, three-quarters, or the whole carcass) was recorded to the nearest kilogram. These data were used to calculate the proportion of carcass tissue condemned due to lesions compatible with bovine tuberculosis.

The direct economic losses associated with carcass condemnation were estimated by multiplying the weight of the condemned carcass or carcass portion by the prevailing market price for the corresponding animal category at the time of slaughter. The total monetary losses were subsequently calculated by summing the estimated values for all condemned carcasses and carcass portions.

2.6. Estimation of economic loss

The total carcass weight of each animal was recorded and used to estimate its potential market value based on the prevailing market price of meat at the time of slaughter (US$ 4.80 per kg). The estimated gross revenue for each carcass was calculated by multiplying the carcass weight by the unit market price. The cumulative weight of all condemned carcass portions was calculated by adding the weight of each condemned section. Direct economic losses associated with carcass condemnation were estimated by multiplying the total condemned carcass weight by the prevailing market value of beef (US$ 4.80 kg^{-1}). The resulting value represented the potential income that would have been obtained if those carcass portions had been approved for human consumption.

The overall economic losses associated with bovine tuberculosis were calculated using the following equations:

$\sum RW$ = total weight (kg) of all condemned carcass portions.

P = market price per kilogram of meat (US$/kg).

$\sum RL$ = Revenue Loss (total economic loss US$ resulting from carcass condemnation), calculated as:

$\sum RL = \sum (RW \times P)$

2.6.1. Calculation of the commercial and replacement value of culled animals

The commercial value of culled animals was estimated using the prevailing market prices for each animal category at the time of the study. Market prices were obtained from the regional livestock market and were used to estimate the financial losses associated with the compulsory culling of tuberculin-positive animals. The commercial value of replacement heifers was estimated at US$1,800.00 per animal, whereas steers were valued at US$2,000.00 per animal. Bulls were assigned a commercial value of US$4,000.00 per animal, based on the average market price irrespective of age.

For lactating cows, replacement costs were estimated under the assumption that each culled cow would be replaced by one replacement heifer. Consequently, the replacement value of the 84 culled cows was calculated using the market price of a replacement heifer (US$1,800.00 per animal).

The commercial and replacement values were calculated using the following equations:

$CW_H = P_H \times N_H$

$CW_S = P_S \times N_S$

$CW_B = P_B \times N_B$

$RV_C = P_H \times N_C$

where:

CW_H = commercial worth of heifers (US$);

CW_S = commercial worth of steers (US$);

CW_B = commercial worth of bulls (US$);

RV_C = replacement value of culled cows (US$);

P_H = market price of one heifer (US$1,800.00);

P_S = market price of one steer (US$2,000.00);

P_B = market price of one bull (US$4,000.00);

N_H = number of heifers;

N_S = number of steers;

N_B = number of bulls;

N_C = number of culled cows requiring replacement.

2.6.2. Calculation of disease surveillance (screening) costs

The costs associated with bTB screening were estimated by calculating the total expenses related to tuberculin used for diagnostic testing and the labour costs of qualified personnel responsible for performing and interpreting the tuberculin skin test.

2.6.3. Tuberculin testing costs

The cost of tuberculin used for bTB screening was estimated based on the total number of animals subjected to the comparative intradermal tuberculin test. For the 100 cattle included in the study, each animal required one dose of bovine purified protein derivative (PPD) tuberculin and one dose of avian PPD tuberculin. The number of tuberculin vials required was calculated according to the manufacturer's recommended number of doses per vial. The total cost of tuberculin was subsequently estimated by multiplying the number of vials used by the purchase price per vial.

The tuberculin testing cost was calculated as follows:

TC=NV×PV

where:

TC = total tuberculin cost (US$);

NV = number of bovine or avian PPD tuberculin vials required;

PV = purchase price per vial (US$).

2.6.4. Labour costs for tuberculin testing

The labour costs associated with bTB screening were estimated based on the daily allowances paid to personnel involved in conducting the comparative intradermal tuberculin test. According to the applicable remuneration schedule, each labour received a daily allowance of US$39.70, corresponding as 70% of the allowance provided to a senior veterinary technician assigned to duties outside the province. Veterinary assistants were considered to receive the same daily allowance.

The screening team consisted of two veterinarians and three veterinary assistants, and the tuberculin testing campaign was completed over two consecutive working days.

The total labour cost was calculated using the following equation:

LC=A×N×D

Where:

LC = total labour cost (US$);

A = daily allowance per worker (US$39.70);

N = total number of personnel involved in tuberculin testing (2 veterinarians + 3 assistants = 5 workers);

D = number of working days (2).

Economic losses associated with bTB in cattle identified at the slaughterhouse (ELBTB)

DSSC (Disease Surveillance Screening Costs)

CRVCA (Commercial and Replacement Value of Culled Animals)

RL (Revenue loss)

RACY (Revenue from approved carcass yield)

ELBTB = (DSSC + CRVCA + RL) – RACY

2.7. Statistical analysis

Descriptive statistics were used to summarize the data. Categorical variables were presented as absolute frequencies and percentages, whereas continuous variables were summarized using means, standard deviations, and minimum and maximum values, where appropriate. Economic losses were estimated based on the weight of condemned carcass portions and current market prices. All statistical analyses were performed using Microsoft Excel 365.

3. Results

3.1. Distribution of condemned carcass portions by animal class

Table 1 summarizes the post-mortem inspection outcomes according to animal category. Of the 100 carcasses examined, 15 (15.0%) were totally condemned, comprising 13 cows and 2 heifers, after being declared unfit for human consumption due to lesions compatible with bTB. In addition, the total condemnations, three cow carcasses were partially condemned, with one quarter of the carcass rejected in each case, while one cow carcass had approximately one-half condemned. Furthermore, the edible organs (viscera) of all affected bulls, heifers, and steers were condemned because of tuberculosis-compatible lesions detected during post-mortem inspection.

Table 1. Condemned carcasses/organs according to animal class

Animal class	Age (Years old, months)	Slaughtered animals	$1/4$ of carcass	$1/2$ of carcass	All carcass	Vísceras
Bulls	26	2	-	-	-	All
Cows	24 - 36	84	3	1	13	Almost all
Heifers	12 - 20	9	-	-	2	All
Steers	12 - 24	5	-	-	-	All
Total		100	3	1	15	-

Table 2. Frequency of condemned carcass and economic loss in slaughtered animals

	Carcass weight Kgs (%)		Total	Estimated monetary loss (in USD at $4.8/kg)
	Cows	Heifers		
Examined	13,844.9		13,844.9	66,455.52
Rejected	2,247.8(16.23)	140.6(1.01)	2,388.4	11,464.32
Difference	-	-	11,456.5	54,991.2

Table 3. Results of the commercial and replacement value of rejected animals.

Animal class	Number of animals	Comercial value (USD)	Replacement value (USD)
Heifers	9	16,200	16,200
Steers	5	10,000	10,000
Cows	84	-	151,200
Bulls	2	8,000	8,000
	Total		$185,400

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Table 4. Costs of bTB screening tests (using bovine and avian tuberculin) and related services. Cost of disease in farm animals present at the slaughterhouse.

Items	Quantity	Unit price (USD)	Total (USD)
Tuberculin			
Bovine	5 Bottles	61.4	307
Avian	5 Bottles	184.3	921.5
Labour	5	198.5/day	397/2 days
			$ 1,625.5

Table 5. ELBTB (Economic losses associated with bovine tuberculosis in cattle identified at the slaughterhouse); DSSC (Disease Surveillance Screening Costs); CRVCA (Commercial and Replacement Value of Culled Animals); RL (Revenue loss); RACY (Revenue from approved carcass yield).

Items	Value (USD)
DSSC	+ 1,625.5
CRVCA	+ 185,400
RL	+ 11,464.32
RACY	- 54,991.2
ELBTB	143,498.62

Table 2 presents the total weight and proportion of carcass tissue condemned following post-mortem inspection. Overall, 17.24% of the total carcass weight was condemned due to lesions compatible with bTB. When analyzed by animal category, a total of 2,247.8 kg of carcass from cows and 140.6 kg from heifers were condemned. No carcass condemnations were recorded for bulls or steers, although the number of animals in these categories was considerably lower than that of cows (Table 1).

3.2. Economic analysis

3.2.1. Commercial and replacement value of culled animals

Table 3 summarizes the estimated commercial and replacement values of the animals affected by bTB. The total commercial value of the culled heifers was estimated at US$16,200.00, while the commercial value of the steers and bulls was US$10,000.00 and US$8,000.00, respectively. The replacement value of the 84 culled cows, calculated based on the market price of replacement heifers, was estimated at US$151,200.00.

3.3. Calculations of disease screening costs

3.3.1. Costs of tuberculin testing

Table 4 summarizes the costs associated with bTB screening. The total cost of the tuberculins used for testing the study animals was estimated at US$307.00 for bovine PPD tuberculin and US$921.50 for avian PPD tuberculin. In addition, the labour cost of the veterinary personnel responsible for administering and interpreting the comparative intradermal tuberculin test amounted to US$397/2 days.

Table 5 presents the costs associated with bovine tuberculosis detected in farm animals at the slaughterhouse.

4. Discussion

The findings presented in Table 2 suggest that bTB has likely been circulating within the production unit for an extended period, indicating a possible endemic infection status in the herd. The management system, characterized by animal confinement, together with the practice of feeding calves with milk from infected cows, may have contributed to the extent of carcass and organ condemnations observed in this study. In addition, a high proportion of visceral organs across all animal categories were condemned due to lesions compatible with tuberculosis. This widespread distribution of lesions indicates systemic infection and suggests extensive dissemination of Mycobacterium bovis within the herd. Previous studies (15) have shown that the oral transmission route, represents a relevant mechanism of infection in neonatal and young calves, particularly when they are exposed to contaminated milk from infected cows. In contrast, in confined production systems, aerosol transmission is considered a major route of infection among adult cattle, including cows and bulls, due to increased close contact and prolonged exposure to infectious aerosols generated by infected animals.

As shown in Table 1, a higher proportion of carcass condemnations was observed in cows compared to other animal categories. When lesions compatible with bTB are detected during post-mortem inspection, affected carcasses or carcass portions are condemned and excluded from the food chain, resulting in direct economic losses to the livestock production sector (16). The higher frequency of condemnations in cows observed in this study may be associated with the greater prevalence of bTB in this animal category.

Previous studies (11) have reported that, due to their longer productive lifespan, adult cattle particularly cows have an increased cumulative risk of exposure to Mycobacterium bovis, which may facilitate infection and contribute to the maintenance and dissemination of the disease within herds.

The extent of carcass condemnation due to bTB observed in this study (17,24% of total carcass weight) can be considered substantial. According to previous reports (17), losses of approximately 5% resulting from partial or total carcass condemnation in slaughterhouses are already regarded as economically significant.

Comparatively, studies conducted in Ethiopia have reported an overall carcass loss of about 5%, including both condemned organs and carcasses, as well as additional production losses such as reduced live weight gain. In the same context, a reduction of approximately 10% in milk production has also been documented in affected herds (18), highlighting the broader economic impact of bTB beyond carcass condemnation alone.

4.1. Economic analysis

According to studies (17,18), The culling of dairy cattle reacting positively to tuberculosis is economically feasible only when the proportion of reactors within the herd is low. In the present study, this condition was not met, as carcass condemnations resulted in a loss of 2.39 tons of meat, corresponding to an estimated revenue loss of US$ 11,464.32. In Spain, a positive tuberculosis test result in cattle leads to revenue losses at the farm level, primarily due to the slaughter of affected animals and the costs associated with replacing culled animals (19). The prevalence of bTB was high, with nearly 69% of animals affected, which may reflect prolonged circulation of Mycobacterium bovis within the herd and explain the high proportion of positive reactors detected. Bovine tuberculosis remains one of the most important infectious diseases affecting cattle because of its significant economic impact on livestock production (20). Previous studies (21) have demonstrated that the removal of productive dairy cows due to bTB infection results in substantial economic losses for farms. In this study, 84 cows and 9 potential replacement heifers were removed from the herd. The occurrence of bTB negatively affected milk and meat production, herd productivity, and the economic sustainability of the farm due to the loss of infected animals. In Nigeria, bovine tuberculosis has been associated with considerable losses in both animal protein resources and economic returns. Providing adequate compensation for condemned carcasses and meat could encourage butchers and producers to comply with tuberculosis control measures (22,23). Bovine tuberculosis also results in the condemnation of carcasses or carcass portions at the slaughterhouse (21), leading to the loss of potential revenue. Jersey cows are considered highly profitable under Mozambican production conditions due to their relatively high milk yield and efficiency in converting feed into milk (24). Consequently, Jersey heifers have considerable commercial value because of their potential to become efficient milk producers.

The assessment of the benefits and costs of animal disease control should not be limited to differences in productivity between “infected” and “disease-free” scenarios. As highlighted by (25), it should also consider whether the implementation of control measures generates significant financial constraints for routine livestock production activities.

In the present study, the salvage value obtained from culled animals (US$54,991.20) was lower than the total costs associated with disease control, including testing and animal replacement. As a result, the farm incurred an estimated net deficit of US$143,498.62, highlighting the substantial economic burden of bTB under the conditions studied.

Similar findings have been reported in South Sudan, where bovine tuberculosis was associated with the highest financial losses among major cattle diseases (26,27). These results reinforce the importance of incorporating both direct and indirect costs when evaluating disease control strategies, as governments typically bear the expenses related to diagnostic testing (including personnel and tuberculin costs), while farmers incur additional costs associated with replacing culled animals in order to maintain production levels.

5. Conclusion

The results demonstrate that bTB generated substantial economic losses in the studied dairy farm, which were closely associated with inadequate prevention and control practices.

The absence of systematic control measures, including test-and-slaughter programs, may have favored the long-term persistence of bovine tuberculosis within the herd, increasing opportunities for transmission and contributing to the maintenance of infection at the farm level.

The absence of structured surveillance and control measures was associated with increased carcass and carcass portion condemnations at the slaughterhouse, generating substantial economic losses.

Furthermore, the mandatory removal of tuberculin-positive cows and heifers represented an additional economic burden for dairy producers, threatening the sustainability of the production system.

Recommendations

- Competent authorities should consider establishing an official certification scheme for bTB-free farms or herds, incorporating preventive requirements such as routine testing and test-and-slaughter strategies to ensure sustained disease-free status.
- Public awareness programmes should be reinforced to increase understanding among livestock owners, farmers, and veterinary stakeholders of the economic consequences of bTB and its relevance as a zoonotic disease with important public health implications.
- High-prevalence regions and high-risk dairy production systems should be prioritized for the implementation of targeted, area-based prevention, control, and eradication programs.

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Author contributions

Higildo Salésio Ernesto Maxlhaieie contributed to conceptualization, methodology, investigation, data curation, writing – original draft, writing – review editing, and visualization.

Julio Gabriel Maxhuza contributed to supervision, resources, validation, investigation, writing – review and editing.

Conflict of interest

The authors have declared no conflicts of interest in this article.

Data availability

The data used in this work are available upon request to the author.

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