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Pathology-Specific Carcass Weight Penalties and Economic Losses in Slaughtered Pigs from Cameroon's Western Highlands: An Abattoir Surveillance Study

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Abstract

Disease-related carcass losses in the production of pigs in Cameroon, which have not been quantified adequately thus far, are investigated herein. A cross-sectional abattoir survey of 444 pigs slaughtered in the Menoua Division during January–April 2018 was performed to quantify the prevalence of lesions, determine specific carcass weight penalties, and evaluate the associated economic consequences. Standard post-mortem examination identified zootechnical features (breed, age, sex, origin) and pathological lesions. Prevalence estimation utilized Wilson 95% confidence intervals; the impact on carcass weight was assessed via Generalized Linear Models (GLM), Generalized Linear Mixed Models (GLMM) with subdivision as a random effect, and bootstrap quantile regression adjusting for possible confounders.

Among the recorded conditions, only ascariosis (prevalence: 5.2%, 95% CI: 3.4–7.8%) and erysipelas (prevalence: 1.8%, 95% CI: 0.8–3.7%) were significantly associated with carcass weight reductions, causing penalties of 4.42 kg (95% CI: -8.15 to -0.69 kg, p=0.020) and 9.01 kg (95% CI: -15.25 to -2.76 kg, p=0.005), respectively. Based on a standard market price of 2,000 FCFA/kg, per-case financial losses equaled 8,837 FCFA for ascariosis and 18,012 FCFA for erysipelas, translating into an estimated baseline annual loss of 405,657 FCFA within the division. Multi-parameter sensitivity analysis confirmed that financial losses are robust across varied parameter spaces, with national worst-case projections exceeding 3 billion FCFA per disease. These findings demonstrate that routine abattoir surveillance offers a robust framework for quantifying subclinical pathology and economic drains, highlighting strategic deworming and systematic erysipelas vaccination as high-priority interventions in tropical pig production systems.

1. INTRODUCTION

Pig production provides essential dietary protein and a vital socioeconomic safety net for smallholders and rural communities throughout sub-Saharan Africa. The sector is anticipated to expand exponentially driven by rising household incomes, urbanization, and the corresponding surge in demand for animal-source foods, including pork (Erdaw, 2023; Adesehinwa et al., 2024). Across the African continent, swine production remains predominantly small-scale, localized within rural and peri-urban ecosystems where biosecurity protocols are minimally enforced (Adesehinwa et al., 2024; Owusu et al., 2024). Consequently, herd productivity is consistently compromised by a spectrum of infectious and parasitic diseases. These pathologies retard growth rates, undermine carcass quality, induce severe organ lesions, and cause substantial carcass condemnations at slaughter, directly diminishing the economic returns of producers and meat operators (Mouiche et al., 2023; Oba et al., 2023; Maes et al., 2023).

In tropical environments, swine productivity is hindered by chronic, subclinical lesions stemming from helminthiasis, bacterial infections, and organ-specific pathologies (Maes et al., 2023; Mathobela et al., 2024). Recent macro-economic assessments indicate that animal diseases inflict catastrophic annual financial drains in low- and middle-income countries (LMICs). Therefore, precisely quantifying the

carcass weight degradation attributable to specific pathologies is critically necessary to justify and guide veterinary interventions (Mathobela et al., 2024). Despite this imperative, empirical data detailing lesion-specific carcass losses in Central Africa remain critically scarce. Most existing African abattoir-based studies fail to adjust for essential zootechnical confounders such as breed, age class, sex, and geographic origin—which fundamentally dictate carcass yield and performance in tropical swine systems (Mpouam et al., 2019; Adesehinwa et al., 2024; Owusu et al., 2024).

Abattoir surveillance represents a highly cost-effective epidemiologic methodology to monitor herd health and quantify disease-associated economic liabilities, as it facilitates simultaneous carcass weighing and standardized post-mortem tracking (Correia-Gomes et al., 2016; Rodarte et al., 2023; Amatucci et al., 2023). Slaughterhouses concentrate livestock from diverse farming systems, allowing researchers to efficiently acquire robust sample sizes and track subclinical pathologies with minimal financial expenditure (Rodarte et al., 2023; Amatucci et al., 2023). Pathological lesions observed at slaughter—ranging from respiratory complexes to systemic and localized conditions have been linked to depressed carcass weights, extensive meat trimming, organ condemnation, and substantial revenue shortfalls (Nwachukwu & Udegbunam, 2020; Maes et al., 2023; Teixeira et al., 2023).

The Menoua Division, located within the Western Highlands region of Cameroon, constitutes a premium agro-ecological zone for swine husbandry. The division supports multiple slaughter facilities across key urban and rural nodes (Dschang, Nkong-Ni, Penka-Michel, Santchou), exhibiting a recorded baseline slaughter throughput that provides an ideal window to assess the economic penalties of subclinical diseases (DDEPIA-MEN, 2017; Mpouam et al., 2019). Diverging from conventional, purely descriptive abattoir surveys, this study explicitly integrates host factors, spatial clustering, and robust multivariable modeling. Specifically, the objectives of this investigation are to: (1) comprehensively characterize the zootechnical features of pigs slaughtered in the Menoua Division; (2) determine the true prevalence of specific pathologies during post-mortem meat inspection; (3) isolate and evaluate the true impact of individual lesions on hot carcass weight after adjusting for zootechnical confounders using advanced modeling techniques; and (4) model the macroeconomic financial losses under volatile market scenarios via multi-parameter sensitivity analyses.

2. MATERIALS AND METHODS

2.1 Study Site

The investigation was executed across the major slaughter hubs of the Menoua Division (geographic coordinates: 5°–5°50' N, 9°40'–10°25' E), situated within the West Region of Cameroon. This zone represents an intensive hub for swine production, characterized by a predominance of smallholder traditional and semi-intensive production systems that align with smallholder environments across sub-Saharan Africa (Aliro et al., 2023; Oba et al., 2023). The region features a subhumid tropical climate, experiencing a bimodal annual rainfall regime ranging between 1,872 mm and 2,378 mm, with altitudinal transitions spanning 600 to 2,200 meters above sea level. These environmental parameters support

year-round pig farming but also favor the persistence of diverse internal parasites and bacterial vectors. Four municipal subdivisions displaying the highest official annual slaughter volumes were targeted for surveillance: Dschang, Nkong-Ni, Penka-Michel, and Santchou.

2.2 Survey Design and Sample Size Determination

A cross-sectional abattoir survey was conducted via biweekly tracking rounds over a four-month period (January to April 2018), targeting the primary livestock market and slaughter days (Wednesdays and Saturdays). This temporal targeting ensured capturing periods of peak animal throughput, minimizing administrative and operational variations (Dauda et al., 2025; Zaba et al., 2025). The minimum required sample size was established utilizing standard epidemiological formulas for prevalence estimation, assuming a 95% confidence level, a 5% margin of error, and an expected baseline lesion prevalence of 5% (Sarabeev et al., 2025). To enhance statistical power and account for potential intra-cluster correlation and non-response, the sample size was intentionally inflated to 444 pigs, conforming to veterinary epidemiological guidelines regarding design effect adjustments (Humphry et al., 2004). To prevent selection bias and achieve authentic representativeness, a comprehensive sampling protocol was maintained: all carcasses slaughtered during the active surveillance windows were inspected without exclusion criteria (Ciui et al., 2023; Dauda et al., 2025).

2.3 Data Collection and Measurements

Data acquisition was formalized using a pre-tested, structured questionnaire administered at the slaughter line, recording zootechnical variables, post-mortem carcass dimensions, and specific organ/tissue lesions.

Zootechnical Characterization: Animals were classified based on geographic origin (direct village purchase vs. intermediate livestock markets), sex, and phenotype-based breed categories (Crossbred, Large White, Local, Landrace, and Pietrain). Phenotypic classification is a standardized, reliable proxy in smallholder contexts where pedigree records or molecular tracking are absent (Oba et al., 2023; Zaba et al., 2025). Individual animal age was estimated via detailed dental eruption patterns, grouping pigs into three distinct commercial maturity classes: 6–8 months, 9–11 months, and ≥ 12 months (Aliro et al., 2023).

Carcass Weighing

Hot carcass weight (HCW) was determined immediately following complete evisceration, splitting, and dressing, prior to carcass chilling. Weighing was executed utilizing a calibrated 100-kg capacity hanging spring balance (precision limit ± 1 kg), adhering to standardized methods for assessing disease-driven tissue penalties (Teixeira et al., 2022; Przyborowska et al., 2024).

Pathological Lesion Identification and Diagnostics

Post-mortem sanitary inspections were performed independently by qualified veterinary officers rigorously trained in official meat inspection protocols (Ciui et al., 2023; Comin et al., 2023). Every

carcass underwent visual examination, palpation, and systematic incisions of visceral organs (liver, lungs, kidneys, spleen, intestines) and associated lymph nodes. Pathological conditions were logged strictly as binary outcomes (presence = 1, absence = 0) (Dauda et al., 2025; Przyborowska et al., 2024). Inter-observer diagnostic reliability was evaluated by subjecting a random 10% subset of carcasses to blind double-inspection. The resulting Cohen's kappa coefficient was 0.87, confirming excellent diagnostic reproducibility and exceeding the analytical thresholds required for abattoir-based surveillance metrics (Comin et al., 2023).

2.4 Advanced Statistical Analysis

All statistical computations were executed within the R computational environment, version 4.5.2 (R Core Team, 2023). Proportion estimates and prevalence metrics were calculated using descriptive frequency tables alongside Wilson's score method for 95% confidence intervals (CIs). Unadjusted cross-categorical variations in HCW were assessed via one-way Analysis of Variance (ANOVA), with subsequent pairwise differences isolated through Tukey's Honest Significant Difference (HSD) post-hoc tests. The fundamental statistical assumptions of normality and homoscedasticity were verified using the Shapiro-Wilk and Levene's tests, respectively.

To isolate the independent impact of individual pathological lesions on hot carcass weight from potential zootechnical confounders, three distinct multivariable regression architectures were deployed:

1. Generalized Linear Model (GLM): An ordinary least squares linear regression framework modeling HCW as a continuous response variable:
$$\mathbf{HCW = \beta 0 + \beta 1(Lesion) + \sum \gamma i(Zootechnical_Confoundersi) + \varepsilon}$$

2. Generalized Linear Mixed Model (GLMM): To explicitly control for spatial clustering and operational variations inherent to individual slaughter facilities, a mixed-effects framework was fitted, treating the municipal subdivision of slaughter as a random intercept:
$$\mathbf{HCW = \beta 0 + \beta 1(Lesion) + \sum \gamma i(Zootechnical_Confoundersi) + uSubdivision + \varepsilon}$$
where $\mathbf{uSubdivision \sim N(0, \sigma u2)}$. The Intraclass Correlation Coefficient (ICC) was calculated to assess the magnitude of cluster-level variance.

3. Bootstrap Quantile Regression (QREG): To evaluate the robustness of lesion impacts across the median ($\boldsymbol{\tau = 0.5}$) of the carcass weight distribution and minimize sensitivity to outliers or non-normal residuals, a median regression model was constructed. Standard errors and 95% CIs were derived using 500 bootstrap replications.
First-order interaction terms between breed types and significant lesions were systematically tested to assess whether disease-driven weight penalties varied across genetic lines. Non-significant interactions ($\boldsymbol{p > 0.05}$) were sequentially removed via backward elimination to preserve model parsimony. Pairwise disease co-occurrence was explored using Pearson's correlation coefficient on the binary matrix to check for multi-collinearity.

2.5 Economic Analysis and Multi-Parameter Sensitivity Modeling

The direct financial loss per infected animal was calculated by multiplying the adjusted lesion-specific carcass weight penalty (**ΔW** in kg) derived from the multivariable GLM by the ruling local pork market price (**P** in FCFA/kg):

Lossper case = ΔW × P

The aggregate annual economic loss within the Menoua Division was calculated by scaling the per-case loss by the respective lesion point prevalence (**Prev**) and the official annual divisional slaughter volume (**NDiv** = 517 pigs/year; DDEPIA-MEN, 2017):

LossDivisional = Lossper case × Prev × NDiv

Macroeconomic impact extensions at the national scale were modeled by extrapolating these baseline dynamics against the estimated annual national slaughter throughput, which ranges between 700,000 and 1,200,000 pigs/year (Kouam et al., 2019; Oba et al., 2023). To address parameters uncertainty and market volatility, a comprehensive multi-parameter sensitivity analysis was performed. This was achieved by systematically varying: (i) retail pork prices from a baseline of 2,000 FCFA/kg up to an intensive market value of 4,500 FCFA/kg; (ii) lesion prevalence boundaries using the lower and upper bounds of the Wilson 95% CIs; and (iii) carcass weight penalties using the limits of the GLM-derived 95% CIs (Andoni et al., 2023; Dauda et al., 2025). This framework generated Minimum, Maximum, and Plausible economic loss scenarios.

2.6 Ethical Considerations

This research relied exclusively on non-invasive data captured during routine, legally mandated post-mortem sanitary inspections overseen by municipal veterinary authorities. No live animal handling, experimental manipulation, or pre-mortem sampling was performed. Consequently, this protocol is fully exempt from formal institutional animal ethics review boards under national and international veterinary surveillance acts (Comin et al., 2023; Zaba et al., 2025). All animal identity markers and owner records were completely anonymized prior to analysis.

3. RESULTS

3.1 Zootechnical Profile of the Slaughtered Population

The comprehensive cross-sectional cohort comprised 444 pigs successfully tracked across the four primary municipal subdivisions of the Menoua Division (Table 1). The operational distribution of slaughters was unbalanced: the Dschang municipal slaughterhouse accounted for the highest volume (42.1%; 95% CI: 37.4–46.8%), followed by Nkong-Ni (27.5%), Penka-Michel (23.7%), and Santchou (6.8%).

Phenotypic breed profiling revealed that crossbred animals constituted the dominant genetic group (51.0%; 95% CI: 46.3–55.8%), followed by Large White (19.6%) and Local indigenous breeds (13.5%), while purebred Landrace (9.2%) and Pietrain (6.8%) were less frequent. Market maturity timelines showed that 51.2% of the slaughters occurred within the 6–8 months bracket. The sex ratio was balanced, consisting of 50.6% males and 49.4% females. Regarding sourcing channels, 54.6% of the pigs were procured directly from rural production villages, while 45.4% were sourced via commercial livestock markets.

Table 1
Zootechnical characteristics and distribution of slaughtered pigs in Menoua Division (N = 444).

Zootechnical Variable	Category	Frequency (n)	Proportion %	Wilson 95% CI
Slaughter Subdivision	Dschang	187	42.1	37.4–46.8
	Nkong-Ni	122	27.5	23.4–32.0
	Penka-Michel	105	23.7	19.8–28.0
	Santchou	30	6.8	4.7–9.6
Breed Type	Crossbred	226	51	46.3–55.8
	Large White	87	19.6	16.1–23.6
	Local Breed	60	13.5	10.6–17.1
	Landrace	41	9.2	6.8–12.3
	Pietrain	30	6.8	4.7–9.6
Age Classification	6–8 months	227	51.2	46.5–55.8
	9–11 months	143	32.2	28.0–36.8
	≥ 12 months	74	16.6	13.4–20.4
Sex	Male	225	50.6	45.9–55.3
	Female	219	49.4	44.7–54.1
Geographic Origin	Village	242	54.6	49.9–59.2
	Livestock Market	202	45.4	40.8–50.1

3.2 Carcass Weight Distribution and Bivariate Comparisons

The mean hot carcass weight across the entire sample stood at 42.11 kg (Standard Deviation: 9.69 kg; absolute range: 18.0 to 82.0 kg). The overall distribution exhibited a slight rightward skewness. Bivariate unadjusted ANOVA models confirmed significant structural differences in carcass weight across multiple host and demographic dimensions (Table 2). Specifically, significant differences were identified

across breed lines (**p** = 0.032), age classes (**p** < 0.001), animal sex (**p** = 0.026), and sourcing channels (**p** = 0.010). Carcasses from purebred Landrace and Pietrain lineages achieved the highest average weights, whereas the youngest market cohort (6–8 months) was significantly lighter than mature counterparts. Notably, female pigs and those procured directly via village channels displayed higher unadjusted mean carcass weights. No significant structural variations in weight were observed across individual slaughter subdivisions (**p** = 0.083). These strong unadjusted baseline variances confirmed the presence of confounding risks, validating the use of multi-variable adjusted modeling.

Table 2
Unadjusted comparisons of hot carcass weight (kg) across zootechnical factors.

Factor	category	Mean HCW (kg)	Standard Deviation (SD)	p-value (ANOVA)
Breed Type	Crossbred	41.25	9.12	0.032*
	Large White	42.1	9.45	
	Local Breed	39.8	8.7	
	Landrace	44.85	10.3	
	Pietrain	45.12	11.15	
Age Class	6–8 months	38.4	7.8	< 0.001***
	9–11 months	44.95	9.6	
	≥ 12 months	48.05	11.2	
Sex	Male	41.12	9.2	0.026*
	Female	43.12	10.1	
Subdivision	Nkong-Ni	41.6	9.4	0.083ns
	Penka-Michel	41.9	9.65	
	Santchou	40.1	9.2	

3.3 Prevalence of Pathological Lesions

The overall recorded prevalence of individual pathological conditions was low across the active surveillance window (Table 3). Visceral abscesses displayed the highest frequency (5.64%; 95% CI: 3.76–8.33%), closely followed by hepatic/intestinal ascariosis lesions (5.19%; 95% CI: 3.39–7.80%). Other detected conditions included abnormal tissue coloration (4.06%), gastrointestinal strongylosis (2.48%), chronic nephritis (2.03%), and swine erysipelas skin/systemic lesions (1.81%). All other specific pathologies, such as respiratory lesions, tuberculosis-like nodules, and localized trauma, occurred at prevalence rates below 1.5%. Pairwise disease correlation matrix computations demonstrated a low rate of co-occurrence within individual animals. The maximum pairwise correlation coefficient was recorded

between ascariosis and strongylosis (**r** = 0.23), with all other combinations falling below 0.15. This lack of overlapping pathologies confirmed that multi-collinearity was negligible, validating the execution of separate lesion-specific models.

Table 3
Prevalence of individual pathological lesions detected during post-mortem meat inspection (N = 444).

Pathological Lesion condition	Number of positive Cases (n)	Prevalence %	Wilson 95% CI
Visceral Abscesses	25	5.64	3.76–8.33
Ascariosis Lesions	23	5.19	3.39–7.80
Abnormal Coloration	18	4.06	2.59–6.31
Strongylosis Lesions	11	2.48	1.39–4.39
Chronic Nephritis	9	2.03	1.07–3.81
Swine Erysipelas	8	1.81	0.91–3.54
Other Conditions **(< 1.5% each)**	6	1.35	0.62–2.91

3.4 Lesion-Specific Carcass Weight Penalties Under Multivariable Models

3.4.1 Generalized Linear Model (GLM) Estimates

After controlling for the confounding influences of breed, age group, sex, origin, and geographic subdivision, only ascariosis and swine erysipelas were significantly associated with lower hot carcass weights (Table 4). The presence of ascariosis lesions was associated with a significant carcass weight penalty of 4.42 kg (95% CI: -8.15 to -0.69 kg; **p** = 0.020), which represents a structural reduction of 10.5% relative to the sample population mean weight. Swine erysipelas lesions induced a severe tissue loss, associated with a weight penalty of 9.01 kg (95% CI: -15.25 to -2.76 kg; **p** = 0.005), a loss of 21.4% of the population mean carcass value. All other pathologically tracked conditions, including abscesses and strongylosis, displayed no significant association with carcass weight metrics (**p** > 0.05).

3.4.2 Generalized Linear Mixed Model (GLMM) Intercepts

The implementation of random-intercept mixed models further confirmed the accuracy of the fixed-effects parameters. The calculated random-intercept Intraclass Correlation Coefficient was very low (**ICC** = 0.034), indicating that variance attributable to individual slaughterhouse facilities accounted for only 3.4% of the overall variation in HCW. Consequently, the GLMM-derived coefficients remained stable, yielding adjusted penalties of 4.61 kg for ascariosis and 9.10 kg for erysipelas. This consistency confirmed that localized slaughterhouse clustering did not meaningfully distort the fixed effect sizes.

3.4.3 Bootstrap Quantile Regression Robustness

Median quantile regression (**τ** = 0.5) incorporating 500 bootstrap resamples confirmed the directionality of the disease impacts. For the ascariosis cohort, the median penalty was estimated at a conservative 2.00 kg. For swine erysipelas, despite a small sample size (**n** = 8 positive cases) that widened the resulting bootstrap confidence intervals across the zero threshold, the median regression isolated a substantial negative coefficient of 8.00 kg. This directional agreement across ordinary least squares, random-intercept mixed models, and median regression architectures underscores the statistical validity of these findings.

3.4.4 Host Genetics Interactions

No significant first-order interaction terms were identified between breed lineages and lesion presence for either ascariosis or erysipelas (**p** > 0.05 for all interaction fields; Supplemental Table S1). This lack of interactive effects indicates that the tissue degradation and carcass weight penalties associated with these pathologies operate uniformly across different swine genetic strains managed within the region.

Table 4
Multivariable modeling comparison for lesion-specific impacts on hot carcass weight (kg).

Pathology Model	1.Generalized Linear Model (GLM)		2.Generalized Linear Mixed Model (GLMM)		3.Quantile Regression (τ = 0.5)	
	Estimate (kg)	95% CI (p-value)	Estimate (kg)	95% CI (p-value)	Estimate (kg)	Bootstrap 95% CI
Ascariosis	-4.42	-8.15 to -0.69 [0.020*]	-4.61	-8.42 to -0.80 [0.018*]	-2.00	-4.85 to 0.85
Erysipelas	-9.01	-15.25 to -2.76 [0.005**]	-9.10	-15.48 to -2.72 [0.005**]	-8.00	-16.20 to 1.15

3.5 Economic Losses and Volatile Sensitivity Matrices

Financial loss projections using the adjusted GLM parameters under baseline market scenarios (pork price locked at 2,000 FCFA/kg) revealed substantial financial losses (Table 5a). Per individual case, the net financial loss was calculated at 8,837 FCFA for every pig exhibiting ascariosis lesions, and 18,012 FCFA per animal diagnosed with swine erysipelas. Aggregating these dynamics against point prevalence rates and local slaughter volumes yielded annual divisional revenue losses of 237,210 FCFA for ascariosis and 168,447 FCFA for erysipelas, totaling a baseline annual drain of 405,657 FCFA within the monitored municipal facilities. Extrapolating these dynamics to the national scale under baseline assumptions indicated large macroeconomic losses, ranging from 321.3 to 550.8 million FCFA for ascariosis, and 228.3 to 391.4 million FCFA for swine erysipelas.

Table 5a: Baseline economic loss estimates for ascariosis and erysipelas (Retail Pork Price = 2,000 FCFA/kg).

Pathology Condition	Per-Case Loss (FCFA)	Divisional Annual Loss (FCFA)	National scale (700k slaughters)	National Scale (1.2M slaughters)
Ascariosis	8,837	237,210	321.3 Million FCFA	550.8 Million FCFA
Erysipelas	18,012	168,447	228.3 Million FCFA	391.4 Million FCFA
Combined Total	—	405,657	549.6 Million FCFA	942.2 Million FCFA

The multi-parameter sensitivity analysis effectively mapped the financial impact of parameter uncertainty and market fluctuations (Table 5b). When evaluated under a high-value consumer market pricing structure (4,500 FCFA/kg) combined with upper-bound Wilson prevalence intervals and maximum statistical weight penalties, the potential national losses increased substantially. Under this worst-case scenario, national losses were projected to reach 3.39 billion FCFA for ascariosis and 3.51 billion FCFA for erysipelas. This modeling confirms that even subclinical conditions with a low prevalence can cause a substantial economic drain when their individual carcass degradation impact is severe.

Table 5b: Multi-parameter sensitivity analysis matrix for divisional and national economic losses (FCFA).

Disease Scenario	Pricing Structure	Divisional Min Loss	Divisional Max Loss	National Min Loss	National Max Loss
Ascariosis	Baseline (2,000 FCFA/kg)	24,310	821,450	32.9 Million	1.91 Billion
	Intensive Market (4,500 FCFA/kg)	54,690	1,848,260	74.1 Million	3.39 Billion
Erysipelas	Baseline (2,000 FCFA/kg)	26,140	692,410	35.4 Million	1.56 Billion
	Intensive Market (4,500 FCFA/kg)	58,810	1,557,920	79.6 Million	3.51 Billion

3.6 Spatial Homogeneity and Lesion Distributions

Categorical independence tests linked specific pathologies to demographic segments (Supplementary Table S1). Ascariosis was found to be statistically homogeneous across the population, showing no significant correlation with breed type, sex, age group, or geographic subdivision ($p > 0.05$). Conversely, swine erysipelas displayed significant spatial clustering ($p=0.025$), with a higher concentration of positive cases identified within the Dschang municipal zone (4.3%) compared to other subdivisions (0.0–1.6%). Gastrointestinal strongylosis showed significant associations with animal sex ($p=0.031$) and geographic zone ($p=0.002$), with a higher prevalence in female pigs (4.1% vs. 0.9% in males) and a

distinct cluster in the Santchou subdivision (16.7%). Diagnostic density plots and violin distributions (Supplementary Figures S1 & S2) confirmed that carcasses with ascariosis and erysipelas had lower weights across the entire weight range, shifting the distribution curves leftward compared to healthy carcasses.

4. DISCUSSION

This investigation demonstrates that subclinical ascariosis and swine erysipelas are critical pathological conditions associated with substantial carcass weight loss among slaughtered pigs in the Western Highlands of Cameroon. Even at relatively low point prevalences, lesions that induce carcass weight penalties of 10% to 20% generate a substantial aggregate economic drain. This pattern aligns with international swine health models establishing *Ascaris suum* and *Erysipelothrix rhusiopathiae* as major threats to commercial pork performance due to their chronic impacts on feed conversion metrics, metabolic efficiency, and tissue deposition (Opriessnig et al., 2020; Zheng et al., 2020).

The identified carcass weight penalty of 4.42 kg per individual ascariosis case is consistent with the known pathophysiology of *A. suum*. During its migratory phase, larval transitions through hepatic tissues induce fibrotic lesions known as "milk spots," while adult worms in the small intestine compete for nutrients and cause mucosal inflammation, impairing nutrient absorption and reducing feed efficiency (Zheng et al., 2020; Habte et al., 2021; Whitehead et al., 2022). This subclinical parasitic burden prevents animals from achieving full genetic growth potential, leading to lower weights at slaughter and frequent liver condemnations (Whitehead et al., 2022). In low-input smallholder production systems, ascariosis remains highly endemic due to the high environmental resilience of infective eggs and inconsistent deworming protocols, with prior European studies estimating losses ≥ 4.61 € per finisher pig (Habte et al., 2021). These dynamics support the introduction of structured, strategic anthelmintic extensions within rural communities to break the parasite's transmission cycle (Zheng et al., 2020).

The parameter consistency observed across the ordinary least squares GLM, random-intercept GLMM, and bootstrap quantile regression architectures supports the statistical reliability of these findings. The low Intraclass Correlation Coefficient (**ICC** = 0.034) indicates that spatial clustering at the individual slaughterhouse level accounted for minimal variance, confirming that the adjusted fixed-effect parameters accurately reflect true biological impacts rather than localized operational biases (Nakagawa et al., 2016; Koo & Li, 2016). While the small sample size for erysipelas (**n** = 8) widened the bootstrap confidence intervals in the median quantile regression model, the negative coefficient remained substantial (-8.00 kg) and directionally consistent with the main linear frameworks (Koo & Li, 2016). Deploying multiple complementary analytical architectures effectively addresses common limitations of abattoir data, such as non-normal carcass weight distributions, cluster variations, and variable disease intensities (Pfuderer et al., 2022; Biden et al., 2024).

From an economic perspective, these assessments show that low-prevalence conditions can generate substantial aggregate financial drains when their individual impact on animal performance is severe.

This aligns with bio-economic disease models where modest prevalence coupled with large individual tissue penalties causes substantial reductions in gross producer margins (Teixeira et al., 2016; You et al., 2021; Pfuderer et al., 2022; Przyborowska et al., 2024). At the divisional scale, annual revenue shortfalls exceeded 400,000 FCFA under baseline parameters, while national extensions projected losses in the hundreds of millions of FCFA. These macro-projections match economic impact models for parasitic and respiratory complexes evaluated in comparable smallholder contexts (You et al., 2021; Pfuderer et al., 2022). Furthermore, the multi-parameter sensitivity analysis highlights how fluctuations in market values, prevalence boundaries, and statistical effect sizes alter financial risk profiles, providing a realistic range of economic outcomes for veterinary planning (Teixeira et al., 2016; Biden et al., 2024).

This research also clarifies the influence of zootechnical factors on hot carcass weight metrics within tropical swine systems. Breed lineage, maturity age class, sex, and geographic procurement channels displayed strong, significant associations with carcass weight, confirming that animal genotype and morphometric maturity are key determinants of market value in smallholder systems (Akanno et al., 2013; Kouam et al., 2019; Nevrkla et al., 2021; Yakubu et al., 2022). Accounting for these host factors is essential to control for confounding bias when modeling the specific impacts of subclinical lesions on carcass yield (Nevrkla et al., 2021; Pozo et al., 2021; Przyborowska et al., 2024).

Several methodological limitations should be noted. First, because data collection occurred exclusively at the slaughterhouse line, it omits animals that died pre-harvest or were culled on-farm. This introduces a classic "healthy survivor" effect that may underestimate true on-farm disease prevalence and associated losses (Pozo et al., 2021; Woldemariyam et al., 2021). Second, lesion identification relied on routine macroscopic post-mortem inspection. Studies on bovine tuberculosis and subclinical parasitism demonstrate that visual inspection can miss early-stage or microscopic lesions, potentially biasing prevalence and impact estimates downward (Woldemariyam et al., 2021; Gómez-Buendía et al., 2025). Third, breed categorization was based on morphological phenotypes rather than genotyping, which may introduce minor misclassification bias (Liljequist et al., 2019; Kouam et al., 2019). Finally, national macroeconomic extrapolations must be interpreted with caution, as production systems, disease dynamics, and market pricing vary across Cameroon's diverse agro-ecological zones (Kouam et al., 2019; Ebwanga et al., 2022; Biden et al., 2024).

Despite these limitations, this study provides clear evidence regarding production losses linked to common subclinical lesions identified at slaughter. The substantial carcass weight penalties associated with ascariosis and erysipelas, across both regional and national extensions, match the documented impacts of chronic parasitic and bacterial complexes in international literature (Pfuderer et al., 2022; Przyborowska et al., 2024; Tu et al., 2023). These findings support the establishment of integrated veterinary extension programs—focusing on structured deworming schedules and systematic erysipelas vaccination—to improve carcass yields and boost producer incomes, in line with biosecurity recommendations for Central Africa (Gómez-Buendía et al., 2025; Tu et al., 2023). Additionally, this methodological framework combining abattoir lesion data, multivariable regression, and sensitivity modeling provides a practical model for evaluating disease-driven production losses using routine

slaughterhouse records in resource-limited settings (Teixeira et al., 2016; You et al., 2021; Biden et al., 2024).

5. CONCLUSION

This investigation demonstrates that while most subclinical pathological lesions identified during post-mortem meat inspection in Cameroon's Western Highlands occur at a low prevalence, ascariosis and swine erysipelas exert disproportionately large impacts on carcass weight and producer returns. After adjusting for essential zootechnical confounders, the presence of ascariosis and erysipelas was associated with substantial carcass weight penalties of 4.42 kg and 9.01 kg, respectively, translating into meaningful financial shortfalls at both divisional and national scales. These findings underscore the importance of integrating regular anthelmintic treatments and systematic erysipelas vaccination into smallholder management frameworks to optimize carcass yields and enhance sector resilience. This study also demonstrates the value of routine abattoir surveillance as a cost-effective tool to monitor subclinical disease trends, evaluate production drains, and prioritize veterinary interventions in resource-limited settings.

Declarations

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Competing Interests

The authors declare that they have no competing financial, institutional, personal, or non-financial interests that could influence or compromise the objectivity and integrity of the work presented in this manuscript.

Author Contributions

All authors contributed significantly to the synthesis of this work. Ngueguim Derrick Fabrice designed the study, coordinated field sampling, performed advanced statistical modeling, and drafted the original manuscript. Saffo A. E. Beaudelaire and Kiambom Tracey managed post-mortem data tracking, validated host profiling, and organized the raw databases. Marc K. Kouam supervised the research layout, provided critical methodological reviews, and performed high-level academic editing for journal submission. All authors read and approved the finalized manuscript.

Submission statement: The authors declare that this work has not been published previously and is not under consideration elsewhere. All authors have approved the manuscript and agree with its submission to *Tropical Animal Health and Production*.

Data Availability Statement

The complete anonymized post-mortem database, epidemiological tracking sheets, and the full R code scripts implementing the Firth penalized regressions and GLMMs are fully available for reproducibility purposes

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