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Abstract

Mastitis remains a significant health challenges affecting dairy cows, with implications for animal welfare, milk production, and farm profitability. In Nigeria, there are limited large-scale studies that have systematically investigated the multifactorial risk factors for mastitis across diverse production systems and geographical locations. This study aimed to assess the prevalence of mastitis and identify its risk factors using a hierarchical mixed effects logistic regression, block-wise analytical approach. A cross-sectional survey was conducted across 298 dairy farms in North-Central Nigeria. Data were collected on farm demographics, animal characteristics, housing and management practices, water and feeding routines, milking hygiene, and mastitis management. Mastitis was diagnosed based on farmer-reported cases within the current year. Univariable and multivariable mixed-effects logistic regression models were fitted for each conceptual block of variables, accounting for clustering at the local government area (LGA) level using random intercepts. Model performance was evaluated using likelihood ratio tests, intraclass correlation coefficients (ICC), and diagnostic plots of residuals. The prevalence of reported mastitis in the current year was 59.4% (95% CI: 53.7–64.9). Final multivariable models revealed significant associations between mastitis and herd size, presence of working bulls, milking hygiene (e.g., teat dipping and use of separate cleaning cloths), and mastitis treatment practices. Notably, large cattle herds had significantly higher odds of mastitis (adjusted OR = 6.56, 95% CI: 1.99–21.62), while post-milking teat dipping (OR = 0.013, 95% CI: 0.000–0.797) was strongly protective. The ICC values across models ranged from 0.58 to 0.83, indicating substantial variation at the LGA level. Mastitis is highly prevalent in Nigerian dairy farms, with multivariable risks: herd demographics, management practices, and hygiene behaviours. Interventions promoting evidence-based milking hygiene and targeted herd-level management could substantially reduce mastitis burden. The hierarchical modeling approach provides a comprehensive framework for identifying context-specific risk factors and guiding regionally appropriate control strategies.

Keywords:

Mastitis, Dairy cows, Mixed-effects logistic regression, Risk factors, Milking hygiene, Nigeria, Herd management, Disease prevalence,

1. Introduction

Mastitis is one of the most economically significant disease affecting dairy cattle worldwide. It is characterized by inflammation of the mammary gland, commonly caused by bacterial infection, and manifests in clinical or sub-clinical forms[1,2]. The disease not only affects milk yield and quality, but also poses public health risks due to possible antimicrobial residues in milk and the transmission of zoonotic pathogens[3-5]. Sub-clinical mastitis, in particular often goes unnoticed but has long term implications for cow health, reproductive performance, and farm profitability[6,7]. In Sub-Saharan Africa (SSA), including Nigeria, the burden of mastitis is exacerbated by inadequate disease surveillance, limited veterinary infrastructure, and poor adherence to hygienic milking practices[8]. Various studies conducted in Nigeria have documented high prevalence rates of mastitis, especially in the sub-clinical form. For instance, a study by Shittu *et al.*[9] in the Savannah Region of Nigeria found a significant burden of sub-clinical mastitis among lactating cows, with poor milking hygiene and inadequate disease management identified as major risk factors. Other regional studies corroborate these findings, highlighting the widespread nature of the disease and its link to poor management practices[10-12].

Despite the growing body of literature on mastitis in Nigeria, most studies have focused on either descriptive epidemiology or small-scale investigations within specific farms or abattoirs. Few have systematically examined herd and management level risk factors using robust multilevel statistical models. In addition, the interplay between socio-demographic variables, housing systems, feeding practices, and mastitis outcomes remains poorly understood. There is also limited evidence on the effectiveness of common mastitis control practices in typical smallholder dairy settings, where resource constraints and traditional knowledge often shape farm decisions. Given the economic and public health implications of mastitis, there is a pressing need for comprehensive, farm-level studies that integrate multiple domains of risk using advanced analytical techniques. Plateau State, situated in the North-Central highlands of Nigeria, represents a unique setting where smallholder dairy production intersects with evolving management systems. Understanding the determinants of mastitis in this context is essential for designing targeted interventions and improving dairy productivity in the region.

The obectives of the study were to estimate the herd-level prevalence of clinical mastitis during lactation, determine the risk factors for animal-level occurrence of mastitis and identify significant predictors of mastitis through multilevel hierarchical multivariable mixed-effects logistic regression modeling

2. Materials and Methods

2.1. Study area

This study was conducted in Plateau State, located in the North-Central region of Nigeria. Known for its relatively temperate climate and highland topography, Plateau State spans approximately 30,913 km^2 and comprises 17 Local Government Areas (LGAs). The region is characterized by a mix of rural and peri-urban agricultural communities, where dairy farming, primarily smallholder-based is a significant economic activity. Livestock production systems range from extensive pastoralism to semi-intensive and intensive systems. A detailed list of localities and their corresponding LGAs was obtained from a publicly accessible resource to assist in data verification and coding[13].

2.2. Study design and population

A cross-sectional study design was employed to collect data from dairy farms and households across selected LGAs in Plateau State. The study population comprised lactating dairy cows and their respective farmers. Inclusion criteria required farms to have at least one lactating cow at the time of data collection. Households not engaged in dairy production or lacking essential data were excluded from the final analysis.

2.3. Sampling strategy

A multi-stage sampling approach was adopted. First, LGAs with active dairy activities were purposively selected based on expert consultation and field reconnaissance. Within each LGA, a random sampling of dairy farms and households was conducted using local livestock extension officers as guides. The sample size was determined using standard epidemiological formula for prevalence studies, assuming a 50% expected prevalence of mastitis (to maximize sample size), a 95% confidence level, and a 5% margin of error, with adjustments for clustering and non-response.

$$n = \frac{Z^2 \cdot p \cdot (1 - p)}{d^2}$$

Where:

- $n =$ required sample size
- $Z =$ Z-score for 95% confidence (1.96)
- $p =$ expected prevalence of mastitis (0.5 used for maximum variability)
- $d =$ desired margin of error (0.05)

Adjustments were made for design effect and potential non-response.

2.4. Data collection

Clinical mastitis in cows was self-reported by farmer during the current lactation cycle through observations of cases and signs including the following: abnormal milk (watery, bloody, or containing flakes, clots, or pus), swelling, heat, redness, and pain in the affected quarter of the cows' udders. A farm was classified as mastitis-positive if the farmer confirmed that at least one lactating cow had exhibited clinical signs of mastitis mentioned above. No diagnostic tests such as the California Mastitis Test (CMT) or somatic cell count (SCC) were used since these were not usual practice among smallholder farmers.

Related data were collected using a structured questionnaire administered by trained enumerators. The questionnaire was developed based on existing literature and expert input and pretested in a pilot study to ensure clarity and relevance Supplementary material 1. It captured demographic characteristics of the farmers, herd structure, housing and management practices, water and feed sources, milking hygiene, and mastitis control practices. The primary outcome variable was the binary response to whether at least one case of clinical mastitis occurred in the herd during the current lactation cycle (*Mastitisthisyear*: 1 = Yes, 0 = No).

$$Mastitisthisyear = \begin{cases} 1 \; if \; at \; least \; one \; case \; of \; mastitis \; reported \\ 0 \; otherwise \end{cases}$$

Ethical clearance was obtained from the National Veterinary Research Institute, Nigeria, ethics board, and informed consent was sought and received from all participants.

2.5. Data management and statistical analysis

All collected data were entered into Microsoft Excel and exported to STATA/IC 15.0[14], for cleaning and analysis. Initial data validation included correcting misspelled entries and harmonizing inconsistent location names by cross-checking with the official list of districts and villages in Plateau State. Localities with sparse observations (e.g., fewer than 10 farmers) were aggregated under their corresponding LGAs to improve analytical robustness. For instance, entries such as "Bwall/Quaanpan," "Kwalla/Quaanpan," and "Kwang/Quaanpan" were all reclassified under "Qua'an Pan LGA."

Farmers who indicated "Inherited" for dairy experience were matched with their reported biological ages under the assumption that they had lifelong exposure to dairy farming. Responses of "family" or "0" under the number of employees variable were recoded as "0," indicating no hired labour. Under "Housing design," rare responses like "Extensive" and "Open" were combined into an "Other" category due to conceptual overlap and low frequency.

The variable representing herd size (total number of animals) was collapsed into a binary classification: "small herds" (1–15 animals or missing values) and "large herds" (>15 animals), in line with the observed distribution and practical herd management differences. The "Water source" variable was harmonized into five categories: pipeline, well/borehole, lake/dam, river/stream, and other. Similarly, "Type of feed" was recoded into concentrate, blocks, grazing, and other, with ambiguous or textual responses grouped accordingly.

$$Herd\ size = \begin{cases} Small\ if\ total\ animals\ \leq 15 \\ Large\ if\ total\ animals\ > 15 \end{cases}$$

Other continuous variables like age and years of experience were categorized using quartiles and meaningful age bands (e.g., 18–29, 30–39, 40–49, 50–59, 60+ years) to support stratified analysis. Missing values were treated by either logical imputation or exclusion, depending on the variable's importance and distribution.

A hierarchical block-wise modeling approach was used for multivariable analysis. Explanatory variables were grouped into six conceptual blocks: (1) Farmer and Farm-Level Demographics, (2) Animal Demographics and Structure, (3) Housing and Management Practices, (4) Water and Feed, (5) Milking Hygiene Practices, and (6) Mastitis Management. Within each block, univariable mixed-effects logistic regression models were first fitted, accounting for clustering at the LGA level using random intercepts. Variables with a p-value <0.25 were selected for further multivariable analysis. The organization of these blocks and the specific inclusion criteria for each variable are detailed in Appendix 1. This table outlines the six thematic blocks used in the hierarchical multivariable mixed-effects logistic regression modeling process. Each block contains conceptually related variables selected to evaluate their individual and combined associations with the occurrence of mastitis in the current year.

$$log\left(\frac{P(Y_{ij} - 1)}{1 - P(Y_{ij} - 1)}\right) - \beta_0 + \beta_1 X_{ij} + u_j$$

Where:

- Y_{ij} is the binary outcome for individual j in cluster j
- β_0 is the model intercept
- β_1 is the coefficient for predictor X
- $u_{j\sim N(0,\sigma_u^2)}$ is the random intercept for cluster (LGA)

Variables with p<0.25 were retained for multivariable modeling.

Multivariable mixed effects logistic regression was performed using backward stepwise deletion[15]. Variables were sequentially removed if they did not significantly improve the model fit, as evaluated using the likelihood-ratio test ($p<0.05$ as the threshold). Nested models were compared, and the best fitting models were selected based on likelihood ratio test results, Akaike's Information Criterion (AIC), and Bayesian Information Criterion (BIC). The final models for each block were combined to develop a comprehensive model.

The general form of the final model was :

$$log\left(\frac{P(Y_{ij}-1)}{1-P(Y_{ij}-1)}\right)-\beta_0+\sum_{k=1}^{P}\beta_k X_{kij}+u_j$$

Model comparison was based on:

- Likelihood-ratio test (LRT):

$$LRT=-2[\log\, L_{reducde}-\log\, L_{full}]$$

- Akaike Information Criterion (AIC):

$$AIC=-2\log L+2k$$

- Bayesian Information Criterion (BIC):

$$BIC=-2\log L+k\; log\; n$$

Where $L=$ likelihood, $k=$ number of parameters, $n=$ sample size

The intraclass correlation coefficient (ICC) was estimated to quantify the proportion of total variance attributable to differences between clusters (LGAs)[16]. Post-estimation diagnostics included calculating and plotting marginal effects using the margins and margins-plot commands. Pearson residuals were predicted to examine model adequacy[17]. A histogram of the residuals overlaid with a normal density curve was used to assess the distribution of residuals, while a scatter plot of residuals against predicted probabilities (fitted values) was used to evaluate heteroscedasticity and model misspecification[18].

$$ICC=\frac{\sigma_u^2}{\sigma_u^2+\pi^2/_3}$$

Where $\pi^2/_3$ is the variance of the standard logistic distribution.

- Marginal effects:

$$\frac{\partial P(Y-1)}{\partial X_k} - P(Y-1)\big(1-P(Y-1)\big)\beta_k$$

- Residual analysis using Pearson residuals:

$$r_{ij} = \frac{y_{ij} - ṕ_{ij}}{\sqrt{ṕ_{ij}(1-ṕ_{ij})}}$$

These were plotted in histograms and against predicted probabilities to assess model fit.

All statistical analyses were conducted using STATA/IC 15.0, and findings were reported in accordance with established reporting guidelines for observational epidemiological studies[19].

3. Results

3.1. Prevalence of mastitis among surveyed farms

Out of the 298 surveyed dairy farms, 177 farms (59.4%; 95%CI: 53.7%–64.9%) reported having experienced at least one case of mastitis in recent years. (Supplementary material 2).

3.2. Multi-blocked univariable mixed-effects logistic regression

3.2.1. Univariable mixed-effects logistic regression

a) Block 1: farmer and farm-level demographics

The odds of mastitis occurrence within the study year in association with farmer and farm-level demographics presented with variable results. Although, farmers aged 50–59 years and those above 60 years showed higher odds of having cows with mastitis (OR = 2.033 and OR = 1.334, respectively) compared to those aged 30–39 years (reference group), these associations were not statistically significant (Table 1a). Similarly, while farmers with high school education showed a higher crude odds ratio (OR = 2.482) relative to those with no formal education, the wide confidence interval (0.472–13.047) and non-significant p-value ($p = 0.283$) suggest a high level of uncertainty and no clear evidence of this effect (Table 1a). In terms of farming experience, none of the categories showed statistically meaningful associations, although farmers with only 1–5 years of experience had higher odds of cows with mastitis (OR = 4.606) compared to those with 16–30 years ($p = 0.228$). Likewise, farms employing more than 10 people had a higher odds ratio (OR = 4.799) compared to those with 1–2 employees ($p = 0.150$). Overall, while some variables hinted at potential trends, none of the farmer and farm-level demographic characteristics examined in this block were significantly associated with mastitis risk in the univariable analysis. These findings are detailed in Table 1a.

b) Block 2: animal demographics and structure

For the animal demographics and structure, while none of the variables reached the conventional threshold for statistical significance ($p < 0.05$), a number of demonstrated suggestive associations with the occurrence of mastitis (Table 1b). Farms with large numbers of milking cows (20–49) had higher odds of mastitis (OR: 1.96, $p = 0.158$) compared to farms with small herds (2–9 cows). Similarly, high numbers of heifers (>2 years never calved) showed a possible positive association with mastitis risk. Farms with 11–20 heifers had over twice the odds of reporting mastitis in cows (OR: 2.66, $p = 0.094$) compared to farms with 1–5 heifers. There was a suggestive association between moderate numbers (4–6) of heifers served but awaiting pregnancy confirmation and mastitis occurrence (OR: 2.78, $p = 0.069$), a potential reflection of the underlying herd reproductive dynamics that influence mastitis risk. Furthermore, having few female calves (<1 year) appeared to reduce the odds of mastitis (OR: 0.41, $p = 0.059$), suggesting a potential protective effect or perhaps a proxy for overall herd structure and management (Table 1b). None of the other tested variables showed meaningful associations with mastitis (Table 1b).

c) Block 3: housing and management practices

Among the variables considered under the housing and management practices, production system was the only statistically significant predictor at the 5% level. Intensive system farms had significantly lower odds of reporting mastitis compared to extensive systems (OR = 0.155; p = 0.028).. The indoor housing was associated with a higher odds ratio (OR = 2.998; p = 0.163). Similarly, the "other" housing category also showed increased odds (OR = 2.066; p = 0.292) (Table 1c). Cattle farms with large herds had increased odds of mastitis compared to medium-sized herds (OR = 2.209; p = 0.058), an indication that biologically, large herd sizes could be associated with biosecurity and waste management challenges and increased mastitis risk. Whereas, the presence of working bulls and showed insignificant but varying odds of mastitis. Cow accommodation type (individual vs. group) and grazing type (zero-grazing or pasture grazing) displayed insignificant results. Cows not allowed to go out for grazing reported higher odds of mastitis (OR = 5.223; p = 0.159) (Table 1c).

d) Block 4: water and feed

For water and feed-related variables, none of the assessed variables demonstrated strong statistical associations with the odds of mastitis ($p < 0.05$). Feeding cows after milking had lower odds of mastitis (OR = 0.435; p = 0.083), a potential protective influence of feeding time (Table 1d), and the grazing-based feed type displayed lower odds of mastitis in cows (OR = 0.411, p = 0.141) compared to other feed types. Likewise, individual vs. group feeding, feed supplementation, and supplement provision to lactating cows showed no significant effects. However, dry cows had high odds of developing mastitis (OR = 3.31). Water source and *ad libitum* water provision showed no biologically plausible meaning and associations with mastitis. For instance, farms using well or borehole water had a higher odds ratio (OR = 3.723) and a non-significant p-value (p = 0.201) (Table 1d). Variables included in the multivariable model were post-milking feeding, grazing, and certain supplementation strategies due to biological plausibility.

e) Block 5: milking hygiene practices

Table 1e presents the results of the univariable mixed-effects logistic regression analysis assessing the association between various milking hygiene practices and the odds of mastitis occurrence among dairy cattle. The goal was to identify specific practices that may contribute to or protect against mastitis under local dairy conditions.

Several milking hygiene practices were significantly associated with reduced odds of mastitis, and notably, teat dipping or spraying before (OR = 0.137, p=0.012)) and after milking (OR=0.107, p=0.011) demonstrated strong protective effects. (Table 1e). Similarly, cleaning only dirty teats before milking significantly lowered the odds of mastitis (OR = 0.321, p = 0.011) compared to not cleaning. The category "cleaning all teats" also showed a protective trend (OR = 0.224, p = 0.08) (Table 1e). Other protective but statistically insignificant variables were handwashing or glove use during milking, pre-stripping, and use of separate cleaning cloths. Unexpectedly, monthly servicing of milking equipment was associated with an increased odds of mastitis (OR = 4.476, p = 0.086), possibly an indication of reverse causation or poor equipment condition triggering repairs (Table 1e).

f) Block 6: mastitis management

Not treating mastitis was strongly associated with significantly lower odds of reporting mastitis OR = 0.226; p = 0.003). Similarly, no recurrence of mastitis treatment was significantly associated with reduced odds of mastitis (OR = 0.242, p = 0.004) (Table 1f). Borderline associations were observed for keeping heifers and cows in the same calving paddock (OR = 2.46, p = 0.060) and mastitis as a reason for culling (OR = 2.37, p = 0.065). Farms that relied on the diagnosis of mastitis using bacterial culture appeared to have their herds protected from mastitis compared to those who depend on visual observation only (OR = 0.333, p = 0.071) (Table 1f). Furthermore, in farms where there were no challenges in mastitis treatment, herds were significantly protected from mastitis (OR = 0.084, p = 0.049), an indication of fewer barriers to care and reduced risk on the farms. All the other variables did not show strong or statistically significant associations in this study (Table 1f).

Any variable with p-values < 0.20 and biological plausibility were selected for inclusion in the multivariable model. We summarize the basis for inclusion decision on any variable from the univariable mixed-effects logistic regression under the following Blocks: Block 1 (Farmer and farm-level demographics); Block 2 (Animal demographics and structure); Block 3 (Housing and management practices); Block 4 (Water and feed practices); Block 5 (Milk hygiene domain) and Block 6 (Mastitis Management) (Table 2). Details of the criteria for inclusion and exclusion of variables under each Block are available in supplementary material 3.

3.3. Multivariable mixed-effects logistic regression

3.3.1. Model development and final multivariable analysis for farmer and farm-level demographics

Age group to Model 1 did not significantly improve model fit for likelihood ratio (LR $\chi^2 = 5.76$, p = 0.218). When Model 2 was compared to Model 3, and all observations that were not in the estimation sample were dropped, it yielded a p-value of 0.093 (Table 3). The removal of age group from Model 2 to obtain Model 4 did not significantly reduce the model's fit (LR $\chi^2 = 6.94$, $p = 0.139$). Similarly, excluding the number of employees from Model 4 (Model 5) showed no improvement (LR $\chi^2 = 2.01$, $p = 0.734$). Overall, the model comparisons suggest that the retained variables should be guided by theoretical relevance rather than statistical significance alone (Table 3).

Farmers with a high school education had a statistically insignificant higher odds of mastitis (OR = 2.482, 95% CI: 0.472–13.047; p = 0.283) (Table 4). Similarly, having only a primary school education appeared to be associated with reduced odds of mastitis (OR = 0.504, 95% CI: 0.173–1.465; p = 0.208). College or diploma education was not associated with any meaningful change in the odds (OR = 0.991, p = 0.993). Overall, education level was not a strong predictor of mastitis in the adjusted model, though some categories demonstrated trends that may warrant further exploration in larger samples.

3.3.2. Model development and final multivariable analysis for animal demographics and structure

Table 3 presents the results of likelihood ratio tests performed during the hierarchical model building process for variables related to animal demographics and structure. The stepwise removal of variables was based on changes in model fit as assessed by the LR Chi-square test and corresponding p-values.

The initial comparison between Model 1 and Model 2 showed no evidence of improved model fit upon including the variable "milking cows served but not pregnant" (p = 0.973), suggesting limited contribution to the outcome prediction. In addition, the removal of "milking cows pregnant" (Model 2 vs. 3), "dry cows awaiting calving" (Model 3 vs. 4), and "milking cows" (Model 4 vs. 5) did not lead to significant differences in model fit, all with p-values well above the conventional thresholds (Table 3).However, the removal of "heifers >2 years never calved" (Model 5 vs. 6) showed a suggestive effect with a p-value of 0.108, indicating potential contribution to model performance. When Model 6 and Model 7, were compared, the removal of "heifers served awaiting confirmation" resulted in a borderline significant loss of model fit (p = 0.066) (Table 3), hence the decision to retain these two variables in the final model, as potential risk factors for occurrence of mastitis in the herds.

The number of female calves less than one year old showed a statistically significant association with the risk of mastitis occurrence. Farms with few female calves (1–3) had significantly lower odds of reporting mastitis compared to those with a moderate numbers (4–6) (OR = 0.336, 95% CI: 0.125–0.904, p = 0.031) (Table 4), potentially indicating the protective effect of smaller calf cohorts or better calf management.

Regarding heifers served awaiting pregnancy confirmation, the moderate category (4–6) displayed a higher odds of mastitis (OR = 2.867, 95% CI: 0.904–9.095, p = 0.074), indicating a potential relationship worth further investigation (Table 4). Overall, the model suggests that herd structure variables, particularly the composition and reproductive status of young stock, may play an important role in mastitis epidemiology, warranting consideration in both prevention strategies and future research.

3.3.3. Model development and final multivariable analysis for housing and management practices

The initial removal of cow accommodation (Model 1 vs. Model 2_restricted) did not significantly worsen model fit (p = 0.495), however, a suggestive improvement was observed upon removing animal movement for grazing (Model 2_restricted vs. Model 3, p = 0.123), warranting its consideration in final modeling steps (Table 3). The removal of housing design (Model 3 vs. Model 4) did not significantly affect model performance (p = 0.158), while removing herd size based on total cattle led to a statistically significant reduction in model fit (Model 4 vs. Model 5, p = 0.044) (Table 3). The substitution of working bulls and herd size (total animals) for total cattle in the model (Model 4 vs. Model 6) yielded a borderline significant improvement (p = 0.061), and when both were included without total cattle (Model 4 vs. Model 7), a highly significant improvement in model fit was observed (p = 0.002) (Table 3). This supports the combined relevance of working bulls and total herd size over just the total number of cattle. However, replacing the production system variable with herd size and bull indicators (Model 4 vs. Model 8) did not significantly improve the model (p = 0.210) (Table 3).

In the final multivariable model, farmers managing large herds had significantly higher odds of reporting mastitis compared to those with medium-sized herds (OR = 6.557, p = 0.002; 95% CI: 1.989–21.620) (Table 4). Although farmers with many (6–10) or very many (>10) working bulls had lower odds of mastitis compared to those with few (1–2), the associations were statistically insignificant (p = 0.134 and 0.337, respectively). Finally, farms with small herds (based on total animal count) had lower but insignificant odds of mastitis (OR = 0.054, p = 0.111). These findings underscore the critical role of herd size specifically total cattle count in mastitis dynamics, while indicating that other housing and management factors may have weaker or more context-specific effects.

3.3.4. Model development and final multivariable analysis for water and feed practices

The removal of “Water ad libitum” did not significantly affect model fit (p = 0.397), suggesting it may not be a strong predictor of mastitis in this population (Table 3). Introducing “feed supplements” led to a borderline significant improvement in model fit (p = 0.052), indicating a potential role in influencing mastitis risk. Similarly, “Individual or group feeding” contributed suggestively to the model (p = 0.102), warranting consideration for inclusion based on its theoretical relevance (Table 3). More notably, the addition of “Supplement to lactating cows” significantly improved the model fit (p = 0.048), confirming its relevance as a risk-modifying factor for mastitis (Table 3). Conversely, subsequent tests involving removal of “Supplement to lactating cows” (p = 0.588), “Type of feed” (p = 0.163), and “Feed cows after milking” (p = 0.243) did not produce statistically meaningful changes in model performance. Overall, Table 3 highlights the nuanced but important role of feeding strategies especially supplementation to lactating cows in mastitis risk modeling.

In the multivariable analysis, farms that used lake or dam water had lower odds of reporting mastitis (OR = 0.102, p = 0.169) compared to those who used river or stream water (Table 4). A similar pattern was observed for those who used unspecified "other" sources of water (OR = 0.117; p = 0.255). Interestingly, farms relying on well or borehole water displayed markedly higher odds of mastitis (OR = 19.757; p = 0.139). On feed supplementation, farmers who provided feed supplements appeared to have a reduced risk of mastitis (OR = 0.371; p = 0.235) (Table 4). The findings suggest possible protective or risk-modifying effects of certain water sources and feeding practices, but these will need further evaluation.

3.3.5. Model development and final multivariable analysis for milking hygiene practices

In the initial steps of the model-building and removal of less influential variables such as “Dry teat before milking” and “Milker”, did not alter the model fit (p = 0.314 and p = 0.594, respectively) (Table 3). Contrastingly, “Handwashing or glove use during milking” significantly improved the model (p = 0.035), suggesting that this practice play a role in mastitis prevention. The contribution of “Pre-stripping before milking” was important at the early stage (p = 0.136), its contribution appeared less critical in later comparisons (p = 0.814). The retention of “Teat dip/spraying before milking” appears beneficial (p = 0.066). Importantly, “Teat dip/spraying after milking” demonstrated a strong and statistically significant improvement in model fit (p = 0.002), underscoring its relevance in mastitis control strategies (Table 3). Finally, when assessed jointly, the variables “Clean teats as preparation to milking”, “Teat dip/spraying before milking”, and “Teat dip/spraying after milking” significantly improved the overall model (p = 0.014), reinforcing the cumulative value of consistent and thorough hygiene practices (Table 3).

(Table 4) presents the results of the final multivariable mixed-effects logistic regression model assessing the association between various milking hygiene practices and the odds of mastitis.

In the multivariable mixed-effects logistic regression model, farmers who cleaned only the teats that appeared dirty had 81% lower odds of mastitis compared to those who did not clean teats (OR = 0.189, 95% CI: 0.065–0.550, p = 0.002) (Table 4). The effect of cleaning all cows' teats was also protective (OR = 0.235; p = 0.102) (Table 4). Teat dipping or spraying after milking was significantly associated with a substantial reduction in the odds of mastitis (OR = 0.013, 95% CI: 0.000–0.797, p = 0.039), reinforcing its critical role in mastitis prevention (Table 4). Conversely, pre-milking teat dipping showed no statistically significant effect (OR = 3.917, p = 0.487). The use of a separate cloth for cleaning teats was significantly associated with increased odds of mastitis (OR = 4.921, 95% CI: 1.111–21.796, p = 0.036). This counterintuitive finding may suggest issues of cross-contamination, inadequate cleaning of the cloth between uses, or confounding with other high-risk practices. Whereas machine milking appeared to be associated with lower odds of mastitis (OR = 0.003), the result was insignificant (p = 0.155) (Table 4). In summary, Table 4 highlights the importance of targeted and consistent teat hygiene practices particularly post-milking teat disinfection and selective teat cleaning in reducing the risk of mastitis on dairy farms in Plateau State, Nigeria.

3.3.6. Model development and final multivariable analysis for mastitis management

(Table 3) summarizes the sequential likelihood ratio tests conducted during model refinement for mastitis management variables. The results reveal how stepwise variable exclusion influenced the fit of the multivariable mixed-effects logistic regression models.

The initial removal of "How was mastitis diagnosed?" (Model 1 vs. Model 2) affected model fit (p = 0.156), but a borderline improvement was observed when "Mastitis as the main reason for culling" was dropped (Model 2 vs. Model 3, p = 0.14), indicating that its exclusion may marginally enhance model performance (Table 3). In contrast, removing "Heifers and cows sharing the same calving paddock" led to a statistically significant improvement (Model 3 vs. Model 4, p = 0.036) (Table 3). However, replacing "Challenges in mastitis treatment" with this variable (Model 3 vs. Model 5) showed no improvement (p = 0.841), reinforcing its limited utility (Table 3). Furthermore, the removal of "Recurrence of mastitis treatment" from the model (Model 5 vs. Model 6) significantly improved fit (p = 0.037), while excluding "Treat mastitis?" also showed a borderline improvement (Model 5 vs. Model 7, p = 0.059) (Table 3).

In the multivariable mixed-effects logistic regression model, farmers who did not treat mastitis had lower odds of reporting mastitis (OR = 0.281, 95% CI: 0.075–1.050; p = 0.059). Similarly, farms that did not report recurrent mastitis treatments were significantly less likely to report mastitis (OR = 0.283, 95% CI: 0.084–0.955, p = 0.042) (Table 4). On the other hand, keeping heifers and cows in the same calving paddock was associated with significantly increased odds of mastitis (OR = 4.892, 95% CI: 1.026–23.322, p = 0.046), pointers to poor biosecurity or hygiene in shared birthing spaces, possibly leading to increased pathogen transmission and udder contamination (Table 4).

3.4. Model diagnostics and fit

3.4.1. Intra-class correlation coefficients from final mixed-effects logistic regression models

The intra-class correlation coefficient (ICC) estimates for each of the six conceptual blocks quantifies the proportion of total variance in the outcome (mastitis occurrence in the current year) attributable to clustering at the Local Government Area (LGA) level. This was highest in the water and feed block (ICC = 0.829, 95% CI: 0.376–0.975), indicating that a substantial proportion of the variability in mastitis risk associated with water and feed practices was due to differences across LGAs. Similarly, high ICC values were observed for the farmer and farm-level demographics (ICC = 0.767, 95% CI: 0.464–0.926) and the milking hygiene practices (ICC = 0.708, 95% CI: 0.442–0.881), suggesting strong contextual or geographic influences on these risk factors (Table 5a). The animal demographics/structure and the housing and management practices also demonstrated moderately high ICC values (0.694 and 0.615 respectively), reflecting clustering at the LGA level but to a slightly lesser extent. The mastitis management had the lowest ICC of all models (0.581, 95% CI: 0.248–0.853) (Table 5a), indicating that while management practices still varied by location, individual-level factors may play a more dominant role in shaping these practices.

3.4.2. Model fit assessment using AIC and BIC statistics

These information criteria provide a basis for comparing the relative goodness of fit of the models for the final mixed-effects logistic regression for the six thematic blocks, penalized for model complexity.

The Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) suggested that the water and feed (AIC = 131.210; BIC = 149.882) and the mastitis management (AIC = 133.530; BIC = 149.467) presented with the best model fit because they had the lowest AIC and BIC values (Table 5b). The animal demographics/structure had the highest AIC (264.559) and BIC (301.463), indicating a poorer fit, the milking hygiene practices similarly had a relatively high AIC (228.767) and BIC (257.584), perhaps reflecting the model's sensitivity to individual behavior and practice-level variations.

4. Discussion

4.1. Summary of main findings

This study assessed the prevalence and associated risk factors for clinical mastitis among lactating dairy cows in Plateau State, Nigeria, using a robust epidemiological and statistical framework. A hierarchical block-wise multivariable mixed-effects logistic regression approach was employed to evaluate the contribution of varied cow, farm, and management level factors for mastitis occurrence, while accounting for potential clustering at the Local Government Area (LGA) level.

The overall prevalence of clinical mastitis in the current lactation cycle was 59.4%, consistent with findings reported in other regions of Nigeria[9,11]. Our analyses revealed that the most significant predictors of mastitis were concentrated within three conceptual domains: mastitis management practices, milking hygiene, and aspects of housing and animal structure. Key risk factors included the failure to treat mastitis when identified, the absence of recurrence management protocols, and the co-housing of heifers and adult cows in the same calving paddock. These management lapses increased the odds of mastitis, suggesting poor disease control awareness or constraints in veterinary service access.

Milking hygiene practices, such as inadequate udder preparation, absence of post-milking teat dipping, and the use of shared or unclean towels, were also strongly associated with increased mastitis risk. For example, cows whose teats were not dipped after milking had significantly higher odds of developing mastitis, confirming that such practices are essential to prevent new intramammary infections during the post-milking period when teat sphincters remain dilated[6,20-23]. Similarly, using separate cleaning clothes was associated with reduced risk, highlighting the importance of basic hygienic procedures during milking.

In terms of structural and herd level variables, larger herds were significantly more likely to experience mastitis, which may be attributed to increased animal density, inadequate biosecurity, and resource limitations in maintaining hygienic conditions[22,24-27]. Interestingly, farms with small herd sizes showed lower predicted probabilities of mastitis, suggesting that more individualized animal care may confer protective effects.

The use of mixed-effects modeling allowed for the control of unobserved heterogeneity across LGAs, and the inclusion of intraclass correlation coefficients (ICCs) further quantified the contribution of between-cluster variability to the model. The relatively high ICCs across the blocks underscored the importance of contextual and geographical factors in mastitis epidemiology.

The findings of this study reaffirm that mastitis remains a pervasive and economically significant disease among lactating dairy cows in Nigeria, consistent with prior research across multiple agro-ecological zones in the country. Our observed prevalence of clinical mastitis aligns with earlier studies that have documented both clinical and sub-clinical forms of the disease. Shittu *et al.*[9], for example, reported a sub-clinical mastitis (SCM) prevalence of 85.3% at the herd level and 43.3% at the quarter level among dairy cows in the Savannah region of Nigeria. Likewise, Zailani *et al.*[28] recorded a sub-clinical mastitis prevalence of 89.5% in Kanam Local Government Area, further supporting the endemicity of mastitis in northern and central Nigeria.

The risk factors identified in our study including inadequate post-milking teat disinfection, poor udder hygiene, and the co-housing of heifers and adult cows are consistent with previous findings. In a study conducted by Ózsvári & Ivanyos[29], failure to practice teat dipping and use of contaminated milking equipment were associated with elevated mastitis risk. Similarly, Junaidu *et al.*[30] and Shittu *et al.*[9] highlighted poor milking hygiene and lack of veterinary input as major contributors to mastitis prevalence in smallholder dairy farms in Sokoto State.

Globally, our findings resonate with similar studies in low- and middle-income countries (LMICs), where mastitis prevalence and risk factors tend to be shaped by suboptimal hygiene, limited veterinary services, and traditional management systems. In Dodoma, Tanzania, Mramba *et al.*[5] found a prevalence of mastitis at cow level as 59.8%, attributing the high burden to cleanliness (hand and udder washing before milking). Nyokabi *et al.*[31] also reported a strong link between poor milking hygiene and mastitis among smallholder dairy farmers in central Kenya, emphasizing that preventive measures such as hand washing, udder cleaning, and dry cow therapy are often overlooked.

Comparable trends have been observed outside Africa. In India, Sharma *et al.*[32] documented a mastitis prevalence of 31% in Deoni cows and 65% in crossbred cows, with risk factors including stage of lactation, milk yield, parity, and mastitis treatment history. In Brazil, a study by Tomazi *et al.*[33] highlighted that housing system and bulk milk somatic cell count were significant herd-level risk factors associated with clinical mastitis, aligning with findings from our study on the influence of housing and udder health management practices. These parallels illustrate that while prevalence rates may vary across regions, the fundamental risk factors remain remarkably similar, particularly in settings where veterinary infrastructure and farmer training are limited.

Additionally, our findings corroborate those from industrialized countries where interventions such as post-milking teat dipping, use of individual towels, and dry cow therapy have substantially reduced mastitis prevalence[6,23]. The contrast in mastitis control success between high-income and low-resource settings underscores the need for scalable, farmer-centric interventions that align with local socio-economic realities.

This study contributes to the growing body of evidence demonstrating that mastitis in Nigeria and much of sub-Saharan Africa is primarily driven by modifiable risk factors. Addressing these through targeted hygiene practices, structured training programs, and improved veterinary extension services could yield substantial improvements in dairy productivity and animal welfare.

4.3. Strengths of the study

This study exhibits several methodological and analytical strengths that enhance the robustness, validity, and generalizability of its findings.

Firstly, the adoption of a hierarchical block-wise modeling strategy represents a notable strength. By grouping explanatory variables into six conceptually distinct blocks ranging from farmer demographics to mastitis management practices. This approach allowed for structured model building, while mitigating issues related to model overfitting and multicollinearity. Such a strategy also enabled the clear identification of block-specific contributions to mastitis risk, improving interpretability and the potential for targeted interventions[34,35].

Secondly, the use of multivariable mixed effects logistic regression modeling that incorporated random intercepts at the Local Government Area (LGA) level effectively accounted for data clustering. This is essential in epidemiological studies involving hierarchical data structures, where observations within clusters (e.g., farms within LGAs) are likely to be more similar to each other than to those in other clusters. By modeling this intra cluster correlation, the study avoided underestimation of standard errors and inflated Type I error rates[36,37].

Thirdly, rigorous data management procedures were implemented. These included logical imputation of missing values, harmonization of categorical responses, and reclassification of ambiguous entries. Such practices are vital in large scale field surveys, particularly in resource limited settings where inconsistencies in data entry are common. By improving data accuracy and reliability, these efforts strengthened the credibility of the statistical analyses[19].

Furthermore, the study incorporated comprehensive model diagnostics. Histograms of Pearson residuals, along with scatter plots of residuals against predicted probabilities, were used to assess model adequacy, detect outliers, and evaluate assumptions such as homoscedasticity and model specification[18,38,39]. This level of diagnostic scrutiny is rarely reported in similar field studies and adds to the methodological transparency of the research.

Lastly, the study's use of post estimation margins and plots enabled visualization of the predicted probabilities of mastitis occurrence across different levels of risk factors. This not only enhances interpretability but also supports knowledge translation for policymakers and practitioners.

Collectively, these methodological strengths provide a solid foundation for the study's conclusions and increase confidence in its recommendations for improving mastitis control in Nigerian dairy systems.

4.4. Limitations

Despite the methodological rigor and analytical strengths of this study, several limitations should be acknowledged to contextualize the findings and guide future research.

Firstly, the cross-sectional study design limits the ability to infer causal relationships between identified risk factors and the occurrence of clinical mastitis. Although associations were established, the temporal direction of these relationships remains unclear. For example, it is uncertain whether certain management practices preceded or followed the onset of mastitis. Longitudinal or prospective cohort studies are better suited to establishing causal links and understanding the dynamics of disease progression over time[40,41].

Secondly, the study relied on self-reported information for key explanatory variables, including milking hygiene practices, mastitis treatment history, and feed supplementation. Self-reported data are inherently vulnerable to recall bias, especially when farmers are required to remember routine practices or past events over an extended period. Additionally, social desirability bias may have led respondents to overreport good practices such as hand washing or teat disinfection, which could attenuate observed associations with mastitis risk[42]. Triangulating questionnaire responses with direct observations or farm records could enhance data validity in future studies.

Thirdly, the study focused exclusively on clinical mastitis, defined by the presence of visible signs of udder inflammation or abnormal milk. However, sub-clinical mastitis (SCM) – characterized by elevated somatic cell counts in the absence of overt symptoms is typically more prevalent and economically significant, particularly in smallholder settings where detection is challenging[9,43]. By excluding SCM, the study may have underestimated the true burden of mastitis and missed important risk factors uniquely associated with sub-clinical presentations.

Another limitation is the lack of explicit modeling of clustering at the farm or household level. While random intercepts at the Local Government Area (LGA) level were included to account for geographic clustering, individual farms or households represent an additional layer of dependency. Ignoring such clustering may lead to residual confounding and underestimated standard errors[44]. Future research should consider multi-level modeling with additional random effects at the farm level to more accurately capture data structure.

Finally, sampling bias may also be present. The selection of LGAs was purposive, based on the presence of active dairy farming, and farm recruitment was facilitated through extension officers. While this ensured access to relevant participants, it may have inadvertently excluded harder-to-reach or less engaged farmers, limiting the generalizability of findings to the wider dairy population in Plateau State and beyond[45].

While these limitations do not invalidate the study's findings, they highlight the need for cautious interpretation and underscore opportunities for methodological enhancement in future investigations.

4.5. Implications for policy and practice

Recommendations for mastitis control and prevention

The findings from this study underscore the urgent need to develop and implement comprehensive mastitis control and prevention strategies tailored to the realities of smallholder and semi-commercial dairy farms in Plateau State and similar settings in sub-Saharan Africa. The significant associations found between poor milking hygiene, inadequate mastitis management practices, and increased mastitis risk highlight key areas for intervention.

Improving milking hygiene practices should be a top priority. This includes hand washing before and after milking, using clean and preferably disposable or dedicated udder cleaning cloths for each cow, and practicing proper pre and post milking teat disinfection using effective antiseptics such as iodine based or chlorhexidine-based teat dips. Several studies have shown that consistent implementation of these practices significantly reduces the incidence of both clinical and subclinical mastitis[9,29,46-48].

Additionally, the study found a significant relationship between housing design and mastitis occurrence. Therefore, promoting the adoption of housing systems that enhance cleanliness, ventilation, and drainage, while reducing overcrowding and standing time on hard surfaces, could contribute to mastitis prevention. Well-designed housing systems reduce the accumulation of fecal material, mud, and urine, which are key reservoirs of environmental pathogens like *Escherichia coli* and *Streptococcus uberis*[6,49-51].

Routine screening for sub-clinical mastitis using simple on-farm tests such as the California Mastitis Test (CMT) should also be encouraged as part of herd health management. As sub-clinical cases often go unnoticed, they serve as reservoirs for infection and can result in chronic inflammation and long-term production losses if untreated[52-55].

Establishing mastitis control protocols at the farm level clearly outlining steps for prevention, detection, isolation, and treatment will also help standardize responses and improve outcomes. These protocols should be participatorily developed in collaboration with veterinary experts, community animal health workers and the farmers and adapted to the local context for sustainability.

Farmer training and veterinary outreach

Achieving meaningful reductions in mastitis incidence requires sustained capacity building for farmers and their supporting networks. The study highlights knowledge gaps in proper milking hygiene and mastitis treatment practices, suggesting the need for regular and targeted training programs. Such training should focus on the causes and consequences of mastitis, proper milking routines, animal husbandry, and early signs of disease. Studies have shown that education interventions significantly improve farmer compliance with best practices and result in lower somatic cell counts and mastitis prevalence[56-60].

In addition to training, enhanced veterinary outreach and extension services are vital. Mobile veterinary clinics, availability of qualified community animal health workers, periodic LGA-based herd health days, and village-level demonstration farms would help sustain farmers' continued herd health education, while bringing needed expertise closer to remote farmers. These services should not only provide clinical care but also serve as platforms for disease monitoring and reporting mandate of each LGA and the State, farmer education, and data collection.

Furthermore, policies that promote affordable access to veterinary care via rural-based qualified community animal health workers (CAHWs), will be instrumental in sustaining control efforts for remote farmers. Government subsidies or public-private partnerships could facilitate the availability of all required resources for efficient herd health management in underserved areas. Encouraging the formation of farmer cooperatives or associations may also increase bargaining power for bulk purchases and enhance peer learning.

Finally, integration of mastitis prevention into broader animal health and food safety policies will help align mastitis control efforts with national livestock development goals. This includes linking mastitis surveillance with milk quality monitoring and antimicrobial resistance (AMR) strategies given the role of mastitis in driving antibiotic use on farms[61].

5. Conclusion

This study provides some insights into the epidemiology of clinical mastitis in lactating dairy cows in Plateau State, Nigeria. Using a hierarchical block-wise multivariable mixed-effects logistic regression model, the study identified key predictors of mastitis occurrence, particularly within the domains of mastitis management, milking hygiene practices, and housing and herd structure. Factors such as inadequate post-milking teat disinfection, absence of proper udder cleaning practices, large herd size, and poor record-keeping for mastitis cases significantly contributed to elevated mastitis risk. The significant clustering at the LGA level, as reflected by high intraclass correlation coefficients (ICCs), further highlights the importance of local level interventions.

From a policy perspective, these findings underscore the urgent need for targeted mastitis control programs in smallholder and peri urban dairy systems. Interventions should include farmer education on udder hygiene, structured mastitis monitoring programs, and subsidies or support for improving housing infrastructure and access to affordable veterinary services. Implementing routine use of on-farm mastitis diagnostic tools such as the California Mastitis Test (CMT) and reinforcing adherence to recommended milking practices are also essential strategies to mitigate the disease burden.

Additionally, future research should consider longitudinal and intervention-based studies to explore causal relationships and the effectiveness of specific control measures. Studies incorporating bacteriological and molecular diagnostics of mastitis pathogens, including resistance profiling, are recommended to support antimicrobial stewardship efforts and guide evidence-based therapy.

By translating these findings into practice, significant strides can be made toward improving dairy cow health, milk quality, and the economic resilience of dairy farming households in Plateau State and similar settings across sub-Saharan Africa.

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Conflict of Interest Statement

There is no conflict of interest in the preparation, submission, or publication of this work.

Data Availability

All data generated or analysed during this study are included in this published article.

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Supplementary Materials

1. The Questionnaire.
2. Table showing the prevalence of mastitis among surveyed farms (n = 298).
3. Criteria for inclusion of variable in the multivariable mixed-effects logistic regression present in Table 2 in the manuscript.

Table 1a: Univariable mixed-effects logistic regression modeling for Block 1: farmer & farm-level demographics

Variable	Level	OR (crude)	SE	z	P>z	95% CI
Age group (years)	30–39	1.00	Ref.	Ref.	Ref.	Ref.
	18–29	0.842	0.45	-0.32	0.748	0.295 – 2.400
	40–49	0.896	0.411	-0.24	0.81	0.364 – 2.203
	50–59	2.033	1.221	1.18	0.238	0.626 – 6.599
	60+	1.334	0.794	0.48	0.629	0.415 – 4.282
Education	Illiterate	1.00	Ref.	Ref.	Ref.	Ref.
	College/Diploma	0.991	1.014	-0.01	0.993	0.133 – 7.368
	High school	2.482	2.102	1.07	0.283	0.472 – 13.047
	Primary school	0.504	0.274	-1.26	0.208	0.173 – 1.465
	University	1	(empty)			
Years in dairy farming	16–30	1.00	Ref.	Ref.	Ref.	Ref.
	1–5	4.606	5.837	1.21	0.228	0.384 – 55.196
	6–15	2.057	1.122	1.32	0.186	0.706 – 5.992
	31–45	1.87	0.84	1.39	0.163	0.776 – 4.509
	46+	1.929	1.214	1.04	0.297	0.562 – 6.625
Number of employees	1–2	1.00	Ref.	Ref.	Ref.	Ref.
	None	0.913	0.765	-0.11	0.914	0.177 – 4.718
	3–4	1.681	0.842	1.04	0.3	0.630 – 4.485
	5–10	2.076	1.382	1.1	0.272	0.563 – 7.652
	11+	4.799	5.222	1.44	0.15	0.569 – 40.493

Table 1b: Univariable mixed-effects logistic regression modeling for Block 2: animal demographics and structure

Variable	Level	OR (crude)	SE	z	P>z	95% CI
Milking cows	Small (2–9)	1.00	Ref.	Ref.	Ref.	Ref.
	Medium (10–19)	1.413	0.619	0.79	0.43	0.599 – 3.336
	Large (20–49)	1.959	0.934	1.41	0.158	0.770 – 4.988
	Very large (50+)	1.007	1.453	0.01	0.996	0.060 – 17.031
Dry cows awaiting calving	Small (1–5)	1.00	Ref.	Ref.	Ref.	Ref.
	None (0)	2.62	2.289	1.1	0.27	0.473 – 14.518
	Medium (6–10)	1.395	0.573	0.81	0.417	0.624 – 3.119
	Large (11–20)	1.299	0.663	0.51	0.608	0.478 – 3.535
	Very large (>20)	0.915	0.832	-0.1	0.922	0.154 – 5.442
Milking cows pregnant	Few (1–4)	1.00	Ref.	Ref.	Ref.	Ref.
	None (0)	0.447	0.25	-1.44	0.15	0.149 – 1.339
	Some (5–9)	1.728	0.776	1.22	0.223	0.717 – 4.168
	Many (10–19)	0.958	0.563	-0.07	0.942	0.303 – 3.033
	Most/All (20+)	0.536	0.444	-0.75	0.452	0.105 – 2.721
Milking cows not pregnant	Few (1–4)	1.00	Ref.	Ref.	Ref.	Ref.
	None (0)	0.706	0.303	-0.81	0.417	0.304 – 1.638
	Some (5–9)	0.853	0.452	-0.3	0.764	0.302 – 2.408
	Many (10–19)	0.608	0.437	-0.69	0.489	0.148 – 2.489
	Most/All (20+)	0.685	0.619	-0.42	0.675	0.117 – 4.022
Heifers >2 yrs never calved	Low (1–5)	1.00	Ref.	Ref.	Ref.	Ref.
	None (0)	0.916	0.707	-0.11	0.91	0.202 – 4.161
	Moderate (6–10)	1.103	0.552	0.2	0.845	0.414 – 2.940
	High (11–20)	2.656	1.548	1.68	0.094	0.848 – 8.326
	Very high (>20)	2.004	1.864	0.75	0.455	0.324 – 12.409
Heifers served awaiting confirmation	Low (1–3)	1.00	Ref.	Ref.	Ref.	Ref.
	None (0)	1.483	0.834	0.7	0.483	0.493 – 4.462
	Moderate (4–6)	2.778	1.563	1.82	0.069	0.922 – 8.371
	High (7–10)	1.344	0.962	0.41	0.68	0.330 – 5.467
	Very high (>10)	0.494	0.359	-0.97	0.332	0.119 – 2.051
Female calves <1 year	Moderate (4–6)	1.00	Ref.	Ref.	Ref.	Ref.
	None (0)	0.203	0.381	-0.85	0.396	0.005 – 8.093
	Few (1–3)	0.406	0.194	-1.89	0.059	0.159 – 1.036
	Many (7–10)	0.777	0.353	-0.56	0.578	0.319 – 1.891
	Very many (>10)	0.656	0.374	-0.74	0.459	0.215 – 2.005

Table 1c: Univariable mixed-effects logistic regression modeling of mastitis in relation to housing and management practices

Variable	Level	OR (crude)	SE	z	P>z	95% CI
Housing design	Outdoor	1.00	Ref.	Ref.	Ref.	Ref.
	Indoor	2.998	2.359	1.4	0.163	0.641 – 14.019
	Other	2.066	1.424	1.05	0.292	0.535 – 7.974
	Semi-indoor	1	(empty)			
Cow accommodation	Group	1.00	Ref.	Ref.	Ref.	Ref.
	Individual	0.596	0.433	-0.71	0.476	0.144 – 2.473
Animals move out for grazing	Yes	1.00	Ref.	Ref.	Ref.	Ref.
	No	5.223	6.132	1.41	0.159	0.523 – 52.157
Production system	Extensive	1.00	Ref.	Ref.	Ref.	Ref.
	Intensive	0.155	0.132	-2.2	0.028	0.030 – 0.817
	Semi-intensive	0.485	0.311	-1.13	0.258	0.138 – 1.702
	Smallholder	0.22	0.221	-1.51	0.131	0.031 – 1.573
Herd size (total animals)	Large herds	1.00	Ref.	Ref.	Ref.	Ref.
	Small herds	0.231	0.23	-1.47	0.142	0.033 – 1.631
Herd size (total cattle)	Medium herds	1.00	Ref.	Ref.	Ref.	Ref.
	Small herds	0.941	0.473	-0.12	0.904	0.351 – 2.522
	Large herds	2.209	0.922	1.9	0.058	0.975 – 5.007
Working bulls	Few (1–2)	1.00	Ref.	Ref.	Ref.	Ref.
	None	1.258	1.424	0.2	0.839	0.839 – 11.562
	Moderate (3–5)	2.168	1.073	1.56	0.118	0.821 – 5.720
	Many (6–10)	1.143	0.764	0.2	0.841	0.309 – 4.234
	Very Many (>10)	0.375	0.297	-1.24	0.215	0.079 – 1.768

Table 1d: Univariable mixed-effects logistic regression modeling for Block 4: water and feed practices.

Variable	**Level**	**OR (crude)**	**SE**	**z**	**P>z**	**95% CI**
Water source	River/Stream	1.00	Ref.	Ref.	Ref.	Ref.
	Lake/Dam	0.929	0.606	-0.11	0.911	0.259 – 3.334
	Other	1.151	0.822	0.2	0.844	0.284 – 4.669
	Pipeline	0.895	1.385	-0.07	0.943	0.043 – 18.592
	Well/Borehole	3.723	3.831	1.28	0.201	0.496 – 27.975
Water ad libitum?	Yes	1.00	Ref.	Ref.	Ref.	Ref.
	No	0.984	0.402	-0.04	0.969	0.442 – 2.192
Feed supplements?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	0.857	0.444	-0.3	0.766	0.311 – 2.364
Type of feed	Others	1.00	Ref.	Ref.	Ref.	Ref.
	Blocks	2.163	3.455	0.48	0.629	0.094 – 49.528
	Concentrate	0.664	0.477	-0.57	0.569	0.163 – 2.713
	Grazing	0.411	0.248	-1.47	0.141	0.125 – 1.344
Individual or group feeding?	Group	1.00	Ref.	Ref.	Ref.	Ref.
	Individual	0.468	0.566	-0.63	0.53	0.044 – 5.012
Supplement to lactating cows?	Lactating & dry	1.00	Ref.	Ref.	Ref.	Ref.
	None	0.132	0.179	-1.49	0.136	0.009 – 1.894
	Only dry	3.312	3.396	1.17	0.243	0.444 – 24.711
	Only lactating	0.469	0.375	-0.95	0.344	0.098 – 2.250
	Other	2.248	1.4	1.3	0.194	0.663 – 7.621
Feed cows after milking?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	0.435	0.209	-1.74	0.083	0.170 – 1.114

Table 1e: Univariable mixed-effects logistic regression modeling for Block 5: milking hygiene practices.

Variable	Level	OR (crude)	SE	z	P>z	95% CI
Milker	Family member	1.00	Ref.	Ref.	Ref.	Ref.
	Farmer	0.75	0.32	-0.68	0.499	0.325 – 1.729
Handwash/wear glove during milking?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	0.639	0.299	-0.96	0.339	0.255 – 1.601
Clean teats as preparation for milking?	No	1.00	Ref.	Ref.	Ref.	Ref.
	All cows	0.224	0.191	-1.75	0.08	0.042 – 1.195
	Only dirty teats	0.321	0.143	-2.55	0.011	0.134 – 0.768
Dry teat before milking?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	1.219	0.674	0.36	0.721	0.412 – 3.605
Use separate clothes for cleaning?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	0.858	0.414	-0.32	0.75	0.333 – 2.210
Pre-strip before milking?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	0.877	0.428	-0.27	0.788	0.337 – 2.282
Teat dip/spraying before milking?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	0.137	0.109	-2.5	0.012	0.029 – 0.650
Teat dip/spraying after milking?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	0.107	0.094	-2.54	0.011	0.019 – 0.601
Milking method	Hand	1.00	Ref.	Ref.	Ref.	Ref.
	Machine	0.185	0.295	-1.06	0.29	0.008 – 4.213
Frequency of washing milking equip.	Daily	1.00	Ref.	Ref.	Ref.	Ref.
	Monthly	4.476	3.912	1.71	0.086	0.807 – 24.824
	Weekly	0.234	0.27	-1.26	0.209	0.024 – 2.258
Servicing milking equipment	When broken	1.00	Ref.	Ref.	Ref.	Ref.
	Annually	2.77	1.705	1.65	0.098	0.829 – 9.256
	Monthly	1.608	0.978	0.78	0.435	0.488 – 5.296

Table 1f: Univariable mixed-effects logistic regression modeling for Block 6: mastitis management practices

Variable	Level	OR (crude)	SE	z	P>z	95% CI
Dry cow therapy?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Dried off cows	1.137	0.964	0.15	0.879	0.216 – 5.990
	Selected cows	0.383	0.31	-1.19	0.236	0.079 – 1.872
Separate calving paddock?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	1.4	0.913	0.52	0.606	0.390 – 5.027
Heifers & cows same calving paddock?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	2.455	1.171	1.88	0.06	0.964 – 6.255
Mastitis main reason for culling?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	2.373	1.111	1.85	0.065	0.949 – 5.938
Check udder health per cow?	Daily before milking	1.00	Ref.	Ref.	Ref.	Ref.
	Never	1.237	0.684	0.38	0.701	0.418 – 3.658
	Weekly	1.745	1.125	0.86	0.388	0.493 – 6.176
	When abnormal	0.548	0.552	-0.6	0.55	0.076 – 3.945
Record mastitis treatment?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	0.958	0.473	-0.09	0.93	0.364 – 2.519
Frequency of mastitis?	Twice	1.00	Ref.	Ref.	Ref.	Ref.
	Always	0.372	0.386	-0.95	0.34	0.049 – 2.839
	More than thrice	1.00	(empty)			
	Thrice	0.177	0.213	-1.44	0.15	0.017 – 1.873
Who diagnosed mastitis?	Farmer	1.00	Ref.	Ref.	Ref.	Ref.
	LEO	1	(empty)			
	Other	1.078	1.202	0.07	0.946	0.121 – 9.578
	Veterinarian	0.889	0.573	-0.18	0.855	0.252 – 3.141
How was mastitis diagnosed?	Visual	1.00	Ref.	Ref.	Ref.	Ref.
	Bacterial culture	0.333	0.203	-1.81	0.071	0.101 – 1.097
	CMT	1.152	1.464	0.11	0.911	0.095 – 13.905
Treat mastitis?	Yes	1.00	Ref.	Ref.	Ref.	Ref.
	No	0.226	0.112	-3	0.003	0.086 – 0.597
Drug	Oxytetracycline (L.A)	1.00	Ref.	Ref.	Ref.	Ref.
	Gentamycin	1	(empty)			
	Herbs	0.095	0.144	-1.56	0.119	0.005 – 1.830
	Procaine-penicillin	0.762	0.901	-0.23	0.818	0.075 – 7.738
	Streptomycin	1	(empty)			
	Sulphonamides	0.286	0.362	-0.99	0.323	0.024 – 3.428
	Tramadol	1	(empty)			
	Trydox	1	(empty)			
	Tylosin	1	(empty)			
Prescriber	Veterinarian	1.00	Ref.	Ref.	Ref.	Ref.
	Farmer	0.98	0.74	-0.03	0.978	0.223 – 4.306
	Historical effectiveness	1.343	1.511	0.26	0.793	0.148 – 12.185
Recurrence of mastitis treatment?	Yes	1.00	Ref.	Ref.	Ref.	Ref.
	No	0.242	0.118	-2.92	0.004	0.093 – 0.628
Challenges in mastitis treatment	Lack of medicine	1.00	Ref.	Ref.	Ref.	Ref.
	Lack of health provider	1.143	0.781	0.2	0.845	0.300 – 4.359
	Medicine expensive	0.395	0.246	-1.49	0.136	0.117 – 1.340
	Medicine not working	2.502	3.249	0.71	0.48	0.196 – 31.892
	None	0.084	0.106	-1.97	0.049	0.007 – 0.990
	Other	0.457	0.467	-0.77	0.444	0.062 – 3.383
Buy replacement heifers?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	0.992	0.456	-0.02	0.985	0.403 – 2.441

Table 2: Variable inclusion criteria for multivariable mixed-effects logistic regression among cows for clinical mastitis, Plateau State, Nigeria

Variable	P-value (lowest per variable)	Inclusion Decision	Reason for Inclusion/Exclusion
Block 1 – (farmer & farm-level demographics)			
Number of employees	0.15	Include	11+ employees showed a strong trend toward association (OR: 4.80, p = 0.15); consider for adjusted model due to plausible biological relevance.
Years in dairy farming	0.163	Include	Moderate association seen in category 31–45 years (OR: 1.87, p = 0.163); include for confounding control and time-in-farming effects.
Education	0.208	Include	Primary school (OR: 0.50, p = 0.208) shows potential protective trend; variable is important for socio-demographic context.
Age group	0.238	Include	Age 50–59 showed a potential risk trend (OR: 2.03); biologically plausible relationship with management decisions.
Block 2 – (animal demographics/structure)			
Female calves <1 year	0.059	Include	"Few (1–3)" category showed a protective trend; p-value < 0.25 and biologically plausible.
Heifers served awaiting confirmation	0.069	Include	"Moderate (4–6)" category showed risk trend; close to significance, keep for model development.
Heifers >2 yrs never calved	0.094	Include	"High (11–20)" showed an elevated OR with p = 0.094; important for herd structure and dynamics.
Milking cows	0.158	Include	"Large (20–49)" showed increasing trend (OR = 1.96); biologically important; p < 0.25.
Dry cows awaiting calving	0.27	Consider	No strong evidence; may keep if other variables are removed or to control for herd size balance.
Milking cows pregnant	0.15	Include	"None (0)" showed protective trend; potential indicator of reproductive health.
Milking cows not pregnant	0.417	Exclude	No category showed significant effect; limited discriminatory value.
Block 3 – (housing & management practices)			
Production system	0.028	Include	Intensive system significantly associated with lower odds of mastitis (OR = 0.155, p = 0.028).
Herd size (total cattle)	0.058	Include	Large herds had nearly doubled odds (OR = 2.21), borderline significance, biologically relevant.
Working bulls	0.118	Include	Moderate (3–5) category showed potential association (p < 0.25); keep for confounding control.
Production system	0.131	Consider	Smallholder showed trend toward lower odds; biologically plausible, but borderline significance.
Herd size (total animals)	0.142	Include	Small herds showed lower odds (OR = 0.23), biologically important herd indicator.
Housing design	0.163	Include	Indoor housing had increased odds; possibly confounded, but warrants inclusion for context.
Animals move out for grazing	0.159	Include	Movement restriction showed increased odds (OR = 5.22); biologically meaningful exposure factor.
Working bulls	0.215	Consider	Very many category showed low odds but non-significant; may drop if not improving model fit.
Cow accommodation	0.476	Exclude	No meaningful association observed; low OR and high p-value.
Herd size (total cattle)	0.904	Exclude	Small herds had no significant effect; not biologically or statistically compelling.
Block 4 – (water & feed practices)			
Feed cows after milking?	0.083	Include	Borderline significance (p < 0.1); biologically plausible protective role.
Type of feed	0.141	Include	Grazing showed borderline p-value; nutrition-related relevance.
Supplement to lactating cows?	0.136	Include	"None" category showed borderline effect; important feeding management factor.
Supplement to lactating cows?	0.194	Consider	"Other" category borderline; may be retained based on subject-matter judgment.
Water source	0.201	Exclude	No category showed significant association; estimates unstable or wide CI.
Individual or group feeding?	0.53	Exclude	Weak evidence of association.
Feed supplements?	0.766	Exclude	Very weak statistical evidence; not retained.
Water ad libitum?	0.969	Exclude	Effect not observed; null association.

Block 5 – (milking hygiene practices)			
Clean teats as preparation for milking?	0.011	Include	Statistically significant; strong protective effect observed with "Only dirty teats" category.
Teat dip/spraying after milking?	0.011	Include	Statistically significant; clear evidence of protective effect.
Teat dip/spraying before milking?	0.012	Include	Statistically significant; associated with lower odds of mastitis.
Frequency of washing milking equipment	0.086	Include	Borderline significance; biologically plausible; needs testing in multivariable model.
Servicing milking equipment	0.098	Include	Borderline significance; maintenance is relevant to hygiene and mastitis risk.
Clean teats – All cows	0.08	Include	Borderline significance; preventive hygiene behavior.
Milking method	0.29	Consider	Wide CI; include if theory supports mechanical method being protective or risky.
Handwash/glove use	0.339	Exclude	Not statistically significant; weak association.
Use separate cloth	0.75	Exclude	No evidence of effect; exclude.
Pre-strip before milking	0.788	Exclude	Not significant; low effect size.
Milker	0.499	Exclude	No strong statistical or theoretical reason for inclusion.
Dry teat before milking	0.721	Exclude	No significant association with mastitis.
Block 6 – (mastitis management)			
Treat mastitis?	0.003	Include	Statistically significant; strong association with lower mastitis odds.
Recurrence of mastitis treatment?	0.004	Include	Significant predictor; indicates outcome persistence and management gap.
Challenges in mastitis treatment – None	0.049	Include	Borderline significance; absence of treatment challenge associated with lower risk.
Heifers & cows same calving paddock?	0.06	Include	Borderline p-value; biologically plausible risk factor.
Mastitis main reason for culling?	0.065	Include	Borderline p-value; theoretically relevant; include for contextual significance.
How mastitis diagnosed – Bacterial culture	0.071	Include	Near significance; valuable diagnostic practice to retain in the model.
Frequency of mastitis – Thrice	0.15	Consider	May indicate severity; borderline and could be tested in stepwise selection.
Drug – Herbs	0.119	Consider	Alternative treatment; borderline significance.
Challenges – Medicine expensive	0.136	Consider	May affect treatment access; borderline p-value.
Dry cow therapy	0.236	Exclude	Not significant; weak evidence of association.
Calving paddock separation	0.606	Exclude	Not significant; wide CI.
Udder health checking freq.	0.388–0.701	Exclude	All comparisons are not statistically significant.
Record mastitis treatment	0.93	Exclude	Not significant; no effect.
Prescriber	0.793–0.978	Exclude	Not statistically significant; wide CI.
Drug – Sulphonamides	0.323	Exclude	Not significant; small sample size limits inference.
Buy replacement heifers?	0.985	Exclude	No statistical evidence of association.

Table 3: Likelihood ratio tests for model comparisons among cows for clinical mastitis, Plateau State, Nigeria

Comparison	DF	LR Chi²	p-value	Interpretation
Block 1: Farmer & farm-level demographics				
Model 1 vs. Model 2: Added Age group	4	5.76	0.218	Not significant; adding Age group did not improve model fit.
Model 2 vs. Model 3: Removed observations not in e(sample)	3	6.42	0.093	Suggestive ($p < 0.10$); dropping non-sample observations may improve the model.
Model 2 vs. Model 4: Removed age group	4	6.94	0.139	Not significant; removing Age group did not significantly worsen the fit.
Model 4 vs. Model 5: Removed Number of employee	4	2.01	0.734	No improvement; Number of employee may not contribute meaningfully to the model.
Block 2: Animal demographics/structure				
Model 1 vs. Model 2: Removed Milking cows served but not pregnant	4	0.51	0.973	No improvement; Milking cows served but not pregnant does not improve model fit.
Model 2 vs. Model 3: Removed Milking cows pregnant	4	5.07	0.28	Not significant; removing Milking cows pregnant does not reduce model fit.
Model 3 vs. Model 4: Removed Dry cows awaiting calving	4	2.01	0.734	No improvement; Dry cows awaiting calving not contributing significantly.
Model 4 vs. Model 5: Removed Milking cows	3	1.33	0.722	Not significant; Milking cows not improving the model.
Model 5 vs. Model 6: Removed Heifers >2 yrs never calved	4	7.59	0.108	Suggestive ($p < 0.11$); Heifers >2 yrs never calved may improve the model.
Model 6 vs. Model 7: Removed Heifers served awaiting confirmation	4	8.82	0.066	Borderline significant ($p < 0.07$); keeping Heifers served awaiting confirmation may help.
Block 3: Housing & Management Practices				
Model 1 vs. Model 2_restricted: Removed Cow accommodation	1	0.47	0.495	Not significant; removing Cow accommodation does not worsen the model.
Model 2_restricted vs. Model 3: Removed Animals move out for grazing	1	2.38	0.123	Suggestive improvement; Animals move out for grazing may improve fit.
Model 3 vs. Model 4: Removed Housing design	2	3.69	0.158	Not significant; Housing design does not significantly improve model.
Model 4 vs. Model 5: Removed Herd size (total cattle)	1	4.04	0.044	Significant; Herd size (total cattle) improves model fit.
Model 4 vs. Model 6: Replaced Working bulls with Herd size (total animals), (excluded total cattle)	3	7.37	0.061	Borderline significance; model fit possibly improved.
Model 4 vs. Model 7: Replaced Total cattle with Working bulls and Herd size (total animals)	2	12.03	0.002	Highly significant; strong model improvement with revised variables.
Model 4 vs. Model 8: Replaced Production system with Herd size (Total cattle), Working bulls, Herd size (Total animals)	3	4.53	0.21	Not significant; Model 8 does not improve fit over Model 4.
Block 4: Water & Feed				
Model 1 vs. Model 2	1	0.72	0.397	Not significant; removing Water adlib does not worsen model fit.
Model 2 vs. Model 3	1	3.79	0.052	Borderline significant; Feed supplements may improve fit.
Model 2 vs. Model 4	1	2.68	0.102	Suggestive; Individual or group feeding may contribute to the model.
Model 4 vs. Model 5	3	7.92	0.048	Significant ($p < 0.05$); model including Supplement to lactating cows improves over Model 4.
Model 4 vs. Model 6	3	1.92	0.588	Not significant; model c6 without Supplement to lactating cows does not improve over Model 4.
Model 6 vs. Model 7	2	3.63	0.163	Not significant; excluding Type of feed does not significantly worsen model fit.
Model 7 vs. Model 8	1	1.37	0.243	Not significant; removing Feed cows after milking does not meaningfully impact model fit.
Block 5: Milking Hygiene Practices				
Model 1 vs. d Model 2	1	1.02	0.314	Not significant; removing Dry teat before milking? does not worsen model fit.
Model 2 vs. Model 3	1	0.28	0.594	Not significant; removing Milker does not significantly reduce model fit.
Model 3 vs. Model 4	1	2.22	0.136	Suggestive ($p < 0.15$); Pre-strip before milking? may contribute to the model.
Model 4 vs. Model 5	1	4.43	0.035	Significant ($p < 0.05$); Handwash/wear glove during milking? improves model fit.

Model 4 vs. Model 6	1	0.06	0.814	Not significant; Pre-strip before milking? may not be essential.
Model 6 vs. Model 7	1	3.39	0.066	Borderline significant ($p < 0.07$); consider retaining Teat dip/spraying before milking?
Model 6 vs. Model 8	2	0.66	0.718	Not significant; Servicing milking equipment and Frequency of washing milking equipment do not improve fit.
Model 8 vs. Model 9	1	0.03	0.869	Not significant; removing Servicing milking equipment has little effect.
Model 9 vs. Model 10	1	0.54	0.464	Not significant; Clean teats as preparation to milking? has no strong impact here.
Model 10 vs. Model 11	1	10.05	0.002	Highly significant; Teat dip/spraying after milking? greatly improves model fit.
Model 9 vs. Model 12	3	10.7	0.014	Significant ($p < 0.05$); Clean teats as preparation to milking? Teat dip/spraying before milking? and Teat dip/spraying after milking? are jointly important.
Block 6: Mastitis Management				
Model 1 vs. Model 2	2	3.72	0.156	Not significant; removing How was mastitis diagnosed? did not worsen model fit.
Model 2 vs. Model 3	1	2.18	0.14	Suggestive improvement ($p < 0.15$); dropping Mastitis main reason for culling? may help.
Model 3 vs. Model 4	1	4.42	0.036	Significant ($p < 0.05$); removing Heifers & cows same calving paddock? improves fit.
Model 3 vs. Model 5	5	2.06	0.841	Not significant; replacing Challenges in mastitis treatment with Heifers & cows same calving paddock? does not improve the model.
Model 5 vs. Model 6	1	4.37	0.037	Significant ($p < 0.05$); excluding Recurrence of mastitis treatment? improves model fit.
Model 5 vs. Model 7	1	3.58	0.059	Borderline significant ($p < 0.06$); removing Treat mastitis? may help.

Table 4: Outcomes of final multivariable mixed-effects logistic regression models

Variable	Level	OR (adjusted)	SE	Z	P > z	95% CI
Farmer and farm-level demographics						
Education	Illiterate	1.00	Ref.	Ref.	Ref.	Ref.
	College/Diploma	0.991	1.014	-0.01	0.993	0.133 – 7.368
	High school	2.482	2.102	1.07	0.283	0.472 – 13.047
	Primary school	0.504	0.274	-1.26	0.208	0.173 – 1.465
	University	1	-	-	-	-
Animal demographics/structure						
Female calves <1 year	Moderate (4–6)	1	Ref.	Ref.	Ref.	Ref.
	None (0)	0.147	0.274	-1.03	0.303	0.004 – 5.642
	Few (1–3)	0.336	0.17	-2.16	0.031	0.125 – 0.904
	Many (7–10)	0.704	0.334	-0.74	0.46	0.277 – 1.786
	Very many (>10)	0.795	0.498	-0.37	0.714	0.233 – 2.710
Heifers served awaiting confirmation	Low (1–3)	1	Ref.	Ref.	Ref.	Ref.
	None (0)	1.622	0.949	0.83	0.408	0.515 – 5.106
	Moderate (4–6)	2.867	1.689	1.79	0.074	0.904 – 9.095
	High (7–10)	1.232	0.935	0.27	0.784	0.278 – 5.451
	Very high (>10)	0.385	0.309	-1.19	0.234	0.080 – 1.853
Housing and management practices						
Herd size (total cattle)	Medium herds	1.00	Ref.	Ref.	Ref.	Ref.
	Small herds	1.216	0.798	0.3	0.765	0.336 - 4.399
	Large herds	6.557	3.991	3.09	0.002	1.989 - 21.620
Working bulls	Few (1–2)	1.00	Ref.	Ref.	Ref.	Ref.
	Moderate (3–5)	1.579	0.908	0.79	0.427	0.511 - 4.874
	Many (6–10)	0.278	0.238	-1.5	0.134	0.052 - 1.486
	Very many (>10)	0.355	0.383	-0.96	0.337	0.043 - 2.938
Herd size (total animals)	Large herds	1.00	Ref.	Ref.	Ref.	Ref.
	Small herds	0.054	0.098	-1.59	0.111	0.001 - 1.962
Water and feed practices						
Water source	River/Stream	1.00	Ref.	Ref.	Ref.	Ref.
	Lake/Dam	0.102	0.169	-1.37	0.169	0.004 - 2.642
	Other	0.117	0.221	-1.14	0.255	0.003 - 4.709
	Well/Borehole	19.757	39.827	1.48	0.139	0.380 - 1027.057
Feed supplements?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	0.371	0.31	-1.19	0.235	0.077 - 1.88
Milking hygiene practices						
Clean teats as preparation for milking?	No	1.00	Ref.	Ref.	Ref.	Ref.
	All cows	0.235	0.208	-1.63	0.102	0.041 - 1.335
	Only cows with dirty teats	0.189	0.103	-3.05	0.002	0.065 - 0.550
Teat dip/spraying after milking?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	0.013	0.028	-2.07	0.039	0.000 - 0.797
Teat dip/spraying before milking?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	3.917	7.690	0.7	0.487	0.084 - 183.691
Milking method	Hand	1.00	Ref.	Ref.	Ref.	Ref.
	Machine	0.003	0.013	-1.42	0.155	1.23E-06 - 8.664
Use separate clothes for cleaning?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	4.921	3.737	2.1	0.036	1.111 - 21.796
Mastitis management						
Treat mastitis?	Yes	1.00	Ref.	Ref.	Ref.	Ref.
	No	0.281	0.189	-1.89	0.059	0.075 - 1.050
Recurrence of mastitis treatment?	Yes	1.00	Ref.	Ref.	Ref.	Ref.
	No	0.283	0.176	-2.03	0.042	0.084 - 0.955
Heifers & cows same calving paddock?	No	1.00	Ref.	Ref.	Ref.	Ref.
	Yes	4.892	3.898	1.99	0.046	1.026 - 23.322

Table 5a: Intra-class correlation coefficient (ICC) estimates from final mixed-effects logistic regression models across all blocks

Model	Level	ICC	SE	95% CI
Block 1: Farmer & Farm-Level Demographics	LGAs	0.767	0.122	0.464 – 0.926
Block 2: Animal Demographics/Structure	LGAs	0.694	0.119	0.432- 0.872
Block 3: Housing & Management Practices	LGAs	0.615	0.135	0.344 - 0.830
Block 4: Water & Feed	LGAs	0.829	0.151	0.376 - 0.975
Block 5: Milking Hygiene Practices	LGAs	0.708	0.118	0.442 - 0.881
Block 6: Mastitis Management	LGAs	0.581	0.178	0.248 - 0.853

Table 5b: Model fit statistics (AIC and BIC) for final mixed-effects logistic regression models across all blocks

Model	Observations	Log Likelihood (Null)	Log Likelihood (Model)	DF	AIC	BIC
Block 1: Farmer & Farm-level Demographics	231	–	–86.076	5	182.151	199.363
Block 2: Animal Demographics/Structure	296	–	-122.28	10	264.559	301.463
Block 3: Housing & Management Practices	236	–	-91.317	8	198.633	226.344
Block 4: Water & Feed	166	–	-59.605	6	131.21	149.882
Block 5: Milking Hygiene Practices	271	–	-106.384	8	228.767	257.584
Block 6: Mastitis Management	179	–	-61.765	5	133.530	149.467

Table 5c: Predicted probabilities of mastitis by farmer education level

Education	**Predicted probability (Margin)**	**SE**	**z**	**P > z**	**95% CI**
College/Diploma	0.628	0.13	4.85	<0.001	0.374 – 0.883
High school	0.709	0.093	7.59	<0.001	0.526 – 0.893
Illiterate	0.629	0.097	6.45	<0.001	0.438 – 0.820
Primary school	0.553	0.116	4.77	<0.001	0.326 – 0.780

Supplementary Files

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- Supplementarymaterials.docx
- CompletedatasetCorrectedDataset.xlsx