

Determinants of Bovine Lameness in Extensive Livestock Farming: Analysis of Risk Factors in the Pastoral Farm of Haut-Lomami (DRC)

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How to cite this paper: Binemo Kanyama, J.C., Mavungu, G.N., Kassata, U.M., Lukamba, S.D., Embeya, V.O., Muyumba, G.M. and Ngoi, M.L.M. (2026) Determinants of Bovine Lameness in Extensive Livestock Farming: Analysis of Risk Factors in the Pastoral Farm of Haut-Lomami (DRC). *Open Journal of Animal Sciences*, 16, 239-255.

<https://doi.org/10.4236/ojas.2026.163017>

Received: May 7, 2026

Accepted: June 26, 2026

Published: June 29, 2026

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Abstract

Bovine lameness is a major animal health problem, significantly affecting welfare and zoo-technical performance. In tropical extensive livestock farming systems, particularly in sub-Saharan Africa, this condition is largely under-documented despite its considerable health and economic impact. This study aimed at identifying and analyzing environmental, zoo-technical, and nutritional risk factors associated with bovine lameness in the Pastoral of Haut-Lomami (PHL) farm in the Democratic Republic of the Congo. A longitudinal descriptive study was conducted on cattle from several sections of the PHL. Data collection was based on field observations, structured surveys, and biochemical analyses of blood mineral concentrations such as Calcium (Ca), Copper (Cu), Zinc (Zn), Manganese (Mn) and Selenium (Se). Environmental and zoo-technical factors were assessed, and data were analyzed by descriptive statistics, analysis of variance (ANOVA), and the Chi-Square test to examine the associations between the studied factors and the occurrence of lameness. The results highlighted a strong link between constraints inherent to the extensive farming system and the development of lameness. Zoo-technical factors include in particular, a high daily grazing distance (5 to 10 km), a natural grazing diet irregularly mineral supplemented, and limited infrastructure. From an environmental perspective, continuous exposure to abrasive, eroded, wet, or slippery soils, especially at watering points and in enclosures, is a major deter-

minant of hoof lesions. Biological analyses revealed a highly significant decrease in mineral concentrations in the dry season compared to the rainy season ($p < 0.0001$). However, no statistically significant difference was observed between lame and non-lame cattle in the same season ($p \approx 0.055$). Lameness in cattle at the PHL farm appears to be a multifactorial condition dominated by environmental and zoo-technical factors, with mineral deficiencies playing an aggravating role. These results demonstrate the need for integrated control strategies adapted to the constraints of extensive tropical systems.

Keywords

Bovine Lameness, Risk Factors, Pastoral Farm of Haut Lomami

1. Introduction

Numerous studies have reported lameness as one of the main reasons for veterinary consultation in intensive cattle farming, highlighting the importance of foot disorders in locomotor pathology and their major consequences for animal welfare and productivity [1]-[5].

According to [6], lameness is a reflex motor response aimed at relieving pain, a definition adopted by [7]. More broadly, lameness is characterized by an abnormal gait resulting from an injury, a pathological condition, or discomfort affecting one or more feet and/or limb segments. It is the most easily detectable clinical sign, its identification is rapid, and it generally does not require animal restraint. However, although easily observable, lameness is not necessarily the most specific or reliable indicator of the location and nature of the underlying lesion. For terminology, many authors use the term “lameness” to designate all locomotor system disorders [4] [8] [9].

Lameness results from damage to the integrity of the supporting structures made of the skeleton, the muscles, and the associated structures. This damage can be the consequence of acute trauma, but most often results from a complex interaction of predisposing factors of mechanical, nutritional, environmental, or metabolic origin.

Clinical examination generally allows the identification of the triggering factor responsible for the expression of lameness; however, this apparent factor may hide pre-existing underlying causes influencing the animal's susceptibility to developing the locomotor disorder [8] [10] [11].

The relative importance of predisposing factors and their complex interactions is still a subject of ongoing debate. However, several studies have indicated the crucial role of hereditary, nutritional, and environmental factors in the predisposition of cattle to limb and musculoskeletal disorders [12] [13].

In summary, the current state of knowledge shows that lameness in extensive livestock farming is an underestimated, multifactorial, and under-documented problem. This farming system is widely practiced in the Democratic Republic of Congo and requires an integrated approach that includes improved monitoring,

field-adapted prevention strategies, and a thorough understanding of the interactions between pastoral practices, the environment, and hoof health.

2. Environment, Animals, Materials and Methods

2.1. Study Area

This study was conducted on a herd of cattle raised at the PHL Company, in Haut-Lomami Province. It covers the town of Kamina and the territory of Kaniama Kasese, encompassing the chiefdoms of Kasongo Nyembo and Mutombo Mukulu. With an area of approximately 220,000 hectares, it is situated between 7° and 9° South latitude and 24° and 25° East longitude, at an altitude varying between 1000 and 1200 meters (m).

Since the 2015 territorial reorganization, the Haut-Lomami Province has been one of the 26 provinces of the Democratic Republic of Congo, formerly belonging to the Katanga Province. It comprises five territories: Bukama, Malemba-Nkulu, Kamina, Kabongo, and Kaniama, as well as the city of Kamina, the provincial capital. The province covers an area of 108,204 km² and has an estimated population of 2,957,000 habitants. Its landscape is dominated by highlands (Kamina) and the large Kamalondo depression in the southeast. The vegetation consists of grassy savannas and areas of open woodlands.

2.2. Livestock

The cattle bred by the PHL is largely crossbred. They are characterized by a significant diversity of coat colors and conformations as a result of multiple cross-breeding in particular between Friesland, Hereford, Aberdeen Angus, Shorthorn, Afrikander, Devon, Brahman, Santa Gertrudis, Simmental, and Bonsmara breeds.

The study focused on sick cattle of all ages and both sexes, monitored in the hospital kraals of the Kelambwe and Kankundwe sections, in the Lovoy sector, as well as Kindele and Makanza, located in the Kileka sector.

The choice of these study areas was based on the similarity of their soil characteristics, dominated by sandy soils, which play a role in the pathogenesis of certain diseases in livestock. Furthermore, their geographical proximity to the urban center of Kamina facilitated the logistical organization of the collection, transport and storage of biological samples to the analysis laboratories, thus assuring the quality and reliability of the collected data.

Table 1. GPS coordinates of study sections.

Sections	Latitude	Longitude
Kiabukwa	8°45'39.1"S	24°50'26.7"E
Kelambwe	8°35'11.9112"S	24°41'24.3186"E
Kankundwe	8°45'25.4"S	24°49'22.4"E
Makanza	8°47'51.3"S	24°16'07.8"E
Kindele	8°38'55.5"S	24°10'42.3"E

Kiabukwa constitutes the administrative section of the Pastoral Farm of Haut-Lomami and hosts the General Directorate of the enterprise. Therefore, this section was not included among the sampling sites used for the comparative analyses of bovine lameness. Consequently, field investigations and statistical analyses were conducted only in the operational livestock sections of Kelambwe, Kankundwe, Kindele, and Makanza (**Table 1**).

2.3. Equipment

2.3.1. Sampling Equipment

Sterile equipment were used to collect blood samples, assuring the reliability of the biochemical analyzes and compliance with biosafety regulations. The equipment included 20 ml sterile syringes; G16 metal needles; Pipettes; Anticoagulant-free collection tubes; Cotton wool; Denatured alcohol; Disposable gloves; An insulated container and 200 g rigid ice packs.

2.3.2. Chemical Analysis Equipment

Blood sample chemical analyzes were done in the laboratory with current analytical standard equipment. The equipment includes:

Laboratory glassware notably: 250 ml Teflon beakers, 100 ml graduated cylinders, 100 to 1000 ml volumetric flasks, 2 to 50 ml volumetric pipettes, 10 ml graduated pipettes, and 10 to 50 ml burettes; a wash bottle, filter paper, and a pipette bulb; Porcelain crucibles and a muffle furnace used to mineralize operations; an inductively coupled plasma atomic emission spectrophotometer (ICP-OES), equipped with an argon supply of $\geq 99.95\%$ purity, computer-controlled, and with a background correction system.

2.3.3. Additional Materials

The on-ground data collection required the following supplementary materials:

A structured survey questionnaire; a notebook; Pens; a mobile phone (iPhone 16 Pro Max) to collect, capture, and document field data, including recording the information gathered and the geo-localization of the study sites by acquiring GPS coordinates; the phone's built-in camera (iPhone 16 Pro Max) for taking pictures to document field observations.

2.4. Methods

2.4.1. Studied Animals

The total number of cattle included in this study was 378 animals. During the rainy season, the distribution was as follows: in Kelambwe, 17 lame and 35 non-lame cattle; in Kankundwe, 18 lame and 35 non-lame cattle; in Kindele, 16 lame and 40 non-lame cattle; and finally, in Makanza, 23 lame and 44 non-lame cattle.

During the dry season, the recorded numbers were: in Kelambwe, 22 lame and 24 non-lame cattle; in Kankundwe, 11 lame and 20 non-lame cattle; in Kindele, 11 lame and 11 non-lame cattle; and in Makanza, 25 lame and 26 non-lame cattle.

The animals included in the lame cattle group consisted of all cattle admitted

to the kraal hospital and presenting lameness during the study period. In contrast, the non-lame cattle group included cattle admitted to the kraal hospitals for conditions other than lameness.

2.4.2. Type of Study

A longitudinal descriptive approach, including the analysis of environmental and zoo-technical factors, was adopted.

This study was conducted between March 2023 and March 2024. Sampling was carried out on a monthly basis throughout the entire follow-up period. The animals evaluated during the rainy season and the dry season constituted distinct groups, with each season having its own study sample.

2.4.3. Risk Factor Analysis

This analysis was based on the observation of various environmental and zoo technical parameters [6] [7], with the aim of:

- Identifying environmental and zoo-technical factors likely to influence the occurrence of pathologies;
- Evaluating the strength of the association between these factors and the identified conditions;
- Detecting conditions promoting the emergence or persistence of foot diseases within the herd [4] [14] [15].

The studied factors include:

- Environmental factors (soil type, humidity, and climate); Zoo-technical factors (grazing system, travel distance) and nutritional factors (mineral status).

Biological Analyses

Blood samples were collected for trace element analysis (Zn, Cu, Mn, Se, and Ca).

2.4.4. Characterization of Lameness

To assess the severity of lameness, a locomotion scoring system based on a five-point visual scale (scores 1 to 5), according to the method described by [16], was assigned to each animal while walking on a hard and flat surface. This evaluation made it possible to assess limb placement, gait characteristics, and the dorsal posture of the animal. An illustration of this lameness scoring classification is presented in **Figure 1**.

2.5. Statistical Analysis

The different data collected were entered and processed using Excel software (Microsoft Office 365). Data obtained from sociodemographic surveys, general herd characteristics, and reasons for animal hospitalization in the different study sections were analyzed using descriptive statistics, expressed as percentages, and summarized in tables.

Furthermore, the classification and distribution of bovine diseases according to seasons were investigated using multivariate statistical methods. A Principal

Component Analysis (PCA), coupled with Hierarchical Cluster Analysis (HCA), was performed to explore the relationships between the different observed disorders and their distribution across the livestock sections. PCA made it possible to reduce the dimensionality of the data while preserving most of the information, through the simultaneous projection of variables (pathological conditions) and statistical individuals (livestock sections) into a two-dimensional factorial space defined by the F1 and F2 axes. The first two factorial axes explained a cumulative variance of 97.66%, thus ensuring a reliable representation of the data structure. The contributions of the variables were illustrated using a biplot, facilitating the identification of associations between pathologies and their spatial distribution.

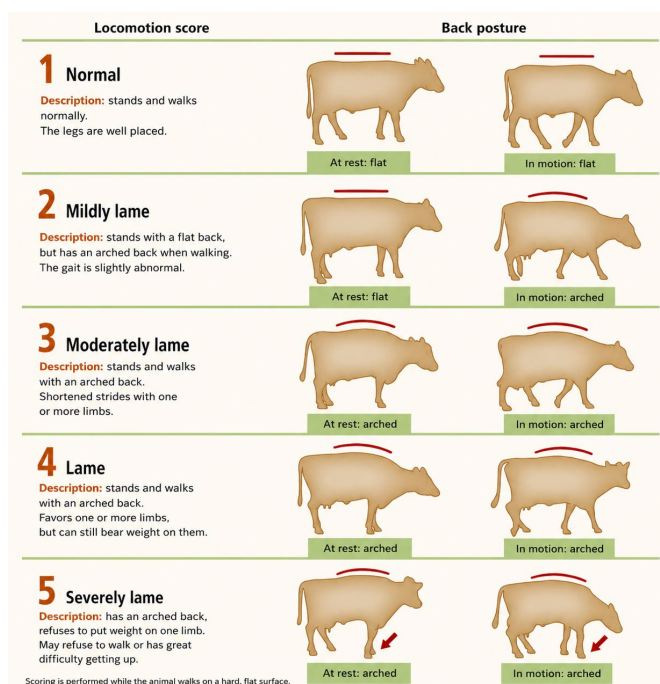


Figure 1. Locomotion score in dairy cattle.

In addition, a Hierarchical Cluster Analysis based on a dissimilarity measure was applied to group the disorders into homogeneous classes. The results were presented as a dendrogram, highlighting the structural proximities and groupings among the different pathologies. All these statistical analyses were performed using XLSTAT software.

The results related to the classification of lameness according to zootechnical categories, animal age, and locomotion scores were expressed as mean $\pm$ standard deviation. Multiple comparisons of group means were performed using one-way analysis of variance (ANOVA).

Student's t-test, with a significance threshold set at $p < 0.05$, was used to assess the effect of lameness on blood mineral concentrations in cattle, taking into account variations related to study sections and seasons. Analysis of variance (ANOVA) was also applied to compare the means of the different animal groups after lameness management. These analyses were performed using GraphPad Prism software.

3. Results

3.1. Description of Environmental and Zoo-Technical Factors in the Study Sections

Table 2 presents the analysis of the main zoo-technical parameters observed in the four study sections, in order to identify conditions likely to promote lameness in cattle. The considered factors include feeding practices, watering methods, animal movement distances, the availability of shelters for resting, and pen management practices. These parameters are key elements in the assessment of zoo-technical risk factors associated with locomotor disorders.

Table 2. Observations of zoo-technical risk factors for lameness.

Observed parameters	Observations
Type of feed	Natural grazing with seasonal mineral supplementation (weekly in the rainy season, bi-monthly in the dry season).
Watering	River water, available all year round
Average distance travelled/day (km)	5 - 10 km/day
Presence of shelters for rest	Rudimentary shelters made from local materials
Pasture rotation frequency	Seasonal rotation according to forage availability

The table above shows that the observed parameters reflect a classic extensive system, with a strong reliance on natural grazing, high daily animal mobility, and limited infrastructure. These conditions constitute cumulative risk factors for the development of lameness, particularly when they are not mitigated by preventive measures.

- Feed type

A natural grazing based diet, supplemented weekly during the rainy season and once every two months during the dry season, exposes cattle to seasonal nutritional imbalances, particularly in energy and minerals. These deficiencies are associated with impaired horn quality, promoting cracks and hoof lesions.

- Watering

Watering from rivers, although permanent, involves repeated movement over wet, uneven, slippery, or stony ground. This factor is associated with an increase in mechanical trauma.

- Average distance covered per day (5 - 10 km)

High daily distance is a major biomechanical factor; the increase in traveled distance is correlated with:

- 1) A worsening of lameness,
- 2) An overload of certain areas of the limb,
- 3) An increased risk of chronic lameness.

- Presence of shelters for rest

Rudimentary shelters offer limited protection against moisture and abrasive soils; the lack of suitable resting areas is associated with insufficient foot recovery, promoting the persistence of lesions.

- Pasture rotation frequency

Seasonal rotation, dependent on forage availability, partially limits pasture overload, but remains insufficiently planned. An unstructured rotation can maintain prolonged exposure to degraded soils, a contributing factor to lameness.

Table 3 presents an assessment of the different livestock sites observed, emphasizing on soil characteristics, including soil type, condition, drainage, and slipperiness. These environmental parameters are key factors in the development of lameness and allow the assessment of the influence of housing and movement conditions on the locomotor health of cattle.

Table 3. Observations of environmental risk factors for lameness.

Observed location	Soil type	Soil condition	Drainage	Slippery floor
Pasture	Sandy	Eroded	Yes	Average
Infirmmary/Kraal Hospital	Concrete	Dry (DS), Muddy (RS)	No	Average
Main aisles	Sandy	Dry and eroded (DS), Muddy and eroded (RS)	Yes	Average
Secondary aisles	Sandy	Dry and eroded (DS), Muddy and eroded (RS)	Yes	Average
Enclosure / Housing	Sandy	Wet and muddy	No	Average
Dipping tank (bath)	Concrete	Wet and muddy	No	Average
Watering troughs	Sandy	Damp, muddy and eroded	Yes	High

Legend: DS = Dry season; RS = Rainy season.

Table 3 shows that environmental observations highlight the constant exposure of cattle to abrasive, wet, or unstable soils in all strategic locations within the livestock system. The combination of eroded sandy soils, poorly drained muddy areas, and wet concrete surfaces constitutes a major environmental factor contributing to the onset, worsening, and chronicity of bovine lameness in extensive systems.

These factors are likely to act cumulatively and synergistically, significantly increasing the risk of mechanical and infectious foot lesions.

Detailed analysis by observed location

- Pastures

The pastures have eroded sandy soils with satisfactory drainage but average slipperiness; erosion promotes excessive trauma to the hooves, while slipperiness increases the risk of micro trauma.

- Infirmmary/Kraal Hospital

The presence of concrete floors alternating between dryness (dry season) and mud (rainy season), combined with insufficient drainage, creates an environment unfavorable to the healing of foot lesions; these conditions are associated with a delayed healing time and the recurrence of lameness.

- Main and Secondary Walkways

The frequently used paths have a sandy surface that is both dry and eroded in the dry season, and muddy in the rainy season. Despite partial drainage, the per-

sistent slipperiness increases the risk of repeated injuries.

- **Enclosure**

The enclosures are characterized by wet and muddy soils, without drainage; these conditions promote infectious foot conditions (dermatitis, inter-digital rot), contributing significantly to the onset of lameness.

- **Dipping Tank**

The area around the dipping tank is made of wet, muddy concrete with no drainage. The slippery surface, combined with the constant dampness, increases the risk of falls and foot injuries.

- **Watering Troughs**

Watering areas present the most unfavorable conditions: wet, muddy and eroded sandy soil, partial drainage but high slipperiness. These areas constitute critical points of lameness.

3.2. Effect of Mineral Concentration in Bovine Blood on Lameness

Tables 4-7 show the mean $\pm$ standard deviation concentrations of Calcium, copper, manganese, selenium and zinc in lame and non-lame cattle during the rainy season (RS) and the dry season (DS), allowing the assessment of the effect of lameness on these essential minerals.

Table 4. Comparison of blood mineral content (rainy season vs. dry season) in Kelambwe.

Modality	Score	Ca	Cu	Mn	Se	Zn	Period
Lame animals	3.5 $\pm$ 0.5	68.3 $\pm$ 46.0	43.7 $\pm$ 43.2	0.2 $\pm$ 0.2	1.4 $\pm$ 0.8	3.6 $\pm$ 2.5	RS
Non-lame animals	1.0 $\pm$ 0.0	54.4 $\pm$ 38.7	36.4 $\pm$ 29.8	0.1 $\pm$ 0.0	1.2 $\pm$ 0.7	2.7 $\pm$ 1.5	RS
Lame animals	3.5 $\pm$ 0.8	5.4 $\pm$ 14.3	0.1 $\pm$ 0.1	0.1 $\pm$ 0.2	0.0 $\pm$ 0.0	0.1 $\pm$ 0.2	DS
Non-lame animals	1.0 $\pm$ 0.0	14.4 $\pm$ 34.8	0.1 $\pm$ 0.3	0.2 $\pm$ 0.2	0.0 $\pm$ 0.0	0.2 $\pm$ 0.4	DS

Considering **Table 4**, lame and non-lame animals display variations in mineral concentrations according to the time of the year (dry season vs. rainy season). In dry season, levels of essential minerals such as Calcium, copper, selenium, and zinc are lower than during the rainy season. The Student t-test, comparing all lame animals to non-lame animals, showed no significant difference between these two groups when comparing lame and non-lame animals by season ($p = 0.055$). However, highly significant differences ($p < 0.0001$) were observed between calcium levels in rainy season and calcium levels in dry season, as well as between copper levels during the rainy season and copper levels in the dry season.

Table 5. Comparison of blood mineral content (rainy season vs. dry season) in Kankundwe.

Modality	Score	Ca	Cu	Mn	Se	Zn	Period
Lame animals	3.6 $\pm$ 0.5	264.3 $\pm$ 150.6	6.3 $\pm$ 5.8	1.4 $\pm$ 4.2	2.4 $\pm$ 1.2	9.6 $\pm$ 6.9	RS
Non-lame animals	1.0 $\pm$ 0.0	277.5 $\pm$ 177.2	8.0 $\pm$ 9.4	0.5 $\pm$ 0.5	2.6 $\pm$ 1.8	11.4 $\pm$ 14.7	RS
Lame animals	3.5 $\pm$ 0.8	0.1 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 4.5	0.1 $\pm$ 0.0	0.0 $\pm$ 0.0	DS
Non-lame animals	1.0 $\pm$ 0.0	0.1 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.1 $\pm$ 0.0	0.0 $\pm$ 0.0	DS

This table indicates that animals generally show lower mineral concentrations during the dry season compared to the rainy season.

The Student's t-test, comparing lame and non-lame cattle, showed no significant difference between these two groups after comparing lame and non-lame individuals by season ($p = 0.055$). However, highly significant differences ($p < 0.0001$) were observed between calcium levels during the rainy season and calcium levels during the dry season.

Table 6. Comparison of blood mineral content (rainy season vs. dry season) in Kindele.

Modality	Score	Ca	Cu	Mn	Se	Zn	Period
Lame animals	3.8 ± 0.5	75.3 ± 58.3	11.4 ± 5.6	0.2 ± 0.1	2.3 ± 0.9	2.1 ± 1.4	RS
Non-lame animals	1.0 ± 0.0	57.8 ± 46.2	8.9 ± 8.7	0.2 ± 0.1	1.5 ± 1.4	1.7 ± 0.6	RS
Lame animals	3.7 ± 0.7	1.1 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	DS
Non-lame animals	1.0 ± 0.7	0.1 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	DS

Table 6 shows that blood mineral concentrations are lower in dry season compared to the rainy season.

Statistical analysis (Student t-test) revealed no significant difference between lame and non-lame individuals in the dry season ($p = 0.055$). However, a highly significant difference ($p < 0.0001$) was noted between calcium levels in the rainy season and calcium levels in the dry season.

Table 7. Comparison of blood mineral content (rainy season vs. dry season) in Makanza.

Modality	Score	Ca	Cu	Mn	Se	Zn	Period
Lame animals	3.6 ± 0.5	139.6 ± 101.6	0.0 ± 4.8	0.5 ± 0.4	2.8 ± 6.2	7.7 ± 6.6	RS
Non-lame animals	1.0 ± 0.0	434.4 ± 262.3	0.4 ± 2.7	0.5 ± 0.4	4.1 ± 3.2	13.1 ± 9.8	RS
Lame animals	3.0 ± 0.6	0.3 ± 0.5	0.0 ± 0.0	0.0 ± 4.5	0.1 ± 0.0	0.0 ± 0.0	DS
Non-lame animals	1.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	DS

This table shows that lame and non-lame animals have lower mineral concentrations in the dry season than in the rainy season.

The results of the statistical analysis (Student's t-test) revealed a significant difference only for Calcium when comparing lame and non-lame animals in the rainy season ($p = 0.05$) and a highly significant difference ($p < 0.0001$) between Calcium in the rainy season and Calcium in the dry season.

Analysis of the correlation matrix (**Figure 2(A)**) reveals a significant structuring of the relationships between trace elements. Calcium (Ca), zinc (Zn), and selenium (Se) show moderate to strong positive correlations, suggesting co-variation and synergistic behavior within the mineral profile of the animals. Conversely, copper (Cu) is negatively correlated with all of these elements, indicating a distinct, potentially antagonistic profile. Manganese (Mn) shows weaker correlations, reflecting a secondary contribution to the overall structuring.

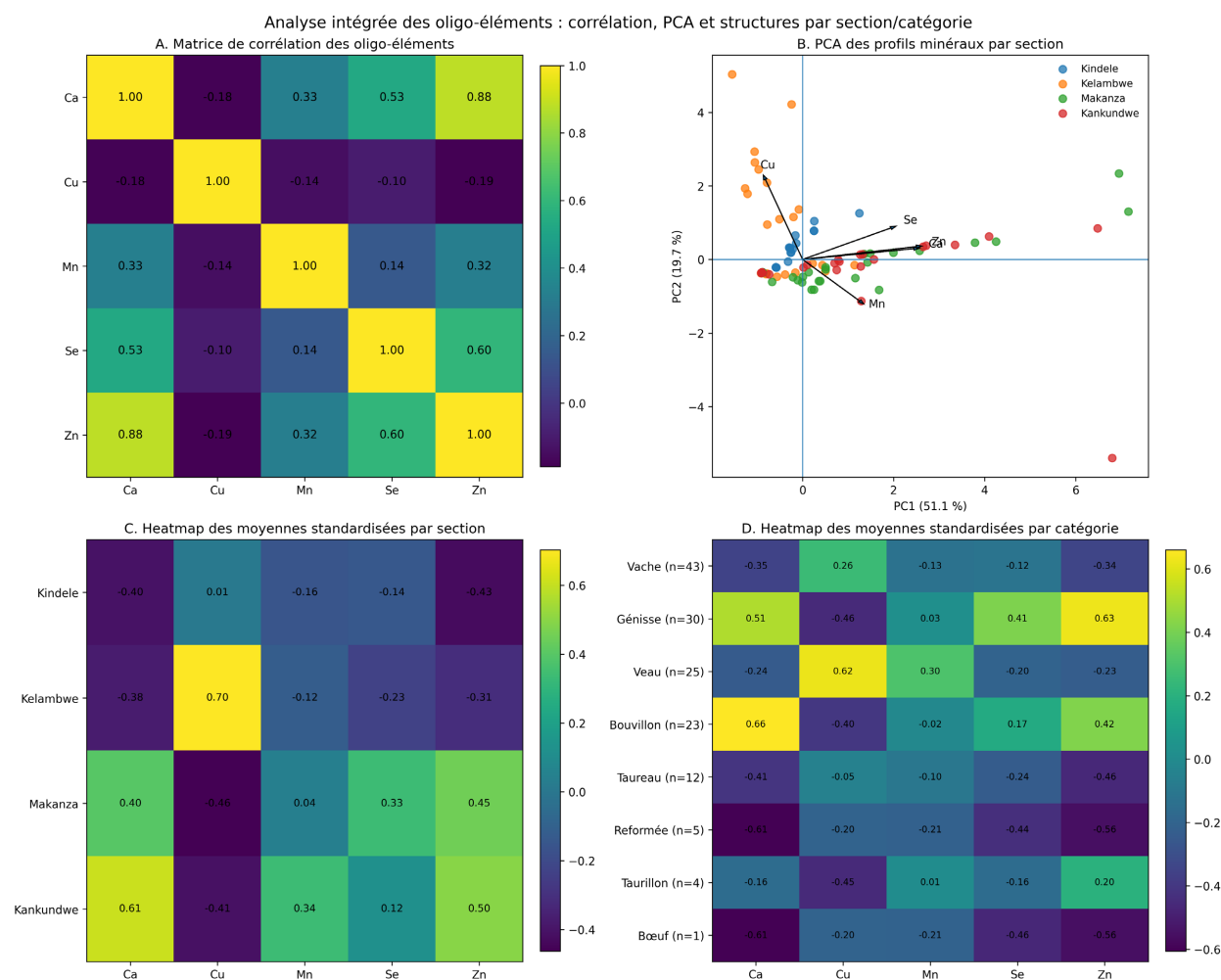


Figure 2. Integrated trace element analysis: correlation, PCA, and structures by section/category.

Principal component analysis (**Figure 2(B)**) confirms this organization by identifying a main axis (PC1) explaining most of the variability, dominated by high positive charges of Ca, Zn, and Se, and opposite to Cu. This distribution reflects the existence of a mineral status gradient, contrasting a profile enriched in Ca-Zn-Se with a profile characterized by a relative influence of Cu. The secondary axis (PC2) reflects additional variability, partly related to Mn and Cu, suggesting finer differences between individuals.

Examination of the heat maps by section (**Figure 2(C)**) reveals marked heterogeneity in mineral profiles between the different rearing areas. Some sections are distinguished by high levels of Ca, Zn, and Se, while others exhibit lower or unbalanced profiles, confirming the influence of local environmental conditions on the mineral status of cattle.

Complementarily, the analysis by animal category (**Figure 2(D)**) highlights significant differences in mineral profiles according to physiological groups. Cows and heifers tend to have higher or better-balanced levels of trace elements, while bull calves and steers show more variable profiles. These observations suggest an

effect of physiological status and specific nutritional requirements on trace element distribution.

Overall, these results indicate that the mineral profile of cattle is structured along a consistent multivariate gradient, influenced by both environmental conditions (farm sections) and the physiological characteristics of the animals (categories), with a dominant organization contrasting a Ca-Zn-Se pole with copper.

4. Discussion

4.1. Zoo-Technical and Environmental Factors Associated with Bovine Lameness

4.1.1. Zoo-Technical Factors

The results concerning zoo-technical and environmental factors observed in the study sections clearly highlight a set of structural conditions that promote the onset, worsening, and chronicity of bovine lameness. These conditions are part of an extensive livestock farming system characterized by high animal mobility, an almost exclusive reliance on natural pasture, and rudimentary infrastructure, a situation widely described in tropical pastoral systems [17] [18].

1) Influence of Feeding Practices on Locomotor Health

Cattle feeding relies primarily on the exploitation of natural pastures, with irregular nutritional supplementation that is highly dependent on seasonal variations. This feeding strategy exposes animals to seasonal deficiencies, particularly in energy, protein, and essential minerals such as Zinc, Copper, and Calcium, elements known for their crucial role in the growth, quality, and mechanical strength of the hoof horn. These observations are consistent with the work of [19], which highlights the impact of nutritional imbalances on hoof health in cattle.

According to [17], chronic nutritional deficiencies lead to impaired horn quality, making it more brittle and more susceptible to cracking, excessive wear, and secondary infections. The results of this study, showing a high prevalence of lameness associated with weight loss, corroborate this close relationship between nutritional status and locomotor disorders. Thus, nutrition appears to be an indirect but fundamental risk factor in the development of bovine lameness.

2) Watering and Associated Mechanical Stresses

Watering cattle from rivers is a common and ongoing practice in the studied sections. However, this practice requires repeated movement on wet, slippery, and sometimes uneven ground. [19] and [20] highlighted that prolonged exposure to moisture and unstable ground promotes inter-digital maceration, mechanical trauma, and the development of infectious foot conditions.

In this study, watering areas appear to be the locations with the highest risk for lameness. The high slipperiness observed in these areas, combined with persistent moisture and soil erosion, constitutes a major aggravating factor, which aligns with [21] observations that wet and slippery surfaces significantly increase the incidence of foot lesions.

3) Effect of Daily Distance Traveled

The average daily distance traveled by cattle (5 to 10 km) is a key biomechanical factor in the development of lameness. According to [19], increased travel distance is directly correlated with excessive hoof wear, overloading of certain weight-bearing areas of the foot, and the onset of chronic lameness.

In extensive systems, this constraint is often unavoidable due to the dispersion of grazing and water resources. However, the absence of compensatory measures such as regular hoof trimming or rangeland management exacerbates the negative impact of this high mobility. The results of this study confirm that travel distance is one of the zoo-technical factors most strongly associated with bovine lameness.

4) Role of Shelters and Resting Conditions

The shelters observed in the different sections studied are characterized by their rudimentary nature, offering limited protection against moisture, mud and abrasive soils.

However, numerous studies have demonstrated that the absence of dry and comfortable resting areas compromises hoof recovery and promotes the chronicity of lesions, thus contributing to persistent lameness. These findings align with the observations reported by [22], who emphasize the importance of housing conditions in maintaining hoof health in cattle.

Statistically, the absence or inadequacy of shelters constitutes an indirect but significant risk factor by reducing effective rest time and keeping animals in prolonged contact with unfavorable surfaces. This situation contributes to the chronicity of lameness, particularly during the rainy season.

5) Pasture Rotation

Seasonal pasture rotation, while partially reducing grazing pressure, remains insufficiently planned and structured. According to [23], effective rotation must be combined with sound stocking management and improved infrastructure to have a significant impact on animal health.

In this study, rotation appears as a weak or insignificant protective factor, suggesting that its potential beneficial effect is neutralized by general soil degradation and the high daily mobility imposed on cattle.

4.1.2. Decisive Influence of Environmental Factors

Analysis of environmental factors reveals continuous exposure of cattle to abrasive, wet, or unstable soils at all strategic sites within the livestock system. Pastures characterized by sandy soils subject to erosion promote progressive and chronic hoof wear. In addition, poorly drained areas, including enclosures, watering points and dipping tanks, provide environments conducive to the development and persistence of infectious foot conditions, as also reported by [20] and [24].

The concrete floors of the infirmary and the hospital kraal, which alternate between dry and muddy depending on the season, constitute a particularly unfavorable environment for wound healing. This observation aligns with the work of [21], which shows that hard, wet surfaces prolong healing time and increase the risk of lameness recurrence.

4.2. Effect of Blood Mineral Concentration on Bovine Lameness

Results displayed in **Tables 4-7** highlight marked variations in blood concentrations of Calcium (Ca), copper (Cu), manganese (Mn), selenium (Se), and zinc (Zn) in cattle, depending on the season (rainy versus dry) and the studied site. These variations underscore the crucial influence of environmental and nutritional factors on the mineral status of animals raised in tropical extensive systems.

4.2.1. Influence of Season on Blood Mineral Status

Across all the sites (Kelambwe, Kankundwe, Kindele, and Makanza), the concentrations of the analyzed minerals were consistently found to be significantly lower during the dry season compared to the rainy season. This difference is particularly explained by the mineral supplementation practices implemented in the different sections, characterized by weekly distribution of mineral supplements during the rainy season, versus bi-monthly distribution during the dry season. However, the latter corresponds precisely to the period when the animals' nutritional needs are highest and when the availability of minerals from natural pastures is most limited, thus promoting the development of mineral deficiencies.

These results are consistent with many previous studies that have shown that, in tropical environments, the dry season is associated with a qualitative and quantitative degradation of forage resources, leading to a decrease in dietary mineral intake and the emergence of secondary mineral deficiencies in ruminants [25] [26].

The highly significant drop in calcium and copper levels between the rainy and dry seasons ($p < 0.0001$) observed in this study is particularly concerning, as these two elements play a key role in bone mineralization, the integrity of keratinized hoof tissue, and immune mechanisms (Suttle, 2010). Prolonged calcium deficiency can impair the mechanical strength of foot structures, thus promoting the development of locomotor lesions [19].

4.2.2. Relationship between Mineral Status and Lameness

Comparisons between lame and non-lame animals within the same season generally did not reveal statistically significant differences for most minerals ($p \approx 0.055$), with the exception of Calcium in Makanza during the rainy season ($p = 0.05$). This lack of a clear difference suggests that the lameness observed in this context cannot be attributed to an isolated mineral deficiency, but rather to a combination of risk factors, including mechanical stress, soil type, long walking distances, and herd health management, as previously reported by [20] and [27].

However, the overall lower concentrations of Ca, Cu, Zn, and Se in lame animals, while not statistically significant, support the findings of [28], who demonstrated that subclinical trace element deficiencies can weaken hoof horn and reduce tissue repair capacity, making animals more susceptible to lameness.

4.2.3. Specific Role of Trace Elements in Foot Health

Zinc and copper are essential for normal keratinization of the hoof horn and for

the healing of foot lesions [29]. Selenium is involved in antioxidant and immune mechanisms, contributing to the prevention of secondary foot infections [30]. The low concentrations recorded in the dry season, sometimes close to zero in certain areas, indicate a severe nutritional deficiency that can worsen chronic lameness.

Although mineral deficiencies did not show a direct statistically significant association with lameness within the season, the marked decrease in Calcium and essential trace element concentrations during the dry season highlights an indirect but crucial role. These deficiencies contribute to the weakening of foot tissues, impaired repair mechanisms, and increased susceptibility to locomotor disorders, thus identifying the dry season as a critical period of vulnerability.

These results underscore the need to implement integrated prevention strategies adapted to the local context, based on:

- Improving environmental conditions, particularly through the development and drainage of at-risk areas;
- Optimizing livestock management practices to reduce mechanical stress;
- Implementing targeted mineral supplementation, especially during the dry season;

Integrating foot prevention measures such as regular hoof trimming. Looking ahead, further studies are needed to quantify the relative weight of each risk factor and evaluate the effectiveness of interventions under real conditions. Improving lameness control in extensive livestock farming requires a holistic approach integrating animal health, nutrition, and environmental management.

However, it should be emphasized that the comparisons made between lame and non-lame cattle were not adjusted for certain potentially confounding variables, including livestock section, season, age, sex, breed or crossbreed type, as well as animal category. Consequently, the associations observed in this study should be interpreted with caution, as they do not allow a definite causal relationship to be established between the investigated factors and the occurrence of lameness. Indeed, part of the observed differences may have been influenced by the combined effects of environmental, zootechnical, and herd management factors specific to the different study sections.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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