



Comparative study of milk production and quality local breed cows (*Bos indicus*) during the dry season in the districts of Mahajanga I and Mahajanga II, Boeny Region, Madagascar

[Étude comparative de la production et de la qualité du lait des vaches de race locale (*Bos indicus*) pendant la saison sèche dans les districts de Mahajanga I et Mahajanga II, région de Boeny, Madagascar]

Rakotonanahary Hery Zo^{1,2*}, Andriamahery Euzedy Voahangimanitra Harfaraso², Razafindrajaona Jean Marie^{2,3}, Koto-Te-Nyiwa Ngbolua⁶, Pius Tshimankinda Mpiana⁵ & Rahelivoloniaina Baholy^{2,4*}

¹Department of Zootechnical, Veterinary, and Fish Farming Research, FOFIFA

²Doctoral School of Industrial, Agricultural and Food Process and System Engineering, University of Antananarivo, Madagascar

³High School of Agricultural Sciences, University of Antananarivo, Madagascar

⁴Laboratory for the Valorization of Natural Resources, Polytechnic High School of Antananarivo, University of Antananarivo, Madagascar

⁵Département de Chimie et Industries, Faculté des Sciences et Technologies, Université de Kinshasa, Kinshasa, République Démocratique du Congo

⁶Département de Biologie, Faculté des Sciences et Technologies, Université de Kinshasa, Kinshasa, République Démocratique du Congo

Abstract

The milk of local bovine breed (*Bos indicus*) has remarkable nutritional value, characterized by its richness in essential bioactive components and its unique functional properties for human health. However, scientific data on the milk production and quality of this breed remains incomplete, despite its essential socio-economic contribution to rural development in Madagascar. This study aims to characterize milk production and quality according to geographical location such as Districts, Municipalities, and Quarter levels. The methodology combines a systematic literature review with a field survey of 33 farmers and an analysis of the production of 123 cows using a LACTOSCAN LW. The results reveal variability depending on location. Average production is 1.143 ± 0.387L for Mahajanga I compared to 1.347 ± 0.513L for Mahajanga II. At the Quarter level, production varied from 1.039 ± 0.292L (Tsararano) to 1.444 ± 0.481L (Ambondrona). In Mahajanga II, the range is more pronounced, ranging from 0.750 ± 0.00L (Ambalakida) to 1.417 ± 0.629L (Belobaka). Physicochemical analysis shows compositional variability correlated with geography. Mahajanga II has higher values for several parameters, with protein content of 2.965 ± 0.129% compared to 2.638 ± 0.484% for Mahajanga I, and lactose content of 4.497 ± 0.184% compared to 3.989 ± 0.761%. The Quarter scale reveals local specificities, such as high fat content in Mahavoky (6.485 ± 1.365%). These results highlight the importance of geography in characterizing traditional dairy production. The establishment of specific quality indicators and the extension of this research to other Regions of Madagascar are essential for promoting the dairy potential of the *Bos indicus* breed and contributing to the sustainable development of the national dairy sector.

Keywords: Cow, local breed, *Bos indicus*, milk, production, physical-chemical quality, Mahajanga I, Mahajanga II

Résumé

Le lait de la race bovine locale (*Bos indicus*) possède une valeur nutritionnelle remarquable, caractérisée par sa richesse en composants bioactifs essentiels et ses propriétés fonctionnelles uniques pour la santé humaine. Cependant, les données scientifiques sur la production et la qualité du lait de cette race restent incomplètes, malgré sa contribution socio-économique essentielle au développement rural à Madagascar. Cette étude vise à caractériser la production et la qualité du lait en fonction de la situation géographique, notamment au niveau des districts, des municipalités et des quartiers. La méthodologie combine une revue systématique de la littérature avec une enquête de terrain auprès de 33 agriculteurs et une analyse de la production de 123 vaches à l'aide d'un LACTOSCAN LW. Les résultats révèlent une variabilité en fonction de l'emplacement. La production moyenne est de 1,143 ± 0,387 L pour Mahajanga I, contre 1,347 ± 0,513 L pour Mahajanga II. Au niveau des quartiers, la production varie de 1,039 ± 0,292 L (Tsararano) à 1,444 ± 0,481 L (Ambondrona). À Mahajanga II, l'écart est plus prononcé, allant de 0,750 ± 0,00 L (Ambalakida) à 1,417 ± 0,629 L (Belobaka). L'analyse physico-chimique montre une variabilité de la composition corrélée à la géographie. Mahajanga II présente des valeurs plus élevées pour plusieurs paramètres, avec une teneur en protéines de 2,965 ± 0,129 % contre 2,638 ± 0,484 % pour Mahajanga I, et une teneur en lactose de 4,497 ± 0,184 % contre 3,989 ± 0,761 %. L'échelle du quart révèle des spécificités locales, telles que la teneur élevée en matières grasses du Mahavoky (6,485 ± 1,365 %). Ces résultats soulignent l'importance de la géographie dans la caractérisation de la production laitière traditionnelle. La mise en place d'indicateurs de qualité spécifiques et l'extension de cette recherche à d'autres régions de Madagascar sont essentielles pour promouvoir le potentiel laitier de la race *Bos indicus* et contribuer au développement durable du secteur laitier national.

Mots clés : Vache, race locale, *Bos indicus*, lait, production, qualité physico-chimique, Mahajanga I, Mahajanga II.

*Auteur correspondant: Rahelivoloniaina Baholy, (baholy.robijaona@univ-antananarivo.mg). Tél. : (+261) 33 15 089 59

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1. Introduction

The milk produced by the indigenous *Bos indicus* cattle breed in Madagascar is a strategic nutritional resource, whose importance transcends the simple dimension of food to become part of a multidimensional development perspective. Its distinctive composition is characterized by a concentration of essential bioactive components (Rasolofo et al., 2021). It is a complete food particularly suited to the needs of populations often faced with structural food shortages (FAO, 2013). Local milk production is a fundamental pillar of food security. The traditional sector generates substantial income for farming households, actively contributes to local job creation, and provides sustainable support for the regional economy (MAEP, 2021).

Despite this multifactorial importance, scientific data on the milk production and quality of the *Bos indicus* breed remains fragmentary and incomplete at the national level. Preliminary observations suggest that administrative location significantly influences milk production parameters, with measurable quantitative and qualitative variations between different territorial entities at the Districts, Municipalities, and Quarter levels. This study aims to analyze the influence of geographical location on the production and quality parameters of *Bos indicus* milk in the Districts of Mahajanga I and Mahajanga II. Specifically, it objectives to compare milk production performance, both quantitative and qualitative, between different administrative divisions and to quantify the seven fundamental physicochemical parameters (fat, lactose, protein, minerals, other elements, freezing point, and electrical conductivity) at each territorial level, while examining their spatial relationships. Achieving these objectives will contribute to establishing the technical benchmarks essential for optimizing breeding practices and sustainably developing the dairy potential of the *Bos indicus* breed in Madagascar.

2. Materials and methods

2.1 Materials

2.1.1. Study area

The Districts of Mahajanga I and Mahajanga II are located in the Boeny Region in northwestern Madagascar. They have a complementary administrative configuration. Mahajanga I is the main urban center and home to the regional capital.

Mahajanga II covers a vast suburban and rural area. The contrasting surface areas between the two Districts are 57km² for Mahajanga I and 4,721km² for Mahajanga II (CREAM, 2013). Administratively, Mahajanga I is subdivided into one Municipality, while Mahajanga II comprises nine Rural Municipalities, with a combined population of approximately 369,973 inhabitants (INSTAT, 2014). The study area has a dry tropical climate characterized by an average annual temperature of between 26 and 28°C and annual rainfall varying from 1,300 to 1,500 mm.

2.1.1. Bibliographic review materials

Bibliographic review was based on a variety of selected primary documentary sources. Indexed scientific publications, including articles from peer-reviewed international journals, doctoral theses, and university dissertations, as well as publications from agricultural research institutes, form the scientific basis of this research. Institutional documents, including ministerial technical reports, INSTAT publications, FAO documents, and development project reports, provided the official framework and essential statistical data.

2.1.2. Survey materials

Data collection was carried out using several structured tools specially designed for this study. Detailed questionnaires for farmers were used to gather comprehensive information on farm identification, herd characteristics including herd size, composition, and breeds, as well as farming and milking practices. At the same time, technical data collection sheets were developed to accurately document individual milk production parameters and reproduction data.

2.1.3. Cow milk quantity measuring equipment

Accurate measurement of milk production relies on the use of specialized instruments adapted to different volume scales. The measuring cup, a transparent plastic cylindrical container, is distinguished by its resistance to impact and chemicals, making it the ideal tool for measuring small volumes. It generally has a capacity of between 500 ml and 2 liters. Its main advantages are that it is easy to clean and disinfect, although its use is limited for measuring complete milk yields.

2.1.4. Cow milk sampling equipment

Preserving the integrity of milk samples requires a rigorously controlled sampling chain. The insulated cooler, with a capacity of 20 to 30 liters, ensures the safe transport of samples from the farm to the laboratory. Its essential function is to maintain a stable

temperature between 0°C and 4°C through the combined use of eutectic plates, thus preventing microbial growth. This equipment was chosen primarily for its autonomy, isothermal performance, durability, and ease of maintenance. These “smart” cold accumulators contain a eutectic solution whose main property is to freeze and melt at a constant temperature, ideally between 0°C and 3°C. Their function is to ensure uniform refrigeration in the cooler, avoiding the temperature variations observed with traditional ice. Their main advantage lies in preventing the risk of partial freezing of samples, while maintaining optimal storage conditions. The 50 ml plastic bottles, which are sterile and single-use, are specifically designed for milk analysis



Figure 1. Eutectic plate
Source : Authors, 2025



Figure 2. 50 ml plastic bottle
Source : Authors, 2025

2.1.5. Cow milk analysis equipment

The LACTOSCAN LW device is a milk analyzer that uses electronic impedance spectroscopy, a technology designed specifically to perform rapid and accurate analyses of milk composition (figure 3 and 4).



Figure 3. LACTOSCAN LW (Source: Authors, 2025)



Figure 4. Alkaline detergent 3% and Acid cleaner 3% (Source: Authors, 2025)

This equipment stands out for its ability to simultaneously determine several physicochemical

parameters of milk in a record time of 60 seconds. The parameters measured are fat (FAT), lactose (LACT), mineral salts (CT), protein (PRO), density (DEN), freezing point (FP), and electrical conductivity (COND). Maintenance of the device is based on three essential solutions. The 3% alkaline detergent solution, composed of sodium hydroxide in distilled water, is used for deep cleaning of lipid and protein deposits. Its application follows a rigorous protocol: after preliminary rinsing with distilled water. The 3% acid cleaner solution is used to remove mineral deposits and milk stone. It is applied after alkaline cleaning. Distilled water has multiple applications: final rinsing after each cleaning, dilution of concentrated solutions, rinsing between samples during analysis series, and preparation of cleaning solutions.

2.1.6. Data processing equipment

Data processing was carried out using statistical software suite. Quantitative analyses were performed using SPSS software. The statistical methods applied covered a complete analytical spectrum, from descriptive analyses to inferential analyses including ANOVA and Pearson correlations. Multivariate analyses used Principal Component Analysis (PCA).

2.2. Methods

2.2.1. Logical framework of the research

This research is structured around a central issue questioning the determinants of quantitative and qualitative variations characterizing milk production in cows of the local breed (*Bos indicus*) in the Districts of Mahajanga I and Mahajanga II. Milk quality is influenced by farming practices and environmental conditions specific to the Region. The health of the animals' udders has a significant impact on the quality characteristics of the milk produced.

The study focuses on milk production in different locations within the study area. It consists of methodically analyzing the physical and chemical characteristics of milk from cows of the local breed (*Bos indicus*). Cross-sectional surveys conducted among farmers provide essential field data. Laboratory analyses of milk samples enable precise characterization of quality parameters. Direct observations of farming practices complete the study.

2.2.2. Bibliographical and webographical review

The documentary research is based on diverse and up-to-date bibliographic and webographical sources. The fundamental works consulted include reference publications. The scientific articles come from specialized journals. The theses and dissertations used include Malagasy academic work, international

research on tropical cattle, and in-depth studies on traditional livestock farming systems. The webographical sources used include prestigious scientific databases such as Google Scholar, Scribd, and ResearchGate.

2.2.3. Study sites selection and delimitation

The selection of study sites was carried out using a rigorous methodology based on three categories of interdependent criteria. Geographical and administrative criteria favored locations in the Boeny Region in northwestern Madagascar, with detailed coverage of the two Districts of Mahajanga I and Mahajanga II. The accessibility of the sites during the dry season and the representativeness of the Region's various ecosystems were key factors in the selection process. Zootechnical criteria focused particularly on the presence of dairy cattle farms and the diversity of farming systems encountered, whether extensive or semi-intensive.

2.2.4. Livestock farmers survey

The survey tools were designed based on a comprehensive structured questionnaire. Livestock farming practices were investigated in depth, covering production systems, housing conditions, and breeding methods. Animal health was assessed through preventive practices, treatments administered, and health problems encountered. A systematic observation grid completed the system, enabling objective assessment of hygiene conditions during milking. Data collection itself was carried out through individual visits to farms, combining direct observations during milking activities.

2.2.5. Measurement of quantity of milk produced by cows

The measurement protocol began with rigorous preparation, including the precise identification of lactating cows, careful verification of the animals' health, and cleaning and calibration of the measuring instruments. The instruments used included a graduated cup with a capacity of 500 ml to 2 liters for partial measurements and a graduated bucket of 10 to 20 liters for total production. The calculations applied made it possible to determine daily production by adding together morning and evening production.

2.2.6. Local breed cow milk analyse

Samples were collected under strict aseptic conditions, after the milk had been thoroughly stirred, in standard 50 ml volumes, using only sterile, single-use bottles. Storage and transport ensured that the cold

chain was maintained through immediate refrigeration at 4°C, transport in a cooler equipped with eutectic plates, and a maximum delay of six hours before analysis. Physicochemical analyses included determination of basic composition using LACTOSCAN LW. Quality parameters included fat (FAT), lactose (LACT), mineral salts (CT), protein (PRO), density (DEN), freezing point (FP), and electrical conductivity (COND). Fraud detection involved measuring the freezing point to detect added water.

2.2.7. Statistical processing

The statistical processing phase began with meticulous data preparation, including the creation of a structured database. The statistical analyses applied covered a full spectrum of methods. Descriptive statistics were used to calculate minimums, averages, maximums, standard deviations, and variability analysis using the coefficient of variation. Parametric statistical tests used Student's t-test, one-way ANOVA, and Pearson's correlations. Multivariate analyses formed the core of the statistical investigation, with the implementation of Principal Component Analysis (PCA) aimed at reducing the dimensionality of the data, identifying structuring variables, and visualizing similarities between samples.

The rigorous statistical processing protocol using SPSS ensured the scientific validity of the results while allowing optimal use of the data collected in the field, thus guaranteeing the methodological soundness of the entire research project.

3. Results

3.1. Distribution of livestock farmers and local breed cows (*Bos indicus*)

The following figure shows the number of livestock farmers and cows of the local breed (*Bos indicus*) in the Districts of Mahajanga I and Mahajanga II.

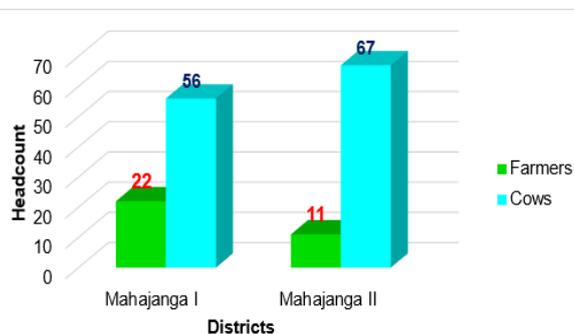


Figure 5. Number of farmers and cows of the local breed (*Bos indicus*) in the Districts of Mahajanga I and Mahajanga II (Source: Authors, 2024)

A comparative analysis of livestock numbers reveals a contrasting distribution between the two Districts: Mahajanga I has 22 livestock farmers, representing 66.7% of the total recorded, while Mahajanga II has only 11 livestock farmers, corresponding to 33.3% of the total number. This difference means that there are twice as many livestock farmers in the Mahajanga I District. The distribution of livestock is 56 cows (45.5% of the total) for Mahajanga I and 67 cows (54.5% of the total) for Mahajanga II. The average herd size in the Mahajanga I District is 2.55 cows per farmer. In contrast, the Mahajanga II District has a significantly higher average herd size of 6.09 cows per farmer. This difference indicates that farms in Mahajanga II are on average 2.4 times larger than those in Mahajanga I.

The structural implications of this distribution reveal two Distinct models: Mahajanga I District has a more traditional, family-based livestock farming structure, characterized by small production units, while Mahajanga II District is distinguished by a more professionalized and commercial livestock farming structure. This more pronounced specialization in the Mahajanga II District reflects a stronger focus on dairy production as the main economic activity.

The territorial context offers relevant explanations for these structural disparities. For the Mahajanga I District, which is located in an urban and peri-urban area, the explanatory factors are limited access to pastoral land, the multiplicity of small family farms, and the multiple activities of livestock farmers. Conversely, the Mahajanga II district is rural in character and benefits from greater land availability, access to more extensive pastures, and a concentration of means of production.

3.2. Place variability of local breed cow (*Bos indicus*) milk production and quality

The table below shows the local breed cow (*Bos indicus*) milk production and quality during the dry season in the districts of Mahajanga I and Mahajanga II

*Table I. Local breed cow (*Bos indicus*) production and quality of milk from during the dry season in the districts of Mahajanga I and Mahajanga II*

Parameters	Mahajanga I	Mahajanga II	P value	Conclusion
Milk (L/day)	1,143±0,387 0,500 ; 2,250	1,347±0,513 0,500 ; 3,000	0,049	S
FAT (%)	5,031±1,591 1,500 ; 8,100	5,354±1,469 1,550 ; 8,950	0,583	NS
Lactose (%)	3,989±0,761 1,590 ; 4,890	4,497±0,184 4,010 ; 5,070	0,003	S
Ash (%)	0,621±0,172 0,230 ; 1,580	0,675±0,026 0,600 ; 0,760	0,034	S
Protein (%)	2,638±0,484 1,050 ; 3,240	2,965±0,129 2,630 ; 3,350	<0,001	S
Others (%)	0,022±0,231 -1,670 ; 0,100	0,054±0,017 0,010 ; 0,100	0,274	NS

*Table I. Local breed cow (*Bos indicus*) production and quality of milk from during the dry season in the districts of Mahajanga I and Mahajanga II (continued)*

Parameters	Mahajanga I	Mahajanga II	P value	Conclusion
Density (g/cm ³)	1,025±0,005 1,010 ; 1,031	1,029±0,002 1,023 ; 1,034	<0,001	S
Freezing point (°C)	-0,472±0,089 -0,569 ; -0,221	-0,531±0,022 -0,606 ; -0,493	<0,001	S
Conductance (mS/cm)	5,293±1,417 4,040 ; 13,060	5,061±0,250 4,380 ; 5,910	0,911	NS

First line: Mean± Standard deviation; Second line: Minimum; Maximum. Identical letters indicate similarity between observed and/or measured milk parameters according to location at the 5% threshold; S: Significant; NS: Not Significant.

A comparative study of milk production (MILK) between the two Districts reveals a marked disparity. The Mahajanga I District has an average production of 1.143L with moderate variability (standard deviation of 0.387L), while the Mahajanga II District performs better with an average of 1.347L, although characterized by greater dispersion (standard deviation of 0.513L). The statistical significance of this difference (p=0.049) confirms the productive superiority of the Mahajanga II District, with an average advantage of 0.210L per cow. Nevertheless, it is important to note the significant individual variability observed in both districts, as evidenced by the respective ranges of 0.500 to 2.250L and 0.500 to 3.000L.

Analysis of milk fat content reveals no statistically significant difference between the two areas (p=0.583). Average fat content is 5.031% for

Mahajanga District I and 5.354% for Mahajanga District II. This reflects a remarkable similarity in the lipid metabolism of the herds, despite a slight numerical superiority in the second District.

The lactose parameter, on the other hand, shows a highly significant difference ($p=0.003$). The average concentration of 4.497% measured in the Mahajanga II District exceeds the 3.989% recorded in the Mahajanga I District. This substantial difference suggests either greater efficiency in the lactic synthesis processes or more favorable sanitary conditions in the Mahajanga II District. The protein content shows a divergence with an extremely significant difference ($p<0.001$). The average value of 2.965% for the Mahajanga II District is associated with remarkable stability (standard deviation of 0.129%). This contrasts with the 2.638% and greater variability (standard deviation of 0.484%) observed in the Mahajanga I District. This disparity could reflect a more balanced diet or more optimal farming practices in the high-performing District. Milk density shows a very significant difference ($p<0.0001$) between Districts. Mahajanga II has higher ($1.029 \pm 0.002 \text{ g/cm}^3$) and extremely stable values, indicating better physical quality of milk compared to Mahajanga I ($1.025 \pm 0.005 \text{ g/cm}^3$).

Mineral analysis reveals a significant superiority ($p=0.034$) of the Mahajanga II District, with a mineral salt content of 0.675% compared to 0.621% for the Mahajanga I District. The particularly homogeneous composition of milk in Mahajanga II (standard deviation of 0.03%) is worth noting. The freezing point shows a highly significant difference ($p<0.001$) between the two Districts. The lower value recorded in the Mahajanga II District (-0.531°C) compared to the Mahajanga I District (-0.472°C) indicates a distinct fatty acid composition, probably attributable to differences in the composition of the feed rations.

Electrical conductivity shows no significant variation ($p=0.911$). The respective values of 5.293mS/cm and 5.061mS/cm are slightly different. They remain within a comparable range and reflect a similarity in ionic composition and mammary health status between the two Districts.

3.3. Quarter level comparison of local breed cow (*Bos indicus*) production and quality of milk during the dry season in the District of Mahajanga I

The following table illustrates the quarter level comparison of local breed cow (*Bos indicus*) milk production and quality in the District of Mahajanga I

Parameters	Ambondrona N : 9	Amborovy N : 13	Antanimalandy N : 13	Mahavoky N : 2	Tsararano N : 19	P value	Conclusion
Milk (L/day)	1,444±0,481 0,750 ; 2,250	1,096±0,427 0,500 ; 2,000	1,135±0,363 0,500 ; 1,750	1,125±0,177 1,000 ; 1,250	1,039±0,292 0,500 ; 1,500	0,259	NS
FAT (%)	5,384±1,575 2,670 ; 7,400	4,485±1,482 1,500 ; 6,750	5,499±1,559 1,950 ; 7,980	6,485±1,365 5,520 ; 7,450	4,764±1,644 1,730 ; 8,100	0,260	NS
Lactose (%)	4,100±0,525 2,950 ; 4,650	3,969±1,031 1,590 ; 4,890	4,102±0,671 2,040 ; 4,580	4,300±0,283 4,100 ; 4,500	3,841±0,765 2,060 ; 4,610	0,633	NS
Ash (%)	0,617±0,081 0,440 ; 0,700	0,594±0,156 0,230 ; 0,730	0,616±0,103 0,300 ; 0,690	0,650±0,042 0,620 ; 0,680	0,641±0,250 0,300 ; 1,580	0,904	NS
Protein (%)	2,698±0,341 1,950 ; 3,060	2,618±0,681 1,050 ; 3,240	2,699±0,440 1,350 ; 3,020	2,820±0,198 2,680 ; 2,960	2,563±0,457 1,360 ; 3,040	0,662	NS
Others (%)	0,054±0,016 0,030 ; 0,080	0,045±0,013 0,030 ; 0,070	0,056±0,016 0,030 ; 0,090	0,060±0,014 0,050 ; 0,070	-0,037±0,396 -1,670 ; 0,100	0,457	NS
Density (g/cm ³)	1,026±0,003 1,022 ; 1,030	1,025±0,007 1,010 ; 1,031	1,026±0,004 1,013 ; 1,029	1,027±0,003 1,024 ; 1,029	1,024±0,005 1,013 ; 1,030	0,889	NS
Freezing point (°C)	11,947±4,789 1,750 ; 20,630	5,662±5,664 0,260 ; 13,780	9,952±4,534 2,130-13,910	13,030±0,580 12,620 - 13,440	8,621±7,285 0,430 - 29,230	0,703	NS
Conductance (mS/cm)	-0,482±0,071 -0,552 -0,327	-0,478±0,094 -0,569 -0,267	-0,485±0,087 -0,583 -0,221	-0,512±0,028 -0,532 -0,492	-0,449±0,100 -0,548 -0,222	0,423	NS

Source: Authors, 2025

N: Number of samples; First row: Mean ± Standard deviation; Second row: Minimum; Maximum. Identical letters indicate similarity between the

observed and/or measured parameters of milk according to Quarter at the 5% threshold; NS: Not Significant.

Analysis of milk production reveals some variability between Quarter of Ambondrona has the highest average production at $1.444 \pm 0.481L$, while Quarter of Tsararano has the lowest average production at $1.039 \pm 0.292L$. The maximum difference observed between these two Quarters is $0.405L$. However, the p-value of 0.259 indicates that there is no statistically significant difference between the five Quarters studied.

The fat content varies between sites. The Quarter of Mahavoky stands out with the highest average lipid concentration ($6.485 \pm 1.365\%$), contrasting with Quarter of Amborovy, which has the lowest average content ($4.485 \pm 1.482\%$). The maximum difference of 2.000% between these two extremes is not statistically significant, as evidenced by the p-value of 0.260.

Lactic acid concentration varies moderately between Quarter of Mahavoky has the highest average content ($4.300 \pm 0.283\%$), while Tsararano has the lowest average value ($3.841 \pm 0.765\%$). The low intra-Quarter variability observed in Mahavoky indicates a certain degree of homogeneity in this parameter. The p-value of 0.633 confirms that there is no significant difference between the areas.

The mineral composition of milk shows relative uniformity. The Quarter of Mahavoky and Tsararano have the highest average contents, 0.650% and 0.641% respectively, while the Quarter of Amborovy has the lowest average concentration at 0.594%.

The particularly high variability observed in Tsararano Quarter (standard deviation of 0.250) contrasts with the overall stability confirmed by the p-value of 0.904.

The protein content shows a homogeneous distribution among the Quarter. The Quarter of Mahavoky has the highest average protein concentration ($2.820 \pm 0.198\%$), while Tsararano has the lowest average value ($2.563 \pm 0.4657\%$). The maximum difference of 0.257% between these two Quarters is not statistically significant, as indicated by the p-value of 0.662.

Milk density shows remarkable uniformity across all Quarter, with values ranging from 1.024 to 1.027 g/cm³. These measurements, all of which comply with pure milk standards, show homogeneity confirmed by the p-value of 0.889, reflecting consistent physical characteristics across the entire study area. The freezing point is an indicator of lipid composition. It varies little between sites. Quarter de Tsararano has the highest freezing point ($-0.449 \pm 0.100^{\circ}C$), while Quarter of Mahavoky has the lowest ($-0.512 \pm 0.028^{\circ}C$). The low variability of the measurements and the p-value of 0.703 indicate a similar lipid profile across all Quarter.

Electrical conductivity which reflects ionic composition and breast health, shows some variation. Quarter of Antanimalandy had the highest average conductivity (5.467 ± 1.383 mS/cm), while Quarter of Ambondrona recorded the lowest average value (5.069 ± 0.441 mS/cm). The particularly high variability observed in Quarter of Tsararano (standard deviation of 1.986) does not affect the overall conclusion of homogeneity, confirmed by the p-value of 0.423.

Parameters	Ambalakida N : 2	Belobaka N : 3	Betsako N : 4	Boanamary N : 58	P value	Conclusion
Milk (L/day)	0,750±0,000 0,750 ; 0,750	1,417±0,629 0,750 ; 2,000	1,188±0,375 0,750 ; 1,500	1,375±0,518 0,500 ; 3,000	0,244	NS
FAT (%)	5,410±0,170 5,290 ; 5,530	6,283±1,975 4,300 ; 8,250	6,283±1,973 4,240 ; 8,950	5,240±1,428 1,550 ; 8,680	0,630	NS
Lactose (%)	4,490±0,000 4,490 ; 4,490	4,493±0,058 4,460 ; 4,560	4,358±0,245 4,010 ; 4,580	4,507±0,185 4,090 ; 5,070	0,736	NS
Ash (%)	0,670±0,000 0,670 ; 0,670	0,677±0,006 0,670 ; 0,680	0,655±0,038 0,600 ; 0,680	0,676±0,026 0,620 ; 0,760	0,758	NS
Protein (%)	2,960±0,000 2,960 ; 2,960	2,957±0,055 2,920 ; 3,020	2,863±0,168 2,630 ; 3,030	2,973±0,130 2,660 ; 3,350	0,651	NS
Others (%)	0,065±0,007 0,060 ; 0,070	0,067±0,021 0,050 ; 0,090	0,065±0,021 0,040 ; 0,090	0,052±0,016 0,010 ; 0,100	0,209	NS
Density (g/cm ³)	1,029±0,000 1,029 ; 1,029	1,028±0,002 1,026 ; 1,030	1,027±0,003 1,025 ; 1,030	1,029±0,002 1,023 ; 1,034	0,321	NS
Freezing point (°C)	-0,531±0,001 -0,532 ; -0,530	-0,537±0,008 -0,546 ; -0,532	-0,524±0,023 -0,549 ; -0,494	-0,532±0,022 -0,606 ; -0,493	0,845	NS
Conductance (mS/cm)	5,005±0,049 4,970 ; 5,040	4,943±0,155 4,770 ; 5,070	5,030±0,158 4,840 ; 5,210	5,071±0,263 4,380 ; 5,910	0,704	NS

N: Number of samples; First line: Mean \pm Standard deviation; Second line: Minimum; Maximum. Identical letters indicate similarity between the observed and/or measured parameters of milk according to municipalities at the 5% threshold; NS: Not Significant.

The analysis of milk production highlights some variability between municipalities, although this is not statistically significant. The Municipality of Belobaka stands out with the highest average production, reaching 1.417 ± 0.629 L, while the Municipality of Ambalakida has the lowest production with only 0.750L. It should be noted that this latter result comes from a sample limited to only two individuals, which may affect the representativeness of this estimate. The maximum difference observed between these two Municipalities is 0.667L. The p-value of 0.244 confirms the absence of a statistically significant difference between the four Municipalities, despite the apparent disparities. The Municipality of Boanamary also has the greatest variability in production, with values ranging from 0.500 to 3.000L, which could reflect a greater diversity of livestock farming systems within this Municipality.

An examination of fat content reveals that the Municipalities of Belobaka and Betsako share the highest average lipid concentration, with 6.283% each. In contrast, the Municipality of Boanamary has the lowest average content at 5.24%. The maximum difference observed between these extremes is 1.04%. The p-value of 0.630 attests to remarkable lipid homogeneity between the Municipalities, suggesting similarities in feeding practices and the genetic potential of the herds. It should be noted that the Municipality of Betsako shows the greatest variation, with values ranging from 4.240% to 8.950%. This could indicate greater heterogeneity in breeding conditions within this Municipality.

Lactose concentration shows exceptional stability across the entire territory. The Municipality of Ambalakida has the highest average content at 4.490%, with remarkable homogeneity between its two samples. The municipality of Betsako has the lowest average concentration at 4.358%. The maximum difference between Municipalities is only 0.132%, which demonstrates remarkable compositional uniformity. The p-value of 0.736 confirms the absence of significant differences. The Municipality of Boanamary stands out with the widest range of

individual values (4.090 to 5.070%), perhaps reflecting greater diversity among the animals sampled.

The mineral composition of milk is perfectly uniform across the Municipalities. The municipalities of Belobaka and Boanamary have the highest average levels at 0.676%, while the municipality of Betsako has the lowest average concentration at 0.655%. The maximum difference between these extremes is only 0.021%, which is negligible from a nutritional point of view. The p-value of 0.758 confirms this remarkable mineral homogeneity. All municipalities also show low intra-municipal variability, suggesting similar mineral supplementation practices across the territory.

Analysis of protein content reveals equally remarkable homogeneity. The municipality of Boanamary has the highest average protein concentration at 2.973%, while the municipality of Betsako has the lowest average content at 2.863%. The maximum difference between these municipalities is only 0.110%. The p-value of 0.651 confirms that there is no statistically significant difference. The Municipality of Boanamary has the widest range of individual values (2.660 to 3.350%), which could be explained by the larger size of its sample. Milk density is stable across the entire territory, with values ranging from 1.027 to 1.029 g/cm³. These measurements, all of which comply with pure milk standards, show homogeneity confirmed by a p-value of 0.321, reflecting uniform physical characteristics. The freezing point is an indicator of fatty acid composition. It shows perfect stability between Municipalities. The Municipality of Betsako has the highest freezing point at -0.524°C, while the Municipality of Belobaka has the lowest value at -0.537°C. The maximum difference between these extremes is only 0.013°C, which is negligible. The p-value of 0.845 confirms this uniformity in the lipid profile. The low variability observed in all Municipalities suggests a similarity in the composition of the diets and genetic characteristics of the herds.

Electrical conductivity which reflects ionic composition and breast health, shows minimal variations between Municipalities. The Municipality of Boanamary has the highest average conductivity at 5.071 mS/cm, while the Municipality of Belobaka has the lowest average value at 4.943 mS/cm. The maximum difference observed is only 0.128 mS/cm. The p-value of 0.704 confirms that there is no significant difference. It is important to note that all recorded values are within acceptable physiological norms, indicating good overall breast health throughout the District.

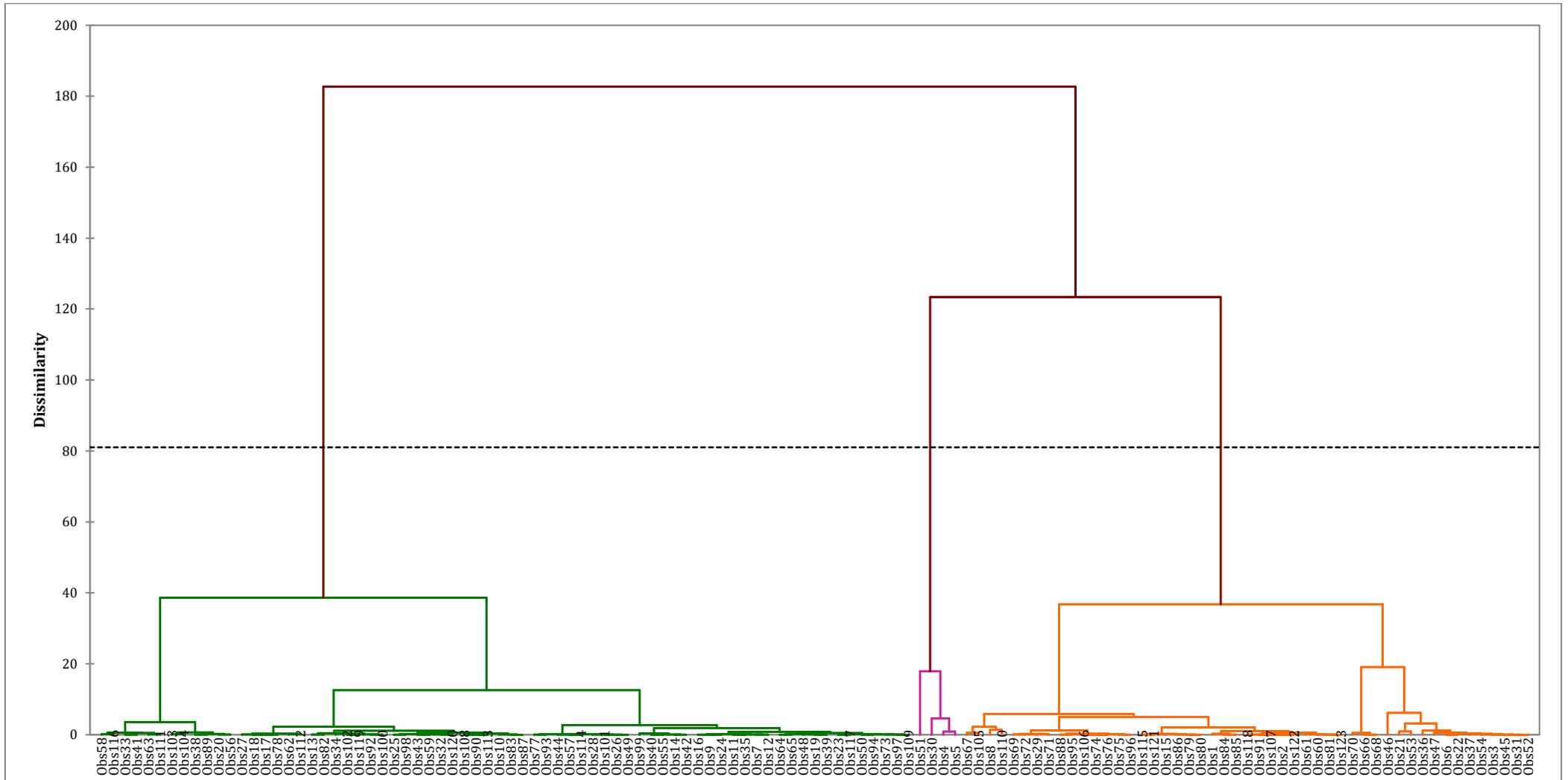


Figure 6. Hierarchical ascending classification of individual cows

The distribution of total variance between inter-class variance (61.50%) and intra-class variance (38.50%) attests to the stability of the established classification. Inter-class variance, which accounts for nearly two-thirds of total variance, indicates a clear differentiation between the identified groups. The ratio of 1.6 between inter- and intra-class variance confirms the statistical relevance of the partitioning, as it explains a significantly larger share of the variability than the internal differences within each class.

Class 1 - “Standard” profile (49 individuals)

This class is characterized by a balanced milk composition, with a moderate fat content (3.999%), high daily milk production (1.536 L/day), and physicochemical parameters in line with physiological standards: freezing point (FP) at -0.492°C and electrical conductivity (COND) at 4.859. This group, which represents the majority of the herd studied, consists of animals with standard zootechnical performance, without any notable characteristics but with presumed good health.

Class 2 - “Atypical” profile (4 individuals)

This minority group has a highly deviant compositional profile, characterized by abnormally low levels of fat (FAT): 1.958%, lactose (LACT): 1.920%, and protein (PRO): 1.268%. The abnormally low density (DEN) (1.012 g/cm³), combined with a high freezing point (FP) (-0.259°C), suggests significant dilution of the milk. The very high electrical conductivity (COND) (9.413) and low milk production (MILK) (0.875 L/day) probably indicate health problems, particularly subclinical mastitis.

Class 3 - “Rich” profile (70 individuals)

This class is characterized by optimal milk composition (MILK), with a high fat content (FAT) (6.238%), higher lactose concentrations (LACT): 4.413% and protein (PRO): 2.900%, and a low freezing point (FP) (-0.527°C) indicating a high concentration of solutes. Despite an average milk yield (MILK) of 1.079 L/day, the exceptional quality of this milk makes it a high value-added product, particularly suited to cheese production.

Geometric analysis of the distances between the barycenter of the classes reveals a spatial structure within the population studied. The moderate distance between classes 1 and 3, measured at 2.310 units, reveals a relationship of relative proximity between these two groups. This configuration suggests that

these profiles share compositional characteristics and participate in a common phenotypic gradient.

Conversely, examination of the distances separating class 2 from the other two groups reveals considerable differences, measured at 5.777 and 6.762 units respectively. The magnitude of these values confirms the aberrant nature of this group within the population structure. The magnitude of these inter-class distances exceeds the variations expected in a homogeneous population.

The overall spatial configuration reveals a distinctive topography. The atypical profile of class 2 appears in a situation of pronounced isolation, forming a distinct and separate cluster. Classes 1 and 3 form a more coherent whole, marked by gradual transitions rather than abrupt breaks. This spatial organization reflects the underlying phenotypic diversity and confirms the structured heterogeneity of the dairy population studied.

3.4. Correlation matrix

The following table illustrates the correlation matrix.

Table IV. Correlation matrix

Variables	RANKL	STAGE	FAT	LACT	CT	PRO	OTHER	FP	COND	MILK	WATER
RANKL	1										
STAGE	0,181	1									
FAT	0,163	0,479	1								
LACT	0,072	0,205	0,421	1							
CT	-0,007	0,277	0,208	0,468	1						
PRO	0,059	0,213	0,384	0,991	0,575	1					
OTHER	0,089	-0,065	0,232	0,316	-0,681	0,190	1				
FP	-0,100	-0,210	-0,511	-0,971	-0,428	-0,954	-0,349	1			
COND	0,028	-0,393	-0,256	-0,416	-0,330	-0,430	-0,005	0,386	1		
MILK	-0,074	-0,520	-0,257	0,213	0,054	0,218	0,061	-0,178	-0,133	1	
WATER	-0,090	-0,283	-0,563	-0,926	-0,532	-0,925	-0,213	0,947	0,459	-0,136	1

LACT :	lactose	PRO :	protein
CT :	mineral salts	WATER :	added water
COND :	electrical conductivity	FP :	freezing point
OTHER :	other elements	RANKL :	lactation rank
		STAGE :	lactation stage

The correlation matrix is a statistical tool used to quantify the strength and direction of the linear relationship between different variables. Correlation coefficients, denoted by ‘r’, range from -1 to +1. A coefficient of +1 indicates a perfect positive correlation, where any increase in one variable is accompanied by a proportional increase in the other

variable. Conversely, a coefficient of -1 indicates a perfect negative correlation, characterised by a perfectly proportional inverse variation between the two variables. A value of zero indicates the complete absence of a linear relationship. In this analysis, only correlations with a degree of statistical significance ($\alpha=0.05$) are considered, which are identified in advance by distinctive formatting.

The correlation observed between lactose (LACT) and protein (PRO) content, with a coefficient of 0.9911, is notable for being almost perfectly linear and positive. This close relationship can be explained by the regulatory function of lactose in the osmotic homeostasis of milk. Any modulation of the lactose concentration induces a compensatory adaptation of the content of other solutes, particularly proteins, in order to preserve the overall osmotic balance. An increase in lactose content is automatically accompanied by a proportional increase in the protein content in unaltered milk.

There are very strong negative correlations between the freezing point (FP) and lactose ($r = -0.9716$) and protein ($r = -0.9547$). These inverse relationships are entirely to be expected, as the freezing point (FP) is a reliable indicator of the overall solute load. A high concentration of osmotically active components, such as lactose (LACT), mineral salts (CT) and protein (PRO), mechanically lowers the freezing point (COND). The strength of these correlations makes them a key marker for certifying the authenticity and absence of dilution in milk.

This logic is reinforced by the very strong negative correlations between the variable added water (WATER) and lactose ($r = -0.9267$) and protein ($r = -0.9253$). The addition of water causes uniform dilution of all milk constituents. The joint and pronounced decrease in lactose (LACT) and protein (PRO) content is the most explicit sign of adulteration by the addition of water. These results also validate the relevance of calculating the WATER variable (added water) based on this principle of dilution.

Among the other associations, there are moderate to strong negative correlations between fat (FAT) and freezing point (FP) ($r = -0.5111$), as well as between fat (FAT) and added water (WATER) ($r = -0.5636$). As a major component, fat (FAT) is effectively diluted when water is added. The lower intensity of these correlations, compared to those involving lactose and protein, can be explained by the less soluble nature of lipids and by their inherently greater behavioral variability. A moderate negative correlation ($r = -$

0.5203) is observed between lactation stage and milk production (MILK).

A moderate positive correlation ($r = 0.4796$) links the stage of lactation to fat content (FAT). This classic evolutionary profile can be explained by a concentration of lipid constituents in a reduced milk volume at the end of lactation. The moderate positive correlation ($r = 0.4593$) between electrical conductivity (COND) and added water (WATER) appears counterintuitive. The addition of pure water, which is weakly conductive, should lower the conductivity of milk. The analysis highlights the general absence of a significant correlation between lactation rank (RANKL) and all other parameters, with the strongest link being only 0.18 with stage.

4. Discussion

4.1. District variation

TMilk production (MILK) recorded in the two Districts, standing at 1,143L for Mahajanga I District and 1,347L for Mahajanga II District, is within the normal range for *Bos indicus* breeds in tropical environments. According to the [FAO. \(2020\)](#), Zebu breeds produce between 1,000 and 3,000 litres per day in traditional farming systems, which corresponds perfectly with our observations. The significant variability observed, with extremes ranging from 0.500 to 3,000 litres, is consistent with the conclusions of [Boudjenah-haroun. \(2019\)](#), who highlights individual productive heterogeneity as an intrinsic characteristic of extensive livestock farming systems.

The fat content (FAT) of 5.031% in Mahajanga I District and 5.354% in Mahajanga II District is fully consistent with the usual values reported in scientific literature. The work of [Boudjenah-Haroun. \(2019\)](#) on local breeds in similar conditions mentions ranges from 4.500% to 6.000%, which encompasses our results. The absence of a statistically significant difference ($p=0.583$) between the two Districts suggests that the lipid metabolism of cows remains stable despite environmental variations, confirming the genetically determined nature of this parameter.

The significant difference observed in lactose concentrations (LACT) between Mahajanga District I (3.989%) and Mahajanga District II (4.497%) deserves special attention. As explained by [Lurquin \(2018\)](#), lactose synthesis (LACT) in the mammary gland is closely dependent on the energy intake of the diet. The superiority recorded in Mahajanga District II could reflect a more energy-balanced diet or more favorable

breeding conditions allowing for better expression of the animals' genetic potential.

The difference in protein concentrations of 2.638% for the Mahajanga I District compared to 2.965% for the Mahajanga II District is explained in the work of [Gaucheron. \(2020\)](#). This author demonstrates that the protein content (PRO) of milk is strongly influenced by the quality of fodder and nitrogen supplementation in the ration. The stability of values in Mahajanga II District (low standard deviation) also suggests greater consistency in feeding practices in this District.

The highly significant difference in milk density (DEN) between the Districts is validated by a p-value of less than 0.0001, with average values of 1.029 ± 0.002 g/cm³ in Mahajanga II compared to 1.025 ± 0.005 g/cm³ in Mahajanga I. This physically validates the qualitative assessment standards established by [Andrianarisoa \(2020\)](#). He notes that milk density is a reliable integrative indicator of the overall quality and compositional authenticity of milk.

The mineral salt (CT) content, which shows a statistically significant difference between the two districts (0.621% versus 0.675%), remains within the usual values reported by [Picque. \(2017\)](#) for cow's milk. The slight superiority observed in the Mahajanga II District could result from more appropriate mineral supplementation or soils richer in mineral elements, resulting in a higher nutritional value of the fodder consumed.

The significant difference in freezing point (FP) between the two districts (-0.472°C versus -0.531°C) reveals distinct fatty acid compositions. As explained by [Michalski. \(2019\)](#), the freezing point (FP) of milk fat (FAT) varies according to the proportion of saturated and unsaturated fatty acids, which is itself influenced by the composition of the diet. This variation could therefore reflect differences in the nature of the fodder and lipid supplements distributed to the animals.

The absence of a significant difference between the electrical conductivities (COND) measured in the two Districts (5.293 mS/cm versus 5.061 mS/cm) indicates a similarity in the ionic composition of the milk. These values, which fall within the normal range established by [Maubois. \(2018\)](#) between 4.000 and 6.000mS/cm, also suggest a satisfactory and comparable udder health status in the two Districts studied (Mahajanga I and Mahajanga II).

4.2. Quarter variation in Mahajanga I

A comparative analysis of milk production (MILK) reveals that the volumes measured in our study range from 1.039 to 1.444 liters depending on the Quarter. These figures are lower than those observed by [Rasolofo et al. \(2020\)](#). The latter report production levels of 1,800 to 2,200 liters for the local *Bos indicus* breed under optimal breeding conditions. This difference could be explained by the extensive breeding conditions prevailing in the Mahajanga I District, characterized by a diet based mainly on natural grazing and limited supplementation. The absence of significant variation between Quarter ($p=0.259$) confirms the work of [Raveloson. \(2019\)](#), which highlights the structural homogeneity of cattle production systems in peri-urban areas of Madagascar.

The fat content (FAT) ranges from 4.485 to 6.485%. The variability is consistent with the data reported by [Rakotoarisoa \(2019\)](#) for zebu milk in tropical areas. The absence of significant differences between Quarter ($p=0.260$) suggests a predominant influence of genetic factors on this parameter, a hypothesis also supported by [Rasolofoniaina. \(2022\)](#) in his in-depth analysis of the determinants of milk lipid composition. This relative compositional stability could be attributed to the genetic homogeneity of the local cattle herd and the similarity of diets based on available forage resources.

The lactate concentrations (LACT) measured in our study (3.841 to 4.300%) appear to be slightly lower than the reference values established by [Andrianaivo. \(2018\)](#) for milk from local Madagascan cows. This discrepancy could be attributable to the stage of lactation of the animals at the time of sampling, a factor identified as decisive by [Ravaomanana. \(2020\)](#). The inter-Quarter stability observed ($p=0.633$) confirms the stability of this biochemical parameter in the face of environmental variations, highlighting its deep metabolic roots.

The measured mineral salt content (CT) (0.594 to 0.650%) falls within the range of values cited by [Rajaonarison. \(2021\)](#) for cattle raised in similar tropical conditions. The variability observed in particular in the Quarter of Tsararano could reflect differences in mineral supplementation practices, a phenomenon already documented by [Raliniaina et al. \(2019\)](#) in their study on the heterogeneity of traditional livestock farming practices. Nevertheless, the overall homogeneity ($p=0.904$) indicates a certain uniformity

in the mineral composition of milk across the entire study area.

The average protein (PRO) content recorded (2.563 to 2.820%) is at the lower end of the usual values for the local breed, as reported by [Rasaminora \(2020\)](#). This observation could be explained by the seasonal context of the study, which was conducted during the dry season. During this period, reduced forage availability negatively affects protein synthesis, as described in detail by [Ranaivoson et al. \(2022\)](#) in their work on the nutritional impact of seasonal forage resources.

The stability of milk density (DEN) ($p=0.889$) between 1.024 and 1.027 g/cm³ confirms the data from [Raherimandimby. \(2021\)](#) that the values reflect the maturity of production practices and the consistency of the overall composition of milk in the region in accordance with quality standards.

The freezing point (FP) values measured (-0.512 to -0.449°C) are fully compliant with the international standards cited by [Razafindrazaka \(2019\)](#). The stability observed between Quarter ($p=0.703$) demonstrates the absence of adulteration by the addition of water (WATER) in all the samples analyzed, thus confirming the perfect integrity and sanitary quality of the milk produced throughout the District. This result attests to the compliance of local farmers with good dairy production practices.

The conductivity values (COND) recorded (5.069 to 5.467 mS/cm) are well below the pathological threshold of 6.5 mS/cm established by [Ralandison \(2021\)](#), indicating good overall udder health in the herd. The variability observed in the Quarter of Tsararano could correspond to subclinical cases of mastitis, a phenomenon frequently described by [RAKOTONDRAVONY A. et al. \(2022\)](#) in extensive farming systems where preventive measures are limited.

4.3. Municipality variation in Mahajanga II

A comparative analysis of our results concerning milk production (MILK), which ranges from 0.750 to 1.417L with no statistical significance ($p=0.244$), reveals remarkable consistency with the work of [Rakotondrao \(2022\)](#). This author reports similar production levels, ranging from 0.800 to 1.500L, for local *Bos indicus* breeds raised in extensive Madagascar farming systems. This convergence of results can be explained by the constraints common to traditional production systems, characterized by a diet based mainly on natural grazing and limited supplementation. The homogeneity observed between

the different Municipalities confirms the conclusions of [Ravaomanalina. \(2021\)](#), who highlights the standardisation of production systems in rural areas of Madagascar, where livestock farming practices and environmental conditions show little significant variation.

The fat content (FAT) varies between 5.240 and 6.283% with no significant difference between Municipalities ($p=0.630$). It shows some nuances compared to data in the scientific literature. Indeed, [Rasolofoniaina. \(2020\)](#) observes slightly lower values, between 5.000 and 5.800%, for zebu milk produced in sub-Saharan Africa. This difference could be explained by differences in the floristic composition of pastures or in feeding practices. The inter-communal homogeneity observed in our study reinforces the hypothesis of a predominant influence of genetic factors and the relative uniformity of forage resources available throughout the study area.

Lactose (LACT) levels range from 4.358 to 4.493%, with no significant variation between Municipalities ($p=0.736$). This exceptional stability is one of the most striking findings of our study. This observation is fully consistent with the work of [Rajaonarison. \(2019\)](#), who established a reference range of 4.300 to 4.500% for milk from local Malagasy cows. The remarkable consistency of this biochemical parameter highlights its resistance to environmental variations and its deep metabolic roots in the genetic characteristics of the *Bos indicus* breed.

The mineral composition (CT) of the milk shows perfect uniformity between the Municipalities, with ash contents varying between 0.655 and 0.677% ($p=0.758$). These values fall perfectly within the range of 0.650 to 0.700% reported by [Raminosoa. \(2021\)](#) for cattle raised in similar extensive conditions. This mineral homogeneity most likely reflects the similarity of soil characteristics throughout the District, as well as the standardisation of mineral supplementation practices, which are generally limited in traditional Malagasy livestock systems.

Protein (PRO) contents range from 2.863 to 2.973% with no significant difference ($p=0.651$). Analysis of these contents places our study in the lower average range of usual values for the local breed, as reported by [Randriambololona \(2020\)](#). This slight inferiority could be explained by the seasonal context of our study, carried out during the dry season, a period during which reduced forage availability and lower nutritional quality negatively affect milk protein synthesis. This phenomenon is well documented in the

scientific literature dealing with the impact of seasonal forage resources on milk composition.

The remarkable stability of milk density (DEN) across the entire study area, objectified by a p-value of 0.321, biologically confirms the physiological data established by [El-Sayed \(2020\)](#). He rightly notes that metrological consistency reflects the overall balance of major solid constituents and objectively demonstrates the maturity and uniformity of milk production practices throughout the District studied.

The measured freezing point (FP) values range from -0.537 to -0.524°C with perfect stability between Municipalities (p=0.845). They demonstrate perfect compliance with the international standards cited by [Razafindrakoto \(2019\)](#). This consistency demonstrates that the milk has not been adulterated by the addition of water and attests to the consistency of the overall fatty acid composition. These results confirm that local farmers are complying with good dairy production practices and that the samples analysed are intact.

The electrical conductivity (COND) values vary between 4.943 and 5.071 mS/cm with no significant difference (p=0.704). They are well below the pathological threshold of 5.5 mS/cm established by [Ralison. \(2021\)](#). This observation indicates excellent overall udder health for the herd throughout the district. The homogeneity of this parameter between municipalities corresponds to similar sanitary conditions and probably uniform animal health management practices throughout the study area.

4.4. Hierarchical ascending classification

The analysis of variance in the hierarchical ascending classification reveals a particularly significant distribution, with 61.50% inter-class variance compared to 38.50% intra-class variance. This distribution attests to a remarkable partition quality, as confirmed by the work of [Saporta \(2011\)](#). He establishes that inter-class variance greater than 60% indicates an underlying structure in the data. The ratio of 1.6 obtained between inter- and intra-class variance exceeds the minimum threshold of 1.5 generally accepted to validate the statistical relevance of a classification. This metrological performance confirms that the partitioning carried out captures real differences between dairy profiles, and not simply random variations.

The identification of the atypical profile (class 2) includes four individuals with highly deviant compositional characteristics. This is relevantly

highlighted in [Rajoelison \(2018\)](#) research on animal health in Madagascan cattle farms. He describes the parameters observed abnormally high electrical conductivity (COND) (9.413), obvious milk dilution (freezing point at -0.259°C) and simultaneous collapse of butterfat (1.958%) and protein (1.268%) levels, correspond to the clinical picture of severe subclinical mastitis. The low milk production (0.875 L/day) recorded in this group confirms the major economic impact of these neglected diseases in traditional farming systems.

Class 3 is characterized by its exceptionally high fat content (6.238%) and protein content (2.900%). It represents an opportunity for the Madagascan dairy industry to add value. These observations confirm the development prospects identified by [Rasamoeli \(2014\)](#). Although this author recognized cheese production as a promising avenue for diversification, he also pointed out the major difficulty of obtaining a reliable supply of high-quality milk. Our identification of a natural group of seventy « cheese-producing » cows thus provides a concrete basis for developing differentiated sectors with higher added value.

The spatial structure revealed by the analysis of distances between barycenter presents a significant configuration. [Lebart et al. \(2006\)](#) assert that this organization is marked by the clear isolation of the atypical class and the relative proximity of the standard and rich classes. It is typical of zootechnical data. The significant distances separating class 2 from classes 1 and 3 (5.777 and 6.762 respectively) exceed the thresholds of practical significance, thus confirming the aberrant nature of this group. The moderate distance measured between classes 1 and 3 (2.310) indicates the existence of a quality gradient rather than a clear separation, which corresponds to the natural phenotypic variability observed in dairy populations.

4.5. Parameters correlation analysis

Correlation matrix analysis is used to decipher the interdependent relationships that govern the various components of milk. This approach is an essential methodological foundation in dairy science. According to [Walstra et al. \(2006\)](#), the composition of milk must be considered as an integrated and finely balanced physicochemical system, where any alteration in a particular component necessarily causes compensatory adjustments among the other constituents. From this perspective, the correlation matrix is a valuable analytical tool for elucidating the complexity of these

interactions. The methodological approach complies with current analytical standards. It allows a reliable distinction to be made between genuine structural relationships and random fluctuations with no biological significance.

The close correlation observed between lactose (LACT) and protein (PRO) content, reflected in a coefficient of 0.9911, can be explained fundamentally by the osmotic regulation mechanisms of milk, in accordance with the principles established by Lucey (2020). Lactose (LACT) appears to be the main regulator of osmotic pressure in milk. Any fluctuation in its concentration leads to proportional adjustments in other solutes, particularly proteins, in order to maintain overall osmotic homeostasis.

The strong negative correlations between the freezing point (FP) and lactose ($r = -0.9716$) and proteins ($r = -0.9547$) confirm the physicochemical principles established by FOX. (2015). The freezing point is defined as an integrative indicator of the total solute load. Taken together, these observations considerably reinforce the value of the freezing point as a fundamental control parameter for detecting any alteration that may affect the compositional integrity of milk.

Correlation analysis reveals moderate associations between fat content and freezing point (FP) ($r = -0.5111$) on the one hand, and with the variable added water (WATER) ($r = -0.5636$) on the other. These relationships can be explained by the distinctive physicochemical characteristics of milk lipids. As demonstrated by Michalski (2016), fat (FAT) exhibits significantly greater behavioural variability than other major milk constituents, such as lactose or proteins. This intrinsic instability, attributable to its emulsified structure and increased sensitivity to individual and nutritional factors, results in less systematic correlations with the overall osmotic parameters of milk. Fat (FAT) exhibits less regular variations than those observed for other milk constituents. Its specific structure, combined with its sensitivity to dietary factors and the animal's own characteristics, makes it a more difficult parameter to anticipate. The analysis reveals a significant negative correlation ($r = -0.5203$) between the stage of lactation and milk production volume, a relationship that fits perfectly within the classic theoretical framework of the lactation curve established by Ragneneau. (2017). This agreement with the expected physiological model confirms the stability of the data collected and validates the fundamental principles of milk production kinetics

during the lactation cycle. The decline in milk production after the peak of lactation results from the normal ageing of mammary tissue and metabolic changes related to gestation.

The observation of a moderately high negative correlation ($r = -0.6815$) between mineral salt content (CT) and the other elements fraction (OTHER) requires a nuanced and contextualized interpretation. This analytical caution is fully justified in light of the work of Gaucheron. (2019), which highlights the complexity of the biological mechanisms governing milk mineral homeostasis. The potentially residual nature of the OTHER variable, often calculated by methodological difference, could indeed generate statistical artefacts that do not necessarily reflect real biological interactions between these compositional parameters.

The moderate positive correlation observed between electrical conductivity (COND) and added water (WATER) finds an explanatory mechanism based on biology in the work of Rajoelison. (2018) devoted to Malagasy farming conditions. In tropical regions, where mastitis without visible symptoms is common, the udder wall becomes more porous, which alters the composition of the milk. This pathology simultaneously leads to an increase in the electrical conductivity (COND) of the milk and an alteration in its composition, which could interfere with the calculation of the WATER variable (added water).

The absence of statistically significant correlations between lactation rank (RANK) and all measured parameters reflects the multifactorial complexity of the determinants of milk production (LAIT). This observation is consistent with the conclusions of Barry (2009), who emphasises that although the theoretical effect of lactation rank on milk yield is well established, its actual expression tends to be attenuated or even masked in real farming conditions by the interaction of other zootechnical, health and environmental factors. This attenuation can be explained by the interaction of several factors: significant physiological variability between individuals, the diversity of management practices employed by farmers and the significant impact of environmental conditions. This dilution of the theoretical effect is particularly marked in extensive farming systems. Data analysis reveals no significant correlation between milk volume and the main compositional parameters, which could be explained by the physiological heterogeneity of the herd studied. As Coulon. (2014) points out, the theoretical dilution effect tends to be neutralized when animals are at

different stages of lactation and in varying physiological states. The diversity of individual profiles characterised by heterogeneous stages of lactation and metabolic conditions contributed to the attenuation of the expression of this expected physiological relationship, thus masking the classic dilution effect normally observable in more homogeneous populations

5. Conclusion

The research undertaken has highlighted significant variations in the production parameters and qualitative characteristics of *Bos indicus* milk depending on geographical location. Comparative analysis reveals higher average milk production in the Mahajanga II District. Physicochemical investigations have demonstrated compositional differences between the two Districts. Examination at the Quarter level has identified particularly marked local specificities, including the exceptional fat content recorded in the Quarter of Mahavoky. This study was conducted in response to a lack of documentation on the production and milk quality parameters of the *Bos indicus* breed in Madagascar.

The detailed characterisation of production and composition profiles according to different geographical scales provides a solid scientific basis for optimising zootechnical practices and strategically guiding efforts to promote local milk production. The implementation of differentiated development strategies according to local conditions, coupled with the strengthening of farmers' technical capacities based on identified potential, would constitute effective levers for sectoral development.

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Conflict of Interest

The authors declare that there are no conflicts of interest, whether financial or personal, that could have influenced the conduct of this study, the analysis of the data, or the interpretation of the results presented.

Ethical Considerations

This research was conducted in accordance with the fundamental ethical principles of scientific research. With regard to the survey phase, particular attention was paid to providing participants with prior information and obtaining their free and informed consent. The confidentiality of the data collected was scrupulously preserved, with no disclosure of personally identifiable information. Finally, the agronomic experiments were carried out in accordance with recognised scientific standards and with respect for the environment.

Author's Contributions

R.H.Z contributed to the study design, data analysis, and manuscript drafting.

A.E, V.H, P.T.M, and K.N.N participated in data analysis and interpretation as well as in the critical revision of the manuscript.

R.B provided scientific supervision and performed the final revision. All authors approved the final version and take responsibility for the content of the manuscript.

ORCID des Auteurs

Rakotonanahary H.Z.: <https://orcid.org/0009-0008-6757-0274>

Andriamahery E.V.H.: <https://orcid.org/0009-0005-9917-6755>

Razafindrajaona J.M.: <https://orcid.org/0009-0006-4316-4007>

Mpiana T.M.: <https://orcid.org/0000-0002-8590-6017>

Ngbolua K.T.N: <https://orcid.org/0000-0002-0066-8153>

R.B: <https://orcid.org/0000-0002-8835-8335>

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