

Multivariate discriminant analysis of African regional dairy production parameters

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Abstract

The importance of regional differentiation in dairy production systems lies in its ability to guide the design of appropriate development policies across Africa. This study aimed to distinguish the dairy production systems in the four major sub regions of the continent: North, West, East and Southern Africa using standardized data from the International Farm Comparison Network (IFCN) Dairy Reports of 2023 and 2024. Fifteen (15) standardized variables related to production inputs, outputs and consumption patterns were assessed using stepwise discriminant analysis. The objective was to identify the parameters most capable of discriminating regional dairy characteristics. Of the 15 dairy production variables examined, only milk consumption per capita was statistically significant (Wilks' Lambda = 0.397; $p < 0.001$) to separate African sub regions. North Africa had highest correct classification success rate (80 %), followed by Southern Africa (60 %), while East Africa (40 %) and West Africa (16.7 %) regions displayed considerable overlap, indicating weak regional distinctiveness in their dairy systems. The findings reveal that production-driven variables such as milk yield and herd size are insufficient to clearly differentiate African regions. Instead, consumption-driven factors shaped by cultural values, purchasing power, and policy frameworks provided clearer distinctions. These results suggest that demand-side processes, particularly market access and dietary references, serve as stronger indicators of structural differences in African dairy systems than production-level metrics. Understanding these consumption-oriented dynamics is therefore essential for formulating targeted and effective dairy development strategies across the continent.

Keywords: dairy production systems; livestock policy; milk consumption; regional classification; stepwise discriminant analysis

Introduction

Global dairy sector is an important integral of agriculture contributing significantly to sustainable agriculture and serves as a principal source of employment, industrialization and provision of protein-rich diet to food menus. The output from this sector has continued to rise steadily, surpassing 950 million tonnes in 2022 (FAO, 2023). Much of this growth is driven by industrial-scale dairy production in Asia, Europe and North America, alongside expanding international dairy trade, which now exceeds 90 million tonnes of milk equivalents (OECD–FAO, 2023). These trends reflect ongoing structural transformations in global food systems, influenced by rising incomes and shifts in dietary consumption patterns.

Despite having a large proportion of the world's ruminant livestock, particularly cattle, Africa contributes far less to global milk output than expected; the continent produces only about 5 % of the world's milk despite holding roughly 20 % of the global cattle population (Dairy Business Middle East and Africa, 2020). This discrepancy reflects persistent productivity constraints across African dairy systems such as low per-animal yields, limited access to quality feed, poor genetic resources, and weak veterinary services which impede greater production and competitiveness. Addressing these barriers through targeted interventions is essential to enhance efficiency, reduce dairy imports, and support long-term sustainability of the continent's dairy sector (Ecofin Agency, 2025b).

Dairy production in Africa relies predominantly on smallholders operating within low-input, low-output systems. Strong regional variation is evident, shaped by agro-ecological conditions, market integration, institutional support and livestock management norms (FAO, 2021). This heterogeneity carries significant implications for both policy and practice. Key production parameters such as breed types, feeding strategies, labour availability, and overall management vary widely across regions and these differences hinder the use of multilateral approaches to dairy development. Therefore, understanding the structural dynamics of African dairy systems is increasingly important as the continent confronts dual challenges of food insecurity and inadequate nutritional supply, both of which are intensified by climate change, rapid population growth, and evolving production pressures.

Existing literature on dairy production in Africa has been valuable in describing value chains, identifying systemic bottlenecks and proposing policy interventions (Ayele et al., 2012; Vall et al., 2021; Malenje et al., 2022; Morrison et al., 2023). However, a significant gap remains in the limited attention given to regional differences in milk production attributes, particularly empirical studies employing multivariate statistical techniques. Most comparative analyses rely on descriptive statistics that fail to capture region and or country-specific applications of production characteristics. Consequently, findings often depend on isolated case studies involving national or subnational comparisons, making broader generalisation difficult and analytically weak.

The usefulness of multivariate statistical tools such as categorical principal component analysis (CATPCA),

cluster analysis and discriminant analysis has been well demonstrated in analysing the complexities of African dairy production systems. Tessema et al. (2022) employed CATPCA and two-step cluster analysis to define typologies of smallholder dairy production across four systems in Southern Ethiopia using, 35 management, environmental and genetic variables. Their findings showed that multifactorial classification techniques provide deeper and more reliable insights into system heterogeneity than traditional univariate approaches, highlighting the value of advanced statistical methods for capturing the structural diversity of dairy systems in Africa. Wairimu (2023) analyzed technical and institutional dairy practices in Kenya using CATPCA and identified four key factors: housing systems, adoption of artificial insemination, hygiene levels, and participation in cooperatives as the main factors contributing to household dairy performance.

Furthermore, Azeze et al. (2024) applied k-means clustering combined with discriminant analysis to characterize dairy production systems among smallholder crop-livestock farmers in the southern Ethiopian highlands, highlighting system heterogeneity. More recently, in Cyprus, Tarapoulouzi and Papademas (2024) employed discriminant analysis alongside Fourier Transform Infrared (FTIR) spectroscopy and chemometric modeling to classify milk samples from goats subjected to different feeding regimes (free-range versus intensive indoor), achieving a high classification accuracy of 95.4 % and demonstrating the power of advanced statistical techniques in dairy research.

The limitations of descriptive and other non-probabilistic statistics underscore the need for the application of multivariate procedure; namely, discriminant analysis to differentiate pre-specified regional groups. This statistical method will empirically identify the production parameters that best discriminate among Africa's regional dairy systems. This multifactorial discriminant analysis will not only improve understanding of regional disparities, but also supports the creation of a typology of dairy production systems grounded in empirical evidence rather than anecdote or institutional labels (Azeze et al., 2024; Moawed et al., 2024; Tadele et al., 2025). In view of the foregoing, the present study was undertaken to discriminate Africa's sub regions based on dairy production parameters using a stepwise discriminant analysis.

Materials and methods

Study area

This study covers all African sub-regions: North, West, East, Central and Southern Africa as defined by the African Union's geo-political groupings. Each region exhibits unique agro-ecological, cultural and economic conditions that influence livestock and dairy production systems.

Data collection

This study utilized secondary data obtained from the 2023 and 2024 International Farm Comparison Network (IFCN) Dairy Reports. The IFCN database is globally recognized, standardized and provides detailed farm and country-specific information on the dairy sector in over 100 countries. It is particularly valuable for assessing global dairy production records because it offers harmonized data on production systems, input-output relationships, cost structures and technology adoption across the dairy industry, enabling robust cross-country and regional comparisons.

Data were collected from four African regions: North, West, East and Southern Africa (Table 1). Central Africa was excluded because Cameroon was the only country with documented dairy production parameters in the 2023 and 2024 IFCN reports. The dairy parameters derived from the 2023 and 2024 IFCN reports represent typical farms in each country. These farms were selected and validated by local experts to accurately reflect the predominant dairy production systems in their respective countries.

The standardization and validation of data procedures employed by IFCN enhance the robustness of cross-regional comparisons, thereby supporting the discrimination of African sub-regions. However, since the 2024 records lacked information on the number of dairy farms and average farm size, these variables were sourced from the 2023 IFCN data to maintain completeness.

The fifteen (15) variables derived from the IFCN dataset include milk yield (tonnes (t) Solid Corrected Milk (SCM)/cow), total production (million t SCM), herd size (thousands of cows), country consumption (million t Milk Equivalent (ME)), population (million people), per capita consumption (kg ME), milk delivered per cow, exports, imports, self-sufficiency, production ranking, average farm size, milk price, farm number growth, and total number of dairy farms.

Table 1. African countries featured in the 2023 and 2024 IFCN Reports

West Africa	East Africa	North Africa	Southern Africa
Nigeria	Kenya	Algeria	Zambia
Ghana	Ethiopia	Tunisia	Zimbabwe
Niger	Uganda	Egypt	Namibia
Gambia	Tanzania	Sudan	South Africa
Senegal	Rwanda	Morocco	Mozambique
Mali	Madagascar	-	Malawi

Statistical analyses

One-way analysis of variance (ANOVA) was used to compare the production variables across the regions. The statistical model used was of the form:

$$Y_{ij} = \mu + G_i + e_{ij} \tag{Eq. 1}$$

Where:

Y_{ij} = Individual observation;
 μ = Fixed overall mean

G_i = Effect of region (i = West Africa, North Africa, East Africa, Southern Africa)

e_{ij} = Experimental error, assumed to be independently, identically and normally distributed with zero mean and constant variance.

Differences between regional means were accessed using Duncan’s Multiple Range Test (DMRT) at 5 % level of probability.

Discriminant analysis

Discriminant parameters with highest discriminatory power among the dairy production parameters in African sub-regions were identified through stepwise discriminant procedure while the regions served as the separating factor. The level of significance ($P > F$), Wilks’ Lambda and F-statistics were used in determining the relative discriminating abilities of the production parameters. The percentage of accurate determination of the region into distinct archetype was mentioned as the efficiency of unstandardized canonical discriminant function in categorizing region. Since the rates of correct classification are likely to be overstated when discriminant analysis is tested on the same sample on which classification rates were derived (Tabachnick and Fidell, 2007), there is the need to use cross validation table. The success rate of classification was thus measured in terms of number of individual regions correctly classified to the various archetypes by using cross-validation test in terms of percentages. The Statistical Package for Social Science (SPSS) (2020) version 20 software was used to carry out all the statistical tests.

Results and discussion

The univariate analysis of production parameters (Table 2) revealed significant ($p < 0.05$) differences in 9 of the 15 variables examined, while population, exports, average farm size, self-sufficiency, farm number growth, and milk delivered were not statistically significant ($p > 0.05$). To the best of the knowledge of the authors, the result herein reported is the first cohort study on application of multivariate discriminant analysis to dairy production systems in Africa’s sub-regions. Hence, paucity of related literature for critical comparisons.

North Africa recorded highest average milk production (4.46 ± 4.16 L) and was significantly ($p < 0.05$) higher than the values recorded for the West and Southern Africa while East Africa was intermediate (3.13 ± 1.73 L). These differences are largely attributed to structural and technological factors. North African countries, particularly Egypt and Algeria, have historically adopted semi-intensive dairy systems, where access to improved breeds and quality feed results in higher milk yields per cow (Elshibly and Elgazzar, 2012; OECD and FAO, 2022) which significantly contributed in the milk production and yield per cow in the region.

The higher milk production in East Africa relative to West and Southern Africa reflects the greater integration of semi-

intensive systems into pastoral systems in countries such as Kenya and Ethiopia. These hybrid pastoral-semi-commercial systems enhance productivity, resulting in comparatively higher milk yields at the regional level (Njarui et al., 2020; Ingutia and Sumelius, 2024). Moreover, recent evidence shows that the emergence of smallholder dairy cooperatives and local milk-processing enterprises has significantly boosted productivity in the region (Mumba et al., 2023; Onyango et al., 2023; Solidaridad Network, 2024).

East Africa recorded significantly ($p < 0.05$) highest mean dairy cow population ($5,485.20 \pm 5,046.95$) compared to other regions. This reflects the central role of livestock in the livelihoods of pastoral and agro-pastoral communities, where large herds hold both economic and cultural significance (Njarui et al., 2020; Mumba et al., 2023; Tadesse et al., 2024). By contrast, Southern Africa records the lowest mean herd size (368.51 ± 368.22), reflecting a commercialized, intensive dairy industry dominated by high-producing cows under strict management (Milksa, 2024a; Gresse, 2024). East Africa, in turn, shows a much larger prevalence of dairy farms ($1,355.44 \pm 1,291.57$), consistent with a more decentralized and inclusive value-chain architecture that favors smallholders (ILRI, 2024; Dairy Business Middle East and Africa, 2025). Nevertheless, East Africa, despite having the largest dairy herds, records lower milk yield per cow and overall production compared to North and Southern Africa regions, indicating a system that remains under-intensified. This highlights the limitations of relying solely on herd expansion without adequate investment in inputs, management, and technology.

It is noteworthy that North Africa ranks first in milk yield per cow and total milk production in the continent but ranked third in the number of dairy farms. This demonstrates how relatively smaller herds producers can achieve a higher productivity and record higher milk yield per animal through superior genetics, structured feeding programmes and solid health infrastructure rather than expanding herd numbers. For instance, Algeria imported high-yield dairy breeds and adopted subsidized crossbreeding and artificial insemination programmes to improve productivity (Benyoucef and Abdelmoutaleb, 2010; Sraïri et al., 2013). Recent trade agreements with the U.S. to import American dairy breeds also reinforce this strategy, enhancing yields per cow without increasing herd size in Algeria (USDA, 2024). These underscore the potential of intensification policies in African dairy systems as a pathway to enhanced output, sustainability, and economic gains.

Among the African sub regions, East Africa recorded highest dairy self-sufficiency (94.40 ± 12.24), reflecting a strong alignment between local milk production and domestic demand. This is largely due to the multiple farms and adoption of small-holder semi-commercial systems in Kenya, Uganda and Ethiopia. Although the yields per cow are modest, the dense concentration of dairy farms and fragmented supply chains enable output to meet local needs (Tessema et al., 2024; MDPI Agriculture, 2024). Besides, limited processing capacity and high informal market participation reinforce reliance on locally produced milk (Kenya Dairy Board, 2024; ILRI, 2025).

In Southern Africa, the dairy self-sufficiency rate is also high (88.60%), driven by industrial-scale farms with relatively

small herds and high productivity through formalized supply chains. This performance reflects substantial technological investment, optimized feeding strategies and well-developed processing infrastructure (IFCN Report, 2024; Dairy Reporter, 2025). Meanwhile, North Africa achieves a self-sufficiency of 83.20% underpinned by strong policy support. Countries like Egypt and Algeria use subsidies and strategic imports to stabilize prices and buffer against shortages (Elshibly and Elgazzar, 2012; IDF, 2023; Dairy Global, 2024; Dairy Business MEA, 2025). Self-sufficiency is lowest in West Africa (67.83 ± 30.84), signifying chronic production shortfalls. The local dairy production is plagued with myriads of structural challenges such as fragmented value chains, reliance on unimproved breeds and inadequate processing infrastructure; thus, making the region to depend heavily on foreign dairy products (Oxfam, 2024; Ecofin Agency, 2024). For instance, Nigeria and Ghana, despite large cattle populations, domestic milk supply fails to meet rapidly growing urban demand, driving imports of powdered milk, especially fat-filled milk powder (Vanguard News, 2024; Oxfam, 2024). This trend underscores structural inefficiencies in West Africa: the region depends heavily on imports to satisfy urban demand while lacking intensity in its milk production systems (Ecofin Agency, 2025a).

There were significant ($p < 0.05$) differences in the volumes of imported and exported dairy products among the African subregions. West Africa consistently recorded the highest levels of both imports and exports, followed by Southern and North Africa at intermediate levels, while East Africa had the lowest. Notably, despite having the highest imports, West Africa recorded the lowest exports. This observation might be attributed to the poor processing facilities, infrastructure such as poor electricity supply and poor distribution chain, which mostly force dairy farmers to dispose milk before spoilage and then rely on importation to meet local demand; hence, making West Africa the highest importer of dairy products in the continent. This dairy import dependence is also largely influenced by growing urbanization in West Africa (Trade Insights, 2024; Dairy Business Middle East and Africa, 2025). On the other hand, Southern Africa (19.46) and East Africa (6.16) had comparatively lower dairy product importation, reflecting relatively more self-sustaining dairy sectors. It is worthy of note that the continent's generally low export performance emphasizes limited competitiveness in the global dairy market, driven by cost-intensive production and structural inefficiencies (Ecofin Agency, 2025c; IndexBox, 2024). In West Africa, the pattern of low self-sufficiency, high milk imports, and substantial re-exports is largely driven by transshipment and middle-man activities: imported milk powders are repackaged and re-exported to neighboring countries, notably in Ghana and Nigeria (Gunarathne and Boimah, 2022; Ecobank Research, 2023). This trend reflects a dual reliance: West African economies depend heavily on imports to satisfy domestic demand while simultaneously functioning as regional hubs for re-exports. It illustrates complex inter-system trade relations, where the dairy industry serves as both receiver and distributor, complicating simplistic assessments of export competitiveness (Gunarathne and Boimah, 2022; Ecobank Research, 2023; IndexBox, 2024).

Surprisingly, changes in dairy-farm numbers were not statistically significant ($p>0.05$) among the regions, yet the mean trends diverged. East Africa had the highest increase (2.30 ± 0.69), confirming its structural growth in the dairy sector (OECD-FAO, 2025). In contrast, North (-1.97) and Southern Africa (-0.64) experienced a decline possibly due to urbanization, consolidation of small farms into larger ones and shifting land-use policies (Dairy Business MEA, 2025). The evidence suggests that dairy growth in Africa is highly context-dependent, and any expansion strategies should consider regional land tenure systems, youth participation, and access to credit (USDA Foreign Agricultural Service, 2025).

The price of unprocessed milk was highest in East Africa, reflecting strong urban demand, informal markets and limited supply chain efficiencies. For instance, in Kenya, the farm-gate price averaged EUR 3.09 per litre (KES 50 \approx US\$0.37) with processors paying KES 5,083 per 100 litres (Dairy Business MEA, 2024). In contrast, milk prices in Southern and Northern Africa are much lower (MilkSA, 2025). While high prices in East Africa may benefit producers, they also highlight inefficiencies that restrict consumer access. Moderate prices in West Africa point to import dependence and fragmented value chains (IndexBox, 2024; Ecofin Agency, 2025c).

Even though the formal share of milk delivered to processors was not significantly different ($p>0.05$) across regions, there are considerable meaningful variations. Southern Africa had the highest formal delivery rate (57.75 ± 37.08), reflecting a well-organized, industrial-scale supply chain with coordinated logistics and processing (Dairy Business MEA, 2025). In contrast, the North and East Africa's moderate formal delivery rates (37.79 ± 29.99) and (33.40 ± 41.53) respectively, reflects a mix of formal and informal marketing systems, with substantial volumes sold directly to consumers (Blackmore et al., 2022; Business Daily, 2024). West Africa plagued with poor farm patterns and weak cold-chain networks limit the volume of milk delivered efficiently. This trend highlights the

urgent need for investment in milk-collection infrastructure, cold storage, and quality-control systems to better integrate producers and processors into more value-added dairy chains (ECOWAS, 2020; Friesland Campina and WAMCO, 2023; Nigerian Cold-Chain Assessment, 2023).

The results of the stepwise discriminant analysis (Table 3) indicated that only country consumption was identified as the principal discriminating variables with a Wilks' Lambda of 0.397, F-value of 8.593 and a p-value of 0.001; thus, indicating that it is not only the separating variable but it is a statistically significant discriminator among dairy-production parameters across African sub-regions.

The low Wilks' Lambda value (close to 0) indicates that country consumption has strong discriminatory power for classifying African dairy-production parameters into distinct clusters. Wilks' Lambda is a widely used multivariate goodness-of-fit index that assesses the ability of a variable to classify subjects to distinct groups; the lower the value, the greater its discriminating capacity (Hair et al., 2010; Tessema et al., 2022; Wairimu, 2023).

Accordingly, the finding that country-level dairy consumption significantly contributes to group separation suggests that regional differences in dairy demand and consumption patterns are the most salient distinguishing features among the East, West, North, and Southern African sub-regions' dairy industries. The high discriminatory power of consumption as a discriminating variable aligns with previous studies on regional livestock and dairy systems. In North Africa, relatively high consumption reflects long-standing cultural acceptance of dairy products, further reinforced by supportive government policies and subsidies that promote dairy intake (IDF, 2023; FAO, 2024; Ingutia and Sumelius, 2024). Furthermore, North Africa benefits from relatively favorable macroeconomic conditions, with high per capita incomes in countries such as Algeria, Egypt, and Morocco. Increased purchasing power drives higher demand for dairy products, enabling consumers to purchase them

Table 2. Descriptive statistics (mean \pm SD) of dairy parameters across African regions

Parameter	East Africa	North Africa	West Africa	Southern Africa
Production (mill t SCM)	3.13 \pm 1.73 ^{ab}	4.46 \pm 4.16 ^b	0.32 \pm 0.24 ^a	0.88 \pm 1.64 ^a
Milk yield (t SCM/cow)	0.75 \pm 0.69 ^{ab}	2.77 \pm 2.69 ^b	0.19 \pm 0.11 ^a	2.17 \pm 2.50 ^{ab}
Milk production ranking	55.20 \pm 42.94 ^a	46.00 \pm 23.42 ^a	118.67 \pm 24.65 ^b	110.60 \pm 41.19 ^b
Cows (in 1000's)	5,485.20 \pm 5,046.95 ^b	3,038.40 \pm 3,314.61 ^{ab}	2,501.50 \pm 2,694.43 ^{ab}	368.51 \pm 368.22 ^a
Number of dairy farms	1355.44 \pm 1291.57 ^b	242.03 \pm 274.82 ^a	347.80 \pm 426.52 ^a	46.13 \pm 58.83 ^a
Self sufficiency	94.40 \pm 12.24 ^a	83.20 \pm 18.19 ^a	67.83 \pm 30.84 ^a	88.60 \pm 18.12 ^a
Country consumption (mill t ME)	3.53 \pm 2.09 ^{ab}	6.02 \pm 4.21 ^b	0.78 \pm 0.65 ^a	0.89 \pm 1.52 ^a
Population (mill people)	56.37 \pm 27.89 ^a	48.11 \pm 33.09 ^a	51.65 \pm 78.94 ^a	23.82 \pm 21.55 ^a
Consumption (kg ME/capita)	61.78 \pm 41.70 ^a	122.05 \pm 36.75 ^b	35.09 \pm 19.23 ^a	32.93 \pm 28.86 ^a
Export	0.98 \pm 1.89 ^a	2.44 \pm 2.68 ^a	17.05 \pm 38.15 ^a	4.34 \pm 5.15 ^a
Import	6.16 \pm 11.16 ^a	18.54 \pm 17.03 ^{ab}	47.53 \pm 40.09 ^b	19.46 \pm 16.28 ^{ab}
Average farm size	3.76 \pm 1.14 ^a	46.68 \pm 85.52 ^a	21.58 \pm 26.88 ^a	130.84 \pm 218.15 ^a
Milk price (100 kg SCM)	6.54 \pm 2.67 ^b	0.68 \pm 5.55 ^a	1.08 \pm 2.51 ^a	0.02 \pm 4.27 ^a
Farm number increase	2.30 \pm 0.69 ^a	-1.97 \pm 6.25 ^a	0.58 \pm 1.45 ^a	-0.54 \pm 3.83 ^a
Milk delivered (cow's)	33.40 \pm 41.53 ^a	37.79 \pm 29.99 ^a	17.09 \pm 21.69 ^a	57.75 \pm 37.08 ^a

^{abc} means with different superscripts are statistically different at $p<0.05$

regularly. Additionally, a well-established policy framework (price controls, subsidies, and strategic imports) helps maintain stable and affordable market supply (FAO, 2020; IDF, 2023; Ingutia and Sumelius, 2024). These factors collectively enhance the consumption and accessibility of dairy across the region. Besides, economic stability in North Africa provides a favorable environment for sustained dairy consumption and investment, creating a consumer-friendly environment for production.

Moreover, consumption as a demand-side parameter is less sensitive to environmental fluctuations than production measures; thereby making it a robust indicator of systemic development shaped by culture, affordability and availability (Grace et al., 2018; FAO, 2023; Umar et al., 2024). Consumer preferences in dairy markets are largely driven by health attributes and flavor even though these perceptions do not always result in habitual purchasing behavior (Paskaš et al., 2025). Additionally, consumption patterns in Africa are increasingly influenced by urbanization and dietary transitions which often take precedence over local production capacity. Rapid urban growth, rising incomes, and shifting preferences toward animal-source foods are driving higher dairy demand across the continent, highlighting the importance of demand-focused strategies alongside production interventions (ECDPM, 2019; Ingutia and Sumelius, 2024). In view of the foregoing, country-scale consumption is a consistent representative of both the regional systems of dairy production and their forms of development.

It is worth emphasizing that the divergence between the discriminating variable identified in this study and those in other livestock studies across different agro-ecological contexts may arise from differences in data coverage, representation and regional socio-economic dynamics. While most previous discriminant analyses have emphasized production indices or yield-related indicators (Kristjanson et al., 2014; Njarui et al., 2020; Tessema et al., 2022), the finding that consumption is the only significant variable emphasizes the central role of market demand and cultural consumption patterns as key determinants of dairy livelihoods in Africa. This highlights the importance of demand-driven approaches in shaping dairy systems and regional development strategies (FAO, 2023; Ingutia and Sumelius, 2024).

The result of the sub-region classification using cross-validation analysis (Table 4), indicated that 40.00, 80.00, 16.70 and 60.00 % of East African, North African, West African and Southern African respective observation were correctly classified into regional dairy systems, and the overall classification success rate was 49.18 %. This moderate classification success is largely contributed by the overlapping features between regional dairy systems most especially between East and West Africa and between East and Southern African.

The low classification accuracy for West Africa (16.7 %) aligns with literature highlighting the region's highly heterogeneous and informal dairy systems, fragmented production structures, and weak infrastructure (Bonfoh et al., 2007; Traoré et al., 2021; FAO, 2023). Similarities in production factors such as low output, small herd sizes, and dependence on imports limit the model's effectiveness in

distinguishing West Africa from other regions most especially, East Africa. In contrast, East and Southern Africa, while experiencing some comparable constraints, they also share some common attributes such as stronger institutional support, cooperative development and better-organized value chains which enhance regional differentiation and contribute to more effective classification in discriminant analyses (Yassegoungbe et al., 2022; Ingutia and Sumelius, 2024).

It is noteworthy that the observed classification patterns across regions in Table 4 are largely driven by similarities in production characteristics and shared systemic constraints. For instance, indicators such as low productivity, small herd sizes and reliance on unimproved indigenous breeds are common in both West and East Africa, reflecting limited regional differentiation. Additionally, Southern and East Africa may overlap in certain cases, as some commercial or peri-urban farms in East Africa, particularly in Kenya resemble the more established systems of Southern Africa (Mutavi and Amwata, 2018). These overlaps reflect adaptive responses to comparable economic and ecological pressures, highlighting the broader tendency for adaptive plasticity in African livestock systems (Auma and Radeny, 2022).

In contrast, North Africa exhibits higher classification success, reflecting the uniqueness of its semi-intensive to intensive dairy systems, relatively high milk yields, and superior infrastructure, which are further reinforced by demand-side incentives (Hemme and Otte, 2010; Elshibly and Elgazzar, 2012; IDF, 2023; FAO, 2023). Cross-validation also confirms that Southern Africa's more commercialized and consolidated dairy industry can be statistically distinguished from the largely informal systems in other African regions, achieving a classification accuracy of 60.0 % (MilkSA, 2024b; Ingutia and Sumelius, 2024). These findings highlight the role of structural organization, technological adoption, and market integration in differentiating regional dairy systems across the continent.

The canonical representation of the clusters derived from African dairy production systems is shown in Figure 1. Reflecting the low regional differentiation reported in Table 4, the canonical plot reveals a high degree of intermixing among regional production clusters, particularly between West and East Africa, with no clearly defined boundaries. This pattern suggests substantial overlap in dairy production variables such as yield measures, herd composition, and productivity indicators thereby weakening the distinctness of regional production typologies.

The overlapping nature of dairy production characteristics across African sub-regions is unsurprising, as agricultural systems in sub-Saharan Africa often exhibit greater intra-regional than inter-regional differentiation (FAO, 2020; Ingutia and Sumelius, 2024). Similar patterns have been observed in

Table 3. Summary of the step-wise discriminant analysis of the African dairy production parameters

Step	Variable entered	Wilk's lambda	F-value	P>F
1	CONS	0.397	8.593	0.001

Table 4. Classification results of the discriminant analysis of dairy production parameters of African Sub-region

	East Africa N = 6	North Africa N = 5	West Africa N = 6	South Africa N = 6	Total
Original	Count				
1	3	1	1	0	5
2	0	5	0	0	5
3	0	0	6	0	6
4	0	0	1	4	5
%					
1	60.0	20.0	20.0	0.0	100.0
2	0.0	100.0	0.0	0.0	100.0
3	0.0	0.0	100.0	0.0	100.0
4	0.0	0.0	20.0	80.0	100.0
Cross-validated	Count				
1	2	1	1	1	5
2	1	4	0	0	5
3	2	0	1	3	6
4	2	0	0	3	5
%					
1	40.0	20.0	20.0	20.0	100
2	20.0	80.0	0.0	0	100
3	33.3	0.0	16.7	50.0	100
4	40.0	0.0	0.0	60.0	100

47.18 % of cross-validated grouped cases correctly classified

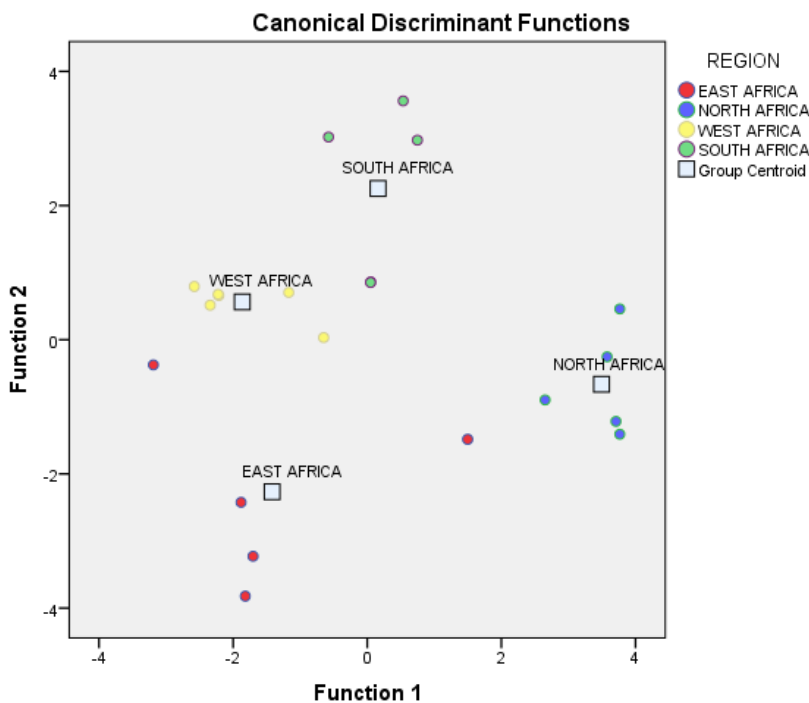


Figure 1. Canonical discriminant function representation of African dairy production systems

canonical analyses of livestock populations in the continent. For instance, studies on DA of West African Dwarf goat breeds reported limited morphometric or genetic differentiation across ecotypes (Awobajo et al., 2016; Mustefa et al., 2024), while examinations of indigenous poultry in Nigeria revealed absence of segregation based on phenotypic or genetic traits

(Oguntunji and Ayorinde, 2014; Adeola et al., 2022). These findings underscore the plasticity and adaptive convergence of livestock, reflecting the ability of animal populations to adjust to comparable ecological, cultural, and management pressures across diverse agro-ecological landscapes.

Conclusion

This study highlights the heterogeneity of African dairy systems, identifying country-level dairy consumption as the primary factor differentiating regional dairy production systems. North Africa's high-yield, efficient, and consumption-oriented model contrasts sharply with the fragmented, lower-productivity systems in East and West Africa. These findings highlight the need for policy frameworks that are not only data-driven but also context-specific and regionally responsive. Given the centrality of food security and nutrition in Africa, the study recommends a shift from production-led paradigms toward demand-driven, consumer-focused

approaches in dairy development. Future research and policy planning should acknowledge regional complexities as both challenges and opportunities, promoting equitable, profitable and transformative investments in the continent's dairy sector.

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Multivarijatna diskriminantna analiza parametara regionalne proizvodnje mlijeka u Africi

Sažetak

Važnost regionalne diferencijacije u sustavima proizvodnje mlijeka ogleda se u njezinoj ulozi u usmjeravanju oblikovanja odgovarajućih razvojnih politika diljem Afrike. Cilj ovoga istraživanja bio je razlikovati sustave proizvodnje mlijeka u četiri glavne afričke podregije: Sjevernoj, Zapadnoj, Istočnoj i Južnoj Africi, koristeći standardizirane podatke iz IFCN (International Farm Comparison Network) Dairy Reports za 2023. i 2024. godinu. Petnaest (15) standardiziranih varijabli povezanih s proizvodnim inputima, outputima i obrascima potrošnje analizirano je primjenom stupnjevite diskriminantne analize. Cilj je bio identificirati parametre s najvećom sposobnošću razlikovanja regionalnih obilježja proizvodnje mlijeka. Od 15 analiziranih varijabli proizvodnje mlijeka, samo je potrošnja mlijeka po stanovniku bila statistički značajna (Wilksova $\lambda = 0,397$; $p < 0,001$) u razdvajanju afričkih podregija. Sjeverna Afrika ostvarila je najvišu stopu uspješne ispravne klasifikacije (80 %), slijedi Južna Afrika (60 %), dok su Istočna Afrika (40 %) i Zapadna Afrika (16,7 %) pokazale znatno preklapanje, što upućuje na slabu regionalnu diferenciranost njihovih mliječnih sustava. Rezultati pokazuju da varijable vođene proizvodnjom, poput mliječnosti i veličine stada, nisu dovoljne za jasno razlikovanje afričkih regija. Nasuprot tome, čimbenici vođeni potrošnjom, oblikovani kulturnim vrijednostima, kupovnom moći i institucionalno-političkim okvirom, omogućuju jasnije razgraničenje. Ovi rezultati upućuju na to da su procesi na strani potražnje, osobito pristup tržištu i prehrambene navike, snažniji pokazatelji strukturnih razlika u afričkim sustavima proizvodnje mlijeka od proizvodnih pokazatelja. Razumijevanje tih potrošački usmjerenih dinamika ključno je za oblikovanje ciljanih i učinkovitih strategija razvoja mljekarstva na razini kontinenta.

Ključne riječi: sustavi proizvodnje mlijeka; stočarska politika; potrošnja mlijeka; regionalna klasifikacija; stupnjevita diskriminantna analiza

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