

RESEARCH ARTICLE

Typology assessment of dairy cattle production in the major productive region of Tunisia

Sarra Hamzaoui¹, Khaoula Attia¹, Aymen Ferij² and Nizar Moujahed¹

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Abstract: The study aimed to identify dairy systems related to purebred cattle in Tunisia and their effects on milk production and quality. A survey of 102 breeders across 17 governorates focused on feeding practices and milk parameters. Principal Component Analysis (PCA) revealed three farm groups: Group I (51% of farms) relies on rainfed systems with limited forage; Group II (26%) employs mixed irrigation with moderate forage; and Group III (23%) uses irrigation, featuring larger farms and diverse diets. Significant differences were observed among groups in terms of farm size, cow numbers, and diet composition ($P < 0.0001$). Results showed that Group III produced the highest daily milk yield (21.59 kg), while Group I had the lowest (16.45 kg). Fat content exceeded the national average in all groups, with Group III showing the highest at 38.2 g/L. Protein levels also surpassed average values, particularly in Group III (30 g/L). Group II had the highest urea content (44.81 mg/dL), indicating dietary imbalances. Overall, the analysis distinguished dairy farms by agricultural systems, with irrigated farms demonstrating superior milk production and quality for purebred cattle.

Keywords: Cropping system, Dairy cattle farms, Performances, Tunisia, Typology

Introduction

Dairy cattle farming is a cornerstone of Tunisia's agricultural economy, playing a key role in food security, rural income generation, and employment. Despite its strategic importance, the sector is facing significant structural and environmental challenges, including declining herd sizes, fluctuating milk production, and vulnerability to climate extremes (Attia et al. 2022). These problems are particularly acute in semi-arid and arid regions, where the majority of small-scale dairy farms are located.

In recent years, Tunisia has experienced substantial reductions in its dairy herd estimated at over 25% between 2017 and 2023 due in part to recurrent droughts, rising feed prices, and inefficient management systems. Many farms operate at small scale, with limited land, unbalanced rations, and no access to milk cooling infrastructure, leading to production losses and milk spoilage (Oueslati-Zlaoui et al. 2023).

Moreover, heat stress has been identified as a major factor affecting milk yield and fertility in Holstein cows during summer months. Experimental studies in Tunisian conditions have shown that high ambient temperatures significantly reduce feed intake, milk production, and reproductive performance in dairy herds (Attia et al. 2022).

Beyond production losses, there is increasing concern about the erosion of genetic diversity. Indigenous cattle breeds, which are more resilient to environmental stress, are progressively disappearing due to unregulated crossbreeding practices and lack of conservation programs. A recent Mediterranean-wide study highlighted the fragile status of native Tunisian breeds and called for renewed efforts to valorize local systems adapted to harsh climates (Mohamed-Brahmi et al. 2022).

Despite these challenges, few studies have systematically assessed the diversity of dairy production systems across Tunisia or evaluated how these systems perform under different agro-climatic conditions. Most existing research remains limited to single regions or technical aspects such as nutrition or health.

¹Research unit of Ecosystems and Aquatic Resources, National Agronomic Institute of Tunisia Unité de

²International Center for Agricultural Research in the Dry Areas Tunisia

(✉) Sarra HAMZAOUÏ (National Agronomic Institute of Tunisia, 0021626638010, Manouba Esprols 9, App 4.3, Manouba, 2010, Tunisia Email: hamzaouisarra1994@gmail.com)

In this context, the present study aims to classify the main dairy cattle production systems in Tunisia based on structural and management characteristics. It also investigates the relationship between system typology, milk yield, and milk quality. The results are intended to support better-informed strategies for increasing resilience and sustainability in the dairy sector, particularly in the face of climate change and growing market pressures.

Materials and Methods

Study area

The current research was carried out in the main dairy production regions of Tunisia, which include: the Northwest (governorates of Béja, Bizerte, Jendouba, Siliana, and Kef), the Northeast (governorates of Ben Arous, Manouba, Ariana, Tunis, Nabeul, and Zaghouan), the Central-East (governorates of Sousse, Monastir, and Mahdia), the Central-West (governorates of Kairouan and Sidi Bouzid), and the Southeast (governorate of Sfax) of Tunisia. These 17 governorates belong to four different bioclimatic regions: humid, subhumid, semi-arid, and arid (Tunisian Ministry of Environment, 2022) and are housing approximately 87% of the national bovine dairy herd.

Farmers, survey and data collection

Data collection was based on a survey conducted among farmers from November 2023 to June 2024, involving 102 farms. The selection of farmers was done in connection with the regional representatives of the Livestock and Pasture Office (LPO) in order to ensure a representative sample of each area, taking into account the diversity of farm types, accessibility, data availability and quality and farmers' receptiveness.

Within each governorate, data collection was highly standardized using the same questionnaire with all farmers. Consequently, we obtained a set of homogeneous data (in terms of variables) collected from heterogeneous farmers (in terms of conditions and locations).

The enquiry comprised four basic sections, as following:

- The first section included questions about the general individual characteristics of the farmers (Age, Gender, and Educational Level), the farm structures and the local natural conditions (climate...).
- The second section contained questions about the herd characteristics (size, composition, categories...).
- The third and the fourth sections respectively covered the types of crops in the farm and the different feeding periods throughout the year.

The inquiry was completed with data on performances and milk quality (average values in the herd: FC: Fat content (%), PC: protein content (%), UC: Urea concentration (mg/dl), SC: somatic cells ($10^3/ml$), D: Density and pH), collected from the official control organization (LPO) in each governorate.

Data treatments and Statistical analysis

We conducted basic statistical analyses using the Proc Mean and Proc Freq procedures for calculating means, standard deviations and frequencies, for various parameters (SAS, 2009).

For the characterization of farm typologies and systems, statistical analyses were conducted using XLSTAT for multidimensional statistics on the data, enabling a more detailed interpretation of the results. In order to identify the clusters of farms, Principal Component Analysis (PCA) was applied at various scales. Then, hierarchical clustering based on individual coordinates along predefined axes allowed the development of a classification of farms (XLSTAT,2016).

The Analysis of Variance was used to investigate the variation of the measured parameters relative to milk yield and composition. It was completed with a PROC ANOVA test to compare factor levels (SAS software, version 9.13, SAS, 2009).

Results and Discussion

Breeders characteristics

The majority of the surveyed breeders (64%) were aged between 40 and 50 years, while 25% were over 55 years old. Farmers aged between 26 and 40 years represented 7% of the sample, and only 4% were under 25 years old. Women accounted for 8.8% of the respondents, reflecting a low female participation rate in formal farm management. However, their role in livestock care and feeding remains significant, as in many rural areas women whether wives, mothers, or daughters contribute substantially to animal husbandry, despite men predominantly managing purchasing, marketing, and financial transactions (Attia, 2021).

Regarding education level, 7% of breeders were illiterate, 23% had completed primary education, 29% had attended secondary school, and 41% held higher education degrees. Overall, around 70% of the surveyed breeders had at least secondary-level education, which may be explained by the fact that the majority (75%) were under 50 years old, a generation that benefited from expanded national education programs implemented after Tunisia's independence.

Classification of Farms Based on Herd Size and Forage Area

The surveyed dairy farms had, on average, a land area of 20.54 ha and a herd size of 34.6 dairy cows. However, herd sizes varied considerably, ranging from 1 to 501 cows, while farm areas ranged

from 0 to 389 ha. Purebred cows represented the majority of animals (59.8%), with crossbred cows accounting for 40.2% of the sampled population. Among tenant farmers, 80% leased all of their land, while the remaining 20% leased half of their Agricultural Used Area (AUA). Irrigation covered 63% of the total agricultural land, whereas 37% of the farms relied solely on rainfed production.

Typology of dairy cow rations

Results related to the used rations are presented in Figure 1. Throughout the year, the average total daily ration of dairy cows consisted of an average of 39% concentrate, 33% dry forages, 23% green forages, and 5% silage on DM (Dry Matter) basis in the total feed composition. The survey identified four types of rations based on the combination of different ingredients. A specific ration type is considered only when its utilization extends over a substantial portion of the year.

The types of rations identified in this study align mostly with those described by Attia et al. (2021) in the North of Tunisia in the region of Bizerte. The authors observed significant variations in dietary practices based on regional specificities. These

differences can be attributed to factors such as forage availability, local agricultural practices, and climatic conditions. For instance, farms in arid regions may rely more heavily on concentrates due to limited access to green forages, while those in more humid areas can incorporate a wider variety of fresh forages into their feeding strategies. The results show that Type TR1 system, characterized by an absence of agricultural land and a reliance on dry forages, presents a lower diversified ration composition. In contrast, Types TR2, TR3 and TR4, which include green forages and silage, benefit from more balanced diets. This highlights the importance of adapting feeding strategies to the available resources and specific climatic conditions of each region.

Typology of cattle production and feeding systems

The results of the PCA yielded a matrix of components showing different groups of variables, aggregated into components, providing the relative importance of each variable within these components. The initial PCA analysis revealed seven categories of factors explaining 71.43% of the total sample variance (Table 1). The clustering analysis classified the surveyed farms into

Table 1: Factors generated through PC analysis, variance explained and accumulated, and correlation coefficients of cattle production systems variables with the corresponding factors

Component no	% variance explained (% variance accumulated)	Observed variables	Correlation of variables with respective factor
1	23.123% (23.123%)	Type of ration	0.375
		System	0.666
		Breed	0.257
		MPCL	0.815
		MPCP	0.602
		DIMPL	0.665
		DIMPP	0.643
2	13.384% (36.508%)	Area	0.629
		Herd size	0.677
		Exploitation	0.575
3	9.468% (45.976%)	FC	0.495
		PC	0.254
		pH	0.232
		Pasture	0.392
4	8.147% (54.122%)	Gouvernorate	0.392
		Bioclimatic floor	0.308
		CIC	0.399
5	7.034% (61.157%)	SC	0.350
6	5.657% (66.813%)	Average age	0.290
		Reproduction	0.279
		Number of meals	0.201
7	4.618% (71.431%)	UC	0.305
		D	0.366
		M/C	0.293

MPCL: Milk Production per Cow in Lactation, MPCP: Milk Production per Cow in Production, DIMPp: average daily individual milk production per present cows. DIMPl: average daily individual milk production per lactating cows. FC: Fat content (%), PC: protein content (%), UC: Urea concentration (mg/dl), SC: somatic cell (10³), D: Density, CIC: calving interval calving.

Fig 1. Identified types of ration and their frequency

CC: concentrate, GF: green forage, DF: dry forage, S: Silage

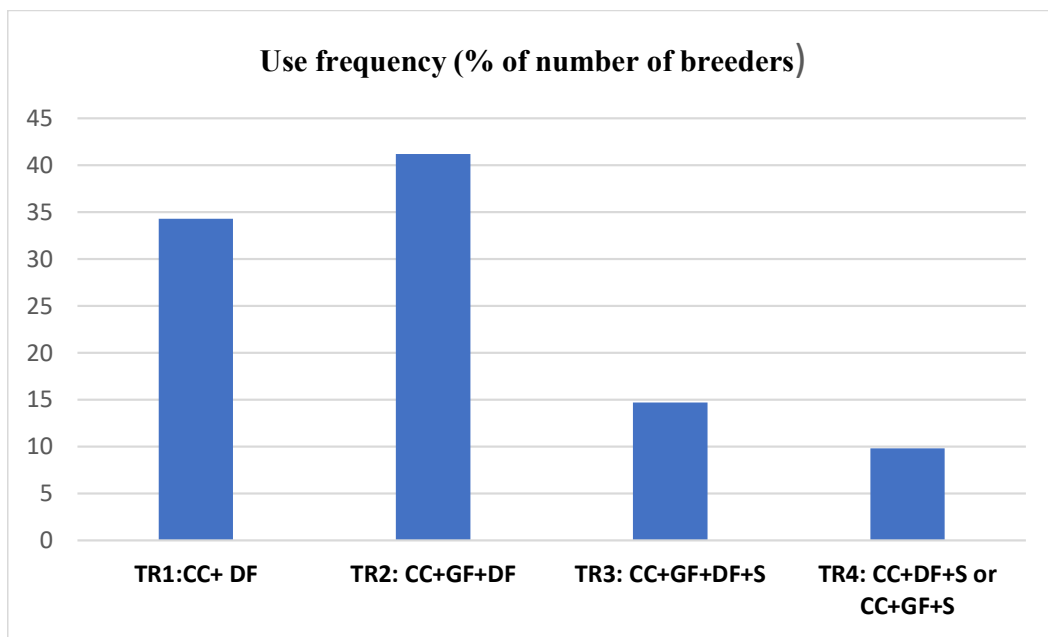
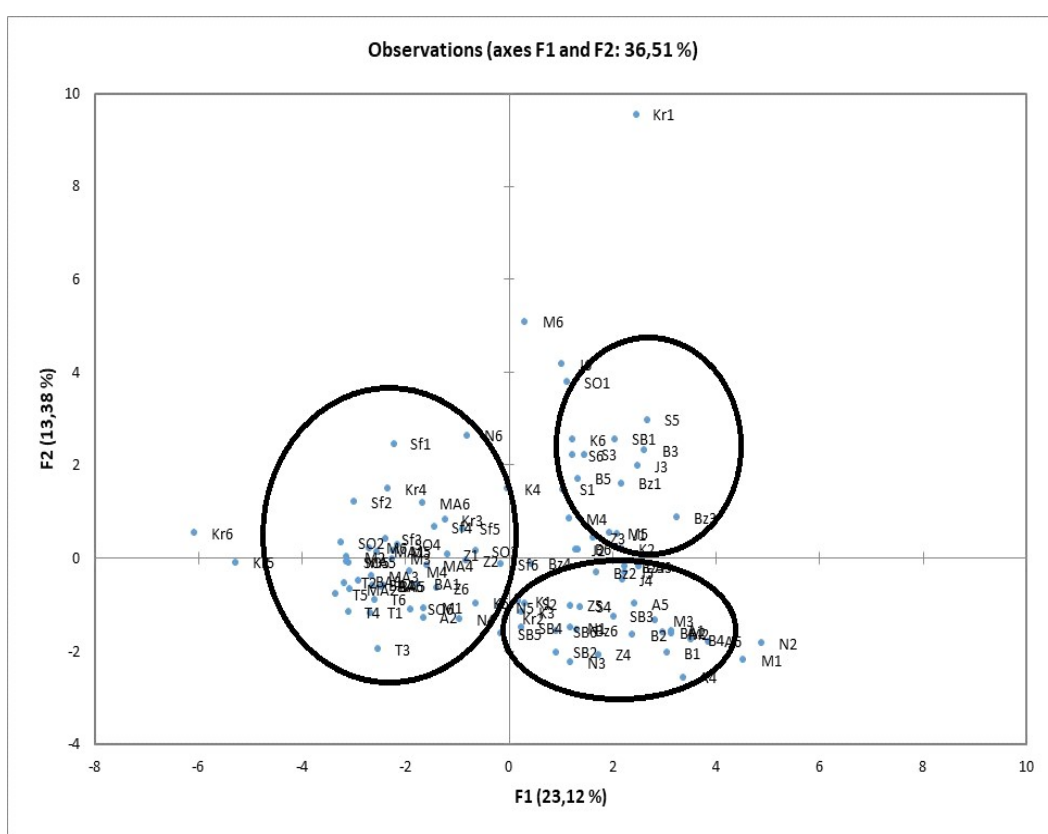


Fig. 2 Distribution of dairy farms based on the scores obtained for Factor 1 and Factor 2 (Group I: Above ground and rainfed production system; Group II: Mixed production system; Group III: Mixed and irrigated production system) from the ACP analysis.



three distinct groups, each defined by a specific set of variables from the PCA. The first group (n = 52; 51% of farms) corresponded to an above-ground and rainfed production system, mainly associated with Components 2, 3, 4, and 6. The second group (n = 27; 26% of farms) represented a mixed

production system combining rainfed and irrigated land, linked to Components 1, 3, 5, and 7. The third group (n = 23; 23% of farms) was characterized as an irrigated production system, primarily associated with Components 1 and 3. Results of the one-way ANOVA indicated that the means of the considered

factors differed significantly among the clusters ($P < 0.0001$), confirming that each group reflects a distinct production system with its own structural and management characteristics allowing the following interpretations (Figure2):

Group I: This group represents 51% of bovine farms, mostly located in the Central-east, Central-west, and South-east regions. The average size of these farms is of about 2.86 ha, comprising mainly 14.86 crossbred cows per farm. This system is characterized by the absence of agricultural land and relies primarily on dry forages. The average diet composition for dairy cows consists of 46% concentrate, 49% dry forage (hay or straw), and 5% green forage on DM basis.

Group II: This mixed system, where farms alternate between rainwater and irrigation based on their needs, constitutes 26% of agricultural operations, mainly in the Northeast. These farms have an average size of 9.7 hectares and approximately 18.15 cows. The average diet throughout the year is mostly composed of 35% concentrate, 30% dry forage, 30% green forage, and 5% silage on DM basis.

Group III: This irrigated or mixed production system groups 23% of farms, characterized by the largest proportion of land compared to other groups, with an average size of 71 ha. This mixed system gathers the largest herd compared to other systems, with approximately 98 cows. The average composition of distributed rations for this group includes 29% concentrate, 26% dry forage, 31% green forage and 14% silage on DM basis.

Both Group II and Group III farms include green forage and silage, but the difference in irrigated area significantly affects the proportions of these ingredients. The identification of three distinct groups Group Type I, Group Type II, and Group Type III highlights the varying reliance on resources and management practices across different regions. Group Type I, which constitutes 51% of farms, predominantly relies on dry forages and lacks agricultural land, indicating a more extensive production system that may be vulnerable to fluctuations in forage availability (Attia et al. 2021).

In contrast, Group Type II demonstrates a mixed system that utilizes both rainwater and irrigation, suggesting a more adaptive approach to resource use. The presence of green forage and silage in this group reflects a shift towards more balanced diets, which can enhance milk production and overall herd health (Oueslati-Zlaoui et al. 2023).

Group Type III stands out with its larger landholdings and herd sizes, indicating a more intensive production system capable of sustaining higher milk yields through better resource allocation. The average diet composition for this group, which includes a significant proportion of green forage and silage, suggests that these farms are well-positioned to meet the nutritional needs of their cattle effectively (Ben Salem and Bouraoui, 2009).

Overall, the differences observed among the groups underscore the need for tailored management strategies that consider local environmental conditions and resource availability. As Tunisia continues to develop its dairy sector, understanding these production systems will be crucial for planning policies and for enhancing productivity and sustainability in the face of changing climatic conditions.

Effect of clusters on dairy performance and main quality parameters

The dairy performance indicators and milk production parameters for each group type are presented in Table 2. The results showed a significant influence of group type on milk production ($P < 0.0001$), with the highest production obtained for Type III (21.59 kg/day), followed by Type II (19.27 kg/day), while the lowest production was observed for Type I with an average of 16.45 kg/day. This difference is likely related to the relative diet composition, as milk production is attributed mainly to variations in feed quality and availability. Therefore, higher milk production corresponds to a higher proportion of green forage in the ration, while lower production corresponds to a lower one (Černý et al. 2016). Similarly, Singh et al. (2015) suggested that the milk production potential of animals reaches its maximum when there is an abundance of green roughage and grazing grass in the production system. This fluctuation observed in milk production

Table 2: Effect of identified cluster on dairy performances and quality

Clusters	MP	M/C	FC	PC	UC
I	16.45 b	1,78 b	3.16 c	2.86	34.56 c
II	19.27 ab	2,31 a	3.43 b	2.98	44.81 a
III	21.59 a	2,56 a	3.82 a	3	39.04 b
SEM	0,3	0,02	0.052	0.024	1.03
P	<.0001	<.0001	<.0001	NS	<.0001

a, b, c : Means with different letters in the same column are statistically different, NS: non-significant. MP: milk production. M/C: Milk concentraite ration. FC: Fat content (%), PC: protein content (%), UC: Urea concentration (mg/dl). P: probabailiy, SEM: Standard error of the mean

may also be linked to bioclimatic stages related to rainfall and temperature. In this case, arid and semi-arid regions are associated with lower forage availability and quality.

Additionally, high Temperature–Humidity Index (THI) values exceeding critical thresholds have been documented to cause heat stress, leading to significant reductions in milk production, feed intake, and feed efficiency (Chen et al. 2024; Polsky & von Keyserlingk, 2017). This phenomenon is particularly pronounced in the arid bioclimatic zones of Tunisia, where production levels are generally lower and heat stress episodes may occur from June to September (Soumri et al. 2025). Heat stress can affect the neuroendocrine system, altering hormonal regulation, energy and water balance, and thermoregulation, ultimately impairing growth, reproduction, and milk yield (Chen et al. 2024). It is noteworthy that the Milk-to-Concentrate (M/C) ratio observed in Type III farms averaged 2.56, likely due to the inclusion of silage and well-balanced rations, which reduce reliance on concentrate feeds. This value falls within the optimal range suggested by recent studies on forage-to-concentrate ratios aiming to maximize feed efficiency commonly between 1:2.5 and 1:3 (i.e., M/C ~2.5–3) (Silva et al. 2022; Mierlita et al. 2022). Moreover, a regional Tunisian survey demonstrated that farms giving at least 50% green forage in the ration achieved notably higher milk yield and improved energy utilization, supporting the effectiveness of balanced forage-based rations in lowering concentrate dependency (Attia et al. 2022).

Our results (Table 2) reveal that the fat content (FC) in all group types exceeds the threshold of 30 g/L set by Tunisian standards for milk acceptance (N.T 14-141-2004). The highest FC ($P < 0.0001$) was noted in Type III group (38.2 g/L), followed by Types II and I, which were similar (averaged: 32.9 g/L). The lower FC for Type I group, characterized by a soilless system, could be explained by the scarcity of high-quality forage in this system and the high proportion of concentrate in the ration. Several studies have reported that low forage intake relative to concentrate reduces milk fat content, while higher proportions of fresh green forage are associated with increased milk fat levels (Hartinger et al. 2024).

The protein content of milk varied among the groups. The Type III group achieved the highest level at 30 g/L, reflecting likely relatively balanced diets composed of forage, silage, and concentrate. In contrast, Group Type II exhibited a slightly lower protein content due to its mixed diet, while Group Type I had the lowest protein levels, likely influenced by its reliance on dry forages and concentrates. These differences underscore the importance of diet composition in optimizing protein synthesis in milk production; the obtained milk protein content relative to all the groups (system), the noted values exceeds 28 g/L as per quality standards in Tunisia.

The variation in protein content is primarily influenced by energy intake. Indeed, Manzocchi et al. (2020) found that corn silage,

hay, or grass had a more significant impact on protein content than silage alone. Thus, Type III produced the highest protein content (30 g/L). This result is consistent with findings from Darej et al. (2019), who studied dairy cattle in Manouba region (North of Tunisia) and found that a diet consisting of forage, silage, and concentrate resulted in a maximum protein content as compared to the other rations (31.9 g/L). This group (Type III) seems to generate a favorable nutrient balance in the rumen, promoting high microbial synthesis. Lu et al. (2019) demonstrated that increasing the energy level in the diet enhances the ruminal microbiome's energy productivity, which stimulates microbial protein synthesis. This stimulation contributes to an increase in milk protein content in dairy cows.

The Type II group exhibits the highest milk urea concentration (44.81 mg/dL). This value exceeds the generally accepted range of 20 to 30 mg/dL, indicating a pronounced ruminal imbalance likely due to excess nitrogen not utilized efficiently (Hérisset and Le Clainche, 2008). The lowest urea concentration was found in the Type I group (34.56 mg/dL), yet it remains above standard levels. Milk urea nitrogen (MUN) is a reliable indicator for assessing protein utilization efficiency, dietary protein-energy balance, and overall metabolic health in dairy cows (Khan et al. 2021). Recent studies have confirmed that monitoring MUN provides valuable insights into nitrogen metabolism and supports the optimization of nutritional management, which also impacts reproductive performance and milk productivity (Spek et al. 2017; Santschi et al. 2016).

Effect of ration type on dairy performance and main quality parameters

In the current study, we evaluated four distinct ration types (RT) for dairy cows, as reported in Table 3 (TR1: concentrate (CC) and dry forage (DF), featuring over 50% dry forage and 39% concentrate; TR2: CC with green forage (GF) and DF; TR3: CC, GF, DF, and silage (S); TR4: CC with either DF or GF combined with silage). The variability in milk performance and quality related to these RTs is summarized in Table 3. Ration type 2 yielded the highest milk production ($P < 0.0001$), while the lowest yield (15.57 kg/cow/day) was observed for ration RT1. These findings are consistent with those of Simoni et al. (2024), who reported that milk production significantly varies depending on the type and quality of forage included in the ration. Similarly, Darej et al. (2019) reported that in Northern Tunisia, the highest milk yield was associated with rations containing green forage and concentrate. significant effect ($P < 0.0001$) of ration type on the M/C ratio. The highest milk-to-concentrate ratio (M/C) (2.28) was recorded for TR3 (CC+GF+DF+S), while the lowest value was observed for TR1 (1.79). For TR2, TR3, and TR4, the M/C values fell within the optimal range of 2 to 2.4, in line with the more recent recommendations of van der Drift et al. (2016), who emphasized that a milk-to-concentrate ratio between 2 and 2.5 is optimal for efficient milk production.

Table 3: Effect of ration type on dairy performances and quality

Type of ration	MP	M/C	FC	PC	UC
TR1	15.57 C	1,79 c	3.29 b	2.97	34.64 c
TR2	20.26 a	2,51 a	3.33 b	2.97	43.07 a
TR3	18.4 b	2,28 ab	3.48 b	2.91	39.26 b
TR4	17.2 b	2.11 bc	3.87 a	3.11	38.76 b
SEM	0,26	0,02	0.05	0.023	1.02
P	<.0001	<.0001	<.0001	NS	<.0001

a, b, c : Means with different letters in the same column are statistically different, NS: non-significant. MP: milk production. M/C: milk to concentrate ratio. FC: Fat content (%), PC: protein content (%), UC: Urea concentration (mg/dl), P: probabailiy, SEM: Standard error of the mean. TR1:CC+DF, TR2:CC+GF+DF, TR3:CC+GF+DF+S, TR4:CC+DF+S or CC+GF+S, CC: concentrate, GF: green forage, DF: dry forage, S: Silage

Our results (Table 3) indicate that the most diverse forage composition in ration TR4 is linked to the highest fat content (FC) in grams per liter. According to Shi et al. (2023), increasing neutral detergent fiber (NDF) levels in the diet is associated with reduced dry matter intake but higher milk fat concentration, indicating a positive relationship between fiber content and milk fat. Zhang et al. (2023) showed that supplementation with pantothenate and thiamine enhances nutrient digestion and fatty acid synthesis in the mammary gland, which may contribute to higher milk fat content. Piantoni et al. (2015) reported that increasing dietary NDF levels improves lactation efficiency in early postpartum cows despite a decrease in dry matter intake. This dietary composition likely promotes greater acetic acid fermentation in the rumen, leading to increased synthesis of milk fatty acids, which constitute about 60% of total milk fat (Zhang et al. 2023). Additionally, Si et al. (2023) demonstrated that variations in rumen bacterial communities are linked to milk fat content, suggesting microbial modulation as a factor in milk fatty acid deposition.

The protein content of milk was notably influenced by the composition of the rations provided to the dairy cows (Table 3). The results indicated that all type of ration exceeded the national standard of 28 g/L for protein content (NT 14-141-2004). Specifically, TR4 demonstrated the highest ($P < 0.0001$) protein concentration (3.11%) and the lowest value was observed in TR3. This observation aligns with findings from Kauffman et al. (2020), who emphasized that dietary energy levels, significantly affect protein synthesis in lactating cows, suggesting that rations high in energy-dense feeds enhance protein output in milk.

Concerning urea concentration in milk, our results (Table 3) showed that TR4 exhibited a significantly ($P < 0.0001$) lower urea level (34.64 mg/dL) compared to TR1, which had the highest urea concentration of approximately 44.81 mg/dL. The urea concentration in milk serves as a crucial indicator of protein metabolism and nitrogen utilization. Our results are consistent with research by Zhao et al. (2025), who found that higher urea levels are often associated with imbalances in dietary nitrogen

and energy, leading to inefficient protein utilization. Furthermore, it is essential to consider that the protein content in dairy diets is primarily determined by the sources of energy and fiber included in the ration. Indeed, according to McCarthy et al. (2018), incorporating high-quality forage and energy sources in the ration can enhance the overall protein availability for lactating cows, thereby improving milk quality. In our study, ration types that included a balanced mixture of concentrates and forages resulted in better nitrogen utilization and lower urea levels, reflecting a more efficient metabolic process.

Overall, our findings suggest that diverse rations can significantly impact both performance levels and quality attributes of dairy production in Tunisia. Future hypotheses may include exploring how specific forage types, animal genetic and health effects and other management factors could influence milk performance and quality parameters at medium and long terms. in the diverse farming systems.

Conclusions

The current study highlighted significant variations in dairy production systems across the Tunisia's major dairy regions. Three primary typological systems were identified: a rainfed system characterized by small farms with limited green forage, a mixed system utilizing both rainwater and irrigation, and an irrigated system featuring larger farms with diverse diets. It was found that the irrigated system demonstrates the highest performance in terms of milk production and quality, significantly outperforming the rainfed one. This underscores the importance of irrigation and effective feeding practices in enhancing dairy productivity. Furthermore, green forages and silage resulted in higher fat and protein content in milk, compared to those primarily composed of dry forage. These findings indicate that optimizing feed composition is crucial for improving milk performances efficiency across different farming systems, especially in the case of pure dairy breeds. Overall, this study contributes to the description of the distribution of dairy cattle farming typologies in Tunisia and to the constitution of a database for the establishment of sustainable and resilient policies for dairy cattle

farming systems in the territory. This is crucial, especially with regard to the challenges of climate changes, which limit and severely affect food resources.

Conflict of Interest

The authors declare that there is no conflict of interest.

IDORCID

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