A MULTIVARIATE STATISTICAL ANALYSIS OF MILK YIELD AND QUALITY IN INTENSIVE DAIRY PRODUCTION SYSTEMS IN PARANÁ STATE, BRAZIL †

[UN ANÁLISIS ESTADÍSTICO MULTIVARIADO DE RENDIMIENTO Y CALIDAD DE LECHE EN SISTEMAS DE PRODUCCIÓN LÁCTEA INTENSIVA EN EL ESTADO DE PARANÁ, BRASIL]

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SUMMARY

Background: Dairy farm manager must apply strategic planning to manage the complexity of dairy production systems and produce high-quality milk. **Objective.** To identify and group dairy farms on the basis of milk yield and composition, animal data, and farm characteristics. **Methodology.** Official milk records and production variables of 26 dairy farms and 45,343 cows in the region of Arapoti, Paraná, southern Brazil (24°49′36″S 49°49′36″W, 860 m elevation), were assessed. Milk yield and composition data were analyzed using multiple correspondence analysis (MCA) and ascending hierarchical classification (AHC) followed by simple linear regression analysis. **Results.** AHC afforded five clusters of dairy farms, grouped according to milk yield and composition. MCA showed that cow age influenced mammary gland health, whereas feed management and lactation stage influenced milk composition. Regression analysis indicated that the relationships between milk composition parameters and lactation number had the same behavior in all clusters; milk protein and lactose contents decreased with increasing lactation number. A relationship was found among cow age, lactation stage, and mammary gland health, as well as among milk yield, cow age, and mammary gland health. Somatic cell count increased with cow age. Low milk yield was associated with high somatic cell counts. Mammary gland health was affected by lactation stage, and milk composition was influenced by feeding management and lactation number (cow age). **Implications**. The comprehension of the relationship between milk production and composition on dairy cattle farms can suggest specific decision-making for group of milk farmers, regarding nutritional and milk quality according to the production, composition and somatic cell count. **Conclusion.** A relationship was found among cow age, lactation stage, and mammary gland health as well as among milk yield, cow age, and mammary gland health. Multivariate statistical analysis helped to understand the relationship between milk production and composition in these dairy cattle farms. Based on these grouping results, we can suggest specific decision-making for each group of producers, regarding nutritional and milk quality according to the production, composition and somatic cell count.

Keywords: Parity; mammary gland; milk quality; multiple correspondence analysis.

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RESUMEN

Antecedentes. El gerente de la granja lechera debe aplicar una planificación estratégica para gestionar la complejidad de los sistemas de producción láctea y producir leche de alta calidad. **Objetivo**. Este estudio tuvo como objetivo identificar y agrupar las granjas lecheras sobre la base de la producción y composición de la leche, los datos de los animales y las características de la granja. **Metodologí**a. Se evaluaron los registros oficiales de leche y las variables de producción de 26 granjas lecheras y 45,343 vacas en la región de Arapoti, Paraná, sur de Brasil (24 ° 49′36 ″ S 49 ° 49′36 ″ W, 860 m de elevación). Los datos de producción y composición de la leche se analizaron mediante análisis de correspondencia múltiple (MCA) y clasificación jerárquica ascendente (AHC) seguido de un análisis de regresión. **Resultados**. AHC proporcionó cinco grupos de granjas lecheras, agrupadas según la producción y composición de la leche. La MCA mostró que la edad de la vaca influyó en la salud de las glándulas mamarias, mientras que el manejo de la alimentación y la etapa de lactancia influyeron en la composición de la leche. El análisis de regresión indicó que las relaciones entre los parámetros de composición de la leche y el número de lactancia tuvieron el mismo comportamiento en todos los conglomerados; el contenido de proteína de la leche y lactosa disminuyó al aumentar el número de lactancias. Se encontró una relación entre la edad de la vaca, la etapa de lactancia y la salud de la glándula mamaria, así como entre la producción de leche, la edad de la vaca y la salud de la glándula mamaria. El recuento de células somáticas aumentó con la edad de la vaca. La baja producción de leche se asoció con un alto recuento de células somáticas. La salud de la glándula mamaria se vio afectada por la etapa de lactancia y la composición de la leche se vio influenciada por el manejo de la alimentación y el número de lactancia (edad de la vaca). **Implicaciones:** La comprensión de la relación entre la producción y composición de la leche en las explotaciones de ganado lechero puede sugerir una toma de decisiones específicas para el grupo de productores de leche, en cuanto a la calidad nutricional y de la leche de acuerdo con la producción, composición y recuento de células somáticas. **Conclusión**. Se encontró una relación entre la edad de la vaca, la etapa de lactancia y la salud de las glándulas mamarias, así como entre la producción de leche, la edad de la vaca y la salud de las glándulas mamarias. El análisis estadístico multivariado ayudó a comprender la relación entre la producción y la composición de la leche en estas granjas de ganado lechero. Con base en estos resultados de agrupamiento, podemos sugerir la toma de decisiones específicas para cada grupo de productores, en cuanto a la calidad nutricional y de la leche de acuerdo con la producción, composición y recuento de células somáticas.

Palabras Claves: Análisis de correspondencia multiple; glándula mamaria; calidad de la leche; paridad.

INTRODUCTION

Production systems are a set of interrelated components organized within an autonomous structure and guided by a common purpose. These overall variable, dynamic, and unpredictable systems are sensitive to the environment with which they interact (Pinheiros, 2000). In the case of dairy production systems, the interaction between components contributes to system complexity, and the different conditions and challenges encountered by farm operators require strategic planning to be overcome (Marton *et al.*, 2016; Todde *et al.*, 2016). Therefore, according to Damasceno (2008), dairy farm operators must use different tools and sources of information to define strategies, tactics, and operational actions for long-, medium-, and short-term results, respectively. The author highlighted that the focus should be on short-term operational actions. Strategies and tactics are often designed empirically, following family traditions of management and reaction to adversities and opportunities, whether economic, climatic, or social.

Efficient management of dairy farms is crucial for the production of high-quality milk, which is valued by dairy industries and demanded by consumer markets (Defante *et al.*, 2019). Dairy industries rely on monthly reports of milk characteristics to set the price of milk paid to dairy producers and to determine whether technical assistance actions need to be implemented (Bodenmüller Filho *et al.*, 2010). Milk samples are evaluated for microbiological and compositional quality once or twice every month, and the results are reported in official records (Forsbäck *et al.*, 2009). Quality parameters determine the value of bulk milk and are increasingly used to detect management failures (Defante *et al*., 2019; Takahashi, 2012), as high-quality milk is generally obtained from healthy, highly productive cows (Forsbäck *et al.*, 2009).

Many studies have identified homogeneous groups of dairy systems (Bánkuti *et al.*, 2020; Marton *et al.*, 2016; Palhares *et al.*, 2015; Zimpel *et al.*, 2017) for a deeper understanding of their productive, technical, and economic efficiencies without resorting to individual study cases, which are generally costly and require long research (Smith *et al.*, 2002; Brito *et al.*, 2015). The current study aimed to apply a multivariate statistical approach to identify and group dairy farms according to milk yield, composition, and somatic cell count.

MATERIAL AND METHODS

The study was conducted in the region of Arapoti, Paraná, a peculiar ecosystem located in southern Brazil (24°49′36″S 49°49′36″W, 860 m elevation). The region comprises 26 municipalities and is one of the most important milk-producing localities in the country.

Data on the yield and composition of milk obtained from 45,343 animals were acquired from the official milk records of the Dairy Herd Analysis Program of the state of Paraná. Information on dairy production systems was obtained directly from dairy farm operators (Table 1).

Table 1. Description of dairy Systems - Feed Systems, Production System and Feed method.

	Description	
Feed Systems	Corn Silage (CS)+dried forages	Dried forrages
	CS+fresh forages	Fresh forages
	CS_only	Only corn silage
Production System	Free-stall	Free-stall system
	Semi-conf	Semi confined
Feed method	Total mix	Total mixture ration
	Without mix	Without total mixture

Milk yield and composition data were subjected to multiple correspondence analysis (MCA) and ascending hierarchical classification (AHC) (Table 2). The first analysis was conducted to explain the causal relationships between milk composition and animal data. MCA is a multivariate statistical technique used to simultaneously analyze two or more variables (Hair *et al.*, 2009). According to Solano *et al.* (2000), before conducting MCA, qualitative variables must be transformed into categories based on objective criteria, such as quantile score. Variables with the highest scores in terms of variance explained were maintained (Kubrusly, 2001). The same variables subjected to MCA were used for AHC (Table 2). In AHC, the Euclidean distance was used to define the numbers of clusters retained. AHC is a multivariate approach for detecting homogeneous groups on the basis of variables or cases (Pestana and Gageiro, 2000).

Regression effects were estimated from data subjected to AHC considering milk quality parameters as response variables and parity as a covariate, according to Eq. (1):

$$\hat{Y} = \beta_0 + \beta_1 x_i + \beta_2 x_i^2 + \beta_3 x_i^3 + \boldsymbol{\varepsilon}_{ij} \quad (1)$$

where $\hat{Y}$ is the estimated value of dependent variables that describe milk quality; β_0 is the intercept, representing the mean value for cluster 1 (group 1); β_1, β_2, and β_3 are the regression coefficients of the linear, quadratic, and cubic terms, respectively; x_i is the independent variable of group *i* corrected for estimated parity; and $\boldsymbol{\varepsilon}_{ij}$ is the error vector associated with group *i* and observation *j*. Data were fitted to the best cubic or quadratic model according to the stepwise method.

Table 2. List of variables applied in Multiple Correspondence Analysis (MCA), Hierarchical Ascendant Classification Analysis - HAC and its level of occurrence from dairy herds in Campos Gerais.

Variable	Level	Avarage (quartiles)
Milk Yield, L.d^{-1}	Low_yield	< 24.34
	Medium_yield	24.35 - 32.68
	Hight_yield	32.69 - 41.10
Milk Yield (3.5% Fat), L.d^{-1}	Low_yield 3,5%	< 23.70
	Medium_yield 3,5%	23.80 - 31.40
	Hight_yield 3,5%	31.50 - 41.10
Fat, %	Low_fat	< 3.04
	Medium_fat	3.05 - 3.66
	Hight_fat	3.67 - 4.00
Protein, %	Low_prot	< 3.13
	Medium_prot	3.14 - 3.34
	Hight_prot	3.35 - 4.00
Lactose, %	Low_lact	< 4.47
	Medium_lact	4.48 - 4.61
	Hight_lact	4.62 - 4.75
TS[1], %	Low_TS	< 11.67
	Medium_TS	11.68 - 12.25
	Hight_TS	12.26 - 12.82
SCS[2]	Low_SCS	< 2.28
	Medium_SCS	2.29 - 2.70
	High_SCS	2.71 - 3.12
Number of lactation (order of Lactation)	1st	One lactation
	2nd	Two lactations
	3rd	Three lactations
Cow age (years)	< 5	< 5
	5 to 6	5.1 - 6.0
	6 to 8	6.1 - 8.0

[1]Total Milk Solids; [2]Log10 of Somatic Cell Score.

We applied simple linear regression with values corrected for lactation order. All assumptions of the model, homoscedasticity, factor independence, normal distribution of residues, were met.

RESULTS

MCA was used to analyze qualitative variables associated with milk quality and composition. The characteristics of dairy production systems and their respective correlations are shown in Figure 1.

The variables that most contributed to dimension 1 were days in milk, lactose content, cow age, somatic cell count, and feeding method (Figure 1).

As shown in Figure 2, dimensions 1 and 2 explained 26.0 and 19.9% of the variance in the dataset, respectively. Dimension 1 was characterized by the relationship between cow age, lactation stage, and mammary gland health. Dimension 2 was characterized by the relationship between milk yield, cow age, and mammary gland health. There was a positive correlation ($p < 0.05$) between cow age and somatic cell count, showing that somatic cell count increases with age.

AHC afforded five clusters. Milk yield and lactation parameters of each cluster are shown in Table 3.

Dairy systems were plotted on the MCA biplot according to their respective cluster (Figure 3). Clusters 1 and 2 were characterized by dairy production systems with intermediate milk yield and somatic cell count, particularly in warmer months (December to March).

Cluster 3 comprised high-yield dairy production systems that produce milk with low somatic cell counts, particularly from June to October, when temperatures are mild.

The relationship between mammary gland health and milk yield was clearly represented by clusters 4 and 5.

Linear simple regression analysis of milk yield and quality parameters of each cluster was performed considering parity as a covariate. Milk yield was found to increase with increasing lactation number, in accordance with the mean lactation number of the study sample (2.5 lactations). The regression model predicted that milk yield would not decrease after the fifth lactation. The relationship of milk composition (somatic cell count, total solids, and fat, protein, and lactose contents) with parity is shown in Fig. 4.

Figure 4a separate the clusters according to milk production with 3.5% fat corrected. It is observed that the cows in cluster 3 are those with the highest yields, in contrast to the cows in cluster 2, which are the cows with the lowest yields. The cows in Clusters 1, 4 and 5 are of intermediate production.

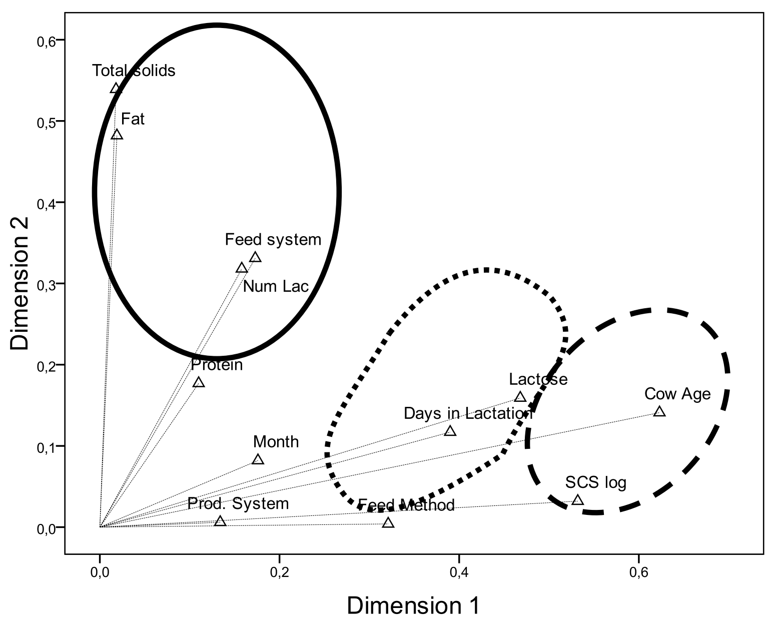

Figure 1. Multiple Correspondence Analysis - MCA. Variable's contributions to dimensions 1 and 2, the variables related to the milk production system and the respective correlations obtained from MCA.

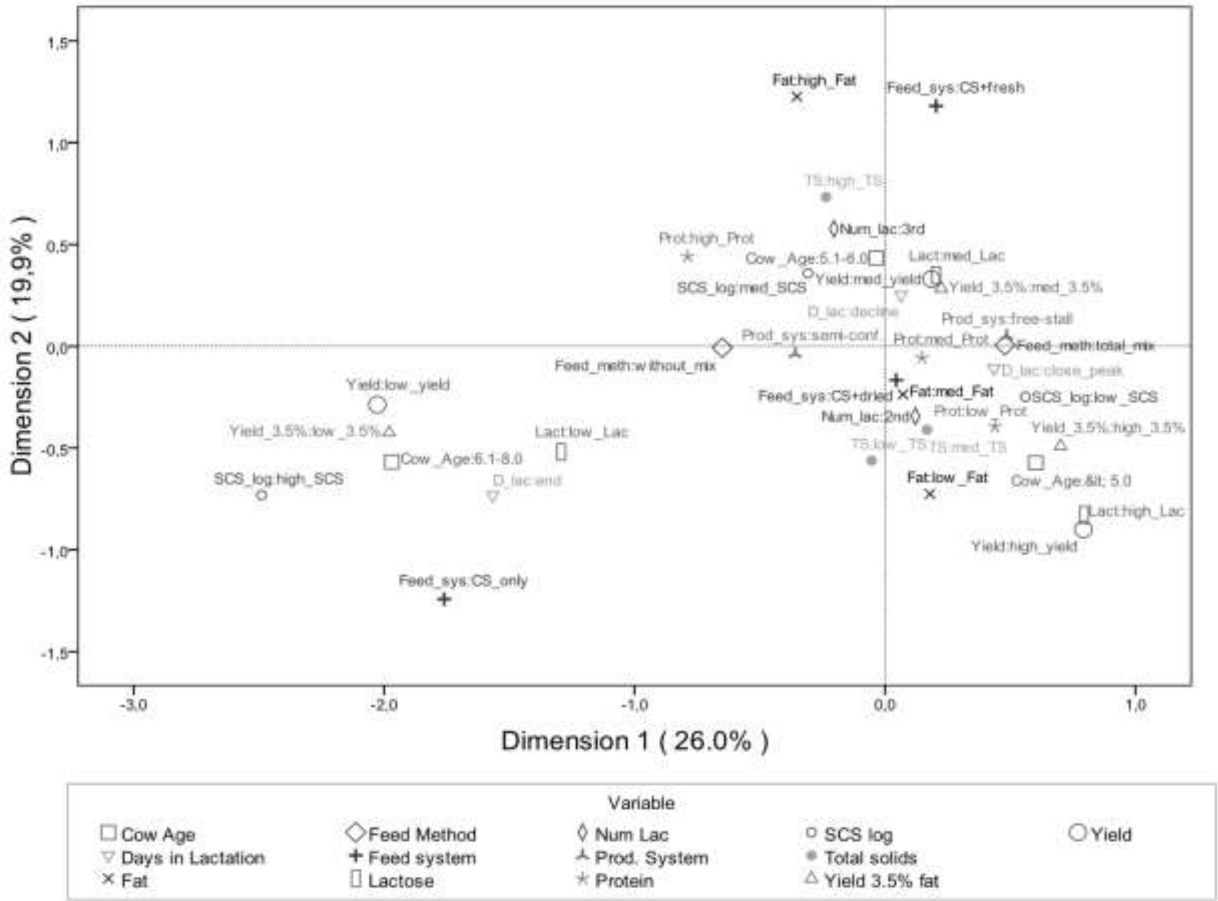

Figure 2. Levels of incidence and variables1 contribution for dimensions 1 and 2.

Table 3. Cluster descriptions.

Variables		Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	General
Number of observations		2.785	22.354	4.718	6.832	8.654	45.343
Milk yield, (L/d (3.5%) (Fat-corrected milk)	Mean	29.70	27.15	32.6	30.31	30.19	28.77
	Max	67.70	73.16	87.4	69.40	69.20	87.40
	Min	10.50	2.45	6.11	3.10	3.20	2.45
	SD	7.80	8.70	8.28	9.35	9.64	8.97
Cow age (years)	Mean	5.30	5.30	5.27	5.12	5.25	5.28
	Max	12.80	14.30	14.2	14.51	12.90	14.5
	Min	2.10	2.00	2.20	1.93	2.05	1.93
	SD	2.10	2.00	2.14	2.05	1.89	2.02
Number of lactations (order of Lactation)	Mean	2.70	2.30	2.70	2.52	2.49	2.50
	Max	9.00	11.0	11.0	10.0	10.0	11.0
	Min	1.00	1.00	1.00	1.00	1.00	1.00
	SD	1.75	1.48	1.78	1.65	1.51	1.57
Lactation stage (days)	Mean	181	205	210	212	196	203
	Max	657	1185	892	1015	1096	1185
	Min	6.0	15.0	16.0	16.0	10.0	6.0
	SD	111	143	137	148	139	142

Max = maximum observed value; Min = minimum observed value; SD = standard deviation.

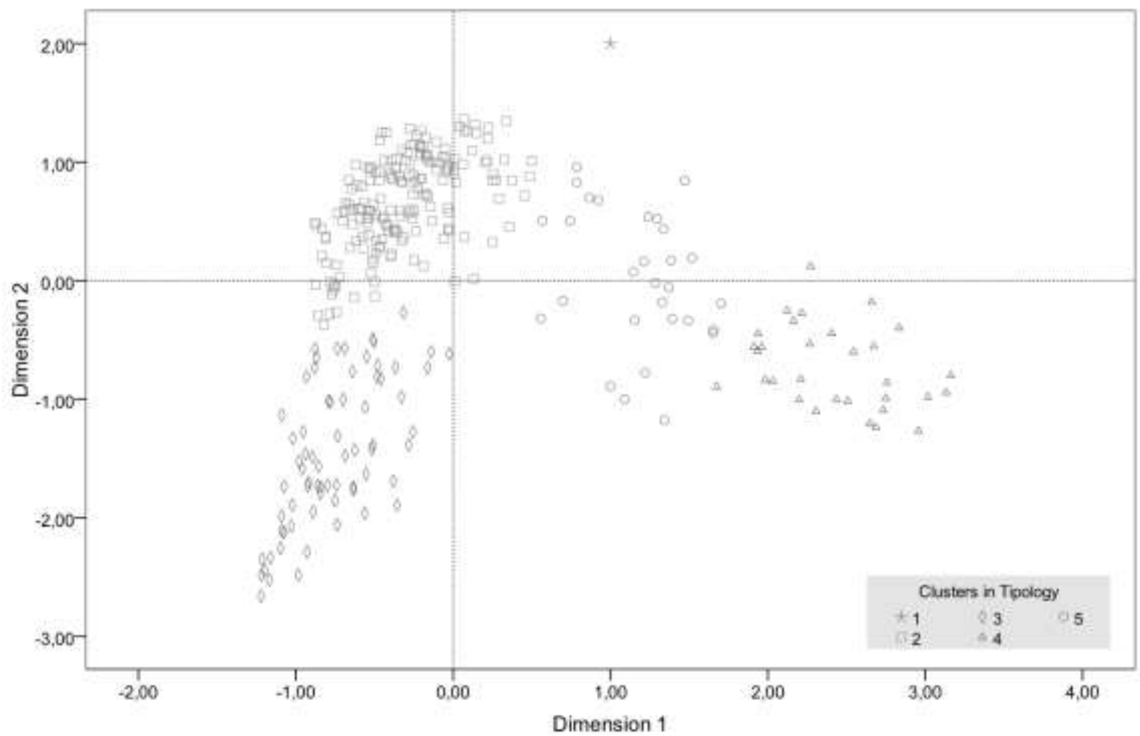

Figure 3. Dairy production system's typology. Five cluster.

In Figure 4b. it is observed that the cows in cluster 1 are the ones that have the highest content of total solids in milk. Which is in line with lower milk production. However, the cows in cluster 4, although they were among those with the lowest milk production, were those that had the lowest total solids content.

Milk protein content, in contrast, decreased with increasing lactation number (Figure 4e). Lactose content showed a similar behavior to milk protein content; the levels decreased with increasing lactation number. Somatic cell count increased with lactation number in all clusters (Fig. 4c). For all clusters, fat content did not vary with lactation number (Figure 4d).

The magnitude and significance of the relationship is presented in Table 4.

DISCUSSION

The characteristics of dairy production systems and their respective correlations are shown in Figure 1. According to Barroso and Artes (2003), variables with the highest values for each dimension are those that contribute the most to the accumulated variance (or inertia). The variables that most contributed to dimension 1 were days in milk, lactose content, cow age, somatic cell count, and feeding method (Figure 1). These variables explain how cow age affects mammary gland health. For dimension 2, total solids, milk fat content, feed management, and parity explained the influence of feeding management and parity on milk composition (Figure 1).

As shown in Figure 2, dimensions 1 and 2 explained 26.0 and 19.9% of the variance in the dataset, respectively. Dimension 1 was characterized by the relationship between cow age, lactation stage, and mammary gland health. Schutz *et al.* (1990) observed an association between lactation stage and variation in somatic cell count; for primiparous cows, somatic cell count is altered at the beginning of the lactation stage, whereas, for multiparous cows, somatic cell count is altered at the end of lactation (Noro *et al.* 2006; Cunha *et al.* 2008). According to Souza *et al.* (2010), parity number is indicative of cow age, which is one of the major factors affecting milk yield and somatic cell count, as also observed in the present study.

Dimension 2 was characterized by the relationship between milk yield, cow age, and mammary gland health (Figure 2). Vallimont *et al.* (2010) observed an increase in milk yield from the first to the third lactation. However, the authors also found that milk yield decreased gradually from the fourth to the eighth lactation. Windig *et al.* (2005) reported that high-yield cows have a higher risk of developing mastitis because of the elevated metabolic demands for milk production and long milking periods, among other factors. Therefore, these cows require stringent attention and effective control measures to prevent the disease. Many factors influence somatic cell count, such as mastitis status, presence of other diseases, lactation stage, parity, season, herd size, and milk yield (Santos and Fonseca, 2019; Philpot and Nickerson, 2002). There was a positive correlation ($p < 0.05$) between cow age and somatic cell count, showing that somatic cell count increases with age.

Clusters 1 and 2 were characterized by dairy production systems with intermediate milk yield and somatic cell count, particularly in warmer months (December to March). As also observed by Bajaluk (2000), milk yield is generally lower under high temperature conditions, as cows are at a higher risk of heat stress.

Cluster 3 comprised high-yield dairy production systems that produce milk with low somatic cell counts. Most lactating cows evaluated in this study were of the Holstein breed, which is highly sensitive to fluctuations in environmental conditions (Bajaluk, 2000). Thus, climatic seasonality must be considered in the planning of animal housing and reproductive, sanitary, and feeding management.

The relationship between mammary gland health and milk yield was clearly represented by clusters 4 and 5. It is known that milk yield decreases with increasing somatic cell count (Noro *et al.*, 2006; Souza *et al.*, 2010). According to data from cluster 4 farms, the higher the animal age and number of days in lactation, the higher the somatic cell count. These results highlight the importance of mammary gland health, not only to reduce losses in milk yield but also to obtain economic gains, as higher-quality milk can be sold for a better price.

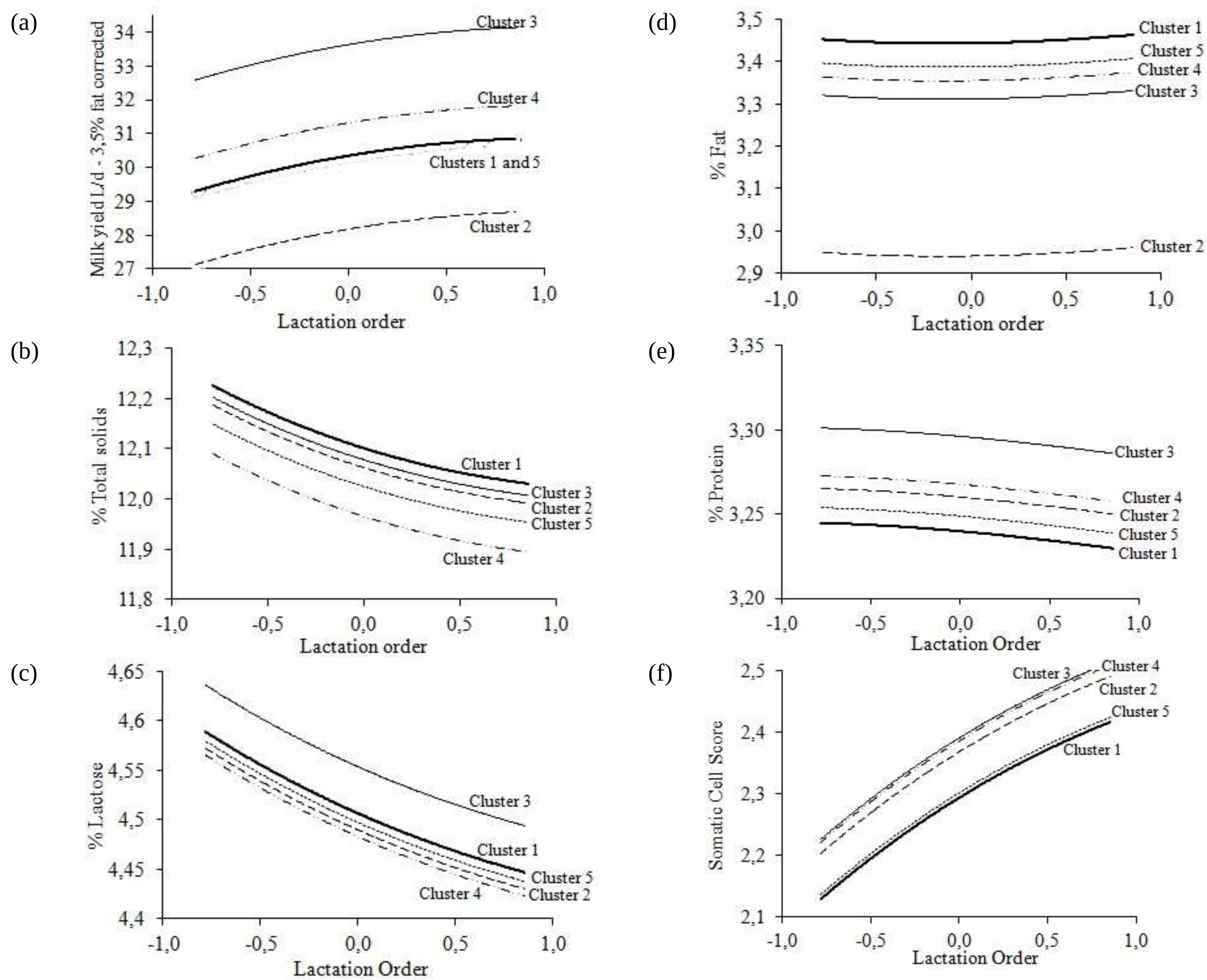

Figure 4. Effect of the lactation order on milk production -Figure 4a, and percentage of total solids - Figure 4b, percentage of lactose -Figure 4c, percentage of fat - Figure 4d, percentage of protein - Figure 4e, and somatic cell score - Figure 4f, based on five cluster.

Table 4. Magnitude and significance of the relationship between milk yield, milk quality parameters and dairy production system's.

	Nb	Dl	Cw	My	Myc	Fat	Pr	Lac	Ts	SSC log	Ps	Fs	Fm
Nb	1												
Dl	0.044	1											
Cw	0.306**	0.223**	1										
My	-0.042	-0.255**	-0.393**	1									
Myc	-0.064	-0.255**	-0.406**	0.774**	1								
Fat	0.022	0.099	0.135*	-0.251**	-0.012	1							
Pr	0.053	0.117*	0.145**	-0.236**	-0.176**	0.147**	1						
Lac	-0.143**	-0.320**	-0.390**	0.472**	0.451**	-0.089	-0.031	1					
Ts	-0.029	0.081	0.066	-0.206**	0.013	0.612**	0.378**	0.083	1				
SSC log	0.194**	0.338**	0.442**	-0.388**	-0.437**	0.102	0.223**	-0.398**	0.016	1			
Ps	0.051	-0.079	0.157**	-0.323**	-0.343**	0.069	0.007	-0.205**	0.057	0.093	1		
Fs	0.286**	0.073	0.262**	-0.024	-0.029	0.027	0.026	0.043	0.091	0.151**	0.039	1	
Fm	0.163**	0.103	0.232**	-0.287**	-0.277**	-0.035	0.296**	-0.215**	0.024	0.301**	0.264**	0.185**	1

Nb (number of lactation), Dl (days in lactation), Cw (Cow age), My (Milk yield), Myc (Milk yield corrected - 3.5% of fat), Fat (fat %), Pt (protein %), Lac (latose %), Ts (total solids %), SSClog (Somatic Cell Score log), Ps (production system), Fs (feed system), Fm (feed method).
*Significativo pelo teste de Kendall (p< 0,05); ** significativo pelo teste de Kendall (p< 0,01).

Milk yield was found to increase with increasing lactation number, in accordance with the mean lactation number of the study sample (2.5 lactations) (Figure 4). The regression model predicted that milk yield would not decrease after the fifth lactation. Previous studies revealed that milk yield increases up to adulthood, with a peak at around the third and fourth lactations, and then declines with age (Freitas *et al.*, 2001; Teixeira *et al.*, 2003; Magalhães *et al.*, 2006; Noro *et al.*, 2006; Andrade *et al.*, 2007; Souza *et al*., 2010).

The milk yield pattern observed in the current study can be explained by the findings of Spurlock *et al.* (2012). The authors found positive genetic correlations between body weight, milk yield, and dry matter intake in Holstein cattle. However, according to Loker *et al.* (2012), the association between body condition score and milk yield is not necessarily the same as lactation number increases. Therefore, the increase in milk yield might be related to mammary gland development; as the organ develops, body weight and number of secretory cells increase. According to Vallimont *et al.* (2010), second- and third-parity cows have higher feed intake capacity than first-parity cows. Indeed, primiparous cows have not yet reached physiological maturity and their mammary system cannot produce large volumes of milk. Adult cows can produce 25–30% more milk than primiparous cows (NRC, 2001).

The relationship of milk composition with parity is shown in Figure 4. For all clusters, fat content did not vary with lactation number (Figure 4d). A similar result was reported by Teixeira *et al.* (2003), who observed that the milk fat percentage remained relatively constant with increasing lactation number. In contrast, Noro *et al.* (2006) reported that the percentage of milk fat was lower in cows with lower lactation numbers and higher in cows with a calving age greater than 84 months. A slight variation in milk fat content with increasing lactation number was observed by Ng-Kwai-Hang *et al.* (1984) in analyzing official milk records from Canada: milk fat percentage decreased linearly at a rate of 0.004% between the age of 2 to 5 years and by 0.05% after 5 years of age. A similar result was also obtained by Ribas *et al.* (1983) in investigating the milk yield of Holstein cows in the municipality of Castro, Paraná, Brazil.

Milk protein content, in contrast, decreased with increasing lactation number (Figure 4e), as also observed in a study by Cunha *et al.* (2008). According to the Santos (2002), milk protein content decreases gradually with increasing cow age. Protein content can decrease by 0.10–0.15 units after five lactations or by 0.02–0.05 units per lactation.

Lactose content showed a similar behavior to milk protein content; the levels decreased with increasing lactation number (Figure 4c). Noro *et al.* (2006), assessed the official milk records of the state of Rio Grande do Sul, Brazil, and found a similar trend to that observed in the present study. The decline in lactose content may be associated with the increase in somatic cell count, as depicted in Figure 4f. According to Fox *et al.* (2000), an increase in somatic cell count leads to an increase in NaCl concentration in milk. As a result, lactose levels decrease to maintain osmotic homeostasis. Thus, the higher the NaCl content in milk, the lower the lactose content.

Somatic cell count increased with lactation number in all clusters (Figure 4c). Similar findings were reported by Magalhães *et al.* (2006), Noro *et al.* (2006), Andrade *et al.* (2007), Cunha *et al.* (2008), Silva *et al.* (2016) and Santos and Fonseca (2019), who found that somatic cell count increases with cow age. According to the authors, such an increase occurs because of the higher exposure of older cows to causative agents of mastitis; primiparous cows, on the other hand, have had less exposure to mastitis risk factors. High somatic cell count may imply lower economic gains, as the parameter is associated with reduced milk yield and quality (leading to economic penalties from the dairy industry), as well as increased pharmaceutical expenditure (Silva *et al., 2016)*. For the dairy processing industry, high somatic cell counts in milk (associated with lower levels of casein, fat, and lactose) often lead to problems during milk processing, affecting production efficiency, product quality, and stability.

CONCLUSIONS

A relationship was found among cow age, lactation stage, and mammary gland health as well as among milk yield, cow age, and mammary gland health. Somatic cell count had a positive correlation with cow age, and lactation number had a positive correlation with milk yield. Milk protein and lactose contents, on the other hand, decreased with lactation number. Mammary gland health was also influenced by lactation stage. Milk composition differed according to lactation number (cow age) and feeding management. Multivariate statistical analysis helped to understand the relationship between milk production and composition on these dairy cattle farms. Based on these grouping results, we can suggest specific decision-making for each group of producers, regarding nutritional and milk quality according to the production, composition and somatic cell count.

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