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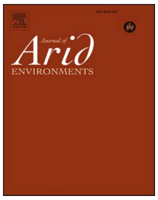

Diversity in smallholder dairy production systems in the Brazilian semiarid region: Farm typologies and characteristics of raw milk and water used in milking

Robson Mateus Freitas Silveira[a,b,*], Valdson José da Silva[c], Josiel Ferreira[d], Raquel Oliveira dos Santos Fontenelle[a], Wilder Hernando Ortiz Vega[e], Danielle Cavalcanti Sales[f], Arthur Pereira Sales[g], Maria Samires Martins Castro[h], Paula Toro-Mujica[i], Angela Maria de Vasconcelos[a]

[a] *State University of Acaraú Valley (UVA), Center of Agricultural and Biological Science (CCAB), Sobral, CE, Brazil*
[b] *University of Sao Paulo (USP), "Luiz de Queiroz" College of Agriculture (ESALQ), Department of Animal Science, Piracicaba, SP, Brazil*
[c] *Federal Rural University of Pernambuco (UFRPE), Department of Animal Science, Recife, PE, Brazil*
[d] *Federal University of the Semiarid (UFERSA), Department of Animal Science, Mossoró, RN, Brazil*
[e] *University Center - UNINTA, Department of Veterinary Sciences, Sobral, CE, Brazil*
[f] *State University São Paulo (UNESP), Department of Animal Science, Jaboticabal, SP, Brazil*
[g] *University of Pécs, Faculty of Business and Economics, H-7622, Pécs, Hungary*
[h] *Federal University of Viçosa (UFV), Department of Animal Science, Viçosa, MG, Brazil*
[i] *Institute of Agrifood, Animal and Environmental Sciences, O'Higgins University, San Fernando, Chile*

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ABSTRACT

Smallholder dairy farms (SDF) producers are being challenged by market demands combined with competition and limited access to productive and market inputs, contributing for reducing its participation in the dairy activity. Thus a sustainability assessment for SDF development is necessary, opening the opportunity for recognizing the diversity between production systems. Farm typologies are often used for this purpose. The objective was to develop a typological analysis of the smallholder dairy farms in the Brazilian semiarid region and evaluate characteristics of raw milk and water used in milking. A semi-structured questionnaire containing social, physical, livestock, herd management, technological, productive, and economic indicators with 49 variables was applied in 28 SDF. Of these, 23 were selected, and collections of milk and water used for milking management were performed. Three multivariate analysis techniques were used: exploratory factor analysis, hierarchical cluster analysis, and canonical discriminant analysis. Three production systems have been identified: *Conventional system*: Mature illiterate and rural farmers, small herds and farms, low technological level, less intensive management, and low milk production with *in nature* marketing (15 farms; 53.6%); *Traditional system*: Mature farmers with basic education, farms managed with hired labor, large herds and areas, extensive management, low technological level, high production of milk for the manufacture of cheese (6 farms; 21.43%); and *Emerging system*: Young farmers with a high level of education, small herds and farms, intensive management, intermediate technological level, and high milk production and productivity with *in nature* marketing (7 farms; 25.0%). The social, physical, livestock, herd management and technological, and productive indicators showed discriminatory power ($P < 0.05$) to differentiate the typologies. Milk and water traits were similar ($P > 0.05$) among the production systems. The average values of the milk composition are in the threshold of the Brazilian legislation, unlike the somatic cell count (CSS) and standard plate count (SPC). Antibiotic residue was not found in milk from any SDF.The water used in milking management was characterized by high counts of aerobic mesophilic bacteria and total and thermotolerant coliforms, hard water, and neutral pH. For the continuity of SDF in the Brazilian semiarid, it is essential (*i*) participation of young people in the sector; (*ii*) feed planning for the dry period; (*iii*) herd health calendar according to legislation; (*iv*) water treatment (chlorination) and use of alkaline detergent

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Abbreviations: PC, Princiapal component.

[*] Corresponding author. University of Sao Paulo (USP), "Luiz de Queiroz" College of Agriculture (ESALQ), Department of Animal Science, Piracicaba, SP, Brazil.
E-mail address: robsonmateus1994@hotmail.com (R.M.F. Silveira).

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for use in milking management, and (*v*) formal marketing of milk and its derivatives. Finally, our results can be used to inform and support public decision-makers responsible for the formulation and implementation of livestock development policy in the Brazilian semiarid region and being useful for other drylands.

Abbreviations

AR	Antibiotic residues
IBGE	Brazilian Institute of Geography and Statistics
CFU	Colony-forming unit
CDA	Canonical discriminant analysis
DDE	Defatted dry extract
EFA	Exploratory factorial analysis
FAO	Food and Agriculture Organization
HCA	Hierarchical cluster analysis
KMO	Kaiser Meyer Olkin
MPN	Most probable number
MAB	Mesophilic aerobic bacteria
MAPA	Ministry of Agriculture, Livestock, and Supply
NI	Normative Instructions
SDF	Smallholder dairy farms
SCC	Somatic cell count
SPC	Standard plate count
TTC	Thermotolerant coliforms
TC	Total coliforms
TS	Total solids
USGS	United States Geological Survey

1. Introduction

Smallholder dairy farms (SDF) support more than 150 million families worldwide [Food and Agriculture Organization (FOA, 2020)] and are located mainly in developing countries. Brazil is the fifth largest milk producer in the world (FOA, 2020), in which the South and Southeast regions are responsible for 69.9% of production, followed by the Midwest (11.9%), Northeast (11.6%), and North (6.5%) [Brazilian Institute of Geography and Statistics (IBGE, 2017)]. Brazilian dairy farming is formed by more than 60.0% of family farmers (Mendonça et al., 2020), especially in the Northeast. This region has 1.542,000 km^2, about 18.3% of the national area, and it is the most densely populated semiarid zone globally (Marengo et al., 2017) with the highest index of rural exodus in Brazil (Alves et al., 2011). The region is characterized by climatic aridity, water scarcity, unpredictable rainfall, poor soils, and high temperatures throughout the year (Silva Neto and Marquesan, 2020).

Dairy production systems present social, cultural, and economic importance in drylands, as they contribute to food security, nutrition, and the source of income for families. Studies carried out in South America (de Oliveira et al., 2013; Balcão et al., 2017), Central America (Rangel et al., 2020), Asia (Alqaisi et al., 2014), and Africa (Kamau et al., 2018; Yerou et al., 2019) to characterize dairy farming in these climatic zones as an activity managed by farmers over the age of 50 years and with a low level of education, dual-purpose (meat and milk), precarious technical assistance, inputs with high costs, and handling of milking without adoption of hygiene practices. The relationship of these factors contributes to low milk production combined with high microbiological counts and antibiotic residues in the milk, which can compromise consumers' health.

The composition of milk is the result of physiological, genetic, climatic, and nutritional factors (Stürmer et al., 2018). At the same time, the hygienic-sanitary characteristics are mainly related to prophylactic measures, milking management, animal health, and the quality of the water used in milking management (Castro et al., 2021a). Thus, the production, composition, and quality of milk are related to the production system indicators, mainly with the physical-structural, herd management, livestock (genotype), and even the social indicator, since farmers with a greater level of education are more susceptible to the adoption of technologies in production systems (Mendonça et al., 2020; Silveira et al., 2021). The economic indicator, on the other hand, is related to the production and milk quality, as payment is made according to the quality standards and composition of the raw material established by the industry based on the legislation.

In Brazil, Normative Instructions (NI) 76/2018 and 77/2018 define the criteria for raw milk production, quality, and composition [Ministry of Agriculture, Livestock, and Supply (MAPA, 2018a,b)]. Failures to meet these institutional and market demands for milk quality lead farmers, especially those on a smaller scale of production, to operate in the informal market and often even abandon dairy farming (Bánkuti et al., 2020) especially smallholder dairy farms in the Brazilian semi-arid region, as these are managed by family labor with limited financial resources, without access to technology and professional technical assistance to efficiently manage the dairy farm (Aguiar et al., 2020). Consequently, the sustainability of SDF is a major concern in the Brazilian semiarid region. Despite this, no investigation has been carried out to date to assess the sustainability of these farms empirically. In this sense, sustainability assessment is a key step in constructing sustainable production systems (Stylianou et al., 2020). Before any sustainability assessment and/or any effort to develop the livestock sector, recognizing the diversity of SDF is essential (Kamau et al., 2018). Given this, *a priori*, it is necessary to understand and capture the heterogeneity of these farms. A simple tool is the definition of a typology of farms (Toro-Mujica et al., 2020; Bánkuti et al., 2020; Silveira et al., 2021), evaluating the composition and quality of the milk of each typology, aiming at increasing the net income through the insertion of these farms in the formal market, which guarantee the medium and long term sustainability.

This study conducted to develop a typological analysis of the smallholder dairy farms in the Brazilian semiarid region and evaluate characteristics of raw milk and water used in milking.

2. Materials and methods

The data were collected and analyzed in two steps:

(i) A questionnaire with 49 questions was applied to farmers of 28 SDF. These data were subsequently analyzed with exploratory statistics for the description of general farming systems and multivariate analysis to construct a smallholder farm systems typology;
(ii) A subsample of 23 SDF was randomly selected to collect raw milk and water used for milking management based on the typology.

2.1. Sampling and area of the study

A sampling of 28 SDF situated in *Ceará* state, Brazil, was used for the typology analysis. The climate of the region is Bsh (B - Dry, s- Semiarid, and h-low latitude - Köppen Climatic Classification) (Alvares et al., 2013). The predominant relief of the region is composed of plains with generally shallow and rocky soils, characterized by low levels of organic matter and fertility (Silveira et al., 2018). The predominant natural vegetation is represented per *Caatinga* biome, rich in forage species in its three strata: herbaceous, shrub, and arboreal.

2.2. Data collection and processing

The variables selected for the questionnaires were defined by extension technicians, dairy farmers, and specialized in dairy production systems as performed by Silveira et al. (2021). Information on farms and farmers on collections results from the application *in loco* of a structured questionnaire with categorical and continuous variables. First, the study project was presented to the farmers, including the objectives and goals. Posteriorly, we asked if he was interested in collaborating by participating in the study. If so, the questionnaire was applied. As a selection criterion, the interviews were conducted only on the farm with the farmers or technicians responsible for the farm. Only two farmers refused to participate in the study.

The interview was made through formal conversation and divided into six blocks of indicators: *i)* social, *ii)* physical and infrastructure, *iii)* livestock, *iv*) herd management and technological, *v)* productive, and *vi*) economic. After completing the questionnaire, a technical visit to the farm was conducted for the reliability of the information collected. The interview time was between 1 and 3 h for each farmer. All interviews were conducted by an agricultural technical from March 2017 to September 2017. The answers were registered on forms and transferred to a spreadsheet. The classification of variables together with their descriptive statistics [quantitative (minimum, median, interquartile range, and maximum) and qualitative (simple frequency)] according to the indicators under study are presented in Table S1 – Supplementary material.

The equipment indexes, dairy cow disposal criteria and preventive health were defined using a scale of scores varying according to the minimum and maximum number of variables recorded in the farmers responses as used in other studies of farm typologies (Gelasakis et al., 2017; Silveira et al., 2021; Castro et al., 2021a). For example, when applying the questionnaire we found that Farm X had "n" equipment, so that would be the score on that farm. The minimum and maximum scores were defined based on the lowest and highest scores of the farms sampled, respectively. For the control of the preventive health program for herds, a vaccination program against diseases such as: endoparasites and ectoparasites, clostridiosis, rabies, and foot-and-mouth disease was adopted, while for the disposal criteria score, 6 criteria were adopted (infertility, reproduction, lost roof, milk production, productive age, and mammary gland health). Finally, the equipment index was considered 6 types of equipment (tractor, animal-drawn wagon, forage harvester, hydraulic pump, threshing machine, and silage machine). The creation of scoring programs was used with the objective of synthesizing several variables in just one index, simplifying the information in the typological analysis, and later in the discussion and characterization of farm typologies.

2.3. Laboratory collection and analysis

2.3.1. Water milking

The water samples were collected in 1 L amber glass bottles in the milking room, which is the representative water that is used by the farmers (Ramires et al., 2009). When there was no tap in the place, a point was sought that represented the water used in the handling of milking. The bottles were sterilized in a vertical autoclave (AV-75, Phoenix, *Piracicaba*, Brazil). After collection were transported using an isothermal box with recyclable ice (maximum temperature of 10 °C) to perform the microbiological and physicochemical analyses of the water.

The total coliforms [TC; (Most probable number - MPN. 100 mL^{-1}] and thermotolerant coliforms (TTC; MPN 100 mL^{-1}) were determined by the Multiple Tubes method. While mesophilic aerobic bacteria [MAB; (Colony-forming unit – CFU. mL^{-1}] were quantified using the "Pour Plate" technique. Both methods were performed as proposed by the American Public Health Association (APHA, 2015). The pH was measured through a potentiometer (AB200 Fisher Scientific™, USA) coupled to the pH indicator glass electrode (Quimis, *São Paulo*, Brazil). Water hardness (mg. L^{-1}) was determined by volumetry using previously standardized ethylenediaminetetraacetate anion (Adolfo Lutz, 2008).

2.3.2. Raw milk

Bulk raw milk was collected in 300 mL aliquots directly from the brass metal after milking is finished and later transferred to a specific bottle for milk analysis. Samples for determination of somatic cell count (SCC) and composition contained Bronopol® (2-bromo-2-nitro-1,3-propanediol) preservative tablet, for standard plate count (SPC) Azidiol® (sodium azide and chloramphenicol), and for antibiotic residues (AR) without bacteriostatic preservatives. Milk samples for analysis of AR were frozen.

The fat (%), protein (%), lactose (%), total solids (TS, %), and defatted dry extract (DDE, %) were determined by near-infrared reflectance spectroscopy (MilkoScan™ Minor Type 78,100, Foss Electric A/S. Hillerod, Denmark). The SCC (cells. mL^{-1}) was determined by Fourier-transform infrared spectroscopy (Fossomatic™, Foss Electric A/S, Hillerod, Denmark), and the SPC (CFU mL^{-1}) by flow cytometry (MicroFoss™ 32 system, Foss Electric A/S, Hillerod, Denmark). The detection of AR (negative or positive) was made by commercial Delvotest-P kits (DSM Food Specialties Dairy Ingredients, Heerlen, Netherlands).

2.4. Statistical methods

Data were analyzed using SPSS® (Chicago, USA) (SPPS, 2011) in seven successive steps:

Step 1st. [*Choice of variables*] The selection of variables was based on an extensive literature review (Gelasakis et al., 2017; Bánkuti et al., 2020; Silveira et al., 2021; Castro et al., 2021a) together with the three criteria: (*i*) availability, (*ii*) quality and (*iii*) relevance proposed by Köbrich et al. (2003). The productive and economic variables were not used in the typological analysis, since milk production results from physical, livestock and herd management factors (Fig. 1), and not a criterion for the classification of farms. The selected variables are shown in Table S_1- Supplementary material.

Step 2nd. [*Variables reduction*] Exploratory factorial analysis (EFA) was performed to reduce the number of variables. EFA is an interdependence technique used to reduce a large set of variables into factors or indicators (Hair et al., 2009). The factor analysis model is expressed by Eq. (1):

$$\begin{aligned} X_1 &= a_{11} \times F_1 + a_{12} \times F_2 + \cdots + a_{1m} \times F_m + e_p \\ X_2 &= a_{21} \times F_2 + a_{21} \times F_2 + \cdots + a_{2m} \times F_m + e_p \\ &\vdots \\ X_p &= a_{p1} \times F_1 + a_{p1} \times F_2 + \cdots + a_{pm} \times F_m + e_p \end{aligned} \tag{1}$$

where X_p is the pth score of the standardized variable (p = 1, 2, …, m), F_m is the extracted factor, a_{pm} is the factor loading, and e_p is the error.

Factor scores for each group were estimated by multiplying standardized variables by the coefficient of the corresponding factor score, as follows Eq. (2)

$$\begin{aligned} F_1 &= d_{11} \times X_1 + d_{12} \times X_2 + \cdots + d_{1j} \times X_{jp} \\ F_2 &= d_{21} \times X_2 + d_{21} \times X_2 + \cdots + d_{2j} \times X_{jp} \\ &\vdots \\ F_j &= d_{p1} \times X_1 + a_{j1} \times X_2 + \cdots + d_{jp} \times X_{jp} \end{aligned} \tag{2}$$

where: F_j is the j-th factor extracted, d_{pj} is the factor score coefficient, and p is the number of variables (Hair et al., 2009). EFA was carried out individually using indicators (social, physical and infrastructure, livestock, and herd management and technological). This procedure was performed to capture the maximum variation of the data for constructing the typology. Principal components with eigenvalues greater than 1 (Kaiser's rule; Kaiser, 1960) were used in the successive hierarchical cluster analysis (HCA). The Kaiser–Meyer–Olkin (KMO) criterion

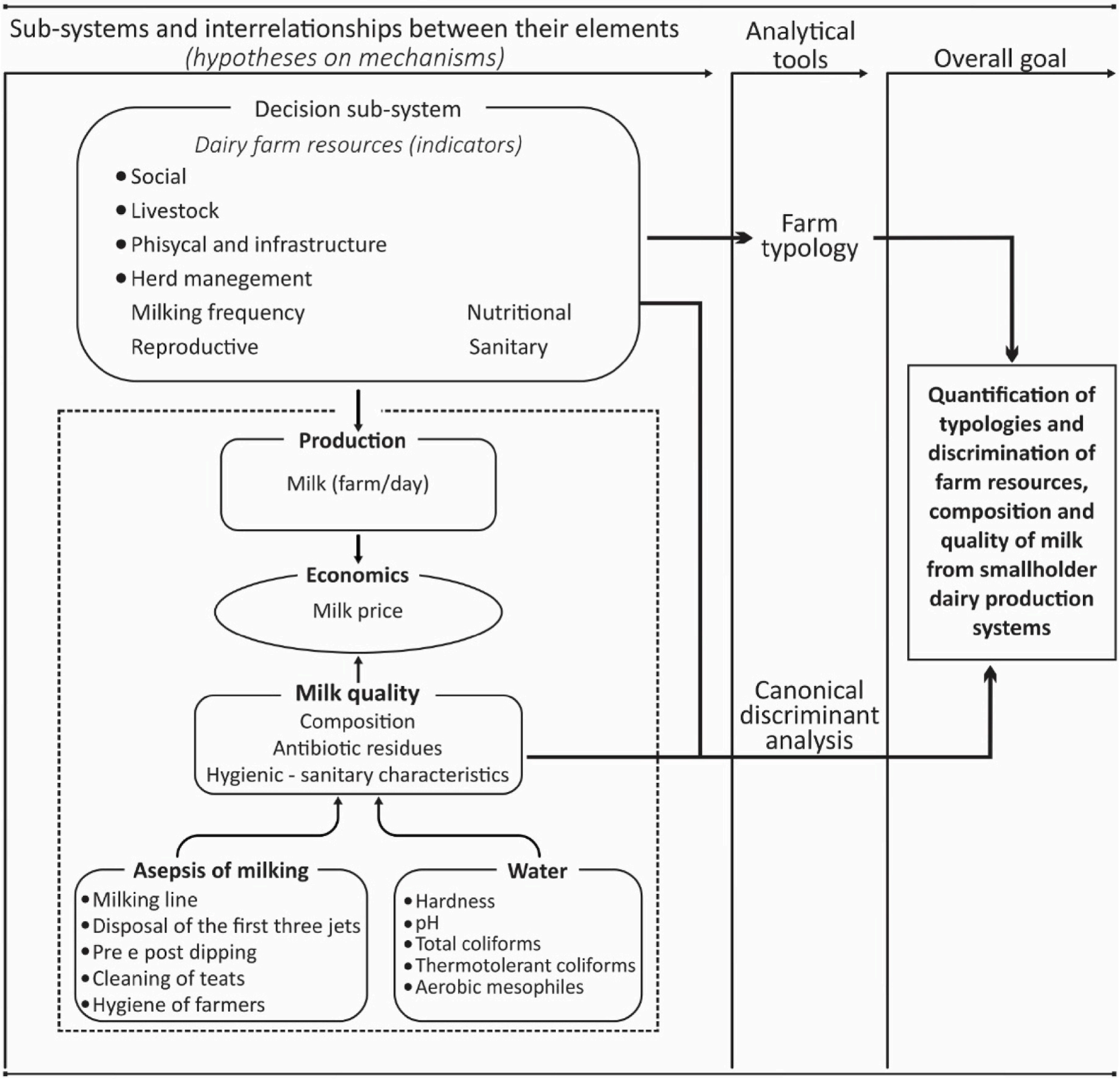

Fig. 1. A conceptual model of the relationship between the indicators of the dairy production system and milk quality, analytical tools and the general objective of their analysis.

and Bartlett's sphericity test were met according to Hair et al. (2009). The rotated component matrix was developed using orthogonal rotation, varimax method.

Step 3rd. [*Number of typologies*] The HCA aimed to group farms into typologies according to their degree of similarity. The model used for hierarchical clustering is described in Eq. (3).

$$d\,[k,\ (i,\ j)] = max\,[\,d\,[\,k, i),\ d\,(k,\ j)] \tag{3}$$

This agglomerative algorithm calculates the shortest distance between elements i and j using the distance matrix dij (Hair et al., 2009). The elbow rule based on Ward method (Ward, 1963) was used in order to decide the most appropriate number of clusters and the Euclidean distance was used as a measure of dissimilarity. To assess the ideal number of clusters, it was necessary to plot the number of clusters against the change of the fusion coefficient for each stage (each stage reflects a combination between 2 clusters) and find the 2 stages with the highest jump in the difference between their distance coefficients (Gelasakis et al., 2012). This was obvious for stages 24 and 25 (Table S_2-Supplementary material). Afterwards, the number of stages (n = 25) was subtracted from the number of observations (n = 28); the result indicated the ideal number of clusters (n = 3).

Step 4th. [*Comparisons between typologies*] First, it is tested the assumptions of homogeneity of variances using Levene's test, normality of the errors using the Shapiro-Wilk's test, and presence of outliers using a box-plot graph. Most of the variables of the quantitative variables did not present residues with normal distribution and normality test. For this reason, non-parametric Kruskal-Wallis analysis was chosen using the median as a measure of central tendency, as it is not affected by extreme values. For categorical variables, the differences between groups were estimated using the Chi-square (χ^2) test with Bonferroni correction. A significance level of 5% was adopted.

Step 5th. [*Discriminatory power of indicators/variables*] Canonical discriminant analysis (CDA) was carried out to discriminate the main variables that differentiate the typologies and which indicators have discriminatory power. The general model of the CDA is described in the Eq (4)

$$Z_n = \propto + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n \tag{4}$$

where: Z_n is the dependent variable (typologies), $\propto$ is the intercept, X_i are the explanatory variables, and β_i is the discriminant coefficients for each explanatory variable. For this, it was used the stepwise method, which is indicated when the researcher has a large number of variables for inclusion in the function. The discriminant power was evaluated by % of variance, Wilks' Lambda statistic, and standardized coefficients.

Step 6th. [*Milk and water*] The data on the characteristics of milk and water were stratified in order to identify the effect of typologies that comply or not with the legislation as carried out by Balcão et al. (2017). The milk data were stratified according to the minimum (composition) and maximum (hygienic-sanitary traits) limits established by NI 76 and 77/2018 (MAPA, 2018a,b). While the microbiological traits of the water were stratified (absence/presence) according to Concierge 2914/2011 (Ministry of Health, 2011). The water was classified in relation to hardness as: soft (0–60 mg L^{-1}), moderately hard (61–120 mg. L^{-1}), hard (121–179 mg. L^{-1}) and very hard ($>$ 180 mg. L^{-1}) according to the report United States Geological Survey (U.S. Geological Survey, 1977). Ultimately, pH water was classified as acid ($0 \leq 5.90$), neutron ($\geq 6.0 \leq 8.90$) and alkaline ($\geq 9.0 \leq 14.0$). The differences between typologies were estimated using the χ^2 test with Bonferroni correction ($P < 0.05$). We also evaluated the effect of the typology on of milk and water traits. The microbiological traits of the water (TC and TTC) and hygienic-sanitary (SCC and SPC) of the milk were transformed into a logarithmic scale ($y = \log_{10} x$). The differences between typologies were estimated using analysis of variance (ANOVA) and compared using the Tukey test ($P < 0.05$).

Step 7th [*Discrimination of milk and water characteristics according to typologies]* The CDA was used to discriminate whether the characteristics of milk and water according to typologies defined in Step 3rd. The CDA was performed using the simultaneous method and the same criteria were used to determine the discriminatory power as described in Step 5th. A graph with the first two discriminant functions was plotted for all indicators, raw milk, and water traits.

3. Results

3.1. Main descriptors for dairy farm classification

The summary, presupposition, explained variance, and factorial loads of the EFA are shown in Table 1. Livestock indicator explained the greatest variation in data (85.01%), followed by social (79.54%), herd management (72.01%), and physical and infrastructure (71.29%), considered the most important indicators for classifying farms into types in terms of order of importance, were livestock < social < herd management < physical and infrastructure.

In the social indicator, the first PC pointed to a positive relationship between the source of information and education, but with negative correlations for the farmer's age, which is the older and less educated farmers. In the physical and infrastructure indicator, the most prominent variables were native and cultivated pastures and grain production; and the livestock indicator was dairy cow and animals bred (ruminant polyculture). Finally, in herd management and technology indicators, where the most important variables were zootecnhinical bookkeeping, milking quantity, discard criteria program, feed balancing, and parturition intervals. The forage conservation: deferred grazing explained on average ≅ 15.5% of the variation of the data. Variables such as

Table 1

Factors selected in the factor analysis, eigenvalues, partial and cumulative variances and correlation coefficients of the variables with the corresponding factor for each indicator of the smallholder dairy farms in the Brazilian semi-arid region.

Indicators	Presupposition		Components	Eigenvalue; % explained variance; (% cumulative variance)	Observed variables	Correlation coefficients	Communality
	KMO criterion	Bartlett test (*P* – value)					
Social	0.509	<0.001	1st	2.10 41.93 (41.93)	Main source of information	0.85	0.79
					Education	0.71	0.80
					Farmers's age	- 0.92	0.86
			2nd	1.88 37.61 (79.54)	Farm administration	0.94	0.88
					Occupation	0.79	0.65
Physical and infrastructure	0.670	<0.001	1st	2.89 48.18 (48.18)	Native pasture [a]	0.91	0.84
					Cultivated pasture	0.89	0.81
					Grain production[b]	0.67	0.72
			2nd	1.39 23.11 (71.29)	Facilities age	−0.80	0.66
					Equipament score[c]	0.71	0.64
					Fodder production[d]	0.76	0.62
Livestock	0.515	<0.001	1st	2.40 58.97 (58.97)	Dairy cow (n)	0.97	0.94
					Lactation cow (n)	0.92	0.88
					Bulls (n)	0.76	0.62
			2nd	1.04 26.04 (85.01)	Bred animals	0.98	0.96
Herd manegement	0.524	<0.001	1st	3.43 42.85 (42.85)	Zootecnhnical boookkeeping	0.79	0.77
					Milking quantity	- 0.79	0.68
					Discard criteria program[f]	- 0.79	0.74
					Feed balancing	0.79	0.76
					Parturition intervals	0.80	0.67
			2nd	1.24 15.49 (58.34)	Forage conservation: Deferred grazing	0.82	0.74
			3rd	1.09 13.67 (72.01)	Preventive health program score[e]	0.58	0.64
					Herd replacement	- 0.74	0.83

[a] Area covered by native vegetation with preservation of water resources, landscape, geological stability and biodiversity.

[b] Area intended for planting grass, mainly elephant grass (*Pennisetum purpureum*, Schum.), sugarcane (*Saccharum officinarum*) and canarana (*Echinochloa pyramidalis*).

[c] A score ranging from 0 to 6 was assigned according to the available equipment (tractor, animal-drawn wagon, forage harvester, hydraulic pump, threshing machine and silage machine).

[d] Area intended for planting crops, mainly with corn (*Zea mays*) and beans (*Phaseolus vulgaris*).

[e] A score ranging from 1 to 4 was assigned according to the available e herd preventive health program (a program of vaccination against diseases caused by against diseases such as endoparasites and ectoparasites gastrointestinal, foot-and-mouth disease, rage, and clostridiosis).

[f] A score of 0–6 was assigned according to the criteria for disposal of dairy cows established by the farmers (infertility, reproduction, lost roof, milk production, productive age and mammary gland health).

preventive health program score and herd replacement were of little importance for classifying farms.

3.2. Smallholder dairy farm typology

Three smallholder dairy production systems: conventional, traditional, and emerging were identified. These three systems are represented by 15 (53.6%), 6 (21.4%), and 7 (25.0%) farms in the total sample, respectively, and the dynamics of the grouping of these systems are shown in Fig. 2.

The median ± interquartile range (IQR) and frequencies (%) for continuous and categorical variables, respectively, and statistical differences between the typologies are shown in Tables 2 and 3. The variables of the indicators: social (marital status, farmer membership, and succession in dairy farming); physical and infrastructure (energy and facilities age); livestock (bulls number, cows breed, and bred animals); herd management and technological (preventive health program score, weaning age, forage conservation: silage and hay, reproductive management, mineral supplementation, herd replacement, milking line, milking type, asepsis practices for milking management, milk heat treatment, knowledge of milk quality legislation); and economic (price milk) was similar ($P > 0.05$) between the typologies.

According to the differences and similarities found between the smallholders dairy productions systems obtained, it is possible to describe them as follows:

1. *Conventional System*: Mature, illiterate rural farmers, small herds and areas, low technological level, less intensive handling, and low milk production with *in nature* marketing (15 farms; 53.6%)

A mature farmer with greater frequency ($P < 0.05$) of illiteracy, residence in the countryside, and the main source of information was TV. This system had the lowest frequency ($P < 0.05$) of entrepreneurial farmers (Table 3). Smaller areas of grain production, native and cultivated pastures, and lower scores in the equipment program ($P < 0.05$). The median herd consisted of 11 cows, 6 in lactation, and one male breeder. Milk production was the lowest ($P < 0.05$) with a median of 35.00 L farm^{-1}, but with productivity similar ($P > 0.05$) to the traditional system.

2. *Traditional System:* Mature farmers with basic education, farms managed with hired labor, large herds and areas, extensive management, low technological level, high production of milk for the manufacture of cheese (6 farms; 21.43%)

Mature farmers aged similar ($P > 0.05$) to the conventional system, but with higher ($P < 0.05$) education. The frequency of farms managed by contracted labor was higher ($P < 0.05$) than the conventional system, together with entrepreneurial farmers and residents in the urban zone (Table 3). This system has larger ($P < 0.05$) areas of native and cultivated pastures, grain production, and the number of cows (total and lactation). Feed balance, zootechnical bookkeeping, milking quantity, and milk productivity were similar ($P > 0.05$) to the conventional system, but with greater ($P < 0.05$) milk production. This system showed a greater frequency ($P > 0.05$) of farms intended for the manufacture of cheese.

3. *Emerging System*: Young farmers with a high level of education, small herds and areas, intensive management, intermediate technological level, and high milk production and productivity with *in nature* marketing (7 farms; 25.0%)

Young farmers ($P = 0.003$) with a high level of education ($P < 0.05$). Areas with native and cultivated pastures were similar ($P > 0.05$) to the conventional system but the area of grain production and the equipment program score, family labor and number of cows (total and lactating) did

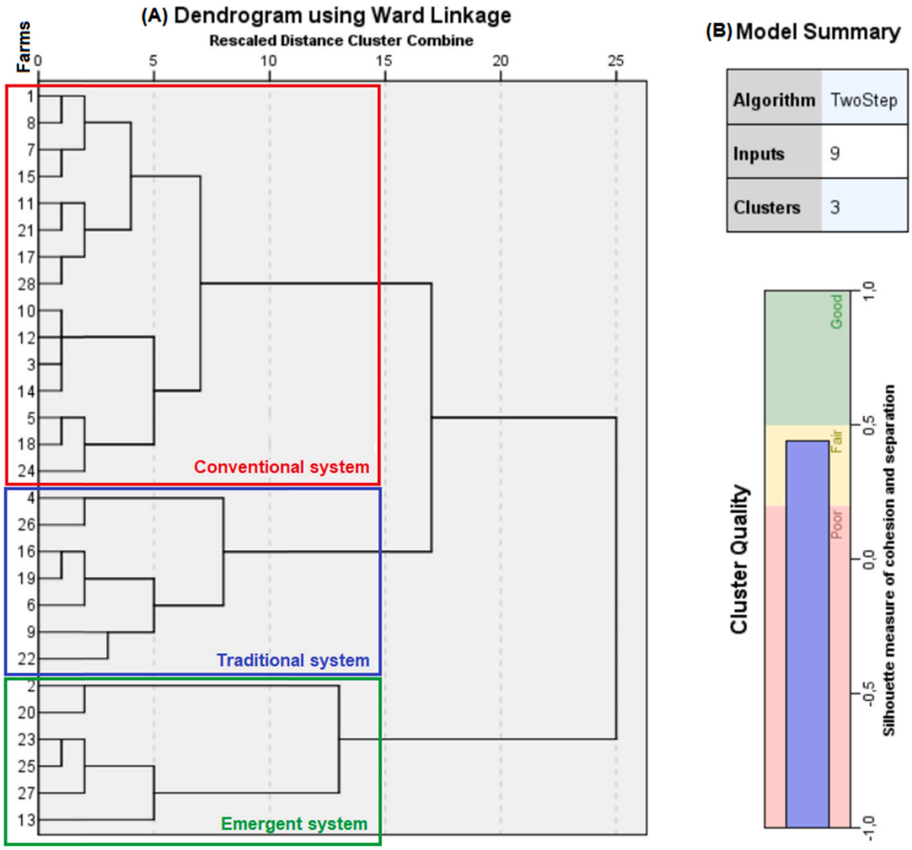

Fig. 2. Dendrogram for hierarchical cluster using the Ward method (A) and goodness-of-fit measure of the number of clusters through two-step cluster (B) for the three smallholder dairy production systems in the Brazilian semiarid region. **Note:** Model summary *Inputs*: 9 is the sum of the principal component (PC) in the exploratory factorial analysis (EFA) (2 PC, social indicator; 2 PC, physical indicator; 2 PC, livestock indicator and 3 PC, herd management indicator) (Table 1).*Clusters*: 3 was determined by Ward method, elbow rule (Ward, 1963) (Table 1 Supplementary material).

Table 2
Median ± interquartile range (IQR) for continuous variables in the three smallholder dairy production systems and comparisons between them (n = 28 farms).

Indicators	Variables	Smallholder dairy production systems						*P* - value
		Conventional		Traditional		Emergent		
		(n = 15 farms)		(n = 6 farms)		(n = 7 farms)		
		Median	IQR	Median	IQR	Median	IQR	
Social	Farmers's age (years)	60.00^{a}	17.00	54.50^{a}	18.50	35.00^{b}	8.00	= 0.014
Physical and infrastructure	Use land (ha):							
	Native pasture [a]	0.00^{b}	5.00	60.00^{a}	77.50	1.00^{b}	20.00	= 0.009
	Crop production [b]	2.00^{b}	2.50	5.00^{a}	3.00	4.00^{ab}	3.50	= 0.009
	Cultivated pasture	26.00^{b}	30.00	145.00^{a}	109.50	20.00^{ab}	160.00	= 0.019
	Fodder production[c]	0.50^{a}	3.00	3.00^{a}	6.50	2.00^{a}	3.00	= 0.164
	Equipament score [d]	2.00^{b}	0.00	4.50^{a}	2.50	4.00^{a}	2.00	<0.001
Livestock	Bulls (n)	1.00^{a}	0.00	1.00^{a}	1.25	1.00^{a}	1.00	= 0.228
	Dairy cow (n)	11.00^{b}	8.00	25.50^{a}	11.50	15.00^{b}	7.00	= 0.009
	Lactation cow (n)	6.00^{b}	4.00	15.00^{a}	6.00	8.00^{b}	4.00	= 0.009
Herd management	Preventive health program score (1–4) [¥; e]	3.00^{a}	1.00	2.50^{a}	2.00	3.00^{a}	2.00	= 0.221
	Discard criteria program (1–6) [f]	2.00^{b}	2.00	2.00^{b}	1.00	5.00^{a}	2.00	<0.001
	Milking quantity (n)	1.00^{b}	1.00	1.00^{b}	0.25	2.00^{a}	0.00	= 0.013
	Weaning age (months)	9.00^{a}	3.00	9.50^{a}	5.00	8.00^{a}	2.00	= 0.123
	Sexual precocity (months)	25.00^{a}	7.00	29.50^{a}	9.00	18.00^{b}	1.00	= 0.017
	Parturition intervals (months)	18.00^{b}	3.00	17.50^{b}	2.50	15.00^{a}	2.00	= 0.006
Production	Milk productividy (L day^{-1} $farm^{-1}$)	5.22^{b}	2.17	5.83^{b}	2.22	9.50^{a}	2.75	= 0,009
	Milk production (L day^{-1} cow^{-1})	35.00^{b}	20.00	97.50^{a}	81.00	70.00^{a}	35.00	<0.001
	Milk production for hectare (L $farm^{-1}$)	1.50^{a}	3.07	0.47^{b}	0.79	4.60^{ab}	7.27	= 0.019
Economic	Milk price (US$) [g]	0.75^{a}	0.15	0.60^{a}	0.17	0.75^{a}	0.00	= 0.638

[ab] Different letters on the same line indicate significant difference by the Kruskal Wallis test with 5% probability.

[a] Area used covered by native vegetation with preservation of water resources, landscape, geological stability and biodiversity.

[b] Area used intended for crop production, mainly with corn (*Zea mays*) and beans (*Phaseolus vulgaris*).

[c] Area used for cut-and-carry forage production, mainly elephant grass (*Pennisetum purpureum*, Schum.), sugarcane (*Saccharum officinarum*) and canarana (*Echinochloa pyramidalis*).

[d] A score ranging from 1 to 6 was assigned according to the available equipment (tractor, animal-drawn wagon, forage harvester, hydraulic pump, threshing machine and silage machine).

[e] A score ranging from 1 to 4 was assigned according to the available e herd preventive health program (vaccination against diseases caused by against diseases such as endoparasites and ectoparasites gastrointestinal, foot-and-mouth disease, rage, and clostridiosis).

[f] A score of 0–6 was assigned according to the criteria for disposal of dairy cows established by farmers (infertility, reproduction, lost roof, milk production, productive age and mammary gland health).

[g] Price receipt value in real (Brazilian coin - R$) where 1 real = 0.319 - Annual quotation of the dollar (US$) in 2017.

not show difference ($P > 0.05$) compared to the traditional system. This system showed earlier animals ($P = 0.017$) with cows with a shorter calving interval ($P = 0.006$). The farmers of this system milked cows with higher productivity ($P = 0.002$) more frequently ($P = 0.002$). Milk production (total and for hectare) is similar ($P > 0.05$) to the traditional system, but with higher percentages of farmers who sell the *in nature* milk.

3.3. Differentiation of smallholder dairy production systems

The classification of farms in their group of origin, the summary of the CDA, and the main variables responsible for discriminating the typologies according to indicators are shown in Table 4. All indicators individually, except the economic, differentiate ($P < 0.01$) the three systems of production. The farms of the conventional system had a higher rate of classification in all indicators under study. No single indicator correctly classified 100% of the farms in the emerging and/or traditional system, except for the production and livestock indicators. The main variables that presented discriminatory power according to the indicators were: social (source of information, farmer's age, and education); physical and infrastructure (equipment score and native pasture); livestock (dairy cow); herd management (discard criteria program and forage conservation: deferred pasture) and productive (production, aptitude of production, and productivity). 100.0% of the farms were correctly classified in their home group when all indicators were used simultaneously (Fig. 3A). The dairy cow, source of information, cultivated pasture, and productivity were responsible for determining 100% of the variation between the three smallholder dairy production systems (Table 4).

3.4. Milk and water the of milking management

The stratification of the traits of milk and water according to the thresholds established by the legislation and the effect of the typology on these traits are shown in Table 5. The composition and sanitary-hygienic traits of milk together with the microbiological and chemical traits of the water used in the milking management, regardless of the milk production systems that meet or not the thresholds, did not differ ($P > 0.05$) among typologies, that is, the farms the three systems need to adapt to comply with the limits established by IN aiming at the commercialization of milk formally, mainly for the hygienic-sanitary traits of milk (SCC and SPC). It did not see antibiotic residues in raw milk on any farm. The water source was similar among ($P = 0.19$) typologies with 89.9% without water treatment. The presence of MAB was observed in 82.6% and TC and TTC in 100% of the samples, which makes the water unsuitable for use in milking management. The water was classified as very hard (> 180 mg. L^{-1}) and hard (121–179 mg. L^{-1})) in 34.8% and 13.0% of the farms, respectively. The 73.8% of the water was classified as neutral pH ($\geq 6.0 \leq 8.90$), which is recommended.

All milk and water traits were similar ($P > 0.05$) among the three smallholder dairy production systems. Finally, the plotting of the first two discriminant functions (Fig. 3A) showed that water and milk traits did not show discrimination (Functions 1 and 2: $P > 0.05$; Fig. 3B and 3C) between production systems.

Table 3
Frequencies (%) and comparisons between the three smallholder dairy production systems for categorical variables (n = 28 farms).

Indicators	Variables		Smallholder dairy production systems			*Pearson Chi-Square (P – value)*
			Conventional (n = 15 farms)	Traditional (n = 6 farms)	Emergent (n = 7 farms)	
Social	Education	*Illiterate*	60.00^{a}	0.00^{b}	0.00^{b}	$P = 0.011$
		Literate	13.30^{a}	0.00^{a}	0.00^{a}	
		Elementary school	13.30^{a}	66.7^{b}	14.1^{ab}	
		Higher school	13.30^{b}	16.7^{b}	71.40^{a}	
		High school	0.00^{b}	16.7^{a}	14.30^{a}	
	Married status		86.70^{a}	100.00^{a}	71.40^{a}	$P = 0.337$
	Farmer membership		86.70^{a}	100.00^{a}	71.40^{a}	$P = 0.337$
	Farm administration	*Family workforce*	80.00^{a}	0.00^{b}	57.10^{ab}	$P = 0.044$
		Mão de obra	20.00^{b}	100.00^{a}	42.90^{ab}	
	Occupation	*Rural farmer*	53.30^{a}	0.00^{a}	28.60^{a}	$P = 0.006$
		Retired	40.00^{a}	16.70^{a}	0.00^{a}	
		Entrepreneur	6.70^{b}	83.30^{a}	57.10^{a}	
		Public server	0.00^{a}	0.00^{a}	14.30^{a}	
	Resides	*Urban zone*	26.70^{a}	100.0^{a}	57.10^{ab}	$P = 0.009$
		Countryside	73.30^{a}	0.00^{a}	42.90^{ab}	
	Source of information	*TV*	100.00^{a}	50.00^{b}	14.30^{b}	$P < 0.001$
		Internet	0.00^{b}	50.00^{a}	85.70^{a}	
Physical	Energy	*Single- phase*	60.00^{a}	66.70^{a}	71.40^{a}	$P = 0.865$
		Theree - phase	40.00^{a}	33.30^{a}	28.60^{a}	
	Facilities age	*0-5 years*	0.00^{a}	33.30^{a}	14.30^{a}	$P = 0.136$
		5-10 years	40.00^{a}	0.00^{a}	28.60^{a}	
		> 10 years	60.00^{a}	66.70^{a}	57.10^{a}	
Livestock	Bulls breed	*Zebu*	20.00^{a}	50.00^{a}	0.00^{b}	$P = 0.046$
		Europeu	26.70^{b}	50.00^{ab}	71.40^{a}	
		Mix[2]	53.30^{a}	0.00^{b}	28.60^{ab}	
	Cow breed	*Mix*	46.70^{a}	33.30^{a}	28.60^{a}	$P = 0.681$
		Crossbreed	53.30^{a}	66.70^{a}	71.40^{a}	
	Bred animals	*Only cow*	46.70^{a}	33.30^{a}	57.10^{a}	$P = 0.692$
		Cow, goats, and sheep	53.3^{a}	66.70^{a}	42.90^{a}	
Herd manegement	Feed balance		6.70^{b}	33.30^{ab}	71.4^{a}	$P = 0.007$
	Forage conservation	Deferred grazing	0.00^{a}	33.30^{b}	0.00^{a}	$P = 0.019$
		Silage	13.3^{a}	16.7^{a}	14.3^{a}	$P = 0.981$
		Hay	86.7a	100.0a	57.1a	$P = 0.106$
	Commercial feed supplementation regimes	*None*	0.00^{a}	16.70^{a}	0.00^{a}	$P = 0.018$
		Once a day	73.30^{a}	66.70^{a}	14.10^{b}	
		Twice o day	26.70^{b}	16.70^{b}	85.70^{a}	
	Mineral supplementation		73.30^{a}	100.00^{a}	85.70^{a}	$P = 0.340$
	Reproductive	*Natural mating*	93.30^{a}	100.00^{a}	71.40^{a}	$P = 0.191$
		Artificial insemination	6.70^{a}	0.0^{a}	28.60^{a}	
	Zootechnical bookkeeping		0.0^{b}	33.30^{ab}	57.10^{a}	$P = 0.001$
	Technical assistance		20.00^{a}	50.00^{a}	57.10^{a}	$P = 0.170$
	Herd replacement		86.70^{a}	100.0^{a}	57.10^{a}	$P = 0.106$
	Milking type	*Manual*	100.0^{a}	100.0^{a}	86.70^{a}	$P = 0.211$
		Mechanics	0.00^{a}	0.00^{a}	14.30^{a}	
	Asepsis of milking	*Milking line*	0.00^{a}	0.00^{a}	0.00^{a}	-
		Disposal of the first three jets	0.00^{a}	0.00^{a}	0.00^{a}	-
		Pre e post dipping	0.00^{a}	0.00^{a}	0.00^{a}	-
		Cleaning of teats	0.00^{a}	0.00^{a}	0.00^{a}	-
	Milk heat treatment		0.00^{a}	0.00^{a}	0.00^{a}	-
	Legislation on milk quality[3]		6.70^{a}	0.00^{a}	14.30^{a}	$P = 0.605$
Production	Aptitude	*Cheese*	6.70^{b}	66.70^{a}	0.00^{b}	$P = 0.002$
		In natura milk	93.30^{a}	33.30^{b}	100.00^{a}	

[ab] Frequencies within a row different superscript differ ($P < 0.05$) by Pearson Chi-Square analysis with P- value adjusted by the Bonferroni method.
[1] Continuity of at least one family member to continue in dairy farming.
[2] Cow descended from multiple breeds of the same species, often breeding without any human intervention, recordkeeping or selective breeding.
[3] Normative Instruction N° 77/2018 of the Ministry of Agriculture, Livestock and Supply, *(MAPA),* Brazil (Ministry of Agriculture, Livestock, and Supply, 2018)

4. Discussion

4.1. Classification, characterization, and differentiation of typologies

Smallholders dairy farms produces about 70.0% of the milk consumed by the Brazilian population. According to FOA (2020), the demand for livestock products is expected to grow by up to 50.0% worldwide by the year 2050, but the production challenges of smallholder farms are aggravated by market demands coupled with competition and limited access to productive and market inputs (Hemme and Otte, 2010). Facing these challenges will require planning to build sustainable strategies to guarantee the insertion of these production systems in the market in the face of these challenges, however, it is necessary to know the diversity of these systems and subsequently define sustainable strategies. We have developed typologies of milk production systems integrating participatory and statistical techniques considering structural, dimensional, social, technological and herd management factors. In addition to assessing whether there are variations in the composition and hygienic-sanitary characteristics of milk and in the factors that influence the quality of SDF milk in a semiarid

Table 4
Summary, farm classification and standardized coefficients of the first two canonical discriminant functions.

Indicators	CCC (%)[a]	Classification (%) by smallholder dairy production systems (n) [b]			Variance Explained (%)		Lambda of Wilks[c] (*P*-value)		Main variables[d]
		Conventional (n = 15 farms)	Traditional (n = 6 farms)	Emergent (n = 7 farms)	F_1	F_2	F_1	F_2	
Social	78.6	93.2 (14)	33.3 (2)	85.7 (6)	86.6	13.4	<0.0001	= 0.01	Source of information < Farmer's age < Education
Physical	85.7	100.0 (15)	83.30 (5)	71.40 (5)	97.1	2.90	<0.0001	= 0.064	Equipment score < Native pasture
Livestock	92.9	93.3 (14)	100 (6)	85.7 (6)	95.2	4.80	<0.001	= 0.063	Dairy cow
Herd management and technological	75.0	86.7 (13)	33.3 (2)	85.7 (6)	86.9	13.1	<0.0001	= 0.016	Discard criteria program < Forage conservation: diferido pasture
Production	100.0	100.0 (15)	100.0 (6)	100.0 (7)	71.1	28.9	<0.0001	<0.0001	Production < Production aptitude < Productivity
Mix of indicadors	100.0	100.0 (15)	100.0 (6)	100.0 (7)	77.9	22.1	<0.0001	<0.0001	Dairy cow < Source of informaion < Cultivated pasture < Productivida

[a] Total percentage of cases correctly classified: CCC = cases correctly classified.
[b] Percentage of cases correctly classified by dairy systems production.
[c] Statistic test: discriminat canonical functions (F_1 and F_2) with $P < 0.05$ of Lambda of Wilks were considered significant.
[d] Hierarchy of the variables was according to the values of the standardized coefficients of the first two canonical discriminant functions.

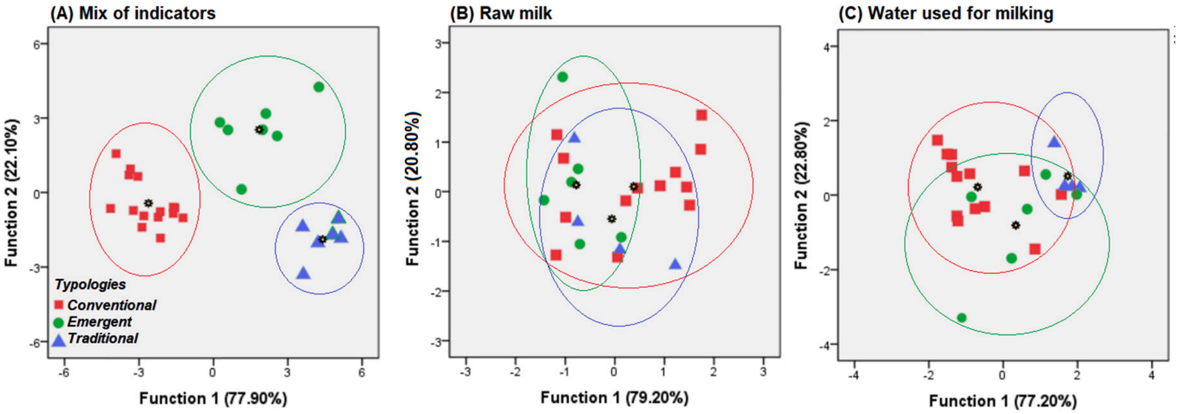

Fig. 3. Biplot of the canonical discriminant analysis (CDA) using mix indicators (A), characteristics of raw milk (B) and water used in the management of milking (C) in smallholder dairy production systems in the Brazilian semiarid region. **Note:** Indicators (social, physical and infrastructure, herd management and technological technological, livestock, production and economic) Milk (fat, %; protein, %; lactose, %, defatted dry extract, %; total solids, %; somatic cell count, cells mL^{-1}; standard plate count, CFU mL^{-1}) and water (total coliforms, MPN 100 mL^{-1}; thermotolerant coliforms, MPN 100 mL^{-1}; mesophilic aerobic bacteria, CFU mL^{-1}; hydrogen potential; hardness, mg L^{-1}).

region.

The adoption of the multivariate approach allowed to capture heterogeneity between the production systems, helping to visualize typologies with different structural and social profiles, herds management, and production objectives. It was identified three typologies of SDF (Fig. 2), from farms with large areas and high production of milk for the manufacture of cheese to smaller farms with low production associated with family farming and fresh marketing. This classification is based on a joint and systematic analysis of specialized methods in typology development (Bánkuti et al., 2020; Toro-Mujica et al., 2020; Silveira et al., 2021). Additionally, we have shown that all indicators, except the economic one (price of milk), had discriminatory power, including social, physical and infrastructure, livestock, productive indicators, and herd management were important to classify the farms into types. Finally, our results showed that the composition and quality of milk and the water traits used in the handling of milking were similar among typologies. We will focus this discussion on the main relevant characteristics to explain the diversity between the typologies in order to define sustainable strategies for the three milk production systems in the Brazilian semiarid region.

4.2. Social indicators

The variables that make up the social indicators were essential to classify and differentiate the farms according to typologies. Although the median age of the farmers was 47 years old, with a low level of education (Table S_1 - Supplementary Material), it was noted that the emerging system is managed by younger farmers aged only ≅ 35 years, with a high level of education (Tables 1 and 2), which corroborates the findings of Moura et al. (2010), that when characterizing the dairy farming systems in the Brazilian semiarid identified a production system with younger farmers (average ≅ 35 years) compared to two other systems. While the low level of education of farmers has already been reported in several studies to characterize milk production systems, not only in the Brazilian semiarid (Alves et al., 2011; de Oliveira et al., 2013) but in other drylands, as in Algeria (Kaouche-Adjlane, 2015) and Sub-Saharan Africa (Ahozonlin and Dossa, 2020). However, in the Brazilian Northeast, this scenario is changing, as farmers in the emerging system present a higher level of education (Table 3). This fact is believed to be the result of the adoption of public educational policies implemented in the last 20 years, such as, the Literate Brazil Program

Table 5
Characteristics of raw milk and water used for milking smallholder milk production systems in the Brazilian semiarid region (n = 23 farms).

Variables	Brazilian legislation[1]	Inverls range	Smallholder dairy production systems (S_{DPS})			General frequency	χ^2 test[2] (*P* - value)	S_{DPS}[3]	ANOVA (*P* - value)
			Conventional (C_S) (n = 13 farms)	Traditional (T_S) (n = 4 farms)	Emergent (E_S) (n = 6 farms)				
-Milk									
Fat	3.0 (%) [¥]	≤ 2.99	23.1^{a}	25.0^{a}	33.3^{a}	26.1	= 0.893	$C_S = T_S = E_S$	= 0.592
		≥ 3.0	76.9^{a}	75.0^{a}	66.7^{a}	73.9			
Protein	2.90 (%) [¥]	≤ 2.89	7.7^{a}	0.0^{a}	0.0^{a}	4.3	= 0.669	$C_S = T_S = E_S$	= 0.801
		≥ 2.90	92.3^{a}	100.0^{a}	100.0^{a}	95.7			
Lactose	4.30 (%) [¥]	≤ 4.29	7.7^{a}	0.0a	33.3^{a}	13.0	= 0.212	$C_S = T_S = E_S$	= 0.229
		≥ 4.30	92.3^{a}	100.0^{a}	66.7^{a}	87.0			
T_S	11.40 (%) [¥]	≤ 11.39	15.4^{a}	25.0^{a}	33.3^{a}	21.7	= 0.668	$C_S = T_S = E_S$	= 0.579
		≥ 11.40	84.6^{a}	75.0^{a}	66.7^{a}	78.3			
D_{DE}	8.40 (%) [¥]	≤ 8.39	100.0^{a}	100.0^{a}	100.0^{a}	100.0	–	$C_S = T_S = E_S$	= 0.510
A_R	Negative [¥]	Negative	Negative	Negative	Negative	–	–	–	
S_{CC}	500 (cells. mL^{-1})[¥]	≤ 499	61.5^{a}	75.0^{a}	16.7^{a}	52.2	= 0.115	$C_S = T_S = E_S$	= 0.569
		≥ 500	38.5^{a}	25.0^{a}	83.3^{a}	47.8			
S_{PC}	300 (CFU mL^{-1}) [¥]	≤ 299	84.6^{a}	100.0^{a}	83.3^{a}	87.0	= 0.693	$C_S = T_S = E_S$	= 0.454
		≥ 300	66.7^{a}	0.0^{a}	33.3^{a}	13.0			
-Water									
Water source (n = 28 farms)		With treatment	6.3^{a}	0.00^{a}	28.6^{a}	10.7	= 0.191	–	
		No treatment	93.7^{a}	100.0^{a}	71.4^{a}	89.3			
M_{AB}	0 (CFU mL^{-1})	Absent	7.7^{a}	50.0^{a}	16.7^{a}	17.4	= 0.149	$C_S = T_S = E_S$	= 0.218
		Presente	92.3^{a}	50.0^{a}	83.3^{a}	82.6			
T_C	0 (MPN 100 mL^{-1})[Ω]	Presente	100.0^{a}	100.0^{a}	100.0^{a}	100.0	–	$C_S = T_S = E_S$	= 0.249
T_{TC}	0 (MPN 100 mL^{-1})[Ω]	Present	100.0^{a}	100.0^{a}	100.0^{a}	100.0	–	$C_S = T_S = E_S$	= 0.604
Hardness[4]	(mg L^{-1})	Solf	30.8^{a}	25.0^{a}	16.7^{a}	26.1	= 0.921	$C_S = T_S = E_S$	= 0.610
		Moderately hard	30.8^{a}	25.0^{a}	16.7^{a}	26.1			
		Hard	7.7^{a}	25.0^{a}	16.7^{a}	13.0			
		Very hard	30.8^{a}	25.0^{a}	50.0^{a}	34.8			
pH[5]	$\geq 6 \leq 9$ [Ω]	Acid	38.5^{a}	25.0^{a}	0.0^{a}	26.1	= 0.207	$C_S = T_S = E_S$	= 0.352
		Neutral	61.5^{a}	75.0^{a}	100.0^{a}	73.9			

Milk (DDE, defatted dry extract; TS, total solids; AR, antibiotic residues; SCC, somatic cell count; SPC, standard plate count).
Water (TC, total coliforms; TTC, thermotolerant coliforms; MAB, mesophilic aerobic bacteria; pH, hydrogen potential).
Note:[1] [¥] Normative Instruction N° 76/2018 of the Ministry of Agriculture, Livestock and Supply, *(MAPA)*, Brazil (Ministry of Agriculture, Livestock, and Supply, 2018).
[Ω] Normative Instruction N°2.914/2011 of the Ministry of Health, Brazil (Ministry of Health, 2011).
[2] [ab] Frequencies within a row different superscript differ ($P < 0.05$) by Pearson Chi-Square test.
[3] Significant differences by the Tukey test with 5% probability.
[4] Water hardness classification according to the United States Geological Survey report: solf (0–60 mg L^{-1}) moderately hard (61–120 mg L^{-1}); Hard (121–179 mg L^{-1}) and very hard (> 180 mg L^{-1}) (U.S. Geological Survey, 1977)
[5] Water pH classification: acid ($0 \leq 5.90$), neutron ($\geq 6.0 \leq 8.90$), and alkaline ($\geq 9.0 \leq 14.0$).

(*Programa Brasil Analfabetizado*) aimed at the literacy of young people, adults, and the elderly. This program was implemented mainly in municipalities with illiteracy rates above 25%, almost all of which, approximately 90%, are found in the Brazilian semiarid region (Diniz et al., 2014).

Some investigations indicate that the age of the farmers has a negative relationship with the production and the sustainability of the farm (Maia et al., 2018; Stylianou et al., 2020), which corroborates with the negative correlation (r^2 = - 0.63; $P < 0.001$) between milk productivity and the age of the farmers found in this study, clearly demonstrating that the young farmers in the emerging system had farms with greater productive efficiency. This system represents the continuity of dairy farming with the possibility of adopting sustainable practices and the adoption of technologies in the Brazilian dairy sector. According to Zimpel et al. (2017) and Mendonça et al. (2020), young farmers with a higher level of education are more likely to accept new technologies of management and financial management on the farm, which can increase milk production with greater economic efficiency, unlike older farmers with a low level of education with a conservative profile inherent to cultural aspects. Maia et al. (2018) found that the education of farmers is positively related to the production of ruminants when they evaluated the strategies of adaptation of the farms to climatic changes in the semiarid region.

The management of the farm, together with the residence, occupation, and source of information of the farmers were important variables for classifying the typologies, which justifies the high eigenvalues in the social indicator (Table 1). The highest percentages of entrepreneurial farmers who live in the urban area of the traditional system, but with hired labor management, usually unskilled, to manage the farms and without investments in the activity indicate that dairy farming is not the main source of income for these farmers. It is believed that these farmers are inserted in dairy farming mainly due to their cultural and non-economic importance. Possibly, these farmers are heirs of large farmers and continue to dairy farming for the preservation of cultural history. On the other hand, it was observed that the farmers of the conventional system live in the rural area and manage the dairy activity with family work, which combined with the other indicators, we can classify this typology as formed by family farmers. This milk production system was predominant in this study, which agrees with several studies carried out in semiarid regions worldwide (Clementino et al., 2015; Vasconcelos et al., 2018). Finally, the emerging system is managed by entrepreneurial farmers compared to farmers in the conventional system, but they reside and manage the farms with frequencies equal to the conventional and traditional systems (Table 3).

The high percentage of affiliation of farmers (85.7%) in contrast to the low percentage of family succession in dairy farming (28.6%)

demonstrates the low level of participation of young people in dairy farming. Even though the reasons for the low level of youth involvement in dairy farming in the Brazilian semiarid region have not yet been investigated, it can be attributed to limited access to land, working conditions coupled with a negative perception of agriculture among young people, associating it to long working hours and limited financial returns, as well as the best job opportunities available for skilled labor in the secondary and tertiary sectors (Kamau et al., 2018; Stylianou et al., 2020). The synergy of these factors explains the high rural exodus in the Brazilian semiarid region, in which young people migrate mainly to the Southeast region in search of better living conditions (Alves et al., 2011). A comparison between the 2017 and 2006 Agricultural Census carried out by Fortini (2020), support our findings, in which they observed an increase in the percentage of agricultural establishments of family farmers in the Brazilian semiarid region with producers over 65 years of age and a reduction in number of young people under 25 years old. It is recommended the adoption of public policies by government agencies for the fixation of young people in agriculture, such as: (*i*) support for full-time education while offering high school and vocational education, with an emphasis on technical courses in the field of agricultural sciences, and (*ii*) incentive for investments in dairy farming through subsidies and/or rural credit with lower interest rates and longer payment terms (Kamau et al., 2018; Zanin et al., 2020; Maia et al., 2021).

4.3. Physical indicators

The size of the farm is a variable usually used in studies of typologies and characterization of production systems (Balcão et al., 2017; Kamau et al., 2018; Mendonça et al., 2020), but the total area is a general dimensional variable, mainly in extensive and/or semi-intensive production systems, where they do not always use the total area of the farm for livestock and feed production. In this way, it was sectioned the farm area with native and cultivated pastures, grain production, and fodder production (Table 2).

The high eigenvalues of self-values attributed to native and cultivated pasture areas and other crop production in factor 1 of the physical indicator (Table 1) were justified by the high variability of these features, that is, the differences found between the production systems (Table 2). The largest pasture areas in the traditional system, together with the other indicators, may indicate that this system adopts extensive management throughout the year. It is interesting to mention, aiming at the environmental sustainability of the farms, that the area of the farm with native pasture can be used as an area of permanent environmental preservation, a requirement of the Rural Environmental Registry (*Cadastro Ambiental Rural*) (Brasil, 2012). This registration is mandatory for all rural farms in the country and constitutes the first step towards environmental regularization, in addition to being one of the necessary prerequisites for access to rural credit and government subsidies it is necessary to adhere to Brazilian environmental standards. Bánkuti et al. (2020) report that the environmental sustainability of dairy farms in southern Brazil is related to economic performance, and those with more resources are able to meet the pattern required for environmental sustainability. The authors also relate the lack of knowledge of environmental laws with the low level of education and high age of farmers.

The higher equipment scores of the traditional and emerging systems indicate that these two systems are more mechanized and technically compared to the conventional. However, caution is necessary, since farmers of the emerging system may be investing in equipment to make the management more technical, while the farmers of the traditional system are investing in equipment such as tractors, threshers and harvesters for land use and annual harvests. On the other hand, farms in the conventional system had mainly basic equipment for milk production, such as a forage engine and hydraulic pump. The low adoption of technologies in the milk production systems in the semiarid is reported by Clementino et al. (2015). Moura et al. (2010) characterized the technological level of milk production systems in the Brazilian semiarid found that 64.0% of farmers replied that the facilities and equipment were insufficient for milk production, which suggests that these farmers, especially in the emerging and conventional systems, are interested in making the production system more technological. Finally, the high and similar percentages of facilities built more than 10 years ago reflect the low investment in infrastructure in production systems, especially in the traditional system.

4.4. Livestock indicators

The greater number of cows, lactating or not, in the production systems was essential to classify the farms, especially those in the emerging and traditional systems, since the physical factors were similar in both systems. The similarity in the number of bulls is explained by the small herds needing only one bull for each farm. During application of the questionnaires, some farms classified in the conventional and emerging systems did not present bulls in the herd. Some farmers in the conventional system reported that they used bulls from neighboring farms, while farmers in the emerging system used artificial insemination (AI). These mentioned that biotechnology was more economically viable than the costs of maintaining the bull on the farm and other advantages of AI.

The breed of bulls and cows was not important to classify farms, as farmers choose the genotype for milk potential. However, they do not change management strategies, nor consider the adaptability and higher nutritional requirements of cows according to milk production. In this study, regardless of production systems, no farm had purebred cows. Most of them raise mix (multiple breeds of the same species, often breeding without any human intervention, recordkeeping, or selective breeding) and crossbred cows (*Bos taurus Indicus* × *Bos taurus Taurus*). The higher percentages of bulls of Taurine breeds in the emerging system may be a strategy of farmers to improve the genetic quality of the herd.

The polyculture of ruminant livestock (cattle, goats, and sheep) among the typologies were explained because in dryland regions, farmers tend to diversify production systems to obtain subsistence security and market opportunities (Figueroa-Sandoval et al., 2019). Our results are supported by Costa et al. (2008), who reported that the associative system, with goats, sheep, and cattle production, is the main production system used by farmers in the Brazilian semiarid. Interestingly, it was observed that these production systems were managed by males, which corroborates with Vidal (2013), who characterized the division of labor in family farming production units in the Brazilian semiarid, reporting that the participation of female labor is more related to monogastric, especially poultry farming.

4.5. Herd management and technological indicators

The adoption of dietary strategies in dairy farms in drylands is fundamental for economic sustainability since feed represents 40.0–60.0% of the costs of milk production, and the low rainfall, which is concentrated in just five months of the year, require farmers to adopt dietary strategies such as forage conservation, use of forage adapted to climatic conditions, and grain storage for the dry period (Ferreira et al., 2009; Yerou et al., 2019). In this study, farmers use different strategies of bulky and concentrated feeds. The higher frequencies of supply of concentrated feed (twice a day) from farms in the emerging system indicate more intensive feed management.

Concerning to roughages, the higher percentages of farms in the traditional system (Table 3) that used deferred grazing reveals that this system uses these pasture conservation tools from the rainy period to be used in the dry period, which can be justified by the higher pasture areas, native and cultivated, of this system. In contrast, the high and similar percentages of hay practice between the three production systems indicate that hay, mainly corn stalks intercropped with beans, was the main source of roughage supplied to animals in the dry period. On the other hand, silage was little used in animal feeding. It seems that the lack of forage planning is one of the main problems faced by farmers in semiarid and arid regions around the world (Ferreira et al., 2009; Njarui et al.,). Given the prospects for sustainable development, it is necessary that dairy farms in the semiarid region, not only in Brazil but those with similar climatic conditions need to immediately adhere to strategies for feed management, as the high prices of inputs based on concentrates seem to be the main problem mentioned by milk farmers in these climatic zones (de Oliveira et al., 2013). Based on our results, we agree with Alqaisi et al. (2014), who reported that smallholder dairy farmers in the semiarid region are unlikely to improve animal performance without institutional support and the allocation of resources to their farms. As global food prices rise, alternative feeding systems with low levels of concentrates need to be developed. In addition, the authors indicate the inclusion of low-priced regional by-products in diets to replace the high proportion of concentrated feeds and, consequently, improve the economic situation of dairy farms.

Reproductive efficiency is the single factor that most affects the productivity and profitability of a herd. However, generally in SDF in drylands, reproductive efficiency is low due to inadequate nutrition most of the year, reproductive diseases, and thermal ambiance (Mungube et al., 2019). In this study, the farms in the emerging system showed females with shorter intervals between calving and earlier heifers and younger cows at the first calving. This system has greater reproductive efficiency than traditional and conventional systems, which justifies the higher percentages of farms that adopt zootechnical bookkeeping and more intensive feed management observed in these farms. However, it should be noted that, even with greater reproductive efficiency, these farms are far from the ideal of reproductive efficiency, which is 12 months for the calving intervals.

It was found that the use of natural mount is still the main reproductive system adopted in the SDF, which agrees with several studies carried out in Brazilian (Alves et al., 2011) and African regions (Lukuyu et al., 2019). However, this scenario may be changing in the Brazilian semiarid region in the coming decades, as AI is expanding mainly in the emerging system. Although we found no differences between the systems in the use of AI, it is believed that the adoption of this reproductive biotechnology with defined technical criteria allows improving the genetic quality of the dairy herd in drylands through crossings between locally adapted breeds × *Bos taurus Taurus* producing F1 animals and/or synthetic breeds with phenotypic plasticity (de Vasconcelos et al., 2019, 2020) making it possible to increase milk production in semiarid conditions.

The low scores for the discard criteria adopted by the farms in the traditional and conventional systems suggest that these two systems only carry out involuntary disposal, which consists of the removal of cows from the herd due to serious health problems, infertility, or any other occurrence that promotes productive incapacity of the animal (Luciana et al., 2019). On the other hand, the greater number of criteria adopted by farms in the emerging system reveals that these farms carry out voluntary and involuntary discards, indicating that they use more technical basic criteria of animal selection for discarding cows, such as: milk production, lactation period, and productive age. It is believed that the highest percentage of farms that use the zootechnical bookkeeping of the emerging system facilitates decision-making regarding targeted disposal. It should be noted that due to the higher numbers of animals grazing in large natural grassland areas, farms in the traditional system may have difficulty in identifying cows with reproductive problems for targeted disposal. Interestingly, the high and similar percentages of herd replacement, mainly of the conventional and traditional systems, is explained by the lack of technical disposal oriented for insertion of primiparous cows in the herd.

The health management of dairy farms in the three production systems was assessed using the preventive health score, already used by Gelasakis et al. (2012) on dairy sheep farms. The low and similar score between systems indicates that sanitary management is precarious, and the animals are immunized mainly against foot-and-mouth disease, rabies and clostridiosis. Currently, only immunization against foot-and-mouth disease, tuberculosis and brucellosis is mandatory in the health calendar of the cattle herd as established by the MAPA (MAPA, 2020). Therefore, to insert these farms into Brazilian health standards, regardless of the system, they need to carry out vaccination against brucellosis, since brucella infections in domestic animals are mainly associated with reproductive problems such as abortion and low fertility rates, in addition to the risk of transmission to farmers and their families (Alves et al., 2011).

Finally, the low use of mechanical milking observed on farms is due to the low levels of technology of the production system and to avoid additional costs with equipment, maintenance, and training of employees. The predominance of manual milking with the presence of a calf is the main milking system in the Brazilian semiarid, which agrees with Moura et al. (2010). The use of mechanical milking aims to facilitate milking, reducing the milking time, and the number of employees. However, the viability of this technology is questionable in SDF with low milk production, where milking is usually performed by family work.

4.6. Productive indicator

The higher milk productivity of cows in the emerging system is justified by the greater number of milking and supplementation of concentrated feeds with a balanced diet. Our results are supported by Bateki et al. (2020), who in their meta-analysis concluded that the management strategies for increasing milk in SDF proposed that improved feeding together with the use of improved livestock breeds is the most reliable strategy to increase milk production on smallholder farms.

The similarity in milk production between the traditional and emerging systems is justified by the higher number of lactation cows in the traditional system (median = 15 cows; Table 1), while the emerging system, even with a lower number of cows (8 cows), showed higher productivity, characterizing the productive efficiency of this system. The lower milk production per hectare of farms in the traditional system is justified by the larger areas of these farms combined with extensive management based mainly on native and cultivated pastures throughout the year. Therefore, it appears that the size of the farm in semiarid regions does not necessarily mean greater milk production and profitability, as described by Ferrazza et al. (2020).

The higher percentages of farms in the traditional system that made cheese can be justified by the lack of demand for the sale of fresh milk, mainly because these large farms are located in the rural area instead of farms in the emerging system that are located in the peri-urban region. It is believed that cheese making is a strategy to extend the life of in nature milk, in addition to adding market value for the product. However, this commercialization of in nature milk and cheese occurs informally, as no farm carried out heat treatment on the milk. In Brazil and in other countries, there are regulatory requirements that all milk must be pasteurized for food security reasons. Given this and due to the low milk production of the SDF and high costs for implementing cooling systems and heat treatment of milk in these farms, we recommend adopting public policies to strengthen dairy farming in SDF through the implementation of community cooling tanks. In addition to the purchase of chilled fresh milk and its derivatives by public entities for inclusion in school meals. The creation of associations and cooperatives of milk farmers is strongly recommended to strengthen the activity.

4.7. Economic indicator

The similarity in the price of milk between typologies is justified because the payment for milk follows a regional market trend. In this way, payment for milk did not occur for quality or chemical characteristics such as fat and protein as it occurs in other regions (Balcão et al., 2017). It is important to mention that no farm sold milk for dairy products, but rather for final consumers and/or for the local market. The non-discriminatory power of the economic indicator is justified because we use only one variable (milk price), which was similar among typologies. We encourage an economic analysis of these production systems to assess whether the intensification of the production system is viable for the farmers.

4.8. Water used in milking management

The similarity in water traits between typologies is explained because most farms, regardless of the production system, used water without treatment (Table 5). It is worth mentioning that the results of the microbiological reports of all water samples were unsatisfactory and based on the minimum TTC value (<1.8 MPN mL^{-1}), all water samples were at odds with the potability standards required by the World Health Organization (World Health Organization, 2008) and Ordinance N^{o}. 2, 914/2011 of the Ministry of Health (Brazil, 2011), in which they define that for water originating from underground sources that have not received any aseptic treatment, the TC presence is tolerated, provided TTC is absent. Contaminations by TTC are indicators of pathogenic microorganisms of enteric origin (Castro et al., 2021b)

The prevalence of 42.33% of TTC in relation to TC may indicate that this contamination has an enteric origin and may be related to the inadequate management of animal waste or due to the proximity of septic tanks to the water source of the farms. The high incidence of contamination by MAB, TC, and TTC in the water used in the handling of milking is reported in studies carried out in all Brazilian regions (Ramires et al., 2009; Vasconcelos et al., 2018; Castro et al., 2021a). Although the source of water contamination was not assessed in this study, it was observed at the time of collecting the water samples, that the problem, in most farms, comes from lack of basic sanitation, inadequate cleaning materials, and lack of periodic hygiene in the water reservoirs, thus allowing the formation of biofilms in the reservoirs. These inadequacies may represent a risk factor for the health of farmers and their families since the analyzed water samples were used both for milk production and family consumption.

The high percentage (73.90%) of farms that use hard water (121–179 mg L^{-1}), unsuitable for use in milking management, is related to the mineralogical formation of the region, which consists predominantly of hornblende, a mineral-rich in Ca^{+2} and Mg^{2+}, where it is easily weathered in the semiarid due to low rainfall. It is also believed that the high concentrations are explained by the collection in the dry period, in which the high temperatures intensify evaporation, consequently increasing the concentrations of water salts.

4.9. Composition and microbiological quality of raw milk

The similarity in the composition and microbiological traits of raw milk is justified because the main factors responsible for the variation in milk were similar between production systems, such as breed, handling, and type of milking, milking (the collections occurred only in the first milking – morning shift), water used for cleaning milking utensils, seasonality (collections occurred in the dry period). Our results are supported by Balcão et al. (2017), who found no differences in the microbiological and composition of milk according to smallholder dairy production.

The average values, regardless of the production system, comply with the minimum thresholds required by Brazilian legislation for the production of raw milk (MAPA, 2018a). Conversely, the average SPC and SCC values do not comply with the current legislative threshold of IN 77/2018 for bulk raw milk (MAPA, 2018b). This result is explained by the milking management of the farms, as there is no pre-milking disinfection protocol and good hygiene practices in milking. Another factor that contributed to the increase in the microbiological quality of milk is the ignorance of the microbiological and physical-chemical quality of the water by the farmers combined with the use of non-specific detergents for cleaning and washing milk utensils with water at room temperature, favoring the increase of microbiological proliferation of milk, as the use of hard water causes neutralization of detergents and precipitation of soaps, low foam capacity, and failure in the removal of fat and hygiene of milk utensils (Guerra et al., 2011). At the same time, microbiological contamination of water in milk occurs by residual contamination of water in cans. The low hygienic-sanitary quality of milk in the Brazilian semiarid region has been reported in several studies (Guerra et al., 2011; Vasconcelos et al., 2018; Meira et al., 2021). It is worth emphasizing that although these studies showed that raw milk from the Brazilian semiarid region is characterized by high microbiological counts, it should be taken into account that these investigations use average values, which is in line with our results. However, when we stratified the microbiological data of milk according to the thresholds established by the legislation, it was found that only 13.00% and 47.80% of the farms did not comply with the values established by normative instruction 77/2018 for SCC and SPC, respectively (MAPA, 2018b). It is suggested to adopt simple milking management to adapt the farms to the legal thresholds. For example, Vallin et al. (2009) found that the adoption of simple milking practices, such as the elimination of the first three milk jets to check for clinical mastitis, adequate washing of materials (and buckets) and eliminating effluent from utensils on farms with manual milking can reduce SPC and SCC by up to 90.83% and 54.76%, respectively, in raw bulk milk. If the SCC and SPC values are reduced to the IN thresholds, the milk produced by these farmers will be subsidized for fat and protein.

5. Study limitations

Our study aimed to develop a typological analysis of SDF using combinations of different methods of multivariate statistical techniques using social, physical, livestock and herd management indicators. Three typologies of SDF were identified, but were no differences in the characteristics of raw milk and milking water between typologies. Our results, however, cannot be extrapolated to all dairy production systems located in Brazilian semiarid given the small sample size. Our results, however, represent the case studies well. It is important to mention that we can find similar patterns similar to other small-sized milk production systems in other states in the Brazilian semiarid region and in other semiarid and arid regions of the world, as previously discussed.

Temporal analysis studies are encouraged for the identification of temporal differences as verified by Toro-Mujica et al. (2020) in dairy systems in the semiarid region of Chile, and help in the definition of specific public policies, since it is known that characteristics of milk and water vary seasonally as a result of environmental condition and herd management.

6. Final remarks and future research

The production systems of smallholder dairy farms in the Brazilian semiarid are diversified in dimensions, social aspects, degree of intensification, size of the herd, management practices, and milk production, but with handling of milking, composition and microbiological quality of raw milk, and water traits used in the cleaning of similar milking tools between systems. The systematic approach using the production system indicators allowed identifying three systems: emerging, conventional and traditional. These share a ruminant polyculture (goats, cattle, and sheep) without feed planning for the dry period, an inefficient health calendar, and informal milk commercialization, but different productive and reproductive efficiency.

The implications of this research are related to the most focused livestock policies, adapted to the different restrictions and opportunities of the SDF. In particular, the development of dairy farming depends on creating projects based on our recommendations aimed at the sustainable intensification of dairy farming in the semiarid region with adaptation of development strategies and interventions according to the production system. The continuity of these systems depends on the participation of young farmers in the sector and the adoption of technologies to increase productive and reproductive efficiency, especially in the traditional and emerging systems. The insertion of milk and its derivatives from the three production systems on the market depends on the adoption of programs for good milking practices, training of milkers, and cleaning of equipment used for milking using specific detergents and water treatment (chlorination) so that these farms comply with the milk quality legislation thresholds.

Future research should be conducted on a larger scale, but using the same multivariate approach with the inclusion of physical, social, livestock, herd management, technological, productive, and economic indicators to assess the economic, environmental and social sustainability of each production system identified here. Finally, these results can be used to inform and support public decision makers who are responsible for designing and implementing livestock development policy in the Brazilian semiarid, as well as being useful for other drylands of the world.

CRediT authorship contribution statement

Robson Mateus Freitas Silveira: Conceptualization, Data collect, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing, Funding acquisition. **Valdson José da Silva:** Conceptualization, Validation, Review Final, Supervision, Writing – review & editing. **Josiel Ferreira:** Final review and, Validation. **Raquel Oliveira dos Santos Fontenelle:** Final review. **Wilder Hernando Ortiz Vega:** Final review, Validation. **Danielle Cavalcanti Sales:** Final Review and, Validation. **Arthur Pereira Sales:** Final review. **Maria Samires Martins Castro:** Review Final. **Paula Toro-Mujica:** Review Final and, Validation. **Angela Maria de Vasconcelos:** Supervision, Project administration, Supervision, Review Final.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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References

Adolfo Lutz, 2008. *Métodos físicos -químicos para análise de alimentos* (4 edição).

Aguiar, S.C., Lima, V.L.A., Silva, P.F., Dantas neto, J.D., Farias, M.S.S., 2020. Sustentabilidade da pecuária leiteira do semiárido brasileiro com base em vulnerabilidade e resiliência socioecológica. Revista Ibero Americana de Ciências Ambientais 11, 236–248. https://doi.org/10.6008/CBPC2179-6858.2020.002.0025.

Ahozonlin, M.C., Dossa, L.H., 2020. Diversity and resilience to socio-ecological changes of smallholder lagune cattle farming systems of Benin. Sustainability 12 (18), 7616. https://doi.org/10.3390/su12187616.

Alqaisi, O., Hemme, T., Hagemann, M., Susenbeth, A., 2014. Nutritional and ecological evaluation of dairy farming systems based on concentrate feeding regimes in semi-arid environments of Jordan. Saudi J. Biol. Sci. 21 (1), 41–55. https://doi.org/10.1016/j.sjbs.2013.05.001.

Alvares, C.A., Stape, J.L., Sentelhas, P.C., De Moraes Gonçalves, J.L., Sparovek, G., 2013. Köppen's climate classification map for Brazil. Meteorol. Z. 22 (6), 711–728. https://doi.org/10.1127/0941-2948/2013/0507.

Alves, A.L., Ribeiro, L.G., De, G.G.L., Vasconcelos, A., Alves, S., Oliveira, C.M., Santos, A., De, L., 2011. Caracterização dos produtores e dos sistemas de produção de leite no perímetro irrigado de Petrolina/PE. Revista Brasileira de Saúde e Produção Animal 12 (1), 209–223.

Alves, E., Da Silva E Souza, G., Marra, R., 2011. Êxodo e sua contribuição à urbanização de 1950 a 2010 1,2. Revista de Política Agrícola 2, 80–88.

APHA, 2015. Compendium of methods for the microbiological examination of foods. In: Compendium of Methods for the Microbiological Examination of Foods. American Public Health Association. https://doi.org/10.2105/mbef.0222.

Balcão, L.F., Longo, C., Costa, J.H.C., Uller-Gómez, C., Filho, L.C.P.M.H., Hötzel, M.J., 2017. Characterisation of smallholding dairy farms in southern Brazil. Anim. Prod. Sci. 57 (4), 735–745. https://doi.org/10.1071/AN15133.

Bánkuti, F.I., Prizon, R.C., Damasceno, J.C., De Brito, M.M., Pozza, M.S.S., Lima, P.G.L., 2020. Farmers' actions toward sustainability: a typology of dairy farms according to sustainability indicators. Animal 14 (S2), s417–s423. https://doi.org/10.1017/S1751731120000750.

Bateki, C.A., Van Dijk, S., Wilkes, A., Dickhoefer, U., White, R., 2020. Meta-analysis of the effects of on-farm management strategies on milk yields of dairy cattle on smallholder farms in the Tropics. Animal 1–9. https://doi.org/10.1017/S1751731120001548.

Brasil Decreto no 7.830 de 17 de outubro de 2012. Dispõe sobre o Sistema de Cadastro Ambiental Rural, o Cadastro Ambiental Rural, estabelece normas de caráter geral aos Programas de Regularização Ambiental, de que trata a Lei no 12.651, de 25 de maio de 2012, e dá outras providências. Disponível em: http://www.planalto.gov.br/ccivil_03/_Ato2011-2014/2012/Decreto/D7830.htm. Acess in: 27/04/2021.

Castro, M.S.M., de Sousa Oliveira, D., dos Santos Fontenelle, R.O., Nascimento, A.P.A., Silveira, R.M.F., Veja, W.O., Silva, L.C da, Soares, A.T.L., Vasconcelos, A.M., 2021a. Understanding the dairy production systems in rural settlements in the Brazilian semi-arid region: characterization, typology, and holistic perception. Trop. Anim. Health Prod. 53, 417. https://doi.org/10.1007/s11250-021-02840-x.

Castro M.S.M., Vasconcelos A.M., Fontenelle R.O. dos S., Julião M.S. da Silva, Soares, A. T.L.S., Da Silva L.C., Silveira R.M.F.. (2021b) Water quality of small ruminant production systems in the Brazilian semiarid region. Biological Rhythm Research DOI: 10.1080/09291016.2019.1608731.

Clementino, I.J., Pimenta, C.L.R.M., Fernandes, L.G., Bezerra, C.D.S., Alves, C.J., Dias, R. A., Amaku, M., Ferreira, F., Telles, E.O., Gonçalves, V.S.P., Neto, J.S.F., De Azevedo, S.S., 2015. Caracterização da pecuária bovina no Estado da Paraíba, Nordeste do Brasil. Semina Ciências Agrárias 36 (1), 557–570. https://doi.org/10.5433/1679-0359.2015v36n1p557.

Costa, R.G., Almeida, C.C., Pimenta Filho, E.C., Holanda, E.V., Santos, N.M., 2008. Caracterização do sistema de produção caprino e ovino na região semi-árida do estado da Paraíba. Brasil. Arch. Zootec. 57 (218), 195–205.

de Oliveira, A.G., De Oliveira, V.S., De Arruda Santos, G.R., Dias Ferreira, A.C., Santos, G. S., De Lima, E.P.T., Dos Santos Sobrinho, D.C., Carvalho, C.T.G., 2013. Diagnóstico socioeconômico da produção leiteira em três assentamentos de reforma agrária no semiárido do Estado de Sergipe. Semina Ciências Agrárias 34 (4), 1869–1878. https://doi.org/10.5433/1679-0359.2013v34n4p1869.

de Vasconcelos, A.M., de Albuquerque, C.C., de Carvalho, J.F., Façanha, D.A.E., Lima, F. R.G., Silveira, R.M.F., Ferreira, J., 2019. Adaptive profile of dairy cows in a tropical region. Int. J. Biometeorol. https://doi.org/10.1007/s00484-019-01797-9.

de Vasconcelos, A.M., de Carvalho, J.F., de Albuquerque, C.C., Façanha, D.A.E., Vega, W. H.O., Silveira, R.M.F., Ferreira, J., 2020. Development of an animal adaptability index: application for dairy cows. J. Therm. Biol. 89 https://doi.org/10.1016/j.jtherbio.2020.102543.

Diniz, G.M., Machado, D. de Q., de Moura, H.J., 2014. Políticas públicas de combate ao analfabetismo no Brasil: Uma investigação sobre a atuação do Programa Brasil Alfabetizado em municípios do Ceará. Rev. Adm. Pública 48 (3), 641–666. https://doi.org/10.1590/0034-76121514.

Ferrazza, R. de A., Lopes, M.A., de Oliveira Prado, D.G., de Lima, R.R., Bruhn, F.R.P., 2020. Association between technical and economic performance indexes and dairy farm profitability. Rev. Bras. Zootec. 49 https://doi.org/10.37496/RBZ4920180116.

Ferreira, M.D.A., Silva, F.M., Bispo, S.V., Azevedo, M., 2009. Strategies for the supplementation of dairy cows in the Brazilian semi-arid. Revista Brasileira de Zootecnia 38, 322–329. https://doi.org/10.1590/S1516-35982009001300032.

Figueroa-Sandoval, B., Coronado-Minjarez, M.A., García-Herrera, E.J., Ramírez-López, A., Sangerman-Jarquín, D.M., Figueroa-Rodríguez, K.A., 2019. Production system diversification and livelihood in the drylands of North Central Mexico. Sustainability 11 (10), 2750. https://doi.org/10.3390/su11102750.

FOA, 2020. Dairy Production and Products: Production. Food and Agriculture Organization of the United Nations. http://www.fao.org/dairy-production-products/production/en/.

Fortini, Rosimere Miranda, 2020. Um novo retrato da agricultura familiar do semiárido nordestino brasileiro [recurso eletrônico] : a partir dos dados do censo agropecuário 2017/Rosimere Miranda Fortini ; coordenador Marcelo José Braga – Viçosa, MG : IPPDS, UFV.

Gelasakis, A.I., Valergakis, G.E., Arsenos, G., Banos, G., 2012. Description and typology of intensive Chios dairy sheep farms in Greece. J. Dairy Sci. 95 (6), 3070–3079. https://doi.org/10.3168/jds.2011-4975.

Gelasakis, A.I., Rose, G., Giannakou, R., Valergakis, G.E., Theodoridis, A., Fortomaris, P., Arsenos, G., 2017. Typology and characteristics of dairy goat production systems in Greece. Livest. Sci. 197 (December 2016), 22–29. https://doi.org/10.1016/j.livsci.2017.01.003.

Guerra, M.G., Galvão, J.G.B., Do Nascimento Rangel, A.H., De Araújo, V.M., Guilhermino, M.M., Novaes, L.P., 2011. Availability and quality of water in milk production. Acta Veterinaria Brasilica 5 (3), 230–235. https://doi.org/10.21708/avb.2011.5.3.2308.

Hair, J.F.J., Black, W.C., Babin, B.J., Anderson, R.E., 2009. Multivariate Data Analysis.

Hemme, T., Otte, J., 2010. Status of and Prospects for Smallholder Milk Production – A Global Perspective.

IBGE, 2017. IBGE | Censo Agro 2017 | Home. Brazilian Institute of Geography and Statistics. https://censos.ibge.gov.br/agro/2017.

Kaiser, H.F., 1960. The application of electronic computers to factor Analysis. Educ. Psychol. Meas. 20 (1), 141–151. https://doi.org/10.1177/001316446002000116.

Kamau, J.W., Stellmacher, T., Biber-Freudenberger, L., Borgemeister, C., 2018. Organic and conventional agriculture in Kenya: a typology of smallholder farms in Kajiado and Murang'a counties. J. Rural Stud. 57, 171–185. https://doi.org/10.1016/j.jrurstud.2017.12.014.

Kaouche-Adjlane, S.G.F.M.A., 2015. Typology of dairy farming systems in the Mediterranean basin (Case of Algeria). Biotechnol. Anim. Husb. 31, 385–396. https://agris.fao.org/agris-search/search.do?recordID=RS2017000635.

Köbrich, C., Rehman, T., Khan, M., 2003. Typification of farming systems for constructing representative farm models: two illustrations of the application of multi-variate analyses in Chile and Pakistan. Agric. Syst. 76 (1), 141–157. https://doi.org/10.1016/S0308-521X(02)00013-6.

Luciana, M., Melo, A. De, Batista, A.M., Santos, G.S., Silva, B.M., Celuta, M., Viana, M., 2019. Fatores de descarte de bovinos leiteiros. Enciclopédia Biosfera 16 (29), 855. https://doi.org/10.18677/EnciBio.

Lukuyu, M.N., Gibson, J.P., Savage, D.B., Rao, E.J.O., Ndiwa, N., Duncan, A.J., 2019. Farmers' perceptions of dairy cattle breeds, breeding and feeding strategies: a case of smallholder dairy farmers in western Kenya. East Afr. Agric. For. J. 83 (4), 351–367. https://doi.org/10.1080/00128325.2019.1659215.

Maia, A.G., Cesano, D., Miyamoto, B.C.B., Eusebio, G.S., Silva, P.A. de O., 2018. Climate change and farm-level adaptation: the Brazilian Sertão. International Journal of Climate Change Strategies and Management 10 (5), 729–751. https://doi.org/10.1108/IJCCSM-04-2017-0088.

Maia, A.G., Burney, J.A., Martínez, J.D.M., Cesano, D., 2021. Improving production and quality of life for smallholder farmers through a climate resilience program: an experience in the Brazilian Sertão. PLoS One 16, e0251531.

Marengo, J.A., Torres, R.R., Alves, L.M., 2017. Drought in Northeast Brazil—past, present, and future. Theor. Appl. Climatol. 129 (3–4), 1189–1200. https://doi.org/10.1007/s00704-016-1840-8.

Meira, A.N., Givisiez, P.E.N., Souza, F.G.C., De Leon, C.M.G.C., Azevedo, P.S., Silva, N.M. V., Oliveira, C.J.B., 2021. Food security and safety mismatch in low-income settings: evidence from milk produced by smallholders in semiarid Paraíba, Northeastern Brazil. J. Arid Environ. 188, 104453. https://doi.org/10.1016/j.jaridenv.2021.104453.

Mendonça, B. S. de, Istvan Bánkuti, F., Soares dos Santos Pozza, M., Leal Perez, H., Teixeira da Silva Siqueira, T., 2020. A typology of corporate and family dairy farms in eastern Goiás, Brazil Tipologia de sistemas produtivos leiteiros familiares e patronais na região leste de Goiás. Ciência Rural. 50 (10) https://doi.org/10.1590/0103-8478cr20190285.

Ministry of Agriculture, Livestock and Supply, 2018a. INSTRUÇÃO NORMATIVA No 76, DE 26 DE NOVEMBRO DE 2018. https://www.in.gov.br/materia/-/asset_publisher/Kujrw0TZC2Mb/content/id/52750137/do1-2018-11-30-instrucao-normativa-n-76-de-26-de-novembro-de-2018-52749894IN 76.

Ministry of Agriculture, Livestock, and Supply, 2020. INSTRUÇÃO NORMATIVA N° 48, DE 14 DE JULHO DE 2020. Diário Oficial da União. Publicado em: 15/07/2020 | Edição: 134 | Seção: 1 | Página: 2.

Ministry of Agriculture, Livestock, Supply, 2018b. INSTRUÇÃO NORMATIVA No 77, DE 26 DE NOVEMBRO DE 2018 - INSTRUÇÃO NORMATIVA No 77, DE 26 DE NOVEMBRO DE 2018 - DOU - imprensa Nacional (230th ed.). Diário Oficial da União. https://www.in.gov.br/web/dou/-/instrucao-normativa-n-77-de-26-de-novembro-de-2018-52749887.

Ministry of Health, 2011. *PORTARIA Nº 2.914, DE 12 DE DEZEMBRO DE 2011.* Diário Oficial da União.

Moura, J.F.P., Pimenta Filho, E.C., Gonzaga Neto, S., Menezes, M.P.C., Leite, S.V. de F., Guilhermino, M.M., 2010. Caracterização dos sistemas de produção de leite bovino no Cariri paraibano. Acta Sci. Anim. Sci. 32 (3), 293–298. https://doi.org/10.4025/actascianimsci.v32i3.7123.

Mungube, E.O., Njarui, D.M.G., Maichomo, M.W., Olum, M.O., Ndirangu, P.N., Kabirizi, J., Ndikumana, J., Mwangi, G., 2019. Reproductive performance indicators of dairy cattle in selected small-scale dairy farms in semi-arid Eastern Kenya. Livest. Res. Rural Dev. 31 (88). Retrieved May 6, 2022. http://www.lrrd.org/lrrd31/6/erick31088.html.

Njarui, D. M. G.; Gatheru, M.; Wambua, J. M.; Nguluu, S. N.; Mwangi, D. M.; Keya, G.A., Feeding management for dairy cattle in smallholder farming systems of semi-arid tropical Kenya. Livest. Res. Rural Dev., 23:5.

Ramires, C.H., Berger, E.L., Almeida, R. De, 2009. Influência da qualidade microbiológica da água sobre a qualidade do leite. Arch. Vet. Sci. 14 (1), 36–42. https://doi.org/10.5380/avs.v14i1.12913.

Rangel, J., Perea, J., De-Pablos-Heredero, C., Espinosa-García, J.A., Mujica, P.T., Feijoo, M., Barba, C., García, A., 2020. Structural and technological characterization of tropical smallholder farms of dual-purpose cattle in Mexico. Animals 10 (1), 86. https://doi.org/10.3390/ani10010086.

IBM Corp Released, 2011. *IBM SPSS Statistics for Windows* (Version 20). IBM Corp, Released.

Silva Neto, O. L da, Marquesan, F.F.S., 2020. As racionalidades que permeiam a bovinocultura de leite no semiárido cearense. Revista Em Agronegócio e Meio Ambiente - RAMA 3 (4).

Silveira, R.M.F., Roberto Sá, J., Maria de Vasconcelos, A., Cristina de Souza Ribeiro, M., Freitas Viera, E., Alves Gonçalves, M., Borges Ferreira, J., 2018. Atributos químicos de um Neossolo Flúvico cultivado com capim elefante (Pennisetum purpureum Schum) no município de Bela Cruz. Agropecuária Científica No Semiárido 14 (4), 325–330. https://doi.org/10.30969/acsa.v14i4.1049.

Silveira, R.M.F., Vasconcelos, A.M., Silva, J. V. da, Vega, W.H.O., Toro-Mujica, P., Ferreira, J., 2021. Typification, characterization and differentiation of sheep production systems in the Brazilian semiarid region. NJAS -Impact of Agricultral and Life Science 93, 48–73. https://doi.org/10.1080/27685241.2021.1956220.

Stürmer, M., Busanello, M., Velho, J.P., Heck, V.I., Haygert-Velho, I.M.P., 2018. Relationship between climatic variables and the variation in bulk tank milk composition using canonical correlation analysis. Int. J. Biometeorol. 62 (9), 1663–1674. https://doi.org/10.1007/s00484-018-1566-7.

Stylianou, A., Sdrali, D., Apostolopoulos, C.D., 2020. Capturing the diversity of Mediterranean farming systems prior to their sustainability assessment: the case of Cyprus. Land Use Pol. 96, 104722. https://doi.org/10.1016/j.landusepol.2020.104722.

Toro-Mujica, P., Vera, R., Pinedo, P., Bas, F., Enríquez-Hidalgo, D., Vargas-Bello-Pérez, E., 2020. Adaptation strategies based on the historical evolution for dairy production systems in temperate areas: a case study approach. Agric. Syst. 182, 102841. https://doi.org/10.1016/j.agsy.2020.102841.

U.S. Geological Survey, 1977. Quality of rivers of the United States, 1975 water year; based on the national stream quality accounting network (NASQAN). https://doi.org/10.3133/ofr78200.

Vallin, V.M., Beloti, V., Paula, A., Battaglini, P., Tamanini, R., Fagnani, R., Lopes Da Angela, H., Livia, Corrêa Da Silva, C., 2009. Milk quality improvement after implantation of good manufacturing practices in milking in 19 cities of the central region of Paraná. Seminas: Ciências Agrárias 181–188.

Vasconcelos, A. M. de, Farias, D. A. de, Gomes, T.C.L., Landim, A.V., Silveira, R.M.F., Martins, T.P., 2018. Characterize of production systems and milk quality of production units in the semiarid region of Ceará. In: Ciência Animal Brasileira, 19. https://www.revistas.ufg.br/vet/article/view/e-52844/26518.

Vidal, D. de L., 2013. Work division in family farm production units: feminine responsibilities typology in a semi-arid region of Brazil. J. Arid Environ. 97, 242–252. https://doi.org/10.1016/j.jaridenv.2013.07.001.

Ward, J.H., 1963. Hierarchical grouping to optimize an objective function. J. Am. Stat. Assoc. 58 (301), 236–244. https://doi.org/10.1080/01621459.1963.10500845.

World Health Organization, 2008. T. Edition, guidelines for drinking-water quality. Disponível em: http://www.iasaude.pt/attachments/article/660/WHO_Guidelines%20for%20drinking-water%20quality.pdf Acesso em: 23/10/2019.

Yerou, H., Homrani, A., Benhanassali, A., Boussedra, D., 2019. Typological assessment of dairy farms systems in semi-arid mediterranean region of western Algeria. Biotechnol. Anim. Husb. 35 (4), 335–346. https://doi.org/10.2298/BAH1904335Y.

Zanin, Antônio, Dal Magro, Cristian B., Bugalho, Diones Kleinibing, Morlin, Francieli, Afonso, Paulo, Sztando, Andrzej, 2020. Driving sustainability in dairy farming from a TBL perspective: insights from a case study in the west region of santa catarina, Brazil. Sustainability 12 (15), 6038. https://doi.org/10.3390/su12156038.

Zimpel, R., Bánkuti, F.I., Zambom, M.A., Kuwahara, K.C., Bánkuti, S.M.S., 2017. Characteristics of the dairy farmers who perform financial management in Paraná State, Brazil. Rev. Bras. Zootec. 46 (5), 421–428. https://doi.org/10.1590/S1806-92902017000500008.