Journal MVZ Cordoba
2021; May-August. 26(2):e2005.
https://doi.org/10.21897/rmvz.2005

Original

Analysis of milk quality variation in Colombia 2008–2019

Andrés Usuga R[1] M.Sc; Dursun Barrios[2] Dr.Sci; Mónica Botero A[3] Dr.Sci;
Mauricio Lopera C[4] M.Sc; Martha Olivera-Angel[1] Dr.Sci.Agr; Luis G Palacio B[1]* Dr.Sci.

[1]Universidad de Antioquia, Faculty of Agrarian Sciences, School of Veterinary Medicine, Biogenesis Research Group. Medellín, Colombia.
[2]Universidad Nacional de Colombia campus Bogota, Faculty of Agricultural Sciences, Department of Rural Development and Agricultural, Biogenesis Research Group. Bogotá D.C., Colombia
[3]Universidad de Antioquia, Faculty of Agrarian Sciences, School of Animal Production, Biogenesis Research Group. Medellín, Colombia.
[4]Universidad de Antioquia, Faculty of Economic Sciences, Mathematics and Statistics Department. Medellín, Colombia.
*Correspondencia: guillermo.palacio@udea.edu.co

Received: April 2020; Accepted: December 2020; Published: March 2021.

ABSTRACT

Objective. This study aims to quantify changes by regions in the hygienic and compositional quality of milk collected formally in Colombia between 2008 and 2019 concerning the issuance and entry into force of regulations. **Materials and methods.** 144 monthly reports on the hygienic and compositional quality of the formally collected milk were used for each milk-producing region of Colombia consolidated by the USP-MADR (Milk Price Monitoring Unit of the Ministry of Agriculture and Rural Development in Colombia). With these reports, three study periods were identified, separated by the implementation of resolutions 017/2012 and 468/2015. The obtained data were analyzed under the quantile regression scheme. **Results**. Differences were found between the analyzed periods for hygienic quality and compositional quality in each region. Hygienic quality yielded the highest variation, which was most evident in region 2. Differences were present in the compositional quality of formally collected milk in Colombia between the periods associated with the entry into force of the regulations, mainly in region 1. **Conclusions.** The implementation of the regulations exerted influence on the hygienic and compositional quality of formally collected milk in Colombia.

Keywords: Food safety; food standards; milk fat; milk hygiene; milk production; milk protein; raw milk (*Source: AIMS, CAB*).

RESUMEN

Objetivo. Cuantificar los cambios en la calidad higiénica y composicional de la leche acopiada de manera formal en Colombia entre 2008 y 2019 asociados a la expedición y entrada en vigencia de la normatividad asociada a pago por calidad de leche cruda **Materiales y métodos**. Se utilizaron 144 reportes mensuales de calidad higiénica y composicional de la leche acopiada de manera formal para cada una de las regiones productoras de leche de Colombia consolidados por la USP-MADR. Con estos reportes se formaron tres períodos de estudio separados por la entrada en vigencia de las resoluciones 017 de 2012 y 468 de 2015. Los datos obtenidos fueron analizados bajo el esquema

How to cite (Vancouver).
Usuga A, Barrios D, Botero M, Lopera M, Olivera-Angel M, Palacio LG. Analysis of milk quality variation in Colombia 2008–2019. Rev MVZ Cordoba. 2021; 26(2):e2005. https://doi.org/10.21897/rmvz.2005

ISSNL: 0122-0268

de regresión cuantílica. **Resultados.** Se encontraron diferencias entre los periodos analizados tanto para los parámetros de calidad higiénica y calidad composicional en cada una de las regiones. La calidad higiénica representó la variación más alta siendo más evidente en la región 2. Se evidenciaron diferencias en calidad composicional de la leche acopiada de manera formal en Colombia entre los periodos asociados a la entrada en vigencia de la normatividad, principalmente en la región 1. **Conclusiones.** Se evidenció que la entrada en vigencia de la normatividad ejerció influencia sobre los parámetros de calidad higiénica y composicional de la leche acopiada de manera formal en Colombia.

Palabras clave: Grasa de la leche; higiene de la leche; inocuidad alimentaria; leche cruda; normas alimentarias; producción lechera; proteínas de la leche (*Fuentes: AIMS, CAB*).

INTRODUCTION

Formal milk collection in Colombia is estimated at 9 million liters per day, which is about 47% of the total milk production from cattle at national level. Colombia is the third highest milk-producing country in South America, and almost all of its production is intended to meet domestic demand, which represents a per capita consumption of 143 liters of milk/year (1,2).

The dairy industry is increasingly demanding with respect to the quality of the milk collected. This quality is measured under three main components: i. health quality, which refers to the application of good livestock practices, including vaccination against foot-and-mouth disease and brucellosis as well as certification as brucellosis and bovine tuberculosis-free herds; ii. hygienic quality, which is given by the measurement of Colony Forming Units/mL (CFU); and iii. compositional quality, which measures the fat, protein, and total solids content of milk (3,4,5,6,7). These parameters help determine the safety and nutritional value of milk and yield when dairy products are prepared (8,9).

The standards of hygienic and compositional quality to be met by raw milk in Colombia were defined by Decrees 616/2006 and 1880/2011. According to these, milk must comprise at least 2.9% protein, 3.0% fat, and 11.30% total solids, and microbiological characteristics measured by aerobic mesophilic count should not exceed 700,000 CFUs/mL (5). Resolutions 012/2007 and 017/2012 issued by the MADR (Ministry of Agriculture and Rural Development in Colombia) are based on these parameters to regulate payment systems for the quality of raw milk to the producer and to regulate the formation, authorization, and accreditation of a network of laboratories for analysis (10,11).

In normative terms, one of the advances presented in Colombia over the last 13 years is that agents who buy raw milk must pay for it based on the evaluation of hygienic and compositional quality performed in a laboratory (10). The pay-for-quality system and accreditation of the laboratory network ensure transparency in the payment of milk.

Initially, since February 2007, milk quality had to be analyzed by a laboratory enabled by Corpoica (now Agrosavia). However, in 2015, the MADR issued resolution 468, which reiterated the mandatory nature of the hygienic and compositional quality evaluation of raw milk and simultaneously stated that the analysis was to be performed by laboratories accredited in NTC-ISO/IEC 17025 by the Colombian National Accreditation Agency (ONAC, by its Spanish acronym); they established August 01, 2016 as the deadline for laboratory accreditation (10). Accreditation in NTC-ISO/IEC 17025 achieves compliance with quality requirements and continuous improvement to achieve the highest levels of recognition at not only national level but also international level (12).

In Colombia, by 10 of August 2020, seven laboratories have been accredited by ONAC to process milk samples and determine quality associated with payment; three of them are independent (two belonging to Agrosavia and one to Universidad de Antioquia) and four of them are from the milk collection industry (Alpina, Colanta, Freskaleche, and Nestle) (13).

The methodology for obtaining the price paid to the producer is based on the results delivered by accredited laboratories in terms of hygienic and compositional quality of milk. Their analysis enables the understanding of the variations in price paid to the producer. The payment was regulated by resolution 017/2012, which states that payment must be calculated on the basis of the protein and fat content or the content of total solids per liter of milk and bonus or deduction for hygienic quality measured in CFUs/mL should also be calculated (10).

This study aims to quantify changes in the hygienic and compositional quality of formally collected milk in Colombia concerning the issuance and implementation of resolutions 012/2007, 017/2012, and 468/2015 for the payment of raw milk.

MATERIALS AND METHODS

Type of study. Retrospective descriptive observational study conducted based on the interrupted time series of hygienic and compositional quality of raw formally collected milk between January 2008 and December 2019. The research is based on the analysis of secondary sources of data on hygienic and compositional quality of raw formally collected milk in Colombia.

Study area. This study was conducted with information generated in the departments of Colombia where formal milk collection is performed. MADR Resolution 017/2012 defined a differential payment of milk by dairy regions (region 1 and 2), corresponding to a set of departments that share similar characteristics from a productive viewpoint (see Figure 1) (10).

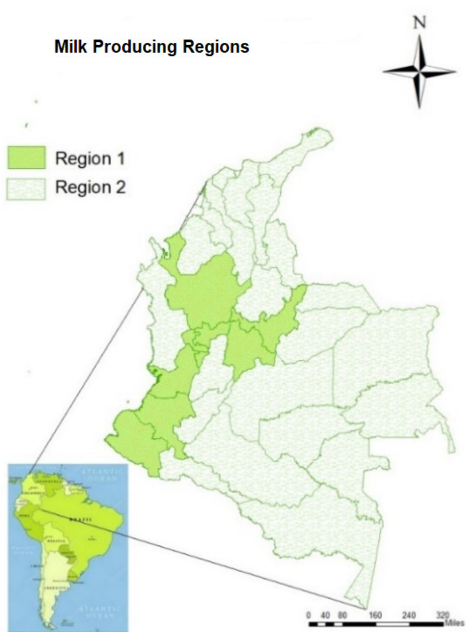

Figure 1. Classification of Colombia by milk-producing regions.

Methods for collecting data on hygienic and compositional quality reports. Milk-purchasing agents fortnightly report volume-weighted microbiological and compositional quality data of milk collected to the USP-MADR (Milk Price Monitoring Unit of the Ministry of Agriculture and Rural Development in Colombia). The USP-MADR consolidates and delivers information at a national level by department and region, which is also weighted by volume. This information is published on the USP-MADR website (1).

Based on the obtained data, a statistical analysis was performed to determine the possible impact associated with the implementation of the three standards related to reports of the quality of formally collected milk during the period from January 2008 to December 2019.

Variables and measurement level. The formal collection variable, expressed in millions of liters of milk per month, was included. Moreover, in addition to the microbiological quality variable, expressed in CFUs/mL, the following compositional quality variables were also included: i. percentage of fat, ii. percentage of protein, and iii. percentage of total solids. These variables are monthly reported on the USP-MADR portal.

Information Analysis. To establish a relationship between hygienic and compositional quality variables and the implementation of resolutions 012/2007, 017/2012, and 468/2015, interrupted time series were built. 144 monthly reports of the hygienic and compositional quality of milk formally collected by the purchasing agents in each region and consolidated by the USP-MADR were used.

The obtained data were analyzed under the quantile regression scheme. Three study periods were formed: 1. from January 01, 2008, following the implementation of resolution 012/2007, to February 28, 2012; 2. from March 01, 2012, when resolution 017/2012 took effect, to July 31, 2016; and 3. from August 01, 2016, with the implementation of resolution 468/2015, to December 31, 2019. The observation period excluded 2007 information as it was unavailable in the USP-MADR (10,11).

Statistical Analysis. The compositional quality variables of milk display seasonal patterns. Thus, the analysis of the implementation of resolutions

012/2007, 017/2012, and 468/2015 had to simultaneously include variables that considered seasonal patterns. Therefore, twelve categorical variables that represented the seasonal effect of each month on each compositional quality variable were included here.

The econometric model used for each compositional quality variable of milk is the one presented for protein, and it is applied for the other variables of interest:

$$Proteina_t=B_1d_{1,t}+B_2d_{2,t}+B_3d_{3,t}+B_4\ d_{4,t}+B_5\ d_{5,t}+B_6d_{6,t}+B_7d_{7,t}+B_8d_{8,t}+B_9d_{9,t}+B_{10}d_{10,t}+B_{11}d_{11,t}+B_{12}d_{12,t}+\propto_2 m_{2,t}+\propto_3 m_{3,t}+\in_t \quad [1]$$

$d_{i,t}=1$, if $t \in$ month i of the year 0, otherwise $i=1,2,…,12$

$m_{j,t}=1$, if $t \in$ for period j 0,otherwise $j=2,3$

where α_2 and α_3 represent the effect of resolutions 07/2012 and 468/2015, respectively, while keeping the other parameters constant.

Since no category variable is available for the period from January 2008 to February 2012 in the model, this period remains as a reference category.

The Model for the reference category is as follows: ($m_{2,t}=0$ and $m_{3,t}=0$)

$$Proteina_t=B_1d_{1,t}+B_2d_{2,t}+B_3d_{3,t}+B_4\ d_{4,t}+B_5\ d_{5,t}+B_6d_{6,t}+B_7d_{7,t}+B_8d_{8,t}+B_9d_{9,t}+B_{10}d_{10,t}+B_{11}d_{11,t}+B_{12}d_{12,t}+\in_t \quad [2]$$

The model for March 2012–July 2016 is ($m_{2,t}=1$ and $m_{3,t}=0$)

$$Proteina_t=B_1d_{1,t}+B_2d_{2,t}+B_3d_{3,t}+B_4\ d_{4,t}+B_5\ d_{5,t}+B_6d_{6,t}+B_7d_{7,t}+B_8d_{8,t}+B_9d_{9,t}+B_{10}d_{10,t}+B_{11}d_{11,t}+B_{12}d_{12,t}+\propto_2+\in_t \quad [3]$$

Finally, the model for August 2016 is ($m_{2,t}=0$ and $m_{3,t}=1$)

$$Proteina_t=B_1d_{1,t}+B_2d_{2,t}+B_3d_{3,t}+B_4\ d_{4,t}+B_5\ d_{5,t}+B_6d_{6,t}+B_7d_{7,t}+B_8d_{8,t}+B_9d_{9,t}+B_{10}d_{10,t}+B_{11}d_{11,t}+B_{12}d_{12,t}+\propto_3+\in_t \quad [4]$$

Given that this model estimates average partial effects, the latter may be influenced by atypical data and heteroscedastic schemes. To avoid its possible influence, a quantile regression scheme was used, which corrects the situation of atypical data and possible heteroscedastic schemes presented by regression models by fully studying the probability distribution of the variable (14). Estimates of this model were made for the median, that is, quantile 50, a central trend measure that is not influenced by possible extreme values. Data were tabulated in Excel workbook and analyzed with free and open-source R software.

Ethical aspects. According to Colombia's resolution 8430/1993, "Establishing scientific, technical, and administrative standards for health research," this study falls into the category of free-from-risk research. Study data were obtained from retrospective documentary review; no intentional modification was made to biological or physiological variables, and no living beings were involved. Thus, informed consent and submission to an ethics committee were not needed.

RESULTS

Volume of formal collection. Figure 2 shows the trend of formal milk collection in Colombia during 2008–2019 (Figure 2A) and the results of the model for the comparison of medians per period of monthly collection volume. Region 1 showed a progressive increase in collection and significant differences between the periods were determinated ($p < 0.001$) (Figure 2B). For region 2, the period analysis showed an increase in the collection volume compared to period 1 (Figure 2C). However, the collection volume decreased in the period 3, compared to period 1. Seasonality became more evident in the volume of formal milk collection that was presented in region 2 with the increase in the amount of milk observed in May–October. Meanwhile, February–April recorded the lowest collection volumes.

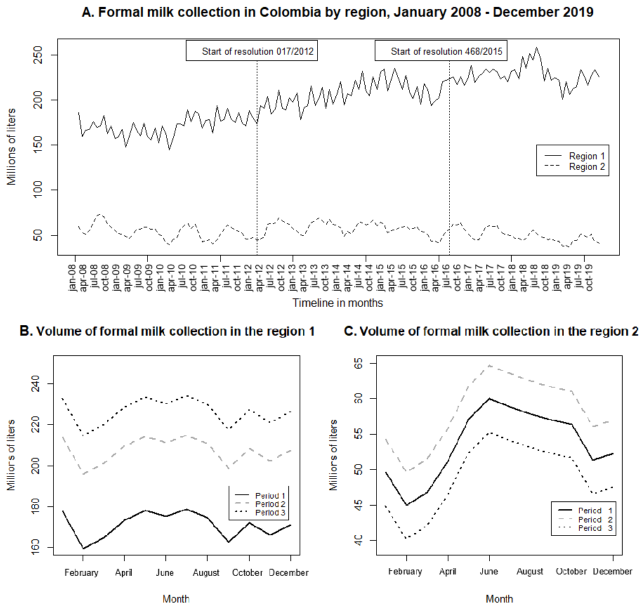

Figure 2. Time series and medians of formal collection of raw milk in Colombia by period and region, according to the months of the year, 2008 - 2019.

Colony Forming Units/mL. CFU time series reported for the formally collected milk from region 1 shows a stable trend (Figure 3A). Figures 3B and 3C show how the CFU medians change in all three periods during the different months of the year. The following coefficients were applied to each month: B_i for the first period, $B_i+\propto_2$ for the second period, and $B_i+\propto_3$ for the third period. Based on this information and the statistical significance ($p<0.01$) of coefficients $\propto_2$ and $\propto_3$, we can conclude that resolutions 017/2012 and 468/2015 were associated with the modification in the reported CFUs in formally collected milk in both regions 1 and 2.

When comparing regions, we observed that the CFU/mL averages reported for region 2 were twice those reported for region 1. Highlighting the marked decrease in CFU of the milk collected in region 2, particularly during the period 2, is necessary (Figure 3A).

The standard errors of each coefficient were estimated using the bootstrap technique with 20,000 replications. Note that all coefficients were statistically significant for region 1 ($p<0.001$). In addition, this model is interpreted in variables $m_{2,t}$ and $m_{3,t}$ with variant intercept with respect to the month. In this way, the estimated median for the CFU variable in month 1 is given by 464865 in period 1; 464865 − 89689 for period 2 and 464865 + 87087 for period 3.

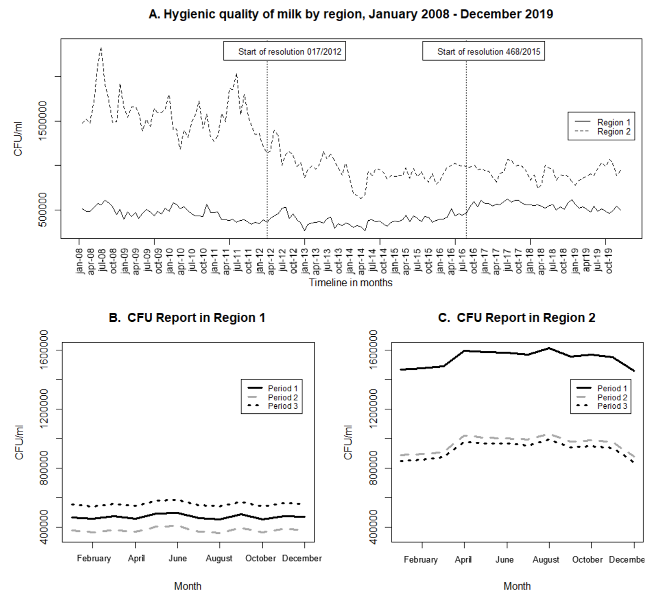

Figure 3. Time series and quantile distribution of the CFUs reported by regions for formally collected milk in Colombia, 2008 – 2019.

In the period 2 of region 1, a significant reduction in CFU was observed compared to period 1 ($p<0.001$). However, in the period 3, it increased in relation to other periods ($p<0.001$). Given the significance of $\propto_2$ and $\propto_3$, we can conclude that the entry into force of resolutions 017/2012 and 468/2015 were associated with a change in the CFUs of formally collected milk in region 1 (Table 1).

For region 2, all coefficients were found to be statistically significant ($p<0.001$). When considering variant intercepts for the month, the estimated median for the CFU variable of formally collected milk in region 2 in month 1 is given by 1465576 in period 1, 1465576 − 578339 for period 2, and 1465576 − 617274 for period 3. Periods 2 and 3 present statistically significant reductions as opposed to period 1, given the significance of $\propto_2$ and $\propto_3$. This change is attributable to the implementation of resolutions 017/2012 and 468/2015 having a positively significant effect on the CFU report on formally collected milk in region 2 (Table 1).

Protein Content in milk. In contrast to the observations in region 1, region 2 peaks are noticeable in the reports of the months of October, showing a marked seasonal trend (Figure 4A).

Table 1. Estimated models for variables milk collection, CFUs, protein, fat, and total solids for formally collected milk in regions 1 and 2 for median regression for period 1.

Variable	Month	Region 1				Region 2			
		Median	Standard error	T value	P value	Median	Standard error	T value	P value
Gathering	January	177.710.590	4.30	41.34	0.00	49.581.510	2.23	22.20	0.00
	February	159.473.800	5.36	29.76	0.00	44.934.400	2.36	19.05	0.00
	March	164.927.900	5.52	29.86	0.00	46.828.640	1.74	26.99	0.00
	April	173.462.410	4.88	35.50	0.00	51.181.810	2.50	20.45	0.00
	May	178.080.990	3.77	47.28	0.00	57.100.640	1.81	31.49	0.00
	June	175.183.260	5.67	30.91	0.00	60.046.910	2.29	26.28	0.00
	July	178.714.020	5.53	32.29	0.00	58.882.910	2.07	28.41	0.00
	August	174.733.280	2.91	59.81	0.00	57.824.750	2.81	20.58	0.00
	September	162.476.870	3.71	43.8	0.00	57.002.190	2.28	25.02	0.00
	October	172.121.400	3.06	56.3	0.00	56.348.620	2.27	24.82	0.00
	November	166.030.550	4.06	40.88	0.00	51.390.490	2.92	17.61	0.00
	December	171.166.420	4.16	41.11	0.00	52.300.220	2.51	20.80	0.00
	α2	36,17	3.04	11.88	0.00	4.68	1.32	3.55	0.00
	α3	55,19	2.59	21.31	0.00	-4.75	1.78	-2.67	0.01
UFC	January	464.685	22.411	20.74	0.00	1.465.576	54.545	26.86	0.00
	February	454.182	24.578	18.47	0.00	1.474.903	63.962	23.05	0.00
	March	471.983	23.267	20.28	0.00	1.489.002	61.884	24.06	0.00
	April	458.220	34.491	13.28	0.00	1.595.434	70.515	22.62	0.00
	May	492.888	25.251	19.59	0.00	1.584.643	93.717	16.90	0.00
	June	497.934	25.912	19.21	0.00	1.581.181	68.745	23.00	0.00
	July	459.606	33.085	13.89	0.00	1.569.017	60.997	25.72	0.00
	August	451.246	25.197	17.91	0.00	1.610.667	57.598	27.96	0.00
	September	485.547	37.234	13.03	0.00	1.555.442	51.174	30.39	0.00
	October	452.930	23.799	19.03	0.00	1.566.737	47.678	32.86	0.00
	November	474.551	24.253	19.56	0.00	1.551.080	77.973	19.89	0.00
	December	470.650	28.325	16.61	0.00	1.457.105	64.692	22.52	0.00
	α2	-89.689	18.738	-4.78	0.00	-578.339	47.988	-12.06	0.00
	α3	87.087	17.727	4.91	0.00	-617.274	47.442	-13.01	0.00
Protein	January	3.04	0.04	76.63	0.00	3.36	0.02	155.6	0.00
	February	3.02	0.02	137.29	0.00	3.31	0.03	130.01	0.00
	March	3.02	0.02	162.84	0.00	3.29	0.02	176.97	0.00
	April	3.01	0.02	159.87	0.00	3.3	0.02	179.22	0.00
	May	3.01	0.02	160.61	0.00	3.31	0.03	120.49	0.00
	June	3.02	0.02	146.85	0.00	3.38	0.02	162.45	0.00
	July	3.02	0.02	130.43	0.00	3.41	0.03	134.66	0.00
	August	3.02	0.02	148.29	0.00	3.41	0.02	185.85	0.00
	September	3.03	0.02	147.87	0.00	3.45	0.02	142.07	0.00
	October	3.03	0.02	137.24	0.00	3.45	0.02	159.5	0.00
	November	3.03	0.02	133.14	0.00	3.43	0.02	217.69	0.00
	December	3.05	0.03	122.05	0.00	3.41	0.03	109.67	0.00
	α2	0.07	0.02	3.69	0.00	-0.07	0.01	-5.65	0.00
	α3	0.14	0.02	7.36	0.00	-0.02	0.02	-1.03	0.31
Grease	January	3.61	0.04	86.00	0.00	3.83	0.06	66.82	0.00
	February	3.60	0.02	184	0.00	3.74	0.05	69.52	0.00
	March	3.59	0.03	134.96	0.00	3.70	0.04	94.22	0.00
	April	3.56	0.02	144.83	0.00	3.69	0.03	109.40	0.00
	May	3.56	0.02	185.09	0.00	3.74	0.04	96.15	0.00
	June	3.56	0.02	189.04	0.00	3.79	0.04	103.43	0.00
	July	3.58	0.02	208.23	0.00	3.79	0.05	83.85	0.00
	August	3.60	0.02	181.95	0.00	3.88	0.10	37.12	0.00
	September	3.60	0.02	189.97	0.00	3.90	0.08	47.17	0.00
	October	3.63	0.02	162.93	0.00	3.98	0.09	43.77	0.00
	November	3.61	0.02	187.1	0.00	3.94	0.08	47.57	0.00
	December	3.60	0.02	158.99	0.00	3.88	0.07	52.68	0.00
	α2	0.06	0.01	4.11	0.00	-0.04	0.02	-1.49	0.14
	α3	0.10	0.02	5.65	0.00	-0.03	0.35	-0.09	0.93

Variable	Mes	Región 1				Región 2			
		Mediana	Error estándar	Valor t	Valor p	Mediana	Error estándar	Valor t	Valor p
Percentage of total solids	January	11.95	0.02	641.21	0.00	12.52	0.04	309.45	0.00
	February	11.96	0.03	409.79	0.00	12.40	0.10	130.03	0.00
	March	11.90	0.03	455.09	0.00	12.37	0.05	273.76	0.00
	April	11.90	0.02	581.64	0.00	12.42	0.04	349.55	0.00
	May	11.96	0.03	457.59	0.00	12.51	0.03	494.40	0.00
	June	11.94	0.02	574.53	0.00	12.55	0.04	301.96	0.00
	July	11.97	0.03	390.53	0.00	12.61	0.03	503.67	0.00
	August	11.96	0.02	675.70	0.00	12.62	0.03	472.09	0.00
	September	11.96	0.09	138.01	0.00	12.64	0.03	411.86	0.00
	October	11.97	0.02	637.57	0.00	12.67	0.04	290.13	0.00
	November	11.98	0.02	672.10	0.00	12.71	0.03	438.91	0.00
	December	11.98	0.02	659.88	0.00	12.65	0.04	285.33	0.00
	$\alpha 2$	0.10	0.01	7.58	0.00	-0.01	0.02	-0.44	0.66
	$\alpha 3$	0.11	0.02	6.66	0.00	-0.04	0.03	-1.37	0.17

Figures 4B and 4C show how protein medians change over all three periods during the different months of the year. Based on Figure 4B and the statistical significance of the coefficients $\propto_2$ and $\propto_3$, we can conclude that resolutions 017/2012 and 468/2015 had a statistically significant effect on the percentage of protein in milk and that the latter resolution, given the higher value of the coefficient, had the highest effect in region 1. Nevertheless, only statistically significant differences were found for region 2 between periods 1 and 2 (Table 1).

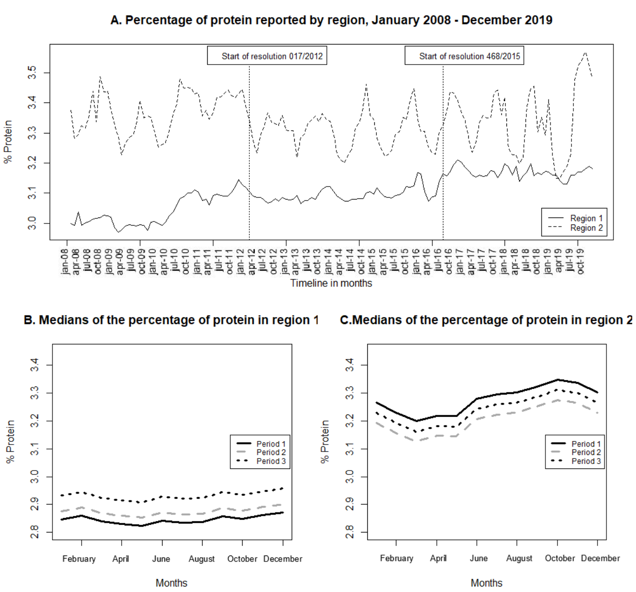

Figure 4. Time series and distribution by quantiles of the percentage of protein reported by regions for formally collected milk in Colombia, 2008 - 2019.

The standard errors of each coefficient were estimated in the same way as those for CFU. Note that all coefficients are statistically significant for region 1 ($p<0.001$). The estimated median for protein in month 1 is 3.04 in period 1, 3.04 + 0.06 for period 2, and 3.04 + 0.14 for period 3. Moreover, a significant increase was observed in the period 3 as opposed to the other periods. Given the significance of $\propto_2$ and $\propto_3$, we can conclude that the implementation of resolutions 017/2012 and 468/2015 had a positively significant effect on the percentage of protein in milk (Table 1).

In region 2, the standard errors for each coefficient were estimated using the same Bootstrap technique, with 20,000 replicates used in previous models. In period 2, a significant reduction from period 1 was observed, while for period 3, no differences were observed with respect to period 1. Given the significance of $\propto_2$, we can conclude that the implementation of resolution 017/2012 had a negatively significant effect on the percentage of protein in milk (Table 1).

Fat content in milk. The milk fat percentage reports meet the parameters set out in the standard. Region 1 shows an upward trend that is constant throughout the observation, reaching even figures similar to those reported for region 2 in period 3. Moreover, region 2 showed marked seasonality and a tendency to decline (Figure 5A).

Standard errors were calculated using the same technique as that for CFU and protein. All coefficients were statistically significant for region 1 ($p<0.001$). In the period 3, a significant increase was observed compared to the other periods. Given the significance of $\propto_2$ and $\propto_3$, we can conclude that the implementation of resolutions 017/2012 and 468/2015 coincided with a positively significant effect on the percentage of fat in formally collected milk in region 1 (p<0.001). When applying the same technique for the region 2 data, no differences were found between the periods (Table 1).

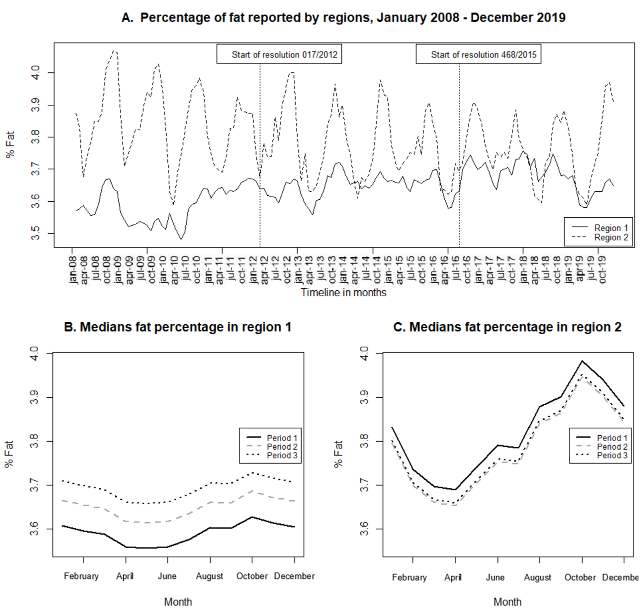

Figure 5. Time series and distribution by quantiles of the percentage of fat reported by regions formally collected milk from January 2008 to December 2019.

Totals solids content in milk. Total solids content of the milk collected in region 1 showed a positive trend throughout the observation, mainly in periods 1 and 2. In addition, the increase in percentages of total solids in milk was constant. In contrast, region 2 displayed marked seasonality in the percentages of total solids reported, although more irregular, when compared to the protein and fat curves of the same region (Figure 6A).

Regarding the comparison of medians, in region 1 the percentages of total solids progressively increased during periods 2 and 3. Moreover, reports were relatively stable throughout the year (Figure 6B). The opposite trend was observed for region 2, where no significant differences were evidenced between the median total solids reported for the periods (Table 1). However, seasonality was evident when comparing the months of the year; the lowest percentages of total solids were reported in March and the highest ones were reported in November (Figure 6C).

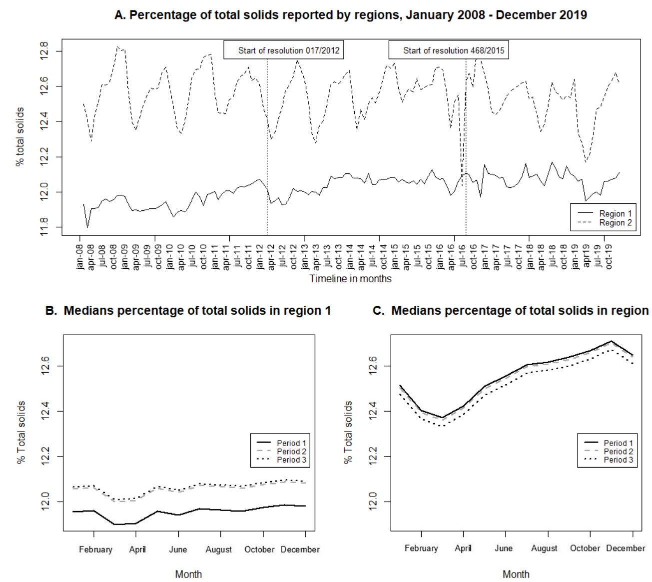

Figure 6. Time series and distribution by quantiles of the percentage of distribution by quantiles of the percentage of total solids reported by regions for formally collected milk from January 2008 to December 2019.

Estimated median regression models for the collection, CFUs, fat, protein, and total solids variables in regions 1 and 2 in Quantile 50 are presented in Table 1.

DISCUSSION

Colombia has increased the amount of milk collected, with an increase of 8.9% in the period observed (2). This increased volume is mainly explained by the increase in milk collection in region 1 (Figure 2A).

Formal milk collection in region 2 showed variations depending on the time of the year. Between December and March, a period that coincides with the dry season, a lower volume of milk collection was reported. The maximum volume was reported between May and September, which traditionally corresponds to the months with rainfall in that region. These results coincide with those reported by Lambertz et al (15), who found that weather variables, such as temperature and humidity indices, directly impact milk production.

Moreover, interlaboratory tests required in resolution 017/2012 (10) coincide with an increase in the hygienic quality of milk, which was considerably more marked in region 2. This could be explained by a greater accuracy of the diagnostic methodologies employed following the implementation of the resolutions. Unfortunately, references that support these claims in the area of interest were not found. However, other knowledge areas, such as public health, have reported improvements in analyzed parameters following the implementation of specific standards (16).

Differences between observation periods regarding CFU/mL reports of formally collected milk in region 2 suggest that the implementation of regulation contributed to improved hygienic quality, evidenced by the fact that the median CFU/mL for periods 2 and 3 were lower than that for period 1. However, the information available in the USP-MADR does not allow a comparison of the period before the implementation of resolution 012/2007 since there is a decreasing trend in CFUs between January 2008 and February 2012. One possible explanation is the implementation of protocols, such as Hazard Analysis and Critical Control Points (HACCP), and good farming practices, which the dairy industry is not oblivious to. According to Papademas and Bintsis (17), such protocols become a cost-effective solution for obtaining a better-quality product, which includes hygienic quality. Similarly, such improvements can be associated with an increased recognition by the producer that quality affects the value paid per liter of milk by the purchasing agent, which is an incentive to act in this regard.

Note that the reported CFUs for milk collected in region 1 increased following the implementation of resolution 468/2015 and, therefore, the analysis of milk in laboratories accredited in NTC-ISO/IEC 17025. Further studies are required to explain this situation. The quantile regression for the median CFUs in region 2 showed no differences between the months of the year, which contradict the results obtained by Martinez et al (6), who found differences in CFU reports between summer and winter, with higher CFU values in the former.

The compositional quality of the milk collected in regions 1 and 2 complied with decree 616/2006 for all periods (5). However, differences in the compositional and hygienic quality of milk by region and by months of the year could be identified for the parameters analyzed. Discrepancies in fat and protein percentages between the periods observed for both regions were also identified. Martinez et al (6) also identified differences in the compositional quality of milk according to the months of the year, which were associated with the frequency and distribution of rainfall.

The median percentages of protein estimated for region 2 in this study differ from those found by Calderon et al (18), who reported averages of 3.28% protein in formally collected milk in Monteria, Cordoba. These differences may be explained by the fact that this study considered results obtained across region 2, while Calderón et al (18) conducted their study in dual-purpose farms in the municipality of Monteria.

The trend observed in these results can be explained by the standardization of measurements at the laboratory level, which afforded accurate results that were appropriately close the actual values. The study by Khodabocus and Balgobin (19) shows that laboratory accreditation in ISO 17025 yield results reliable and accurate as parameters like those obtained using gold standard tests and narrow standard deviations.

Reported fat percentages evidenced differences between periods, particularly in region 1, where a progressive increase was observed. The fat percentage differs from the results obtained for region 2, where the percentages of milk fat decreased as periods progressed. In the case of region 1, this progressive increase in fat content could be explained by the different supplementation methods implemented, such as protected fats that generate a higher percentage of milk fat or selection of bulls that transcend this characteristic (20). The quality associated producer payment system mentioned in the standards described could encourage improvements in animal nutrition systems that directly influence milk fat content, particularly in region 1 (21).

The differences found in the median percentage of fat for region 2, which decreased as periods progressed, can be explained by the modification of different analysis techniques in laboratories during the study period. These results differ from those found by Calderon et al. (18), who reported fat percentages of 3.70% for formally collected milk in Monteria, Cordoba for 2012, and Arrieta et al. (22), who found an average fat percentage of 4.95% in raw milk samples marketed in municipalities of Sucre.

The strong seasonal pattern of fat reported in region 2 corresponds to that found by other studies, which identified the influence of weather variables on milk production and quality. This influence was mainly identified when cows were subjected to unfavorable environmental conditions, such as high temperatures and low precipitation, which results in low milk production and lower compositional quality (23). However, these findings contrast with those reported by Rodriguez-Rodriguez et al. (24), who found no differences between the percentages of fat analyzed according to the time of year in raw milk samples from the dual-purpose system in the department of Cordoba, Colombia.

Finally, regarding the total solids reported for the milk collected, only region 1 showed differences between periods. A progressive increase was observed in the reports, possibly associated with improvements in technical, productive, and administrative parameters that influence the compositional quality of milk, such as genetics, herd health, and animal nutrition (25). For region 2, no differences were observed in the reports when the period comparison was performed.

However, marked seasonality was evident in the percentages of total solids reported in region 2, which were similar to that observed for fat and protein. Oliszewski et al (26) found that in Argentina, total solids vary significantly during the year, with the highest levels in autumn, compared to winter and spring. According to Lambertz et al (15), production and compositional quality of milk are affected by the interaction between animals and various environmental conditions, such as extreme temperatures.

The results found in this study can be associated with the highest restrictions implemented by ONAC on accredited laboratories to ensure that the measurements obtained correspond to the actual values of the analyzed sample. These requirements are reflected in the number of accredited laboratories, which changed from 108 accredited laboratories in April 2012 to seven accredited laboratories in NTC-ISO/IEC 17025 in august 2020.

In conclusion, the observed differences suggest an association between the implementation of the standards initially issued by the MADR for the authorization of milk quality analysis laboratories and the requirement of NTC-ISO/IEC 17025 for laboratory accreditation and hygienic and compositional quality of formally collected milk in Colombia. However, this association was unequally reflected in both regions. In some cases, a positive influence was observed that indicated an improvement in the analyzed parameters, such as the percentage of fat and protein in region 1 and CFUs in region 2, but in other cases significant differences were observed that showed the detriment of the quality of the CFUs of region 1 in the third period.

Based on the evaluated information, we conclude that further exhaustive analyses are required to explain the reasons why differences in compositional and hygienic quality of milk occur. Moreover, knowing the reasons why the identified differences are most evident in region 1 will be useful.

Conflict of interest

The authors declare that there are no conflicts of interests regarding the publication of this paper.

Acknowledgements

We would like to thank Sistema General de Regalias (SGR), Government of Antioquia and MINCIENCIAS for the support of the project "Business strengthening of milk producers in the department of Antioquia by improving the quality and safety of milk through the production, use, and evaluation of a technological development product," contract 80740-013-2019, within the framework under which this publication was generated.

REFERENCES

1. USP-MADR. Precio por litro de leche pagado al productor a nivel nacional y regional. Unidad de Segumiento de Precios de la Leche. Ministerio de Agricultura y Desarrollo Rural: Colombia; 2020. http://uspleche.minagricultura.gov.co/precio-pagado-al-proveedor-con-bonificaciones-voluntarias-nacional-y-regional.html

2. Restrepo-Betancur LF, Peña-Serna C, Zapata-López N, Restrepo-Betancur LF. Disponibilidad de Leche de los Países Sudamericanos en las Últimas Cinco Décadas: Elementos para Análisis y Perspectivas Futuras. Inf tecnol. 2019; 30(4):77–84. http://hdl.handle.net/10495/12387

3. Gaona RC, Terranova MV, Hernández E, Alegría KG, Benavides RM, Guerrero HS, et al. Genetic improvement in dairy cows. The essence of true animal production. Acta Agron. 2016; 64(3):296–306. https://revistas.unal.edu.co/index.php/acta_agronomica/article/view/50263/56012

4. Vásquez JF, Loaiza ET, Olivera M. Calidad higiénica y sanitaria de leche cruda acopiada en diferentes regiones colombianas. Orinoquia 2012; 16(2):13. https://orinoquia.unillanos.edu.co/index.php/orinoquia/rt/printerFriendly/251/737

5. Decreto 616. Por el cual se expide el Reglamento Técnico sobre los requisitos que debe cumplir la leche para el consumo humano. Ministerio de la Protección Social: Colombia; 2006. https://www.ica.gov.co/getattachment/15425e0f-81fb-4111-b215-63e61e9e9130/2006D616.aspx

6. Martínez M, Gómez C. Calidad composicional e higiénica de la leche cruda recibida en industrias lácteas de Sucre, Colombia. Biotecnología En El Sector Agropecuario Y Agroindustrial. 2013; 11(2):93-100. https://revistas.unicauca.edu.co/index.php/biotecnologia/article/view/309

7. Rodríguez RV, Calderón RA, Vergara GO. Calidad de leches crudas en tres empresas acopiadoras en Córdoba. Rev Colomb Cienc Anim RECIA. 2014; 6(1):103–15. https://doi.org/10.24188/recia.v6.n1.2014.222

8. D'Amico DJ, Donnelly CW. Microbiological quality of raw milk used for small-scale artisan cheese production in Vermont: Effect of farm characteristics and practices. J Dairy Sci. 2010; 93(1):134-147. https://doi.org/10.3168/jds.2009-2426

9. Smigic N, Djekic I, Tomasevic I, Miocinovic J, Gvozdenovic R. Implication of food safety measures on microbiological quality of raw and pasteurized milk. Food Control. 2012;25(2):728–31. https://doi.org/10.1016/j.foodcont.2011.12.022

10. Resolución 017. Por el cual se establece el sistema de pago de leche cruda al proveedor. Ministerio de Agricultura y Desarrollo Rural: Colombia; 2012. [Consultado octubre de 2019]. https://www.icbf.gov.co/cargues/avance/docs/resolucion_minagricultura_0017_2012.htm

11. Resolución 468. Por la cual se modifica la resolución 017 de 2012, modificada por la resolución 077 de 2015. Ministerio de Agricultura y Desarrollo Rural: Colombia; 2015. [Consultado octubre de 2019]. https://www.icbf.gov.co/cargues/avance/docs/resolucion_minagricultura_0468_2015.htm

12. Norma técnica NTC-ISO/IEC Colombiana 17025. Requisitos generales para la competencia de los laboratorios de ensayo y calibración. Instituto Colombiano de Normas Técnicas (ICONTEC): Colombia; 2005. [Consultado diciembre 2019]. https://www.invima.gov.co/images/pdf/red-nal-laboratorios/resoluciones/NTC-ISO-IEC_17025-2005.pdf

13. Organismo Nacional de Acreditación – ONAC. Directorio de laboratorios acreditados: Colombia; 2020 [Consultado 10 de agosto 2020]. https://onac.org.co/directorio-de-acreditados

14. Koenker R. Quantile regression. New York. Cambridge University Press. 2005. https://books.google.com.co/books?id=hdkt7V4NXsgC&printsec=frontcover&hl=es&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false

15. Lambertz C, Sanker C, Gauly M. Climatic effects on milk production traits and somatic cell score in lactating Holstein-Friesian cows in different housing systems. J Dairy Sci. 2014;97(1):319–329. http://dx.doi.org/10.3168/jds.2013-7217

16. Hoye A. Recommend or mandate? A systematic review and meta-analysis of the effects of mandatory bicycle helmet legislation. Accid Anal Prev. 2018; 120:239–249. https://doi.org/10.1016/j.aap.2018.08.001

17. Papademas P, Bintsis T. Food safety management systems (FSMS) in the dairy industry: A review. Int J Dairy Technol. 2010; 63(4):489–503. http://dx.doi.org/10.1111/j.1471-0307.2010.00620.x

18. Calderón A, Rodríguez V, Arrieta G, Martínez N, Vergara O. Calidad fisicoquímica y microbiológica de leches crudas en empresas ganaderas del sistema doble propósito en Montería (Córdoba), Rev UDCA Act & Div Cient. 2012; 15(2):399–407. https://revistas.udca.edu.co/index.php/ruadc/article/view/841

19. Khodabocus F, Balgobin K. Implementation and Practical Benefits of ISO/IEC 17025:2005 in a Testing Laboratory. Univ Mauritius Res J. 2011;17(1):27–60. http://dx.doi.org/10.4314/umrj.v17i1.70730

20. Duarte V. J, Ramírez Z. G, Castañeda S. R. Grasa sobrepasante: Aplicaciones y su proceso de obtención para la alimentación de rumiantes en el trópico. Rev Colomb Cienc Anim - RECIA. 2016; 8(2):228. https://doi.org/10.24188/recia.v8.n2.2016.192

21. García C, Montiel R, Borderas Y. Grasa y proteína de la leche de vaca: componentes, síntesis y modificación. Arch Zootec. 2014; 63:85-105. https://doi.org/10.21071/az.v63i241.592

22. Arrieta B, Gomezcaceres P, Albis F, Calderón-Rangel A, Rodríguez R. Calidad de la leche cruda para consumo humano en dos localidades de Sucre (Colombia). Rev MVZ Córdoba 2019; 24(3):7355–7361. https://doi.org/10.21897/rmvz.1829

23. Hill DL, Wall E. Dairy cattle in a temperate climate: The effects of weather on milk yield and composition depend on management. Animal. 2014; 9(1):138–149. http://dx.doi.org/10.1017/S1751731114002456

24. Rodríguez-Rodríguez V, Acosta-Ruiz A. Calidad de leches crudas en sistemas doble propósito en Córdoba (Colombia), en condiciones de máxima y mínima precipitación. Rev Vet Zootec. 2014; 8(2):72-86. http://190.15.17.25/vetzootec/index.php/component/content/article?id=104

25. Escoto FC, Vargas AC, Oño IM. La calidad estándar de la leche en el estado de Hidalgo, México. Rev Mex Cienc Pecu. 2013;4(1):82. https://cienciaspecuarias.inifap.gob.mx/index.php/Pecuarias/article/view/2827

26. Oliszewski R, Cisint J, Medina CF. Caracterización composicional, fisicoquímica y microbiológica de leche de vaca de la cuenca de Trancas. COCINET. 2016; 36(4105):31–9. https://www.conicet.gov.ar/new_scp/detalle.php?keywords=&id=31611&articulos=yes&detalles=yes&art_id=6712611