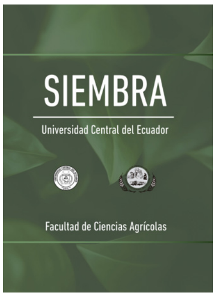
Pilot plan to improve the nutritional quality and somatic cell count of bovine milk produced by small producers in the Province of Pichincha-Ecuador, applying a training program



Plan piloto para el mejoramiento de la calidad nutricional y conteo de células somáticas de leche bovina, producida por pequeños productores de la provincia de Pichincha-Ecuador, aplicando un programa de capacitación

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Abstract

Dairy production in Ecuador is a source of economic income for many small and medium producers, however the lack of technical advice leads to problems in the quality of milk and affects their production volume. The purpose of this investigation was to conduct a pilot plan to improve the quality of milk produced by 57 small producers from different parishes of the cantons of Quito, Rumiñahui and San Miguel de los Bancos in the province of Pichincha, through a training plan in good milking practices and feeding strategies. Two initial samplings were carried out (between October and November 2021) prior to the training, and two final samplings (in June 2022) to measure the impact of the training. A total of 1.273 samples were collected, of these only 4.02 % (52/1273) (of the samples) complied with the reference values of the national regulations, while 95.98 % (1243/1273) did not comply with any of the evaluated parameters; however, the vast majority of the milk is suitable for human consumption, yet its nutritional quality needs to be improved. We were able to reduce considerably (although not statistically) the somatic cell count (SC, from an initial average of 623530 CS ml^{-1} to 365660 CS ml^{-1} after training, being correlated with the significant increase in the percentage of lactose between the initial and final sampling; there were also significant differences in the percentage of fat and total solids, although in these two cases their values decreased after training (fat from 2.58 % in the initial sampling to 2.10 % in the final sampling and total solids of 11, 44 % to 11.00 %);showed no significant differences between samples. It is concluded that the training was beneficial since the considerable decrease in the somatic cell count increased the volume of milk production of the small producers, and therefore their economic income. For the rest of the parameters, it is recommended to reinforce training in nutrition, feeding, pasture management, etc., in order to increase their values, as well as to maintain constant training programs for producers, supported by academia, private and public entities.

Keywords: milk, quality, training, Pichincha

Resumen

La producción láctea en Ecuador es una fuente de ingresos económicos para muchos pequeños y medianos productores; sin embargo, la falta de asesoría técnica conlleva a que tengan problemas en la calidad de la leche y se vea afectado su volumen de producción, por lo que la presente investigación tuvo como finalidad realizar un plan piloto para el mejoramiento de la calidad de leche producida por 57 pequeños productores de diferentes parroquias de los cantones Quito, Rumiñahui y San Miguel de los Bancos de la provincia de Pichincha, mediante un plan de capacitación en buenas prácticas de ordeño y estrategias de alimentación. Se realizaron 2 muestreos iniciales (entre octubre y noviembre de 2021), previo a la capacitación, y 2 muestreos finales (en junio de 2022) para medir el impacto de estas. Se recolectaron 1.273 muestras, donde solamente el 4,02 % (52/1.273) de las mismas, cumplen con los valores referenciales de la normativa nacional, mientras que el 95,98 % (1.243/1.273) no cumple con alguno de los parámetros evaluados; sin embargo, la gran mayoría de dicha leche sí es apta para el consumo humano, pero requiere ser mejorada en su calidad nutricional. Se logró disminuir considerablemente (aunque no estadísticamente) el conteo de células somáticas, de un promedio inicial de 623.530 CS ml^{-1} a 365.660 CS ml^{-1} luego de la capacitación, siendo correlacionado con el aumento significativo del porcentaje de lactosa entre el muestreo inicial y el final; también existió diferencias significativas en el porcentaje de grasa y sólidos totales, aunque en estos dos casos disminuyeron sus valores luego de la capacitación (grasa de 2,58 % en el muestreo inicial a 2,10 % en el final y sólidos totales de 11,44 % a 11,00 %). El resto de los parámetros no mostraron diferencias significativas entre los muestreos. Se concluye que la capacitación fue beneficiosa, pues la disminución considerable del conteo de células somáticas aumentó el volumen de producción de leche de los pequeños productores y, por ende, sus ingresos económicos. Para el resto de los parámetros se recomienda reforzar las capacitaciones de nutrición, alimentación, manejo de pasturas, etc., para incrementar sus valores, así como mantener constantes programas de capacitación a los productores, apoyados desde la academia, la empresa privada y entidades públicas.

Palabras clave: leche, calidad, capacitación, Pichincha

1. Introduction

In Ecuador, dairy production generates employment for around 1.3 million people. Most beneficiaries are small and medium-sized producers, contributing about 65 % of the total milk produced (Torres Gutiérrez, 2018). Manual milking is the most widely used method due to the number of animals available, though this practice has hygiene deficiencies in milk collection. Moreover, most milk industrialization processes are artisanal (Centro de la Industria Láctea [CIL], 2015; Terán Flores, 2019). In 2021, daily milk production reached 570 million liters, with 74.85 % sold as liquid, 16.39 % processed on farms, 6.76 % consumed by calves, and 2 % used for other purposes (Instituto Nacional de Estadísticas y Censos [INEC], 2023).

The largest production is concentrated in the Sierra or inter-Andean region, especially in the province of Pichincha, which produces approximately 1,085,747 liters of milk per day, which represents close to 19 % of total production, with an average yield of 11 .27 l cow^{-1} (INEC, 2022). Although dairy production has had an increase of 18.5 % in the last ten years, between 2020 and 2021, it decreased by around 7% due to the COVID-19 pandemic (Corporación Financiera Nacional [CFN], 2022; INEC, 2023).

The Ecuadorian Technical Standard (*Norma Técnica Ecuatoriana* in spanish) NTE INEN 9:2012 establishes the microbiological, organoleptic, and physicochemical characteristics that raw milk must have to be suitable for human consumption before further treatment. The minimum permitted limits are the following: minimum fat of 3 %, total solids of 11.2 %, non-fat solids of 8.2 %, protein of 2.9 %, and a maximum somatic cell count of 7.0 x 10^5 CS ml^{-1}. However, there are several drawbacks to Ecuadorian dairy production (De los Reyes González et al., 2010). Information on milk quality has been relatively scarce, although it has been increasing in recent years, which has made it possible to control said quality, advise farmers, and develop databases (Contero Callay et al., 2021).

2. Materials and Methods

2.1. Population and samples

The study was carried out by taking samples of raw milk from 57 small producers located in the parishes of Lloa, Checa, El Quinche, Yaruquí, Píntag, Nanegalito, and Gualea (Quito canton), Rumipamba and la Moca (Ruminahui canton) and San Miguel de los Bancos (of the same canton) of the province of Pichincha. The sampling design regarding the selection of small producers in the project was for convenience since they are producers to whom the mobile veterinary clinics of the del Gobierno Autónomo Descentralizado de la provincia de Pichincha [GADPP] provide technical assistance. The cow selection was carried out using a completely randomized design.

At the end of the research, a total of 1,273 samples of raw milk were collected (one sample per cow, corresponding to a milk pool from its four mammary glands, obtained after milking the animals by the producers themselves) in four samplings, the same that were executed two before and two after the training. It was carried out on two occasions, with an interval of 15 days between each sample, to reduce the degree of error and have a more realistic average of the parameters to be analyzed. The first sampling was conducted in October and November 2021, giving 634 samples. With the results obtained in the laboratory, training on best milking practices [BMP] and nutritional strategies was provided to small producers, carried out in April 2022. After this training, 639 raw milk samples were collected on two more occasions, in June and July 2022. An attempt was made to take samples from the same cows, both in the pre-and post-training sampling, in all cases being animals from the same producers.

2.2. Sampling and laboratory analysis

The samples were obtained directly from the cows at the time of milking, from all their functional rooms, following the guidelines indicated in the Ecuadorian Technical Standard NTE INEN-ISO 707 for sampling of dairy products and in the Instructions INT/CL/010 for "Sample taking of raw milk and whey" (AGROCALIDAD, 2020). They were subsequently stored and identified in plastic containers containing the preservative bronopol.

The collected samples were identified with an alphanumeric code and were stored and transported refrigerated at a temperature between 2 and 8 °C in a cooler containing cooling gels. They were then analyzed (in less than 48 hours) in the Milk Quality Laboratory of the Gobierno Provincial de Pichincha, which is located in the Uyumbicho Experimental Center, belonging to the Facultad de Medicina Veterinaria y Zootecnia of the Universidad Central del Ecuador, located in the Mejía canton, south-east of Quito, with an altitude of 2,740 m a.s.l.

Various nutritional and hygienic parameters of raw milk were analyzed, including the percentage of fat, protein, total solids, non-fat solids, lactose, and somatic cell count, using an automatic analyzer, the Combifoss, equipment that includes Milkcoscan and Fossomatic (FOSS, Nils Foss Allé 1, DK-3400 Hilleroed—Denmark) from GADPP.

2.3. Training program

Before carrying out the training program, it was necessary to carry out prior sampling to know the reality or state of the quality of raw bovine milk produced at the study site. Once the results were obtained, topics were raised to help improve the quality of raw bovine milk produced, addressing topics such as feeding programs and nutritional supplements focused on dairy cows, good livestock practices, and good milking practices. In the same way, issues such as the importance of the mammary gland for milk production, anatomy, injuries, pathologies found in this organ, and the importance of the dry period for its recovery were discussed. The training program was done personally, that is, by the producer, since, based on the results, it was observed that each one had a different problem. Follow-up visits were carried out randomly to verify that the recommendations made were carried out.

2.4. Statistical analysis

The data obtained was stored in a Microsoft Excel sheet. The free statistical program "R Studio" version 1.2.5019 (RStudio Inc. Boston, MA, USA) was used for data analysis using a significance of $p < 0.05$. A descriptive statistical analysis was conducted, and percentage frequency tables were used to ensure compliance with the regulations.

For the quantitative results (% fat, protein, total solids, non-fat solids, lactose, and somatic cell count), a normality analysis was carried out using the Kolmogorov-Smirnov test, observing that all parameters did not follow a normal distribution since the p-value in all cases was < 0.05. So, non-parametric tests (Wilcoxon and Kruskal Wallis test and a post-hoc analysis using the Mann-Whitney test with a Bonferroni correction) were used to compare the means. These data were compared by individual and general sampling, that is, the average of the sampling carried out before and after training, as well as between parishes and cantons.

3. Results

3.1. Total Results

Table 1 describes the values obtained from the analyzed parameters of all the samples, detailing the minimum, maximum, and average values and the level of general compliance with each parameter concerning the NTE INEN. 9:2012. It was determined that only 4.02 % (52/1,273) of the samples comply with the reference values of the national regulations, while 95.98 % (1,243/1,273) do not comply with any of the evaluated parameters. Although most milk is suitable for human consumption, its nutritional quality requires improvement.

Table 1. Minimum, maximum, average values and their compliance with NTE INEN 9: total results.

Parameter	NTE INEN 9 Requirement	Min. Value	Max. Value	Mean	Complies	Not compliant
Fat (%)	Min. 3,2	0,38	7,89	2,34	286/1.273 22,47%	987/1.273 77,53%
Crude protein (%)	Min. 2,9	1,43	6,63	3,45	1113/1.273 87,43%	160/1.273 12,57%
Total solids (%)	Min. 11,2	6,2	16,88	11,22	543/1.273 42,66%	730/1.273 57,34%
Non-fat solids (%)	Min. 8,2	4,35	11,22	8,86	1145/1.273 89,95%	128/1.273 10,05%
Lactose (%)	4,8 - 5,5	0,1	5,47	4,66	494/1.273 38,81%	779/1.273 61,19%
Somatic cells (CS ml^{-1})	Max. 700.000	4.000	13.555.000	494.090	1.083/1.273 85,07%	190/1.273 14,93%
TOTAL					52/1.273 4,02%	1.243/1.273 95,98%

The fat percentage is the parameter that shows the least compliance since it was found that 77.53 % (987/1,273) of the samples are below the minimum stipulated by local legislation (3%). Only 22.47 % (2.86/1.273) is above it. The study's average was 2.34 % (lower than the minimum required), with a minimum value of 0.38 % and a maximum of 7.89 %. The second most non-compliant parameter is the percentage of lactose since 61.19 % (779/1,273) of the samples are below what is established by international regulations (NTE INEN 9:2012 does not indicate reference values of lactose). So only 38.81 % (494/1,273) meet the minimum required of 4.8 %. An average of 4.66 % was determined, ranging between 0.10 % and 5.47 %. Likewise, based on the two previous parameters, the total solids percentage shows that 57.34 % (730/1,273) does not meet the reference value (minimum 11.2 %), while 42.66 % (543 /1.273) does. The minimum value found was 6.20 %, the maximum was 16.88 %, and an average of 11.22 % (Table 1). Regarding the protein percentage, 12.57 % (160/1,273) of the samples do not comply with the minimum of 2.9 % established by Ecuadorian regulations, while 87.43 % (1,113/1,273) do. Likewise, an average of 3.45 % was found, with minimum and maximum values of 1.43 % and 6.63 %, respectively. In the case of non-fat solids, 10.05 % (128/1,273) of the milk analyzed does not comply with the minimum reference value (8.2 %). In comparison, 89.95 % (1,145/1,273) have values above them, finding a minimum value of 4.35 % and a maximum of 11.22 %, with an average of 8.86 % (Table 1).

Regarding somatic cell count, NTE INEN 9:2012 is quite permissible with the maximum value, as it accepts up to 700,000 CS ml^{-1}. At the same time, international regulations indicate that values below 200,000 CS ml^{-1} indicate the mammary gland's health, accepting a maximum between 200,000 and 400,000 CS ml^{-1}.

When comparing the results based on the Ecuadorian standard, it was found that 14.93 % (190/1,273) do not comply with Ecuadorian legislation, as they have counts higher than the maximum allowed. The remaining 85.07 % (1,083/1,273) presents values lower than the same, with an average of 494,090 CS ml^{-1} and a range between 4,000 and 13,555,000 CS ml^{-1} (Table 1). When comparing with international regulations, it was found that 55.77 % (710/1,273) of the samples have values less than 200,000 CS ml^{-1}, 18.22 % (232/1,273) between 200,001 CS $ml^{-1}$and 400,000 CS ml^{-1}, and 26.00 % (331/1,273) more than 400,000 CS ml^{-1}.

3.2. Initial sampling results: Pre-training

Table 2 describes the values obtained from the analyzed parameters of all the samples, detailing the minimum, maximum, and average values and the level of general compliance of each parameter concerning the NTE INEN. 9:2012 in the initial sampling, that is, before the training. It was determined that only 4.73 % (30/634) of the samples comply with the reference values of the national regulations, while 95.27 % (604/634) do not comply with any of the evaluated parameters. Once again, it is necessary to indicate that most of the milk is suitable for human consumption, but its nutritional quality needs improvement.

Table 2. Minimum, maximum, average values and their compliance with NTE INEN 9: pre-training sampling.

Parameter	NTE INEN 9 Requirement	Min. Value	Max. Value	Mean	Complies	Not compliant
Fat (%)	Min. 3,2	0,38%	7,89	2,58%	176/634	458/634
					27,76%	72,24%
Crude protein (%)	Min. 2,9	2,19	6,63	3,46	545/634	89/634
					85,96%	14,04%
Total solids (%)	Min. 11,2	7,5	16,88	11,44	307/634	327/634
					48,42%	51,58%
Non-fat solids (%)	Min. 8,2	6,36	11,22	8,86	565/634	69/634
					89,12%	10,88%
Lactose (%)	4,8 - 5,5	2,31	5,34	4,62	235/634	399/634
					37,07%	62,93%
Somatic cells (CS ml^{-1})	Max. 700.000	4.000	13.555.000	623.530	515/634	119/634
					81,23%	18,77%
TOTAL					30/634	604/634
					4,73%	95,27%

Regarding the fat percentage, it is the parameter with the least compliance since it was found that 72.24 % (458/634) of the samples are below the minimum stipulated by local legislation (3 %), and only the 27.76 % (176/634) is above it. The study's average was 2.58 % (lower than the minimum required), with a minimum value of 0.38 % and a maximum of 7.89 %. The second most non-compliant parameter is the percentage of lactose since 62.93 % (399/634) of the samples are below what is established by international regulations (NTE INEN 9:2012 does not indicate lactose reference values). So only 37.07 % (235/634) meet the required minimum of 4.8 %. An average of 4.62% was determined, ranging between 2.31 % and 5.34 %. Likewise, based on the two previous parameters, in the percentage of total solids, 51.58 % (327/634) does not meet the reference value (minimum 11.2 %), while 48.42 % (307/634) 634) does. The minimum value found was 7.50 %, the maximum was 16.88 %, and an average of 11.44 % (Table 2).

Regarding the protein percentage, 14.04 % (89/634) of the samples do not comply with the minimum of 2.9 % established by Ecuadorian regulations, while 85.96 % (545/634) do comply. Likewise, an average of 3.46 % was found, with minimum and maximum values of 2.19 % and 6.63 %, respectively. In the case of non-fat solids, 10.88 % (69/634) of the milk analyzed does not comply with the minimum reference value (8.2 %). In comparison, 89.12 % (565/634) have higher values, finding a minimum value of 6.36 % and a maximum of 11.22 %, with an average of 8.86 % (Table 2).

In the case of the somatic cell count, when comparing the results based on the Ecuadorian standard, it was found that 18.77 % (119/634) do not comply with Ecuadorian legislation since they have counts higher than the maximum allowed. While the remaining 81.23 % (515/634) present values lower than this, with an average of 623,530 CS ml^{-1} and a range between 4,000 and 13,555,000 CS ml^{-1} (Table 2). When comparing with international regulations, it was found that 54.73 % (347/634) of the samples have values less than 200,000 CS ml^{-1}, 14.67 % (93/634) between 200,001 CS ml^{-1} and 400,000 CS ml^{-1}, and 88.17 % (559/634) more than 400,000 CS ml^{-1}.

3.3. Final sampling results: Post-training

Table 3 describes the values obtained from the analyzed parameters of all samples, detailing the minimum, maximum, and average values and the level of general compliance of each parameter concerning the NTE. INEN 9:2012 in post-training sampling. It was determined that only 3.44 % (22/639) of the samples comply with the reference values of the national regulations, while 96.56 % (617/639) do not comply with any of the evaluated parameters. Although most milk is suitable for human consumption, its nutritional quality requires improvement.

Table 3. Minimum, maximum, average values and their compliance with NTE INEN 9: post-training sampling.

Parameter	NTE INEN 9 Requirement	Min. Value	Max. Value	Mean	Complies	Not compliant
Fat (%)	Min. 3,2	0,41%	7,22	2,10%	110/639 17,21%	529/639 82,79%
Crude protein (%)	Min. 2,9	1,43	5,36	3,44	568/639 88,89%	71/639 11,11%
Total solids (%)	Min. 11,2	6,2	15,5	11	236/639 36,93%	403/639 63,07%
Non-fat solids (%)	Min. 8,2	4,35	10,58	8,86	580/639 90,77%	59//639 9,23%
Lactose (%)	4,8 - 5,5	0,1	5,47	4,69	380/639 40,53%	380/639 59,47%
Somatic cells (CS ml^{-1})	Max. 700.000	4.910	9.372.000	365.660	568/639 88,89%	71/639 11,11%
TOTAL					22/639 3,44%	617/639 96,56%

Regarding the percentage of fat, which is the parameter with the least compliance, it was found that 82.79 % (529/639) of the samples are below the minimum stipulated by local legislation (3 %), and only the 17.21 % (110/639) is above this. The study's average was 2.10 % (lower than the minimum required and lower than the initial sampling), with a minimum value of 0.41 % and a maximum of 7.22 %. The second parameter that most fails to comply is the percentage of lactose since 59.47 % (380/639) of the samples are below what is established by international regulations (NTE INEN 9:2012 does not indicate lactose reference values). So only 40.53 % (380/639) meet the required minimum of 4.8 %; An average of 4.69 % was determined, with a range between 0.10 % and 5.47 %. Likewise, based on the two previous parameters, the percentage of total solids 63.07 % (403/639) does not meet the reference value (minimum 11.2 %), while 36.93 % (236/639) does. The minimum value found was 6.20 %, the maximum was 15.50 %, and an average of 11.00 % (Table 3). Regarding the percentage of protein, 11.11 % (71/639) of the samples do not comply with the minimum of 2.9 % established by Ecuadorian regulations, while 88.89 % (568/639) do comply. Likewise, an average of 3.44 % was found, with minimum and maximum values of 1.43 % and 5.36 %, respectively. In the case of non-fat solids, 9.23 % (59/639) of the milk analyzed does not comply with the minimum reference value (8.2 %), while

90.77 % (580/639) have values above this, finding a minimum value of 4.35 %, maximum of 10.58 %, with an average of 8.86 % (Table 3).

In the case of the somatic cell count, when comparing the results based on the Ecuadorian standard, it was found that 11.11 % (71/639) do not comply with the legislation, as they have counts higher than the maximum allowed. While the remaining 88.89 % (568/639) present values lower than this, with an average of 365,660 CS ml^{-1} and a range between 4,910 and 9,372,000 CS ml^{-1} (Table 3). When comparing with international regulations, it was found that 56.96 % (364/639) of the samples have values less than 200,000 CS ml^{-1}, 21.75 % (139/639) between 200,001 CS ml^{-1} and 400,000 CS ml^{-1}, and 21.28 % (136/639) more than 400,000 CS ml^{-1}.

3.4. Comparison between pre and post-training results between samples, parishes, and cantons

Table 4 details the statistical analysis of the parameters of raw bovine milk obtained in the sampling carried out before and after the training of the small producers of Pichincha, indicating the average values between each one and comparing the means between the sampling, parishes, and cantons studied. Likewise, Figure 1 details the box plots of the analyzed parameters, comparing the initial and final samplings.

Table 4. Statistical comparison of raw bovine milk parameters by sampling, parishes and cantons.

Parameter	Initial sampling average	Final sampling average	P value sampling	P value parishes	P value cantons
Fat (%)	2,58	2,10	6.833e-11*	2.827e-12*	0,02229*
Crude protein (%)	3,46	3,44	0.6682	1.558e-06*	0,03575*
Total solids (%)	11,44	11,00	1.797e-06*	2.151e-08*	0,0007183*
Non-fat solids (%)	8,86	8,86	0.1102	3.403e-07*	0,001391*
Lactose (%)	4,62	4,69	0.007088*	0.1963	0,07152
Somatic cells (CS ml^{-1})	623.530	365.660	0.0653	2.2e-16*	0,01196*

* Significant differences between means ($p < 0.05$).

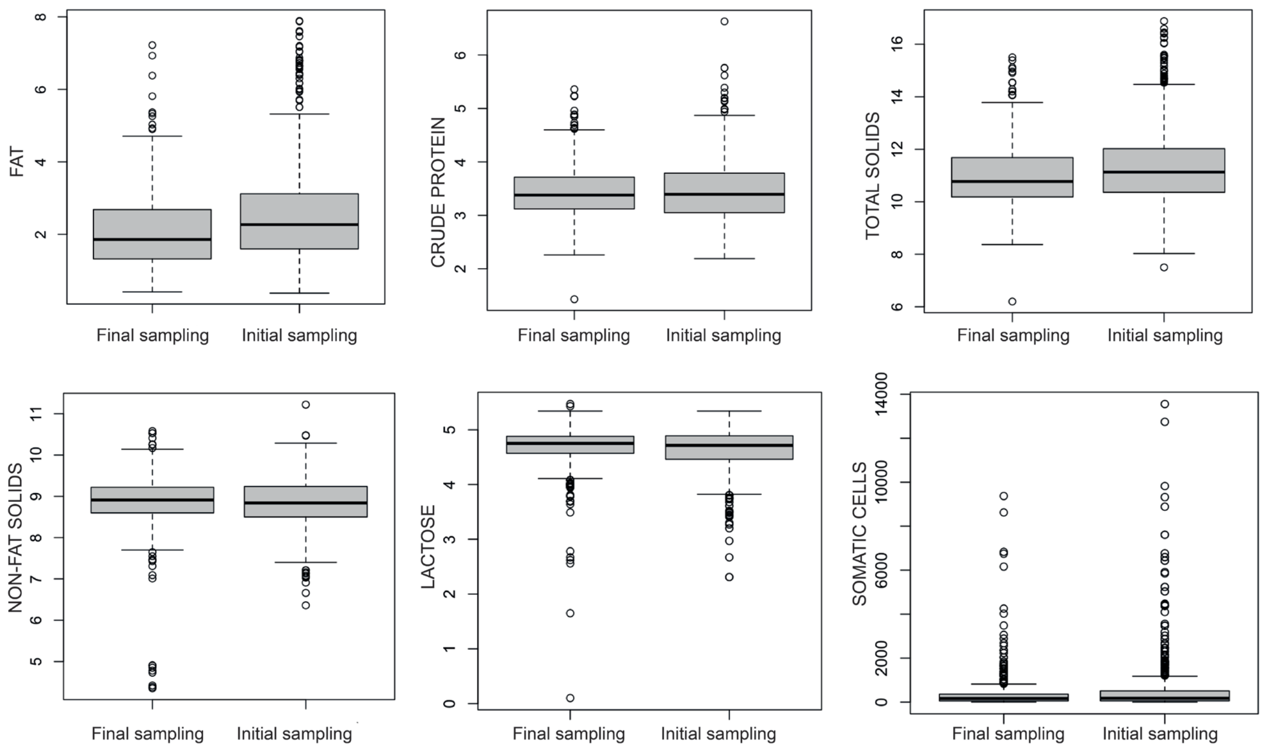

Figure 1. Boxplot of the parameters evaluated between the initial and final sampling.

By analyzing the evaluated parameters, the percentage of fat, total solids, and lactose showed significant differences between the initial and final sampling. Notably, in the case of fat and total solids, the values decreased in the second sampling, indicating that compositional quality declined after the training program. Regarding lactose, its percentage increased post-training, which can be attributed to the significant reduction in the percentage of somatic cells after the milking hygiene training. While this reduction is not statistically significant, it is numerically considerable, with a post-training reduction of about 45% compared to the initial values. This decrease is highly relevant from a physiological perspective, significantly improving milk production. The other parameters did not show significant differences between the samplings (Table 4 and Figure 1).

When comparing the parameters between the studied parishes (Table 4), it can be observed that there are no significant differences between the sampled parishes, only in the case of lactose; for the other parameters, such differences exist. For example, the percentage of fat differs mainly between the parishes of El Quinche with Gualea, Lloa, Nanegalito, and Píntag; also, between Gualea and Lloa, San Miguel de los Bancos, Nanegalito, Rumipamba, and Yaruquí; and finally between Píntag and San Miguel de los Bancos and Yaruquí. In the case of protein, differences exist between Nanegalito and El Quinche, Píntag, and Yaruquí; also between Yaruquí and Lloa and San Miguel de los Bancos; and finally between Lloa and El Quinche. The percentage of total solids differs between Gualea and El Quinche, Lloa, San Miguel de los Bancos, and Nanegalito; also, between Píntag and El Quinche, San Miguel de los Bancos, and Nanegalito; and finally, between San Miguel de los Bancos and Lloa. Regarding non-fat solids, there are marked differences between the parishes of San Miguel de los Bancos and Checa, El Quinche, Píntag, and Yaruquí; also, between Yaruquí and Lloa and Nanegalito; as well as between Lloa and El Quinche and Yaruquí; and finally between El Quinche and Nanegalito. Lastly, the somatic cell count varies between the parishes of Yaruquí and Lloa, San Miguel de los Bancos, Nanegalito, Píntag, and Rumipamba; also between El Quinche and Lloa, San Miguel de los Bancos, Nanegalito, Píntag, and Rumipamba; and finally between Checa and San Miguel de los Bancos, Nanegalito, and Píntag.

Again, when comparing the parameters between the sampled cantons, only the percentage of lactose does not show significant differences. In contrast, the other parameters do (Table 4), with the differences occurring between the cantons of Quito and San Miguel de los Bancos.

4. Discussion

Several studies have been conducted in Ecuador to determine the quality of raw milk based on NTE INEN 9:2012. These studies have reported variable results, with heterogeneity exceeding 90 %. In other words, depending on the study, the results differ significantly in various milk parameters (Puga-Torres et al., 2022). Furthermore, very few studies have analyzed the effects of previous training sessions.

Regarding the somatic cell count, the average values of both samplings (623,530 and 365,660 SC ml^{-1}) and the final average (494,090 SC ml^{-1}) were below the maximum allowed by Ecuadorian regulations (700,000 SC ml^{-1}), with compliance exceeding 85%, which is quite similar to the report by (Mera Ruíz, 2013), who found an average of 494,300 SC $ml^{-1}$and compliance of 87.04%. Additionally, in a study conducted across several provinces, the average was 447,000 SC ml^{-1} (Contero Callay et al., 2021). However, the results obtained are higher than those reported in the study conducted in the Rumiñahui canton (Pichincha), where the average was 254,000 SC ml-1, with 95.62% compliance. This discrepancy may be due to better hygienic controls during milking (Montes Guaycha, 2021). Lower somatic cell counts are synonymous with good sanitary conditions in the mammary gland, which translates into better economic profitability (Valdivia Ávila et al., 2021). As a result, international regulations recommend much lower somatic cell values, aiming for fewer than 200,000 SC ml^{-1}, so the mammary gland can fully function in lactose synthesis and produce more milk (Alhussien & Dang, 2018).

The decrease in somatic cell count in post-milking milk was due to the particular emphasis placed on good milking practices during training, specifically on the hygiene of milking personnel, equipment, and animals. Recommendations included frequent hand and arm washing by the milker, proper washing and drying of cow teats with individual disposable towels, and mandatory post-milking teat sealing. These suggestions were monitored because poor milking practices affect udder hygiene and health, being one of the leading causes of increased somatic cells in milk (Hernández Reyes & Bedolla Cedeño, 2008), as part of the immune response to threats posed by microorganisms, especially pathogens, to the mammary gland of dairy cows. This, in turn, allowed an increase in milk volume, as during infection, the rise in somatic cells leads to a reduction in lactose synthesis due to damage to lactocytes, which affects water intake, thereby decreasing milk volume (Alhussien & Dang, 2018; Pegolo et al., 2021; Reyes et al., 2017).

The final average lactose percentage was 4.66 %, with compliance of only 38.81 % relative to the minimum of 4.8 % established by international standards. This is similar to the work done in Rumiñahui (Pichincha), where a mean of 4.79 % and 38.10 % compliance were reported (Montes Guaycha, 2021). Lactose is the component that determines milk volume, so its increase is associated with higher milk production. The caloric density of the diet may influence its concentration. However, the main factor justifying the below-recommended results is the presence of subclinical mastitis, which causes inflammation, dysfunction in blood-mammary gland permeability, and disruption of osmotic balance, leading to reduced lactose production in lactocytes and, therefore, decreased milk volume (Costa et al., 2019).

Regarding fat percentage, which in our study had 77.53 % non-compliance among all analyzed samples, this is like the work by Mera Ruíz (2013), who found that 84.84 % of 409 samples from Machachi (Pichincha province) were below local legislation. Similarly, in Rumiñahui-Pichincha, it was found that 69.40 % (n=160) of analyzed samples did not meet NTE INEN 9:2012 (Montes Guaycha, 2021). In contrast, other studies have shown high compliance with fat percentages. For example, in the Carchi province, only 7.47 % of samples (n=616) had values below 3 % (De la Cruz et al., 2018), while in the Manabí cantons of Pedernales and El Carmen, values ranged from 2.67 % to 6.71 %, with very few samples showing low-fat levels (Vallejo Torres et al., 2018). A study of dairy farms in Pichincha province determined an average fat value of 3.92 %, indicating that larger producers allocate more resources for pasture improvement, dietary supplements, etc., favoring better fat parameter results (Espinosa Benítez, 2017). In a large retrospective study analyzing data from 99,271 raw milk samples from 12 Ecuadorian provinces, a high level of compliance with fat parameters was found, with an average fat content of 3.80 % (Contero Callay et al., 2021).

Fat is the parameter that shows the most significant variability in milk, depending on various factors such as nutrition, genetics, and/or physiology (Ambuludi et al., 2017), which may explain the values found in this study. This could be attributed to very poor animal sanitary management, especially from a nutritional standpoint, as fat is directly related to this characteristic (De la Cruz et al., 2018). The decrease in fat percentage indicates that the nutritional training did not positively affect the cows under study, mainly because they belong to small-scale producers with limited economic resources. This made it difficult for them to purchase balanced feed, provide their animals with mineral salts or dietary supplements, or address problems related to poor pasture management. This was evident during the training programs, where it became clear that nutritional supplementation is not a common practice among producers. Additionally, during drought or when pastures have not been adequately fertilized, the grasses (stems and leaves) become lignified, decreasing their digestibility and, consequently, milk fat content. This is because rumen bacteria cannot digest cellulose and hemicellulose, and high-quality pastures increase the percentage of milk fatty acids (Vargas Romero, 2016). Furthermore, breeds like Holstein have lower fat values than the Jersey breed (Acosta-Acosta et al., 2020). In this study, most cows were crossbreeds with Holstein breed characteristics, although in the northwestern region of Pichincha, there are also mixes with Zebu breeds. Finally, this may be due to the milk fat depression syndrome, which is characterized by milk having very low-fat content. This is caused by low fiber levels in the diet and a high amount of unsaturated fatty acids, which ultimately affects ruminal pH, leading to an increase and accumulation of lactic acid. This, in turn, impacts the synthesis of volatile fatty acids (propionic, acetic, and butyric acids), along with excessive insulin secretion, reducing the precursors necessary for the formation of milk fat (Koch & Lascano, 2018; Siurana et al., 2023).

Regrding the percentage of total solids, the final average value (11.22 %) was slightly higher than the minimum acceptable of the Ecuadorian standard (11.20 %), but with low compliance of all samples, of only 42.66 %. These values are higher than those reported by Montes Guaycha (2021) and Mera Ruíz (2013), where the average was 11.12 % and 10.41 %, and compliance of 36.90 % and 21.76 %, respectively. Likewise, the results obtained are lower than those reported by Contero Callay et al. (2021), who reported an average of 12.36 %. It is important to mention that total solids correspond to the sum of fat, protein, lactose, and minerals present in milk, and therefore, a significant increase or decrease in one of these components directly impacts the total value of total solids, which is one of the most determining factors of milk quality and performance for the production of derivatives (Guevara-Freire et al., 2019). One of the scenarios that generates a decrease in total solids is the increase in the volume of milk since the amount produced is greater and, therefore, the concentration of nutrients is lower (Acosta-Acosta et al., 2020).

Regarding the decrease in total solids values, as explained in the fat parameter, they vary depending on the diet administered to the animals, as well as their age and the time of lactation, being also inversely proportional to the volume of milk. Therefore, one of the possible reasons for the reduction in the percentages of nutritional components in post-training milk may be due mainly to the fact that by increasing the volume of milk (due to the reduction in somatic cell values), the percentage of fat and, therefore, the percentage of total solids was especially affected, since they are inversely proportional to the volume of milk (Costa et al., 2019; Foroutan et al., 2019).

Regarding the average percentage of protein in this work (3.45 %) and compliance with the regulations (87.43 %), it is similar to what was reported by Mera Ruíz (2013) and Montes Guaycha (2021), who reported compliance of 90.22 % and 77.50 %, respectively. (Contero Callay et al., 2021) found an average of 3.12 % in all cases, presenting the averages above the minimum required by local legislation (2.9 %). In general, relatively, a good percentage of protein is because it generally reaches adequate levels even with diets based mostly or only on mixtures of grass and legume forages (Magan et al., 2021). However, it is essential to note that this parameter can also be influenced by the lactation stage or the genetics of the cows (Calvache García & Navas Panadero, 2012).

It is necessary to indicate that research carried out in countries such as the United States, where training programs for producers have been successful, usually include continuous training for about four months, along with periodic reinforcements, since this methodology allows better implementation of good practices in livestock farmers (Rodrigues & Ruegg, 2005). Despite the relatively short duration of the training carried out in our research, it is relevant that somatic cell counts improved, which indirectly allows an increase in lactose production and, therefore, in milk volume (Costa et al., 2019).

5. Conclusions

The present study provides essential results from a pilot plan to improve milk quality from small producers in the province of Pichincha, the largest milk producer in Ecuador. It was evident that a high percentage of samples do not comply with the considerations stipulated in the Ecuadorian raw milk legislation; however, the vast majority are considered suitable for human consumption. At the end of the research, it was evident that training in good milking practices was beneficial since the producers wholly followed the indicated recommendations, which led to a considerable numerical (although not statistical) decrease in the somatic cell count, which was translated into an increase in the volume of milk production of small producers and, therefore, their economic income. However, in the present case, the training on nutritional strategies, due to its economic limitations and the management of pastures, did not turn out to be beneficial for the producers, since in the percentage of fat and total solids, there was a statistically significant decrease in their values after of training. At the same time, there was no difference between the rest of the parameters. It is recommended to reinforce training in nutrition, feeding, pasture management, etc., to increase their values and constant advice on training programs for producers, supported by academia and private and public companies, to increase milk quality in all aspects.

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Contribuciones de los autores

- Byron Puga-Torres: conceptualization, investigation, methodology, resources, writing – original draft, writing – review & editing.
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- César Raúl Guanoluisa Vargas: writing – review & editing.

- Tania Villarreal: data curation, formal analysis, writing – review & editing.

Ethical implications

The authors declare that there are no ethical implications, since the research did not involve human beings, nor were animal specimens manipulated. Milk samples were obtained by the owners during the regular manual milking process.

Conflict of interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

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