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Physicochemical characteristics of milk marketed by family production units in the Atoyac River Basin in Puebla and Tlaxcala, Mexico

Rosas-Gallo, Anabel[1]; **Guerrero-Rodríguez, Juan de D.**[1]; **Escobedo-Garrido, José S.**[1]; **Argumedo-Macías, Adrián**[1]; **Maroto-Molina, Francisco**[2]; **Calderón-Sánchez, Francisco**[1*]

[1] Colegio de Postgraduados *Campus* Puebla, Programa de Estrategias para el Desarrollo Agrícola Regional. Boulevard Forjadores No. 25, Santiago Momoxpan, San Pedro Cholula, Puebla, México, 72760.

[2] Universidad de Córdoba, *Campus* de Rabanales Departamento de Producción Animal, Escuela Técnica Superior de Ingeniería Agronómica y de Montes (ETSIAM), Ctra. Madrid-Cádiz, km 396, Córdoba, España, 14711.

* Correspondence: fsanchezs@colpos.mx

ABSTRACT

Objective: To determine the physicochemical characteristics and possible adulteration of raw milk marketed in dairy family systems located in the Atoyac River Basin in Puebla-Tlaxcala.

Design/methodology/approach: The physical characteristics of milk were determined: pH, acidity and freezing point; and chemical characteristics: fat, protein, lactose, minerals, non-fat solids, total solids and water content. This milk is produced and marketed by 264 family production units to three cheese producing companies in the Atoyac River Basin in the states of Puebla and Tlaxcala. The data were analyzed by company and subsequently grouped with the Cluster technique of the SAS software.

Results: Significant differences ($p<0.05$) were found in the physical and chemical characteristics of the milk marketed by the producers with the three processing companies. In general, the milk is acid and adulterated with an average of 11.49% water; this results in a loss of $0.67/liter and in a dilution of its components, particularly protein and lactose, which leaves it outside the parameters established by normativity. The multivariate analysis generated four groups of producers and suggests the possibility that a group of producers adulterates with water, but also adds some kind of compound to increase the fat content to mask the adulteration.

Limitations on study/implications: The study of this topic, where the economic interests of the primary actors in the production chain can be affected, is delicate and difficult to carry out; however, it is necessary in order to know the quality of the products that are generated and their implication in the economy and the health of consumers.

Findings/conclusions: This study showed that the milk marketed by producers to processing companies does not comply with current regulations due to adulteration with water and the possible addition of compounds that replace fat; therefore, verification programs for compliance of the regulations are required, hoping with this that producers will receive a fair price for their production and will not have the need to adulterate the milk.

Keywords: milk adulteration, cheese companies, dairy regulations.

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INTRODUCTION

Within the food industry in Mexico, dairy production is the third of highest economic importance (CANILEC, 2021), contributing 24.3% of the agriculture and livestock GDP, which corresponds to 1.23% of the total national GDP. In the last year, the national milk production was 12.8 million tons (SIAP, 2021), giving it 16th place globally; however, this volume only covers 69% of the national demand, which is why there are imports of powdered milk and other derivatives, unfortunately affecting the price of milk paid to the producers (Ángeles *et al.*, 2004; Espinoza-Arellano *et al.*, 2019).

Dávalos (2020) shows a structural polarization of national dairy production, highlighting that 73.95% of the 95,887 production units have less than 20 cows and concentrate barely 28% of the dairy cattle, while 4.4% of the units have more than 50 cows and have 48.4% of the 2,274,366 dairy cattle in the country.

Strictly speaking, the first stratum cited above corresponds to family dairy production, characterized by being part of a diversified peasant economy with low-production animals (Abrego, 2011), deficient facilities (Botero *et al.*, 2012), and the lack of an organizational structure to sell or transform their production, so that they are dependent on intermediaries, who fix the price and the conditions of milk trade.

On the other hand, the families devoted to this activity, in addition to being vulnerable to the imports and the inequality there is between the price of raw milk paid and the price of processed milk and substitutes exhibited in commercial centers (Munguía, 2015), have been scarcely benefitted with government programs, among them the guaranteed prices announced in the present administration, where one of the conditions to fulfill is the quality standards of milk determined by the normativity (NMX-F-700-COFOCALEC-2012).

Traditionally, in the commercial producer-intermediary relationship, the quality of the milk in terms of its physical characteristics, chemical composition, bacteria load, and content of adulterating agents, has been scarcely valued and of low interest (Bernal *et al.*, 2007), which is partly because there is not a differential payment treatment based on quality, and on the other hand, because the normativity established by regulating institutions for quality control is voluntary and without supervision.

Facing this scenario, the producers can resort to adulterating practices with the aim of increasing the yield and economic value of the milk (Rodríguez-Pérez, 2011), with the addition of water being the most common practice. In this sense, the objective of this study was to determine the physical and chemical characteristics of milk traded by family production units located in the Atoyac River Basin in the states of Puebla and Tlaxcala, and to identify the economic effect of a possible adulteration.

MATERIALS AND METHODS

Study zone

This study was carried out in family type dairy farms, located in the Atoyac River Basin in the states of Puebla and Tlaxcala, which are part of the list of intermediary clients who collect milk to deliver it to three cheese producing companies located in Santa Ana

Xalmimilulco, Huejotzingo, Puebla. Traditionally, milk is collected by intermediaries, called "boteros", who make verbal agreements with the producers to collect milk every morning from the two milking events (afternoon and morning). They deliver it to processors, which are cheese companies that process on average 30,000.00 liters per day to elaborate fresh cheese, such as Oaxaca, Panela and Ranchero cheeses, in addition to semi-mature cheeses that are distributed locally and regionally.

Milk was sampled from 264 production units, distributed in 12 municipalities located in the Center-West region of the state of Puebla and in the South of the state of Tlaxcala. The cows are Holstein breed, fed with cut fodders produced in small irrigation areas, farm residues, and balanced meals.

Sampling

By duplicate, 100 mL of raw milk were collected from the mixture of the morning milking and the afternoon milking from the prior day. It was taken from the container where the total production from each farm was placed, at the time of being delivered to the "botero". To obtain a representative sample, the milk was previously mixed with a 52-point homogenizer, making circular movements by one minute. The samples were placed in sterile Dorninc tubes labeled under the NOM-109-SSA1-1994 and transported in an ice box at a temperature of 4 °C to the laboratory, for their corresponding analysis within the next two hours.

Laboratory analyses

The analyses of the samples were conducted in the shelf life laboratory of the Universidad Tecnológica de Huejotzingo. A Lactoscan, LA, was used with 4 lines × 16 characters LCD screen, Milkotronic Ltd, 8900, Nova Zagora Bulgaria, where the physical variables (acidity, pH, and freezing point) and the chemical variables (content of protein, fat, lactose, minerals, non-fatty solids, total solids and water) were determined by triplicate. Based on the results obtained on water content in the samples, an additional variable referring to the economic profit of producers or the loss by collectors, considering a price of $8.20/liter of milk (guaranteed price), which was called "economic loss". In addition, a correction was made to estimate the real content of the milk components, subtracting the amount of water added and adjusting for each component with a significance level of 5%.

To contrast the results, the NMX-F-700-COFOCALEC-2012 was consulted, which regulates the quality of raw milk (Table 1).

A classification analysis was also conducted, based on the physical and chemical characteristics of milk, which had the purpose of grouping producers with homogeneity between individuals and heterogeneity between the different resulting groups, performed with the Cluster method of the SAS software, version 2003. The information from the classification analysis came from the review and selection of variables. Then, a variance analysis between defined groups was carried out; again, with the Proc-GLM procedure of the statistical package SAS.

Table 1. Data from NMX-F-700-COFOCALEC-2012.

FAT (%)	Class A ≥ 3.2 Class B 3.1 minimum Class C 3.0 minimum
Protein (%)	Class A ≥ 3.1 Class B 3.0 to 3.09 Class C 2.8 to 2.99
Lactose (%)	4.3 to 5.0
Minerals (%)	Less than 1%
Non fat solids (%)	8.3 minimum
Total solids (%)	10.5 and 15.5%
Added water (%)	------------
Cryoscopic point (°C)	Between −0,510 (−0,530) and 0,536 (−0,560)
pH	6.5 to 6.8
Acidity (%)	0.13 to 0.17

RESULTS AND DISCUSSION

Analysis by processing company

The results obtained evidenced significant differences ($p<0.05$) in the physicochemical characteristics of the milk sold by family production units to the three processing companies. Table 2 shows the values found for each variable, where it can be seen that regarding the normativity table (Table 1), the pH in companies 2 and 3 is found within the acceptable ranges, although not in company 1 which is slightly lower and statistically different ($p<0.05$); however, the average value of pH in the milk is acceptable. The acidity and the freezing point are outside the values specified in the norm, indicating that there is adulteration with water in the milk that the three companies acquire and, on the other

Table 2. Physicochemical characteristics of raw milk traded by family production units and collected in three cheese companies of the Atoyac River Basin.

Variable	ET 1 (n=14)	ET 2 (n=75)	ET 3 (n=175)	MEAN	LSD
pH	6.33b	6.67a	6.56a	6.58	0.17
Acidity (%)	0.21b	0.22b	0.25a	0.24	0.03
Cryoscopic point (°C)	−0.47a	−0.47a	−0.45a	−0.46	0.03
Fat (%)	3.49a	3.5a	2.82b	3.05	0.53
Protein (%)	2.61b	2.76a	2.65ab	2.68	0.12
Lactose (%	3.91b	4.15a	3.98ab	4.03	0.18
Minerals (%)	0.61a	0.62a	0.59a	0.6	0.03
Non fat solids (%)	7.33a	7.57a	7.26a	7.35	0.32
Total solids (%)	10.81a	11.07a	10.09b	10.4	0.6
Added water (%)	6.83b	8.67b	13.07a	11.49	4.01

Samples with the same letter in the lines are statistically similar, according to Fisher's means comparison (α=0.05); PC=Processing company; n: Number of sample.

hand, there are acidification problems that reduce their hygienic quality, with a higher notoriety of company 3, which has a statistically higher value ($p<0.05$) than the two other companies.

Concerning the chemical composition of milk, the average values indicate that regarding the normativity, the milk is normal in fat but diluted in protein, lactose and minerals; therefore, it is milk low in non-fatty solids and slightly low in total solids. In the analysis by company, the fat in 1 and 2 is within the parameters marked by the normativity and without difference between them, although with statistically higher values ($p<0.05$) than those of company 3, which does not comply with the norm. For the three companies, protein and lactose contents in the milk are outside and lower than the parameters established, with company 1 being still more remarkable, where the lowest and statistically different values were found ($p<0.05$). Regarding minerals and non-fatty acids, no differences were observed between companies. Meanwhile, water addition was identified as a common practice for milk from the three companies, with this habit being even more evident for company 3, which is statistically higher.

In the estimations carried out with corrected data for the amount of water added and specified in Table 3, it can be seen that all the components increase considerably and comply with the normativity, except the non-fatty acids from company 1, which are statistically the lowest ($p<0.05$) compared to companies 2 and 3. This is a similar trend to the previous table, the content of fat and total solids did not show differences between processing companies, although their values were within the normativity. In function of the water content, it was found that company 3 has an economic loss per liter of milk received, statistically higher ($p<0.05$) than those of the other companies, which show similar losses between them.

The classification carried out with the Cluster analysis (Figure 1) resulted in 4 groups of milk that producers in the study zone traded, and the grouping was basically given by the fat content and the added water content (Table 4). The first group included 18.18% of the producers, which correspond to the highest in fat content and in total solids, but with deficient levels of protein, lactose and minerals, even outside the official norm. Group 2,

Table 3. Chemical composition and economic loss of raw milk, corrected by water content in family production units, which is collected by three cheese companies from the Atoyac River Basin.

Variable	ET 1	ET 2	ET 3	MEAN	LSD
	(n=14)	(n=75)	(n=175)		
Fat (%)	3.76^{a}	3.86^{a}	3.26^{a}	3.46	0.63
Protein (%)	2.81^{b}	3.03^{a}	3.05^{a}	3.03	0.03
Lactose (%)	4.2^{b}	4.55^{a}	4.59^{a}	4.55	0.04
Minerals (%)	0.66^{b}	0.68^{a}	0.68^{a}	0.68	0.01
Non fat solids (%)	7.87^{b}	8.29^{a}	8.35^{a}	8.31	0.07
Total solids (%)	11.63^{a}	12.15^{a}	11.61^{a}	11.77	0.59
Loss ($/L)	0.4^{b}	0.5^{b}	0.76^{a}	0.67	0.23

Means with equal letters in a line are statistically equal, according to Tukey's means comparison ($\alpha=0.05$); PC=Processing company; n: Number of sample.

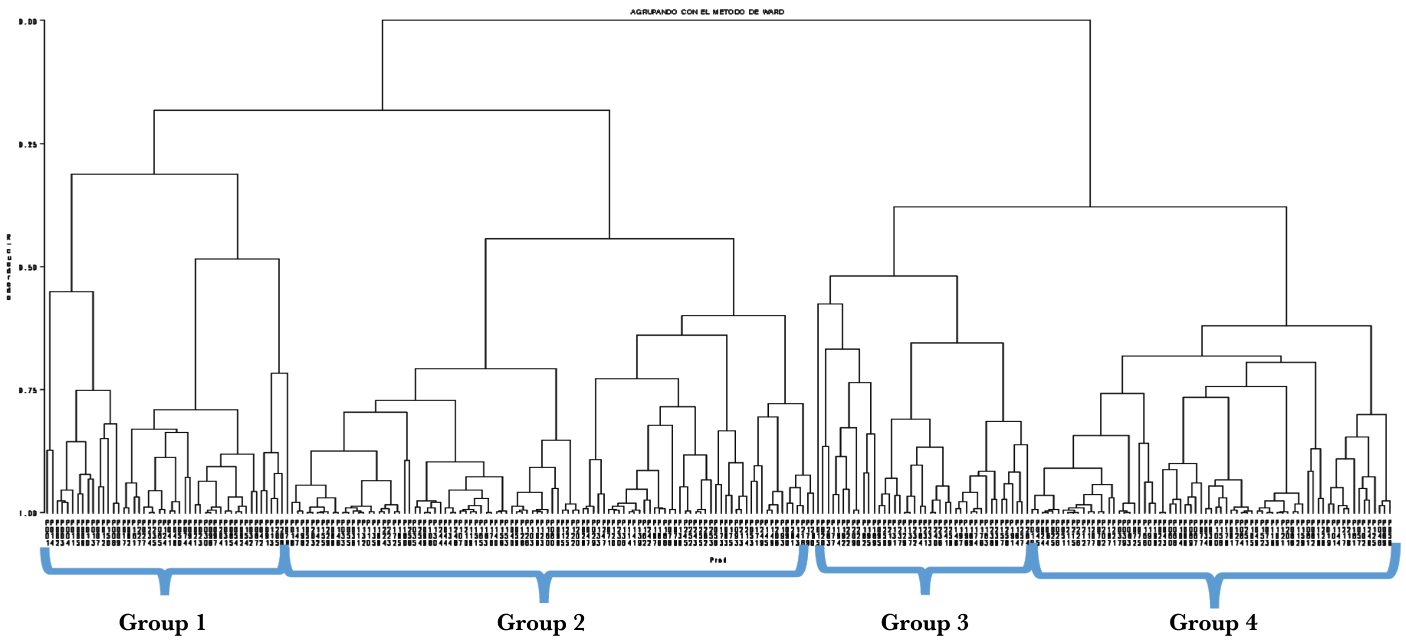

Figure 1. Dendrogram of 264 producers classified by the characteristics of raw milk they trade in the Atoyac River Basin.

which included 39.01% of the producers, stands out because it is the one that adulterates the milk the most with water and, therefore, all the components are diluted and fall outside the parameters established by the norm. Group 3 was made up by 15.90% of the producers and corresponds to those with the lowest levels of fat and with problems of hygienic quality due to its low level of pH and high acidity. Finally, group 4 includes 26.91% of producers that add the least amount of water and, therefore, of highest content of non-fatty solids and its components.

Table 4. Chemical composition of the raw milk traded by family production units from the Atoyac River Basin grouped by multivariate analysis.

Variable	G 1	G 2	G 3	G 4	Mean	LSD
	(n=48)	(n=103)	(n=42)	(n=71)		
pH	6.58[a]	6.68[a]	6.19[b]	6.67[a]	6.58	0.22
Acidity (%)	0.23[b]	0.22[b]	0.32[a]	0.23[b]	0.24	0.04
Cryoscopic point (°C)	−0.45[b]	−0.43[a]	−0.47[b]	−0.49[c]	−0.46	0.03
Fat (%)	4.31[a]	2.76[bc]	2.47[c]	2.96[b]	3.05	0.67
Protein (%)	2.63[b]	2.54[d]	2.75[b]	2.88[a]	2.68	0.15
Lactose (%)	3.95[c]	3.81[d]	4.13[b]	4.32[a]	4.03	0.23
Minerals (%)	0.59[c]	0.56[d]	0.61[b]	0.64[a]	0.6	0.03
Non fat solids (%)	7.25[c]	6.95[d]	7.53[b]	7.87[a]	7.35	0.41
Total solids (%)	11.05[a]	10.47[b]	10.06[b]	10.08[b]	10.4	0.76
Water (%)	10.08[b]	16.98[a]	10.22[b]	5.21[c]	11.49	5.06

Means with equal letters in a line are statistically equal, according to Tukey's means comparison (α=0.05); G=Group; n: Number of sample.

Table 5 presents the values of the components corrected by subtracting the content of water. It can be seen that in the milk produced, with the exception of the fat content which is very high in group 1 and very low in group 3, the other components were within the acceptable ranges indicated by the normativity. On the other hand, the same table specifies the economic profit that producers obtain from adding water, or the loss of the companies, showing that group 2 is where producers obtain a higher profit per liter of milk.

Fulfilling the parameters established by the norm is one of the challenges that family production units face. Statistically, there are differences between companies and between the groups resulting from the multivariate analysis in the pH of raw milk, and it seems like there is a positive association with acidity; however, Negri (2005) mentions that there is not necessarily an association between both variables, and relates the pH with the stability of milk in the presence of industrial thermal treatments. On the other hand, Rodríguez-Pérez *et al.* (2011), in a study where water addition to raw milk was controlled, found that adding 20%, the pH increases a percentage unit and technically has a probable repercussion on the loss of the acid-base regulating capacity of the components of raw milk.

Concerning the acidity, in general the milk collected has high values and outside the normativity, which can be attributed to the lack of hygiene in milking (Cervantes *et al.*, 2011) and inappropriate storage that allows the development of the bacteria load, problem that increases later due to bad transport conditions (without refrigeration equipment) and the time that the collection by "boteros" takes; however, in the study zone this quality can be favorable because this milk is destined to elaborate string cheese or Oaxaca cheese, where the acid milk is used, and therefore eases for the companies to advance in their transformation processes. Naturally this action can bring consequences in the shelf life of the products and in the health of consumers, because it is a product made with unpasteurized milk.

WingChing and Mora (2014) mention that the freezing point of the milk corresponds to the temperature at which it freezes, and in which the liquid part and the solutes are in balance; they report that this parameter changes proportionally in function of the amount of water added up to 15% and, on the other hand, that the minimal addition of 1% of water to the milk

Table 5. Correction in the chemical composition of raw milk and economic loss from the addition of water in family production units in the River Atoyac Basin grouped by multivariate analysis.

Variable	G 1 (n=48)	G 2 (n=103)	G 3 (n=42)	G 4 (n=71)	Media	DMS
Fat (%)	4.85[a]	3.32[b]	2.77[c]	3.11[cbc]	3.46	0.79
Protein (%)	2.92[c]	3.06[a]	3.06[a]	3.03[b]	3.03	0.03
Lactose (%)	4.39[c]	4.60[a]	4.61[a]	4.56[b]	4.55	0.05
Minerals (%)	0.66[b]	0.68[a]	0.68[a]	0.67[a]	0.68	0.01
Non fat solids (%)	8.07[c]	8.38[a]	8.39[a]	8.31[b]	8.31	0.1
Total solids (%)	12.93[a]	11.71[b]	11.17[c]	11.43[cbc]	11.77	0.76
Loss ($/L)	0.82[b]	1.39[a]	0.83[b]	0.42[c]	0.67	0.29

Means with equal letters in a line are statistically equal, according to Tukey's means comparison (α=0.05); n: Number of sample.

dilutes their components. The results obtained in this study show the considerable presence of water in the milk and are comparable to those reported by Barham *et al.* (2014) in Pakistan, where they found values between −0.534 and −0.441 and agrees with what was reported by Escoto *et al.* (2013) in the dairy basins of the state of Hidalgo, where they also mention that adulteration is more accentuated in small-scale livestock farmers.

Regarding the chemical composition, the results in Table 2 show a quite marked dilution in protein and lactose, and therefore in non-fatty solids, due to the addition of water, in agreement with a growing proportion between processors, 6.83, 8.67 and 13.07% for companies 1, 2 and 3, respectively; these values agree with those reported by WingChing and Mora (2019) in a specific study where different percentages of water were added intentionally to milk from Holstein cows.

It can also be seen that fat is only diluted in company 3, so it is possible that some producers who sell to companies 1 and 2 adulterate milk with fat substitutes. This possibility is marked more in Table 3, where group 1 is formed by making the adjustments by removing the added water with 18.18% of producers whose milk averages 4.85% of fat, abnormal value that considerably exceeds the minimum fixed in the normativity and is very high for this type of farm.

Milk adulteration with water is the most common practice in many countries and responds to different needs, among them the high demand and the limited offer of milk as in China (Gale and Hu, 2007), although the one most disseminated is to increase the volume and to obtain higher income (Bernal *et al.*, 2007), which causes for components to be diluted and for there to be the need to add other adulterants that substitute or mask them.

To increase the fat content in milk adulterated with water, plant or animal fat may be used (Bernal *et al.*, 2007) or vegetable oil (Barham *et al.*, 2014); to trick the value of protein or nitrogen component, urea can be used (Zhao and Zhang, 2019) accompanied by surfactant products to make it foamy (Sadat *et al.*, 2006); on the other hand, to falsify the protein content, a compound called melamine can be added (Wu *et al.*, 2009). To simulate lactose, sugar is a cheap source of sweetener, and therefore, it can be assumed that sugar from sugarcane is added diluted into the raw milk to improve the flavor (Chanda *et al.*, 2012).

Milk is also adulterated with starch, wheat flour and rice flour, which help to increase the non-fatty solids (NFS) content and viscosity of the milk. Other components are caustic soda, sodium carbonate and bicarbonate, to neutralize the pH and the acidity of the milk (Fakhar and Law Walker, 2006; Afzal, 2011). On the other hand, the addition of hydrogen peroxide is very common to minimize microbe growth and control the degradation of milk (Paixao and Bertotti, 2009), although beneficial microorganisms are harmed for the elaboration of cheeses and their byproducts.

The consequences of intentionally adding substances that are not allowed and some with toxic effects such as melanin bring with it serious health problems (Lam *et al.*, 2008). In China, they also add synthetic powders to increase the protein value, and milk traders dilute the milk (Gale and Hu, 2007).

According to Lateef *et al.* (2009), milk adulteration can be with water, urea, formalin, hydrogen peroxide and sugarcane. Díaz *et al.* (2002) and Gutiérrez *et al.* (2009) evaluated adulterations of milk and dairy products with animal and plant fats in pasteurized and ultra-pasteurized milks. Some other countries are also suffering from this unethical activity. In general, the results obtained by groups of milk corrected with water, when compared with norm NMX-F-700-COFOCALEC-2012, indicate that the physicochemical composition of the raw milk from the Atoyac River Basin fulfill the parameters established. These results are highly important for producers since with them the processor and the consumers can be guaranteed a product of quality and high nutritional value; however, the price at which it is paid and the lack of normative vigilance makes it possible for the producer to adulterate with water and add other components in order to mask this action, which demerit the value of the production and can cause health problems in the consumers.

CONCLUSION

Based on the results found, it can be concluded that milk produced by family production units in the Atoyac River Basin complies with the parameters of the current normativity; however, due to the deficient management, it is sold acidified, and it is adulterated with water on average with levels of 11.49%, with which transforming companies loose on average $0.68/liter of milk. Significant differences were observed in the physicochemical characteristics of milk that is sold to the three companies studied, where adulteration with water is common in the three cases, causing for the components to be diluted, particularly protein and lactose, which mostly make up the non-fatty solids. The multivariate analysis generated four groups of producers, with one of them standing out, where when correcting the components from the addition of water, the possibility of adding fat to mask water addition can be seen.

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