Physicochemical characterization of milk in 5/8 Holstein × 3/8 Zebu crossbred cows in tropical Mexico

Caracterización fisicoquímica de la leche de vacas mestizas 5/8 Holstein × 3/8 Cebú en la región tropical de México

Caracterização físico-química do leite de vacas mestiças 5/8 Holandesa × 3/8 Zebu na região tropical de México

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Abstract

Background: Milk price depends on the concentration of milk components, which are influenced by several factors. **Objective:** To determine the effect of cow intrinsic variables on the physicochemical composition of raw milk in a dual-purpose production system. **Methods:** Twenty-five 5/8 Holstein-Friesian × 3/8 Zebu (5/8H3/8Z) lactating cows aged 5-10 years and 1-6 births were selected. Body condition score (BCS) and milk production were recorded. Milk samples were taken throughout lactation from each cow at mid-milking every eight days. Milk composition analysis was carried out using an automatic Lacticheck equipment. **Results:** Average daily milk production per cow was 4.10 L, with 1.03 g/cm^3 density, 32.70 g/L fat, 34.50 g/L protein, 50.20 g/L lactose, 91.30 g/L non-fat solids, and 127.00 g/L total solids. The BCS influenced milk composition ($p<0.01$). Cows with higher BCS (>3.25) showed greater density, protein and lactose, while BCS between 2.00 to 2.50 positively affected fat content (39.20 g/L). Elder cows had increased milk production. In early lactation, milk production was the highest with less fat percentage. **Conclusion:** Although cow production per day is low, milk composition from 5/8H3/8Z cows complies with the standards established in the Mexican norm and is considered to be of good quality.

Keywords: *body condition; cattle; cows; crossbred; dual-purpose; lactation; milk composition; milk yield; quality.*

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Resumen

Antecedentes: El precio de la leche cruda depende de la concentración de sus componentes físico-químicos, los cuales están influenciados por varios factores. **Objetivo:** Determinar el efecto de variables intrínsecas de las vacas sobre la composición fisicoquímica de la leche cruda en un sistema de producción de doble propósito. **Métodos:** Se seleccionaron 25 vacas 5/8 Holstein-Friesian × 3/8 Cebú (5/8H3/8Z) lactantes, con edades entre 5 a 10 años y con 1 a 6 partos. Se registró la condición corporal (BCS) y la producción de leche. Se tomaron muestras de leche de cada vaca durante toda la lactancia a la mitad del ordeño y cada ocho días. El análisis de la leche para determinar la composición se realizó con un equipo automático Lacticheck. **Resultados:** La producción promedio de leche fue de 4,10 L por vaca por día, con una densidad de 1,03 g/cm^3, 32,70 g/L grasa, 34,50 g/L proteína, 50,20 g/L lactosa, 91,30 g/L sólidos no grasos y 127,00 g/L de sólidos totales. La BCS influyó en la composición de la leche ($p<0,01$). Las vacas con mayor BCS (>3,25) mostraron una mayor densidad y mejor proteína y lactosa, mientras que una BCS de 2,00 a 2,50 solo afectó positivamente el contenido de grasa (39,20 g/L). Las vacas más viejas tuvieron mayor producción de leche. En la lactancia temprana, la producción de leche fue más alta con menos porcentaje de grasa. **Conclusión:** Aunque la producción diaria por vaca es baja, la composición de la leche de vacas 5/8H3/8Z cumple con los estándares establecidos en la norma mexicana, y se considera de buena calidad.

Palabras clave: *composición de la leche; calidad; condición corporal; cruce; doble propósito; ganado; lactancia; producción láctea; vacas.*

Resumo

Antecedentes: O preço do leite cru depende da concentração de seus componentes físico-químicos, que são influenciados por diversos fatores. **Objetivo:** Determinar o efeito de variáveis intrínsecas das vacas sobre a composição físico-química do leite cru em um sistema de duplo propósito. **Métodos:** Foram selecionadas 25 vacas em lactação 5/8 Holandês-Frísia × 3/8 Zebu (5/8H3/8Z) de 5 a 10 anos de idade e 1 a 6 nascimentos. O escore de condição corporal (BCS) e a produção de leite foram registrados. Amostras de leite foram coletadas durante toda a lactação de cada vaca no meio da ordenha a cada oito dias. A análise do leite para determinação da composição foi realizada em equipamento automático Lacticheck. **Resultados:** A produção média de leite foi de 4,1 L por vaca por dia, com densidade de 1,03 g/cm^3 32,70 g/L de gordura, 34,50 g/L de proteína, 50,20 g/L de lactose, 91,30 g/L de sólidos não gordos e 127,00 g/L de sólidos totais. BCS influenciou a composição do leite ($p<0,01$). Vacas com maior BCS (>3,25) apresentaram maior densidade, proteína e lactose, enquanto um BCS de 2,00 a 2,50 afetou positivamente apenas o teor de gordura (39,20 g/L). As vacas mais velhas tiveram maior produção de leite. No início da lactação, a produção de leite foi maior com menor percentual de gordura. **Conclusão:** Embora a produção por vaca por dia tenha sido baixa, a composição do leite das vacas 5/8H3/8Z atendeu aos padrões estabelecidos na norma mexicana e é considerada de boa qualidade.

Palavras-chave: *composição do leite; condição corporal; cruzando; dupla finalidade; gado; lactação; produção de laticínios; qualidade; vacas.*

Introduction

Cattle raising in Mexico provides animal protein products such as meat and milk. During 2021, cow milk and meat production amounted to 12.8 billion L and up to 2.1 million tons, respectively (SIAP, 2021). Livestock in the Mexican tropic contributed 35% of the meat and 16% of the milk consumed in the country (Arieta-Román, 2020).

Beef and dairy farms in tropical Mexico are characterized by low performance due to inefficient technologies, poor nutritional management, breed miscegenation, climatic conditions, and cattle difficulties to adapt to the environment (Vite *et al.*, 2015). Although interactions between environmental, genetic and social factors are important for livestock productivity (Rangel *et al.*, 2020), cattle production is flexible and can change from milk to meat production (calf) through the seasons (Cuevas-Reyes and Rosales-Nieto, 2018).

Milk price is affected by quality, measured as physicochemical composition and microbiological concentration (Contero-Callay *et al.*, 2021). Milk quality parameters are defined by standards and regulations for raw milk. The NMX-F-700-COFOCALEC-2012 is the Mexican norm currently used to assess milk quality according to good production practices. The minimum values for protein, fat and density at 15 °C are 30 g/L, 30 g/L and 1,03 g/cm^3, respectively.

The Mexican legislation establishes incentive payments at LICONSA'S collection centers for exceeding milk composition standards. Nevertheless, the factors that determine milk composition in the tropical region of Mexico are little known due to low demand for quality standards in the local market. As few collection centers are established in southeastern Mexico the farmers depend on cheese makers, who do not pay bonusses for milk quality (Ortiz-Hernández *et al.*, 2016).

Therefore, the aim of this study was to determine the effect of intrinsic variables of dairy cows on the physicochemical composition of raw milk in a dual-purpose production system under the humid conditions of tropical Mexico.

Materials and Methods

Ethical considerations

This project was approved by the general direction of research and graduate studies of Universidad Autónoma Chapingo, Mexico, and procedures were performed according to Mexican norm NOM-051-ZOO-1995 on humane treatment during transportation of animals.

Location

The study was conducted at the experimental farm of Unidad Regional Universitaria Sursureste, belonging to Universidad Autónoma Chapingo in Teapa, Tabasco state, Mexico. It is geographically located between 17° 31' 30"' N and 92° 55' 46"' W, and 80 m above sea level. The climate is warm humid, with 3,816 mm average rainfall and 26 ºC average annual temperature (CONAGUA, 2023). The soils are of sedimentary origin: limestone, sandstone and shale-sandstone. The types of soil in the municipality are: Acrisol, Gleysol, Regosol, Leptosol, Cambisol and Phaeozem (INEGI, 2017).

Animal handling

Twenty-five 5/8 Holstein-Friesian × 3/8 Zebu (5/8H3/8Z) lactating cows 5 to 10 years-old with 1 to 6 births were selected. The cows resulted from rotational cross with zebu breeds such as Brahaman and Gyr, and the line has been maintained with Gyr-Holando bulls locally purchased. Feeding was based on rotational grazing in five paddocks with 60 days rest and 15 days occupation in pastures of *Urochloa decumbens* (3 Ha), mombaza (*Megathyrsus maximus*, 3 Ha), and *Paspalum notatum* and *P. conjugatum* (6 Ha). The botanical composition corresponds to 66% improved pastures mixed with naturalized species. The management of the paddocks consisted of manual weeding and, in some cases, chemical control of shrubs. A stocking rate of two heads per hectare was used. Cows received 50 g of salt per day, with no additional supplementation, and with free access to water.

Cows were selected from a herd of 100 animals at the beginning of lactation to have the closest records between lactations. In addition, calving dates were used to adjust lactation length (in weeks) and have uniformity in the data. Mechanical milking was conducted once a day, in the mornings, with oxytocin injection (2 ml; Aranda Laboratories, Santiago de Querétaro, Mexico) to achieve milk letdown. Only three teats were milked, leaving one teat left to nurse the calf. Subsequently, cows were placed on pasture while calves locked in a corral and fed forage and concentrate.

Sampling and laboratory analysis

The study was conducted during the rainy and cold season from September 2019 to February 2020. One milk sample (50 ml) was taken every eight days during 6 months from each cow at mid-milking to ensure an average quality of milk. Once the sample was obtained, it was transported in conical tubes with thread from the farm to the animal nutrition laboratory of the University, located less than 1 km away, for immediate physicochemical analysis.

Lactation was divided into three stages, in a similar way to that indicated by Briñez *et al.* (2003). The stages were as follows: early lactation (from 1 to 90 days), mid lactation (from 91 to 180 days), and late lactation (from 181 days onwards).

Milk composition

Milk composition was determined immediately after samples arrived at the laboratory using a Lacticheck automatic analyzer (Page & Pedersen®, Massachusetts, USA). The samples were heated in a water bath at 35°C, then homogenized with a magnetic stirrer and, finally, analyzed to obtain fat (%), density (g/cm^3), protein (%), lactose (%), and water (%).

Milk quality classification

The reference values to determine milk quality were taken in accordance with the Mexican Standard NMX-F-700-COFOCALEC-2012, which establishes three categories in relation to fat and protein contents.

a) Class A: must contain more than 32.00 g fat/l and more than 31.00 g protein/l.

b) Class B: a minimum of 31.00 g fat/l and 30.00 to 30.90 g protein/l.

c) Class C: a minimum of 30.00 g fat/l and 28.00 to 28.90 g protein/l.

Body condition score (BCS) and age

The BCS was evaluated every 15 days by the same person using a scale of 1 to 5 according to the methodology proposed by Ferguson *et al.* (1994). To analyze age, cows were grouped considering three stages: young, intermediate and old cows, and age groups were 4-6 years (5 years), 7-9 years (8 years), and 10-11 years (10 years).

Statistical analysis

An analysis of variance was performed using the GLM procedure of SAS (SAS, 2017) and the comparison between means was made with Tukey's test. The independent variables were body condition, age, lactation stage, and lactation week nested into stage. The statistical model used was as followss:

$$Yijklm = \mu + \varsigma i + \lambda j + \varphi k + \pi(\varphi)l(k) + \varsigma i^* \lambda j + \varsigma i^* \varphi k + \varsigma i^* \pi(\varphi)l(k) + \lambda j^* \varphi k + \lambda j^* \pi(\varphi)l(k) + \xi ijklm$$

Where:

Yijklm = Response variable

μ = General mean

ςi = ith effect of BCS

λj = jth effect of cow age

φk = kth effect of lactation stage

$\pi(\varphi)l(k)$= lth effect of week nested in lactation stage

ςi* λj = Interaction of BCS and age

ςi*φk= Interaction of BCS with lactation stage

ςi* π(φ)l(k) = Interaction of BCS and week nested in lactation stage

λj*φk = Interaction of age and lactation stage

λj*π(φ)l(k) = Interaction of age with week nested in lactation stage

ξijklm = random error

Results

Raw milk composition

Physicochemical composition of raw milk is presented in Table 1. The average content for all components was within normal values indicated in the raw milk quality control standards manual according to Mexican norm NMX-F-700-COFOCALEC -2012 (SEDESOL, 2007). In accordance with the Mexican Standard, raw milk corresponds to class A and is considered of good quality.

Milk production per cow

The average milk production was 4.1 L per cow per day. The highest yields occurred during the first stage (first 13 weeks) followed by a gradual reduction. At the beginning of lactation, 5.7 L of milk per cow per day were obtained. However, no peak of lactation was observed (Figure 1).

Body condition score and milk composition

The BCS affected milk composition ($p<0.01$). Cows with BCS >3.25 produced milk with the

Table 1. Chemical composition of raw milk from 5/8 Holstein × 3/8 Zebu crossbreed cows in tropical Mexico.

Composition	Density (g/cm^3)	Fat (g/L)	Protein (g/L)	Lactose (g/L)	NFS (g/L)	TS (g/L)
Raw milk	1.03	32.70	34.50	50.20	91.30	127.00
Reference values*	1.03	30.00	30.00	43.00	100.00	130.00

NFS: Non-fat solids. TS: Total solids. *NMX-F-700-COFOCALEC (SEDESOL, 2007).

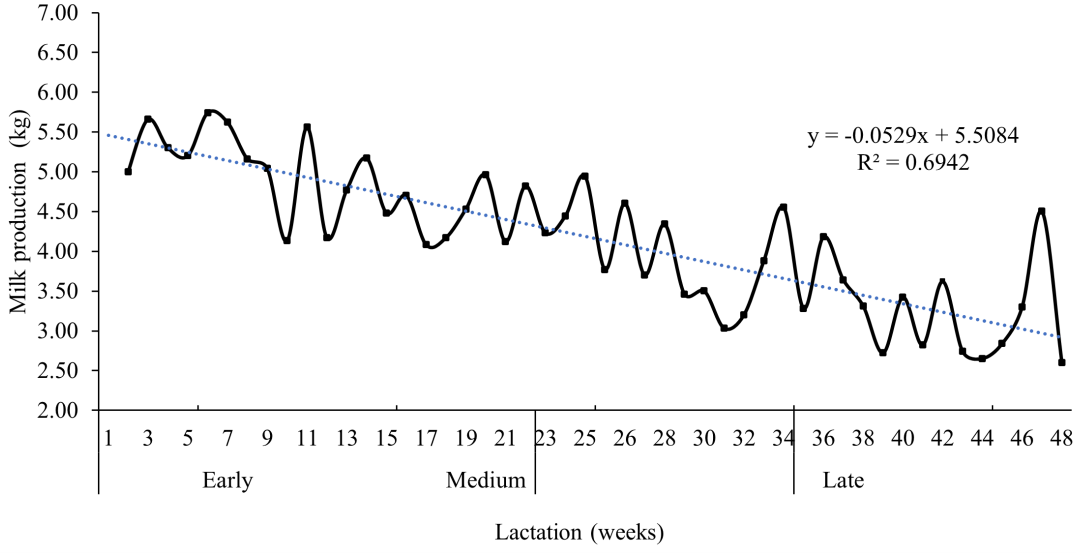

Figure 1. Daily milk production per week in dual-purpose cows (5/8 Holstein × 3/8 Zebu) under the humid warm weather conditions of tropical Mexico.

highest density, protein, and lactose, while cows with low BCS (2.0–2.50 points) produced milk with more fat content. This same BCS favored increased percentage of total solids in milk (Table 2). Total solids in milk increased along with the fat content, while the non-fat solids decreased.

Age in milk composition

Milk composition was significantly affected by age of cows ($p<0.01$). The highest values of fat, protein, and lactose in milk occurred in 5-years-old cows, but their milk production was lower than the obtained by 10-years-old cows, without differences with 8-years-old cows. The elder cows had the highest milk production and its composition did not differ from the obtained in the 8-years-old cows (Table 3).

Lactation stage and milk composition

Lactation stage had an important effect on milk production and composition ($p<0.01$). A gradual decrease in production was observed as lactation stage advanced. In this sense, all milk components had similar behavior during the first 25 weeks of lactation, while they showed the highest values in late lactation, highlighting highest fat and protein content with a mean of 41.00 g/L and 35.80 g/L, respectively. As milk production decreased, the percentages of milk composition increased (Table 4).

Table 2. Effect of body condition score (BCS) on milk composition of dual-purpose cows (5/8 Holstein × 3/8 Zebu) in tropical Mexico.

Variable	Body condition score						
	≥2.00 to <2.50		≥2.50 to <3.25		≥3.25		
	Mean	SD	Mean	SD	Mean	SD	p
Production (kg)	3.90^{b}	1.79	4.37^{a}	1.54	3.60^{b}	1.86	0.004
Density (g/cm^3)	1.031^{c}	0.004	1.033^{b}	0.003	1.034^{a}	0.003	0.001
Fat (g/L)	39.20^{a}	3.07	29.40^{b}	2.58	23.60^{b}	1.60	0.01
Protein (g/L)	34.10^{a}	3.60	34.60^{a}	3.20	35.40^{a}	2.50	0.07
lactose (g/L)	49.40^{b}	5.50	50.50^{ba}	4.50	51.90^{a}	3.80	0.02
NFS (g/L)	90.40^{a}	9.60	91.50^{a}	10.50	94.40^{a}	6.60	0.10
TS (g/L)	132.50^{a}	35.00	124.00^{ba}	29.70	120.90^{b}	20.40	0.002

NFS: Non-fat solids. TS: Total solids. SD: Standard deviation. Means within rows with different superscript letters ($^{a, b}$) are significantly different ($p<0.05$).

Table 3. Milk production and composition of dual-purpose cows (5/8 Holstein × 3/8 Zebu) in tropical Mexico.

Variable	Age						
	5 years		8 years		10 years		
	Mean	SD	Mean	SD	Mean	SD	p
Production (kg)	4.02^{b}	2.32	3.93^{b}	1.36	4.40^{a}	1.69	0.001
Density (g/cm^3)	1.03^{a}	0.004	1.03^{a}	0.004	1.03^{a}	0.003	0.07
Fat (g/L)	42.00^{a}	3.38	28.40^{b}	2.21	33.40^{b}	2.95	0.001
Protein (g/L)	36.40^{a}	4.00	34.00^{b}	2.90	34.20^{b}	3.30	0.001
Lactose (g/L)	52.70^{a}	5.50	49.50^{b}	4.60	49.80^{b}	4.60	0.004
NFS (g/L)	95.20^{a}	15.60	90.50^{b}	8.00	90.50^{b}	7.90	0.009
TS (g/L)	141.10^{a}	39.90	121.80^{b}	24.40	126.60^{b}	32.90	0.001

NFS: Non-fat solids. TS: Total solids. SD: Standard deviation. Means within rows with different superscript letters ($^{a, b}$) are significantly different ($p<0.05$).

Interactions

Among the interactions indicated in the statistical model, the week nested in lactation stage was not significant, nor was the age associated with week nested in lactation stage, except in milk production. The interaction of BCS and week nested in lactation stage was also not significant.

Interaction between age and lactation stage

The age with lactation stage affected most of the variables (Figure 2), observing that 5-year-old females had the highest production of milk components in late lactation.

Interaction between body condition score and age

The 5 and 10-years-old cows had the highest amount of fat in the 2.00 to 2.50 BCS, so total solids were higher than in the other categories (Figure 3).

Interaction between age, week, and lactation stage and milk production

During the early and mid-lactation, the highest and more stable production was found in cows older than 10 years. While young cows (5 years-old) showed a marked decrease from week 30 of lactation, they produced higher volumes in the first weeks. The 8-years-old cows started with an average production of 5 L per cow per day during early lactation and presented a very high drop in production, ending with an average of 2 L (Figure 4).

Discussion

Milk production from dual-purpose cows (5/8 Holstein × 3/8 Zebu) in the present study was comparable to that obtained in similar climatic conditions in Mexico, such as La Frailesca, Chiapas, where production was around 4.96-12.2 L per cow per day (Camacho-Vera *et al.*, 2021). Also, under similar climatic conditions in Cuba with Mambí bovines (3/4 Holstein × ¼ Zebu), an average milk production of 4.49 kg was obtained during 1991-2006, indicating that the genotype-environment interaction was very important (Hernández *et al.*, 2012). Also, in Colombia, a production of 12 L was observed in specialized Holstein-Friesian cows, while in dual-purpose cows, milk production was 3-5 L per day (Carulla and Ortega, 2016). However, values higher than 9 L per cow per day were also reported in a Holstein × Gyr cross in Juárez, Chiapas (Peralta-Torres *et al.*, 2021). Under other climatic, feeding, and management conditions in Northwestern Mexico, production from Holstein-Friesian cows reached 15-33 L per cow per day (Anzures-Olvera *et al.*, 2015). In this case the cows received 4 kg of pelleted commercial concentrate and alfalfa hay, which results in great difference in milk production compared to that obtained in the tropics of Mexico.

Table 4. Effect of lactation stage on milk production and its composition in dual-purpose cows (5/8 Holstein × 3/8 Zebu) in tropical Mexico.

Variable	Lactation stage						
	Early		Middle		Late		
	Mean	SD	Mean	SD	Mean	SD	p
Production (kg)	5.06^{a}	1.33	4.48^{b}	1.55	3.51^{c}	1.68	0.001
Density (g/cm^3)	1.031^{b}	0.003	1.032^{b}	0.003	1.033^{a}	0.004	0.001
Fat (g/L)	25.90^{b}	2.60	23.60^{b}	2.02	41.00^{a}	2.98	0.001
Protein (g/L)	32.80^{b}	1.90	33.50^{b}	2.70	35.80^{a}	3.70	0.001
Lactose (g/L)	47.90^{b}	2.60	49.00^{b}	3.60	51.90^{a}	5.50	0.001
NFS (g/L)	86.10^{b}	11.40	88.80^{b}	6.40	95.00^{a}	9.70	0.001
TS (g/L)	116.00^{b}	28.00	115.20^{b}	20.80	138.80^{a}	34.00	0.001

NFS: Non-fat solids. TS: Total solids. SD: Standard deviation. Means within rows with different superscript letters ($^{a, b}$) are significantly different ($p<0.05$).

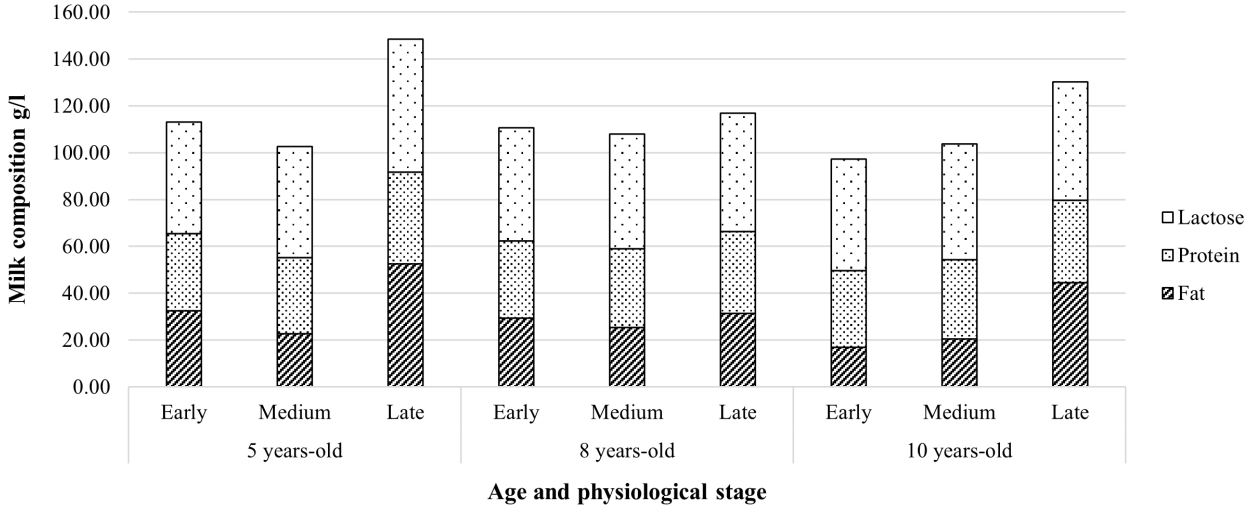

Figure 2. Milk composition per age and physiological stage of dual-purpose cows (5/8 Holstein × 3/8 Zebu) under humid warm weather conditions of tropical Mexico.

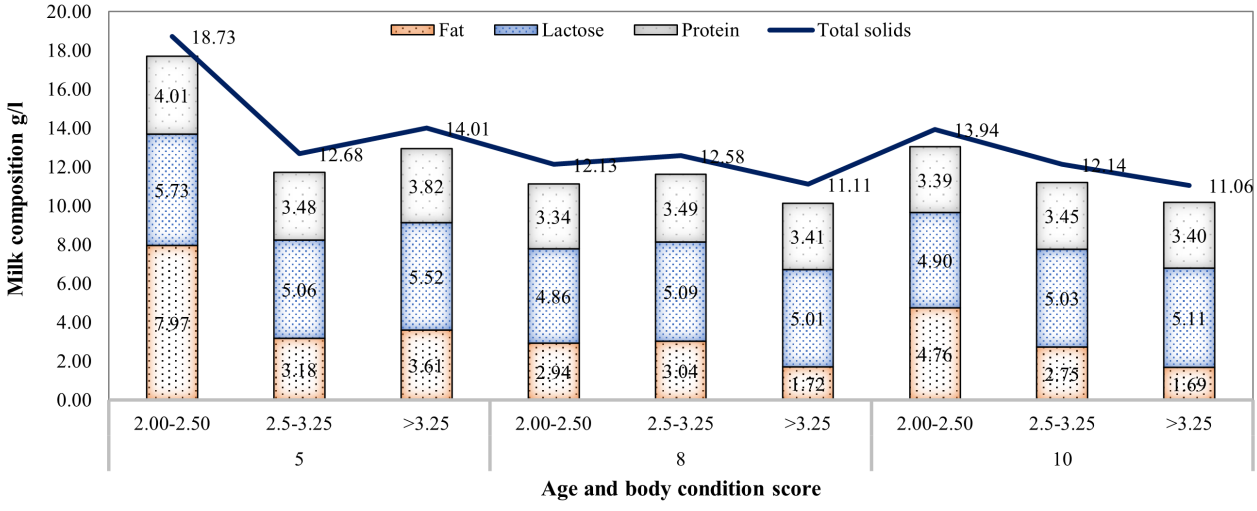

Figure 3. Milk composition per age and body condition score of dual-purpose cows (5/8 Holstein × 3/8 Zebu) under humid warm weather conditions of tropical Mexico.

Similar to the present study, high milk production is related with low concentration of fat and protein, as evidenced in Holstein cows (Lainé *et al.*, 2017). For dual-purpose cows with low milk production, as in the present study, the concentration of milk components is greater than the official standard. This opens up an opportunity in Holstein × Zebu breeds to obtain milk with high in protein and lactose, with a higher yield for cheese making (Pretto *et al.*, 2013).

The variation in protein percentage (3.14 to 3.55%) reported in various studies (Mendes-Costa *et al.*, 2020; Ignatieva and Nemtseva, 2020) is similar to that of the present study with Holstein × Zebu cows (3.25-3.50%). This behavior was also found in Holstein × Zebu cows in Brazil (Lima *et al.*, 2021), and it results from the interaction of multiple factors. The general trends indicate that variation in milk protein can be attributed to breed, cattle management, and

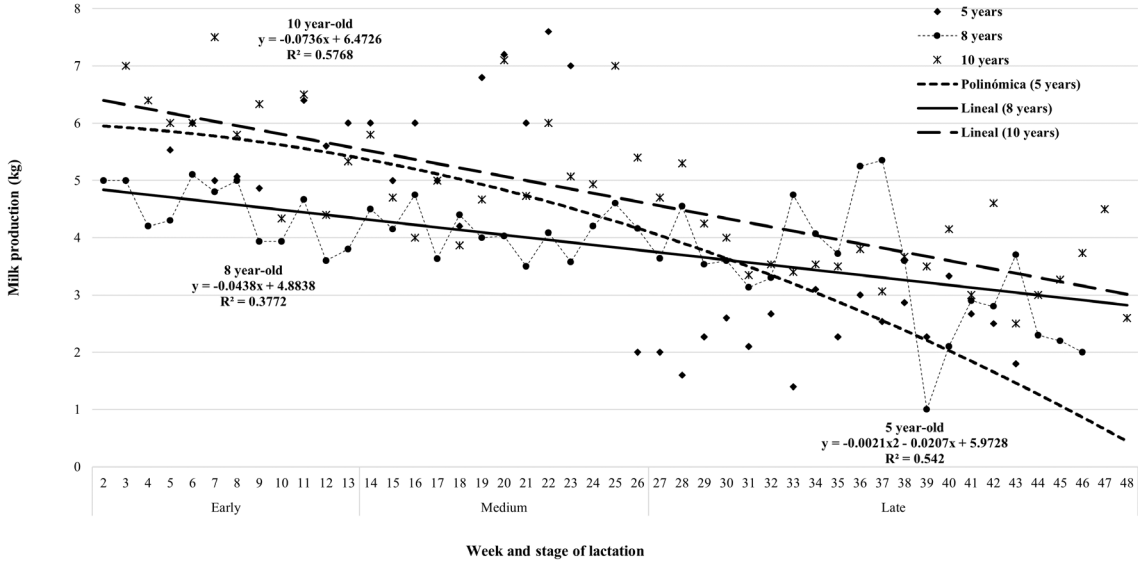

Figure 4. Milk production of dual-purpose (5/8 Holstein × 3/8 Zebu) cows by age and lactation stage in tropical Mexico.

mainly diet affects the chemical composition of milk (Moreira-Santiago *et al.*, 2019). In this study protein percentage was affected by cow age, BCS, and stage of lactation.

Fat content in milk is important because several organoleptic traits of cheese depend on this component, so high fat percentage is required to provide a specific aroma and flavor (Nudda *et al.*, 2014). The main factors involved in fat percentage are breed, lactation stage, genetics, and diet. Diet is especially relevant when comparing concentrate and pasture-based feeding systems (Schwendel *et al.*, 2015). In the present study, the results found percentages slightly lower than those reported by Cervantes Escoto *et al.* (2013) for fat content.

The recommended BCS of cows must be between 2.75-3.0, because as BCS decreases, milk protein decreases (Bewley and Schutz, 2008). High BCS coincides with high percentage of milk protein, similar to indicated in a study with a Holstein × Gyr cross (dos Santos *et al.*, 2019). The BCS is positively correlated with fat and protein contents, while negatively with milk production. Milk production steadily declined beyond four months postpartum, while BCS showed initial decrease followed by a slight increase similar to that indicated in the literature (Mushtaq *et al.*, 2009).

The higher fat production observed in lean cows compared to the fat ones (Table 2) is attributed to the higher dry matter intake by leaner cows (Bewley and Schutz, 2008). Cows that are in low body condition in early lactation produce more milk with higher concentration of fat and protein, although a negative effect is later observed. Therefore, cows should be in good BCS during the dry period (Singh *et al.*, 2020). The BCS alone (by itself), taken at any time of lactation, does not properly represent the changes in milk components, so it must be analyzed according to lactation stage.

Age, together with calving number, is an indicator of maturity, so several studies show an increase in milk production as cows reach physiological maturity. This behavior has been observed in dual-purpose crossbred cows (Briñez *et al.*, 2008). The 10-years-old cows had the highest milk production, but total solid contents decreased. Young cows in production have not finished body development, so they first meet maintenance and growth requirements

and later those of production, which is why they produce less milk (Briñez *et al.*, 2008).

Lactation stage has an influence on milk production (Vijayakumar *et al.*, 2017) and main milk components. In the present study, very notable differences were observed in all components between early and late lactation, but no difference was observed between early and mid-lactation. In general, all components increased at the end of lactation, while the opposite was observed with milk production with lowest production in late lactation. Similar results have been obtained with Holstein cows in Belgium showing the effect of physiological stage on fat and protein (Lainé *et al.*, 2017).

In the present study, a reduction in milk production was observed as days of lactation increased with a descending line. This is commonly observed in dairy cows (Ferro *et al.*, 2022); although in the present study the reduction was gradual because milk production was low; therefore, reducing from 0.044 to 0.074 L per week, while reduction of lactation curves in specialized dairy breeds reaches 0.054 L per day (0.378 L per week; Pollot, 2000). This behavior was probably due to low dairy potential of the cross, which was also affected by the environmental conditions of Mexican tropic and farm management (Arce-Recinos *et al.*, 2017). In a herd of Siboney cattle (5/8 Holstein × 3/8 Cuban Zebu), the maximum daily milk production per cow reached 4.9 kg with curves similar to those presented with the Wood and Wilmink modelling (Palacios-Espinosa *et al.*, 2016). A similar situation occurred in Colombia with Gyr cattle (Ferro *et al.*, 2022).

Average content of all milk components (density, fat, protein, lactose, non-fat solids, and total solids) was found within the values indicated in the average quality control of raw milk and considered of good physicochemical quality. Mexican legislation establishes a minimum content of 3.0% fat and 11.5% total solids; these two parameters were exceeded in this study, which is explained by the low milk yield, similar to those of the region (Arce-Recinos *et al.*, 2017), which favors the highest concentration of fat and protein.

As a conclusion, lactation stage and cow age affect milk production and composition in 5/8 Holstein × 3/8 Zebu crossbred cows. The highest production occurs in 10 years-old cows. In addition, at early lactation, milk production is higher but has lower fat content and total solids than in late lactation. Milk components were considered of good physicochemical quality according to the Mexican legislation for raw milk.

Declarations

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Conflicts of interest

The authors declare they have no conflicts of interest with regard to the work presented in this report.

Author contributions

Domínguez-Peregrino designed the experiment, wrote the manuscript and carried out the experiment. González-Garduño performed the statistical analysis and wrote the manuscript. Ortíz-Pérez edited and reviewed the manuscript.

Use of artificial intelligence (AI)

No AI or AI-assisted technologies were used during the preparation of this work.

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