

Evaluation of factors affecting milk production and composition in dual-purpose systems

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ABSTRACT

Objective: This study aimed to evaluate the genetic and environmental effects on milk production and composition in dual-purpose cows in the Veracruz tropics.

Methodology: A population of 79 cows grouped by crossbreeds in different proportions of Zebu×Holstein (17), Zebu×Swiss (50), and Zebu×Holstein×Swiss (12) was used. Milk samples were collected at 28-day intervals and analyzed using infrared (IR) spectrophotometry (MilkoScan FT-120, A/S FOSS Electric®). Adjusted means were estimated using PROC GLM from SAS®. The fixed effects included in the model were: genotype, herd, season, lactation number, year, and cow identification. The response variables were: lactation duration (days), production (kg), fat, protein, and lactose (%).

Results: The duration of lactation averaged 307 ± 71.95 days, with total production of $1,240 \pm 468.19$ kg. The values for protein, fat, and lactose were 3.18 ± 0.41 , 3.49 ± 0.82 , and 4.42 ± 0.47 , respectively. Significant differences ($p < 0.05$) were found for the effects of year, calving season, and number of calvings on lactation duration (319 ± 6.6 days) during the dry season and total milk production per lactation during the same season ($1,239 \pm 40.6$ kg) by number of calvings. The longest lactation duration was reported in primiparous cows (345 ± 7.5 days). The effect of sampling season on milk composition was significant ($p < 0.05$) in the rainy season for protein (3.4 ± 0.03 %) and fat (3.8 ± 0.08 %).

Study limitations: This study is limited to a dual-purpose production system with crossbred cattle of different racial composition, under the management and environmental conditions of the participating herds.

Conclusions: The results indicate that milk production and composition are influenced by environmental factors and by differences between the groups evaluated.

Keywords: lactation, fat, protein, genetic, environmental.

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INTRODUCTION

It is estimated that by 2050, the world population will reach 9.7 billion, creating a need to increase animal products (UN, 2022). Cow milk production is one of the most important livestock activities worldwide to meet this demand (North *et al.*, 2023).



Mexico ranks 14th worldwide in cow's milk production in 2023, with 13.5 billion liters per year (CANILEC, 2024). This production takes place under diverse agroecological, technological, and socioeconomic conditions (Barrón *et al.*, 2023), which has given rise to three production systems: specialized or intensive, semi-specialized or family-based, and dual-purpose (SDP) (SIAP, 2021; CANILEC, 2024). Among these, SDP is mainly found in the tropical region, mainly in the state of Veracruz, which accounts for 6.1% of national milk production (SIAP, 2024). The tropical zone offers potential for increasing milk production and quality through genetic crossbreeding used in SDP (Quero *et al.*, 2018, INIFAP, 2018). One of the challenges for livestock farming in this area is to identify, analyze, and estimate milk production and quality parameters and compare them with reference values (Loera & Banda, 2017). In this regard, understanding the variability of milk composition and production in SDP cows will allow for the identification of factors that influence their performance, such as agroecological conditions, nutritional management, and milking practices. This will facilitate the design of strategies to improve milk quality, optimize resources, and increase producer profitability, strengthening the dairy sector and promoting sustainability and economic development in rural communities that depend on this system.

Therefore, the objective of this study was to evaluate the genetic and environmental effects on milk production and composition in dual-purpose cows in the Veracruz tropics.

MATERIALS AND METHODS

Study location

The research was conducted with lactating cows from three dual-purpose (DP) dairy herds located in the central region of the state of Veracruz de Ignacio de la Llave, Mexico. Herd 1 was located in the municipality of Cotaxtla (18.83° N, -96.31° W; 116 m above sea level), herd 2 was located in the municipality of Jamapa (18.59° N, -96.15° W; 22 m above sea level), and herd 3 was located in the municipality of Veracruz (19.10° N, -96.12° W; 14 m above sea level). All three herds have a warm subhumid climate (Aw) according to the Köppen classification modified by García (García, 2004).

Study population

A population of 79 crossbred cows in a dual-purpose production system was used. All animals had production and pedigree data. The grouped genotypes were Holstein×Zebu (H/C) crosses (n=17), Brown Swiss×Zebu (S/C) crosses (n=50), and Brown Swiss×Holstein×Zebu (S/H/C) crosses (n=12).

Animal handling

The animals were fed using controlled rotational grazing with grass varieties such as *Digitaria decumbens*, *Brachiaria decumbens*, *Brachiaria brizantha*, *Brachiaria dictyoneura*, *Cynodon nlemfuensis*, *Megathyrsus maximus*, and native grass (*Paspalum* spp. and *Axonopus* spp.). Supplementation consisted of commercial feed containing 18% protein, supplied at milking time (2 kg per cow), in addition to mineral salts (phosphorus 18%, calcium 18%, sodium 5%, magnesium 4.5%) and free access to water.

The recorded production corresponded to milk milked. In the three herds studied, milking management involved restricted suckling of the calves. During the first 60 days of life, the calves were left a quarter of the udder with residual milk and then only residual milk until weaning. It is estimated that the milk consumed by the calf accounts for approximately 17% of total production (Cervantes *et al.*, 2007; Betancourt *et al.*, 2012). Milking was done mechanically once a day, in the morning.

Reproductive management was by direct mating and artificial insemination. In terms of health management, vaccination was carried out twice a year against bovine paralytic rabies and clostridial diseases, as well as annual deworming.

Milk sampling

Milk production for cows in herd 3 was recorded using the milk weighing device on the mechanical milking machine, while for the other two herds it was recorded using a mechanical clock scale. A total of 652 records were obtained for the period from January 2023 to September 2024.

Milk samples were obtained at 28-day intervals using a simple mechanical milking system. In each herd, 100 ml of milk samples, without preservatives, were collected in capped bottles and kept refrigerated (8 °C) until analysis. Each sample was collected individually at the time of milking to exclude possible adulteration with water, in accordance with the parameters established in Mexican Official Standard NOM-155-SCFI-2012 and the methods of the Association of Official Analytical Chemist (AOAC International, 2016).

In order to consider the seasonal effect, the samples were classified into three periods: dry (March to May), rainy (June to November), and windy season (December to February).

Analysis of milk samples

The milk composition analysis was performed in duplicate during the first 24 hours after collection using infrared (IR) spectrophotometry using a MilkoScan FT-120 equipment, A/S FOSS Electric[®]. The values recorded were: milk production (kg), fat (%), protein (%), lactose (%).

Compilation of information on production units and animals used in research

The production units were characterized by recording information on pedigree, genetic group, cow age, number of lactations, milk production, calving date, and days in lactation. The variables under study were: duration of lactation (days), milk production (kg), fat, protein, and lactose (%).

Statistical analysis

SAS (SAS Institute Inc., Cary, NC, USA) version 9.4 (SAS 2024) was used for data exploration and analysis. The response variables were verified to be normally distributed using the Kolmogorov-Smirnov test of the UNIVARIATE procedure.

An analysis of variance was performed using the least squares method through a general linear model, with the GLM procedure including the fixed effects of genetic group, year,

herd, sampling period, calving period, and number of calvings. The duration of lactation was included as a covariate in the corresponding models.

$$Y_{ijklmn} = \mu + a_i + b_j + c_k + d_l + e_m + f_n + g_o + \varepsilon_{ijklmno}$$

Where: $Y_{ijklmno}$ = Duration of lactation (days), Milk production (kg), fat, protein, and lactose (%); μ = Overall average; a_i = i -th genetic group effect; b_j = j -th year effect; c_k = k -th herd effect; d_l = effect l -th sampling period; e_m = m -th effect number calving period; f_n = f -effect: number of calving; g_o = covariate; $\varepsilon_{ijklmno}$ = random error.

The final model included the main effects and interactions that were significant ($P < 0.05$) in preliminary analyses. Fisher's protected LSD test was used to determine statistically significant differences ($P < 0.05$) between the effects considered in the final models. A Pearson correlation analysis was performed using the CORR procedure in SAS[®] (2024) between the concentration of its components and the total milk production variable.

RESULTS AND DISCUSSION

Descriptive statistics

Table 1 shows the average values, number of observations, and descriptive statistics for the animals used in each analysis, by variable analyzed.

The duration of lactation averaged 307 ± 71.95 days, which is higher than the 219 ± 39.6 days reported by Peralta *et al.* (2021) in SDP. This variation may be associated with differences in reproductive management and drying criteria, since in the herds evaluated, cows were dried off upon confirmation of pregnancy, so the duration depended on the open days (Cristóbal *et al.*, 2007; López *et al.*, 2009; Recinos *et al.*, 2017).

The average total production was 1,240 kg, lower than that reported by Magaña *et al.* (2016), who documented an average of 1,490 kg with an average lactation period of 213 days. This difference can be attributed to the fact that, in the study by Magaña *et al.*, the cows had access to forage throughout the year, with irrigation of the pastures, and therefore milk production was not affected by seasonality (Jayasinghe *et al.*, 2024). In terms of composition, the average protein content was 3.18%, fat 3.49%, and lactose 4.42%, which is within the acceptable range according to NOM-155-SCFI-2012. The protein, fat, and lactose values were similar to those reported in previous studies by Cervantes *et al.* (2015) and Juárez *et al.* (2016) under dual-purpose system conditions.

Table 1. Number of observations and descriptive statistics for lactation duration (days), production (kg), protein (%), fat (%), and lactose (%).

Variable	N	Average	SD	Minimum	Maximum
Duration of lactation	480	307	71.95	127	436
Total yield per lactation (kg)	471	1,240	468.19	152.5	2,375.56
Protein	652	3.18	0.41	1.89	5.37
Fat	652	3.49	0.82	1.73	5.95
Lactose	652	4.42	0.47	1.98	5.86

Effects of the model

Table 2 shows the significance level ($Pr > F$) of each fixed effect included model of the variables analyzed.

The genotype showed a highly significant effect only on the duration of lactation. In contrast, the herd influenced total production and fat content ($p < 0.01$) and, to a lesser extent, protein ($p < 0.05$), suggesting differences between production units associated with management, forage availability and quality, and animal variation (Aranguren *et al.*, 2011). The sampling year affected the duration of lactation, total production, and protein ($p < 0.01$), and showed a minor effect on fat ($p < 0.05$), reflecting interannual variation in climatic conditions and/or management practices. The sampling period influenced total production and protein ($p < 0.01$) and fat ($p < 0.05$), while the calving period affected the duration of lactation, total production, and fat ($p < 0.01$), highlighting the role of seasonality on productive response (Calunga *et al.*, 2007). Finally, the number of calvings had a highly significant effect on lactation duration and total production, and a significant effect on fat, which is consistent with the expected physiological variation between primiparous and multiparous cows (Roca *et al.*, 2012).

Table 3 presents the least square means ($\pm SE$) for year, sampling season, and calving season for lactation period and total production per lactation.

Table 2. $Pr > F$ values for the fixed effects included in the models.

Effect	Lactation duration (days)	Total production (kg)	Protein (%)	Fat (%)	Lactose (%)
Genotype	<0.0001**	0.1454	0.3586	0.9560	0.6988
Herd	0.644	<0.0001**	0.0204*	0.0013**	0.0895
Sampling year	<0.0001**	<0.0001**	0.0004**	0.0434*	0.0961
Sampling season	0.0548	0.0009**	<0.0001**	0.0259*	0.0646
Calving season	<0.0001**	<0.0001**	0.1107	0.0051**	0.4943
Calving number	<0.0001**	<0.0001**	0.0650	0.0235*	0.1529

** Highly significant ($p < 0.01$); * Significant ($p < 0.05$).

Table 3. Least square means ($\pm SE$) by year, sampling season, and calving season for lactation period and total milk production per lactation.

Effect	Lactation period (days)	Total milk production per lactation (kg)
Year	2023	321 \pm 6.1 ^a
	2024	283 \pm 5.8 ^b
Sampling period	Dry	297 \pm 6.5 ^a
	Rain	292 \pm 6.0 ^a
	Windy	313 \pm 7.1 ^a
Calving season	Dry	319 \pm 6.6 ^a
	Rain	286 \pm 5.1 ^b
	Windy	297 \pm 6.1 ^b

^{a-c}: Different letters within each column and effect indicate differences ($P < 0.05$).

Differences ($P < 0.05$) were observed in lactation duration and total milk production per lactation associated with year and calving season, as well as differences in milk production by sampling season (Table 3). In 2023, lactation duration was longest (321 ± 6.1), but total production was lower (905 ± 37.4 kg) compared to 2024 (283 ± 5.8 days and $1,323 \pm 36.5$ kg). This demonstrates the impact of analyzing production records for decision-making, as preliminary results for 2023 showed that cows remained in milking for a long time and it was possible to make adjustments to this parameter to optimize the efficiency of the system. The sampling period did not alter the duration of lactation ($P > 0.05$); however, total production was higher during the rainy season ($1,232 \pm 36.9$ kg) than during the dry season and windy season (Table 3), which coincides with the influence of seasonality on forage availability and quality and, therefore, on productive performance (Arias *et al.*, 2008).

In terms of calving season, cows that calved during the dry season had the longest lactation period (319 ± 6.6 days) and highest total production ($1,239 \pm 40.6$ kg) than those that calved during the rainy and windy seasons (Table 3). These results are consistent with those reported by Castillo *et al.* (2017), who mention that cows that calved during the dry season had higher milk production adjusted to 305 days, with almost 150 kg more milk than cows that calved during the rainy season. The timing of calving has an effect on production trajectory, since, as Vélez de Villa (2013) mentions, when calving occurs at least two months before the peak of maximum forage production, cows tend to produce milk fairly uniformly during the first four months of lactation. Table 4 presents the least square means (\pm SE) for genotype, herd, and number of calvings in lactation length and milk production per lactation.

Concerning to the effect of genotype, significant differences were observed in the duration of lactation; cows in the H/C group had the shortest duration (273 ± 11.0 days), compared to the S/C and S/H/C groups (327 ± 8.9 and 339 ± 9.8 days, respectively) (Table 4). However, the results obtained differ from those reported by Ríos *et al.* (2015), who obtained 266.92 ± 61.61 days. This may be largely due to the management practices used in each of the herds in the different studies. There were no significant differences between genotypes ($p < 0.05$) in milk production per lactation.

For the herd effect, significant differences were found in milk production per lactation ($p < 0.05$); herd 3 had the lowest value ($1,168.9 \pm 35$ kg), compared to herds 1 and 2 ($\approx 1,500$ kg) (Table 4). These differences may be due to the quality and availability of feed resources, even though efforts were made to standardize management conditions (Magaña *et al.*, 2016).

With regard to the number of calvings, a clear pattern can be seen: first-calf cows produced less milk (828 ± 47.3 kg), even with more days in lactation (345 ± 7.5 days), compared to cows with two or more calvings (Table 4). As the number of calvings increased, the duration of lactation decreased slightly, while milk production increased, reaching its peak in cows with five or more calvings. These results are consistent with those reported by Calderón *et al.* (2025), who report that first-calf cows had lower milk production compared to cows with two or more calves. This reflects, as mentioned by Salazar *et al.* (2014), that milk production in the first lactation is influenced by the growth rate and age at first calving.

Table 4. least square means (\pm SE) by genotype, herd, and number of calvings for lactation duration and milk production per lactation.

Effect		Duration of lactation (days)	Milk production per lactation (kg)
Genotype	H/C	273 \pm 11.0 ^a	1,191 \pm 49.7 ^a
	S/C	327 \pm 8.9 ^b	1,092 \pm 31.3 ^a
	S/H/C	339 \pm 9.8 ^b	1,058 \pm 46.6 ^a
Herd	1	299 \pm 7.3 ^a	1,498 \pm 44.6 ^a
	2	306 \pm 9.3 ^a	1,501 \pm 56.7 ^a
	3	297 \pm 5.8 ^a	1,168.9 \pm 35.4 ^c
Number of births	1	345 \pm 7.5 ^a	828 \pm 47.3 ^c
	2	267 \pm 8.0 ^b	1,154 \pm 50.2 ^{ab}
	3	301 \pm 6.5 ^c	1,125 \pm 39.7 ^b
	4	300 \pm 8.1 ^c	1,189 \pm 49.8 ^{ab}
	5+	290 \pm 7.7 ^c	1,272 \pm 47.2 ^a

^{abc}: Different letters within each column and effect indicate differences (P<0.05).

Composition

Table 5 presents the least square means (\pm SE) for year, sampling season, calving season, genotype, herd, and number of calvings for protein, fat, and lactose.

Table 5. least square means (\pm SE) by effect for protein, fat, and lactose (%).

Effect		Protein (%)	Fat (%)	Lactose (%)
Year	2023	3.1 \pm 0.03 ^a	3.6 \pm 0.08 ^a	4.4 \pm 0.05 ^a
	2024	3.3 \pm 0.03 ^b	3.8 \pm 0.08 ^b	4.2 \pm 0.04 ^b
Sampling period	Dry	3.1 \pm 0.04 ^a	3.5 \pm 0.08 ^a	4.2 \pm 0.05 ^a
	Rain	3.4 \pm 0.03 ^b	3.8 \pm 0.08 ^b	4.4 \pm 0.04 ^a
	Windy	3.1 \pm 0.04 ^a	3.7 \pm 0.09 ^{ab}	4.3 \pm 0.05 ^a
Calving period	Dry	3.2 \pm 0.04 ^a	3.6 \pm 0.08 ^a	4.3 \pm 0.05 ^a
	Rain	3.1 \pm 0.03 ^a	3.6 \pm 0.07 ^a	4.3 \pm 0.04 ^a
	Windy	3.2 \pm 0.03 ^a	3.8 \pm 0.08 ^b	4.3 \pm 0.05 ^a
Genotype	H/C	3.3 \pm 0.05 ^a	3.7 \pm 0.10 ^a	4.38 \pm 0.06 ^a
	S/C	3.2 \pm 0.03 ^a	3.7 \pm 0.06 ^a	4.32 \pm 0.04 ^a
	S/H/C	3.2 \pm 0.04 ^a	3.7 \pm 0.10 ^a	4.35 \pm 0.06 ^a
Herd	1	3.2 \pm 0.04 ^a	3.5 \pm 0.09 ^a	4.36 \pm 0.05 ^a
	2	3.2 \pm 0.05 ^a	4.0 \pm 0.12 ^b	4.25 \pm 0.07 ^a
	3	3.3 \pm 0.03 ^b	3.6 \pm 0.13 ^a	4.44 \pm 0.04 ^a
Number of births	1	3.2 \pm 0.04 ^a	3.7 \pm 0.10 ^a	4.42 \pm 0.06 ^a
	2	3.2 \pm 0.05 ^a	3.7 \pm 0.11 ^a	4.29 \pm 0.06 ^a
	3	3.2 \pm 0.04 ^a	3.7 \pm 0.08 ^a	4.40 \pm 0.05 ^a
	4	3.3 \pm 0.05 ^b	3.9 \pm 0.10 ^{ab}	4.37 \pm 0.06 ^a
	5 +	3.2 \pm 0.04 ^a	3.5 \pm 0.10 ^a	4.29 \pm 0.06 ^a

^{abc}: Different letters within each column and effect indicate differences (P<0.05).

Regarding to the effect of year, significant differences were observed between 2023 and 2024 for protein, fat, and lactose (Table 5). In 2024, higher values were recorded for protein ($3.3 \pm 0.03\%$) and fat ($3.8 \pm 0.08\%$), while lactose was slightly lower ($4.2 \pm 0.04\%$) compared to 2023. These differences may be related to climatic, nutritional, and management variations between years (Jayasinghe *et al.*, 2024).

In terms of the sampling season, there were significant differences in protein ($3.4 \pm 0.03\%$) and fat ($3.8 \pm 0.08\%$) content during the rainy season compared to the dry and windy season (Table 5). This could be associated with better forage quality and availability, since during the dry season it tends to be more fibrous and less nutritious, which reduces nutrient intake (Bolaños *et al.*, 2011). Similar results were reported by Martínez *et al.* (2020), who observed higher fat values during the rainy season.

As for lactose, no significant differences were found by sampling period ($p > 0.05$). Cervantes *et al.* (2015) reported higher average values under SDP conditions, which may be related to higher lactation production. In general, lactose plays an osmotic role in the mammary gland, regulating water entry into the alveoli and, therefore, the volume of milk secreted (Sadovnikova *et al.*, 2021).

For the effect of calving season, fat was the component significantly affected, with higher content in cows that calved in the windy season ($3.8 \pm 0.08\%$) (Table 5). This behavior may be associated with production volume (dilution effect), in which higher volumes tend to be accompanied by lower fat concentrations and vice versa (Angulo *et al.*, 2009). In this study, total milk production per lactation was lower in the windy season ($1,002 \pm 43.4$ kg) and was associated with higher fat concentration.

No significant differences were observed in terms of genotype, herd, and number of births ($p > 0.05$), which differs from the findings reported by Cervantes *et al.* (2015). This discrepancy could be attributed to the possible genotype \times environment interaction, where the effect of genotype may not manifest itself in the same way under different environmental conditions, especially in tropical regions (Silva *et al.*, 2021).

In relation to the number of calvings, significant differences were observed only in fat ($p < 0.05$): cows at calving 4 had the highest value ($3.9 \pm 0.10\%$), and the content tended to decrease in subsequent calvings (Table 5). This pattern has been reported in cows in tropical grazing systems (Rosendo *et al.*, 2021). Some studies, however, report increases in protein with the number of lactations (Vargas *et al.*, 2016; Heinrichs *et al.*, 2005).

Table 6 shows Pearson's correlations between total milk yield per lactation.

Significant correlations were observed between some milk components (Table 6). Total production showed a weak negative correlation with fat content ($r = -0.114$; $p = 0.004$), while no significant correlations were detected with protein or lactose content. This behavior is consistent with a dilution effect, in which, as milk volume increases, the concentration of certain components may decrease (Vargas *et al.*, 2016). On the other hand, protein was correlated with fat ($r = 0.582$; $p < 0.0001$) and lactose ($r = 0.469$; $p < 0.0001$). Similar results have been reported by Barrientos *et al.* (2015) and Plascencia *et al.* (2021), although with higher magnitudes.

Table 6. Pearson correlations (r) between total lactation yield and milk components ($n=652$).

Variables	r	p
Total production vs. Protein	-0.027	0.4896
Total production vs. Fat	-0.114	0.0038*
Total production vs. Lactose	-0.016	0.6868
Protein vs. Fat	0.582	<0.0001*
Protein vs. Lactose	0.469	<0.0001*
Fat vs. Lactose	0.182	<0.0001*

* Significant correlation ($p < 0.05$).

Taken together, these results suggest that, in addition to production volume, variation in milk components responds to physiological mechanisms of the mammary gland and the availability of substrates for milk synthesis (Rodríguez and Gómez, 2013).

CONCLUSIONS

In dual-purpose systems in the humid tropics, milk production and composition vary depending on environmental effects and animal characteristics. The duration of the lactation and total production were associated with year, sampling season, calving season, genotype, and number of calvings. These sources of variation should be incorporated into the analysis of productive performance for a more accurate interpretation of the results.

REFERENCES

- Angulo, J., Rodríguez, J., & Suárez, H. (2009). Synthesis, composition, and modification of bovine milk fat: A physiological and nutritional approach. *Journal of the Faculty of Veterinary Medicine and Animal Husbandry*, 14(3), 391-400. <https://www.scielo.org.co/pdf/mvz/v14n3/v14n3a10.pdf>
- AOAC International. (2016). Official Method 972.16: Freezing point of milk. In Official methods of analysis of AOAC International (20th ed.). AOAC International.
- Aranguren Méndez, J. A., Villasmil Ontiveros, Y., Yáñez Cuéllar, L., Ochoa Ordaz, G., & Román Bravo, R. (2011). Analysis of milk production at 244 days in dual-purpose cattle with alternate crossbreeding between Holstein and Red Brahman breeds. *Scientific Journal*, 21(1), 1-11. <https://www.redalyc.org/articulo.oa?id=95945988007>
- Arias, R., Mader, T., & Escobar, P. (2008). Climatic factors affecting the productive performance of beef and dairy cattle. *Archives of Veterinary Medicine*, 40(1). <https://doi.org/10.4067/s0301-732x2008000100002>
- Barrientos, J. M. J., Miranda, J. R., Sánchez, C. E. M., Santos, B. H., Gamboa, E. P., Aldapa, C. a. G., Rivera, P. D., & Herman-Lara, E. (2015). Evaluation and classification of the quality of commercial milk consumed in Tuxtepec, Oaxaca, Mexico. *Ecosistemas Y Recursos Agropecuarios*, 2(6), 327-337. <https://doi.org/10.19136/era.a2n6.71>
- Barrón-Bravo, O. G., Avilés-Ruiz, R., Sahagún-Ángel, C. A., Alcalá-Rico, J. S. G. J., Arispe-Vázquez, J., & Garza-Cedillo, R. D. 2023. Characterization of family cattle production units, Llera, Tamaulipas, Mexico. *Abanico Technical Bulletin*, 2, 1-21
- Betancourt López, L., Pareja Mejía, R. I., Conde Pulgarín, A., Castellanos, Á. F., & Moreno Martínez, D. (2012). Nutritional management of commercial zebu calves subjected to restricted suckling and early weaning in the foothills of Casanare. *Revista Ciencia Animal*, 1(5), 21-30.
- Bolaños Aguilar, E., Meléndez Nava, F., Enríquez Quiroz, J., & Esqueda Esquivel, V. (2011). Production and management of tropical forages. Coyoacán, Mexico: National Institute of Forestry, Agricultural and Livestock Research
- Calderón, Rene & Calderón Chagoya, Rene & Utrera, Ángel & Vega-Murillo, Vicente & Hernández López, Carlos & Lagunes, Juvenio. (2025). Milk Production in Dual-Purpose Cattle Systems under a Humid Subtropical Climate Af(c). *Agro Productivity*. 18. 226-232. 10.32854/agrop.v18i2.3261.

- Calunga, M. M., Valdés, J. A. B., Balmaseda, R. A., Viera, R. G., Viera, G. G., & De Oca, R. V. M. (2007). Seasonality in milk production in a cattle herd. *Animal Production Journal*, 19(1). <https://revistas.reduc.edu.cu/index.php/rpa/article/download/3035/2748>
- National Chamber of Milk Industrialists (CANILEC). Dairy Sector Statistics 2011-2021 (2024).
- Castillo, M. Á., Alpizar, A., Padilla, J., and Keim-San, J. (2017). Effect of age at first service, number and season of calving on the behavior of the lactation curve in Jersey cows. *Tropical Animal Nutrition*, 11(2), 1-22.
- Cervantes, A. P.; Hernández B. A.; Domínguez, M. B.; Villagómez, C. J., and Carrasco García, A. A. 2015. Production and composition of bovine milk in tropical conditions: influence of management and genotype. Page 35. Velázquez, O. V.; Castañeda, V. H.; Wolter, W.; Svarc, G.; Bedolla, C. C. and Guerra, E. L. Milk Production and Quality. ISBN: 978-607-737-094-9
- Cervantes, P. A., Luna, M. R., Hernández, A. B., Pérez-Gil, F., Ponce, P. C., & Uffo, O. R. (2007). Genetic polymorphism at the kappa-casein locus in cows of different breeds and crosses in the Mexican tropics. *Revista Salud Animal*, 29(2), 78-84.
- Cristóbal, C. V., Ordaz, R. L., Muñiz, J. G. G., Valverde, R. R., Flores, A. R., & Ordaz, R. L. (2007). Milk production and reproductive behavior of dual-purpose cows consuming tropical forages and concentrates. *Veterinaria*, 38(1), 63-79. <https://www.medigraphic.com/pdfs/vetmex/vm-2007/vm071g.pdf>from climate change. *Environmental Research Letters*, 18(9), 094027.
- García, E. (2004). Modifications to the Köppen climate classification system (to adapt it to conditions in Mexico) (5th ed., corrected and expanded). National Autonomous University of Mexico.
- Heinrichs, J., Jones, C., & Bailey, K. (2005). Milk components: Understanding the causes and importance of milk fat and protein variation in your dairy herd. DAS 05-97. Pennsylvania State University, University Park.
- Hernández, A., & Ponce de León, R. E. (2024). Effect of genetic group and heterosis on productive traits of Holstein crosses with Zebu. *Livestock Research for Rural Development*, 36(1).
- INIFAP. National Institute of Forestry, Agricultural, and Livestock Research. 2018. INIFAP development program. 2018-2030. Greater productivity in harmony with the environment. Mexico City: SAGARPA.
- Jayasinghe, J. M. P., Pembleton, K. G., Donaghy, D. J., Ramilan, T., & Barber, D. G. (2024). Long-term evaluation of pasture production, seasonality, and variability: An application of the DairyMod pasture model for three tropical species. *European Journal of Agronomy*, 156, 127103. <https://doi.org/10.1016/j.eja.2024.127103>
- Jayasinghe, J., Pembleton, K. G., Barber, D. G., Donaghy, D. J., & Ramilan, T. (2024). Modelling of tropical pasture growth using DairyMod: Model parameterisation and validation across multiple environments. *European Journal of Agronomy*, 156, 127146. <https://doi.org/10.1016/j.eja.2024.127146>
- Juárez B., J. M., Díaz R., P., Rodríguez M., J., Martínez S., C. E., Hernández S., B., Ramírez R., E., Torruco U., J. G., & Herman L., E. (2016). Characterization of milk and quality classification using cluster analysis in dual-purpose systems. *Revista Mexicana de Ciencias Pecuarias*, 7(4), 525-537. <https://doi.org/10.22319/rmcp.v7i4.4280>
- Loera, J., & Banda, J. Dairy industry in Mexico: Parameters of milk production and supply of the internal market. *Rev. investig. Altoandín*. [online]. 2017, vol.19, n.4, pp.419-426. ISSN 2313-2957. <http://dx.doi.org/10.18271/ria.2017.317>
- López-Ordaz R, Vite-Cristóbal C, García-Muñiz JG, Martínez-Hernández PA. Reproduction and milk production in cows with different proportions of *Bos taurus* genes. *Arch Zoot* 2009;58(224):683-694.
- Magaña-Monforte, J. G., Osorio, E., Centurión-Castro, F., Segura-Correa, J. C., Aké-López, R., & Aguilar-Pérez, C. F. (2016). Milk production and pregnancy rate of dual-purpose cows in southeastern Mexico. *Live-stock Research for Rural Development*, 26(4).
- Martínez, G. M., Carabajal, R. L., Martínez, F., & Suarez, V. H. (2020). Influence of the seasons on the composition and sanitary quality of bovine milk in the Lerma Valley, Salta. *FAVE Veterinary Sciences Section*, 19(1), 35-39. <https://doi.org/10.14409/favecv.v19i1.9446>
- United Nations. World Population Prospects 2022: Summary of Findings. UN DESA/POP/2022/TR/NO. 3; United Nations: Geneva, Switzerland, 2022.
- North, M. A., Frank, J. A., Ouweneel, B., Trisos, & C. H. (2023). Global risk of heat stress to cattle
- Peralta T, JA, Izquierdo C, Y., Severino L, VH, and Segura C, JC (2021). Milk production of Holstein × Gyr cows in a dual-purpose system in the tropics. *Revista MVZ Córdoba*, 27(1). <https://doi.org/10.21897/RMVZ.2359>
- Quero, A., Enríquez, J., Bolaños, E., and Villanueva, A. 2018. State of the art in research and technological innovation in tropical cattle farming. Chapter II: Forages and grazing in tropical Mexico. Technical book. 2nd Ed. National Council for Science and Technology. Mexico. pp. 66-91.

- Recinos, C. A., Ibáñez, E. M. A., Arce, M. M. O., Garduño, R. G., Rivera, P. D., & Cuellar, J. a. H. (2017). Evaluation of productive and reproductive parameters in a dual-purpose herd in Tabasco, Mexico. *Mexican Journal of Animal Science*, 8(1), 83-91. <https://doi.org/10.22319/rmcp.v8i1.4347>.
- Ríos UA, Hernández HVD, Amezcua MEV, Zárate MJP. Milk production of Simmental × Zebu and Brown Swiss × Zebu cows in a tropical climate. *Agron Mesoam* 2015;26(1):17-25.
- Roca, A. I., González, A., & Vázquez, O. P. (2012). Effect of calving date and number of calvings on milk production and quality in grazing cows. 51st Scientific Meeting of the Spanish Society for the Study of Pastures. Public University of Navarra. Retrieved from <https://academica-e.unavarra.es/entities/publication/ba2f1f12-f71f-46fb-8b0a-c1aa08af38ce>
- Rodríguez, C. E., & Gómez, D. F. (2013). Effect of supplementation with different doses of protected fat on production and compositional parameters of bovine milk. *Tropical Animal Science*, 37(4), 299-310. https://ve.scielo.org/scielo.php?script=sci_arttext&pid=S0798-72692013000400004
- Rosendo-Ponce, A., Sánchez-Gómez, A., Ríos-Ortíz, Á., Torres-Hernández, G., & Becerril-Pérez, C. M. (2021). Milk yield and chemical composition of Lechero Tropical native cows under grazing and supplementation. *Agricultural Science and Technology*, 22(1), e1515. https://doi.org/10.21930/rcta.vol22_num1_art:1515
- Sadovnikova A, Garcia SC, Hovey RC. A Comparative Review of the Cell Biology, Biochemistry, and Genetics of Lactose Synthesis. *J Mammary Gland Biol Neoplasia*. 2021 Jun;26(2):181-196. doi: 10.1007/s10911-021-09490-7. Epub 2021 Jun 14. PMID: 34125364; PMCID: PMC8236053.
- Salazar C, M., G. Castillo B, J. Murillo H, F. Hueckmann V, and J.J. Romero Z. 2014. Effect of age at first calving on first lactation milk yield in Holstein cows from Costa Rican specialized dairy herds. *Open J. Vet. Med.* 4:197-203. doi:10.4236/ojvm.2014.49023
- SAS. SAS/STAT[®] (versión 9.4) User's guide. Cary, NC: SAS Institute Inc.
- Ministry of Economy. NOM-155-SCFI-2012. Milk, milk formula, and combined milk products, physical and chemical specifications, commercial information, and testing methods. Mexico. 2011.
- SIAP. (2024). Agri-Food and Fisheries Information Service. <https://www.gob.mx/siap/documentos/siacon-ng-161430>
- Silva, D. A., Lopes, P. S., Costa, C. N., Silva, A. A., Silva, H. T., Silva, F. F., Veroneze, R., Thompson, G., & Carvalheira, J. (2021). Genotype by environment interaction for Holstein cattle populations using autoregressive and within- and across-country multi-trait reaction norms test-day models. *Animal*, 15(2), 100084. <https://doi.org/10.1016/j.animal.2020.100084>
- Agricultural, Livestock, and Fisheries Information and Statistics System (SIAP). (2021). Livestock sector statistics. Secretariat of Agriculture, Livestock, Rural Development, Fisheries, and Food. Mexico.
- Vargas S., D., Murillo H., J., Hueckmann V., F., & Romero Z., J. J. (2016). Fat/protein ratio and urea nitrogen values in milk from dairy cows in the northern region of Alajuela and Heredia, Costa Rica. *Veterinary Sciences*, 34(2), 67-80. <https://doi.org/10.15359/rcv.34-2.1>
- Vargas Sobrado, D., Murillo Herrera, J., Hueckmann Voss, F., & Romero Zúñiga, JJ (2016). Fat/protein ratio and urea nitrogen values in milk from dairy cows in the northern region of Alajuela and Heredia, Costa Rica. *Veterinary Sciences*, 34(2), 67-80. <https://doi.org/10.15359/rcv.34-2.1>
- Vélez de Villa, E. (2013). Environmental factors affecting milk production in cattle under semi-intensive grazing. National University of San Marcos. Retrieved from: <https://www.produccion-animal.com.ar>