Colegio de Postgraduados

Relationship between feeding protocols and their cost with body development of lactating calves in family milk-production units

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ABSTRACT

Objective: Characterize the feeding protocols and feeding costs, as well as their relationship with the body development of lactating calves until weaning in family milk-production units (FMPU).

Methodology: A prospective observational cohort study was carried out. The feeding protocol, and its cost were recorded, in addition, the daily gains in weight (DWG) and height (DHG) between birth and weaning of 193 calves (n=12 FMPU). The information was subjected to descriptive statistics and analysis of variance.

Results: In some FMPU, up to 5 feeding protocols were used, and calves with a range of 49 to 138 days until weaning. The predominant feeding consisted of milk replacer plus starter concentrate (28.5%). The costs of the feeding protocols (1162 to 2395 pesos), as well as the DWG (0.346 to 0.721 Kg/day) and DHG (0.114 to 0.216 Cm/day), were statistically different between FMPU ($P<0.01$). The most expensive feeding protocol had a DWG of 0.555 kg/day and a DHG of 0.161 cm/day.

Limitations of study/implications: The nutrient contributions of the feeding protocols were not determined, consequently, whether they covered the calves' nutritional requirements.

Conclusions: In FMPU, there is a lack of standardization in feeding protocols and a high variation in their costs, as well as in the duration to weaning. The body development of the calves is suboptimal, influenced by the feeding protocol, where the highest cost is not reflected in the best body development rate.

Keywords: Economic cost, body development, Holstein calves.

INTRODUCTION

The replacement heifer rearing process represents one of the most significant production costs in dairy herds. Typically, the investment begins to be recouped when the heifers reach

their first lactation, although full recovery may not occur until even the sixth lactation (Boulton *et al.*, 2017). Therefore, it is essential to direct efforts to ensure that replacements achieve an adequate body development rate at the lowest possible economic cost, enabling them to express their full productive potential throughout their adult life (Akins, 2017).

In production units that use the Holstein breed, performance indicators have been established to assess whether replacement rearing objectives are being met. It is accepted that heifers should conceive between 13 and 15 months of age, reaching 55% of their mature body weight, so that they can calve for the first time between 22 and 25 months of age, reaching 85% of their mature body weight (Akins, 2017; DCHA, 2016). In small-scale family dairy farms, which contribute approximately 30% of the national milk production, it has been reported that replacements receive their first service at an average age of 20 months and have their first calving at an average age of 29 months (Espinosa-Martínez *et al.*, 2012). These values indicate that the rearing objectives are not being met.

During the heifer rearing process, the lactation period coincides with the time when they are most susceptible to issues affecting their viability, body development, and consequently, their future performance (Bazeley *et al.*, 2016; Urie *et al.*, 2018a). Additionally, this period is costly due to the prices of the feed required for calves (Heinrichs *et al.*, 2013) and is a critical period to promote adequate ruminal development, allowing them to subsequently utilize lower-cost feeds such as forages (Akins, 2016). However, the body development of calves, as well as production costs during lactation, will largely depend on the feeding conditions to which they are exposed (Svensson and Hultgren, 2008; Heinrichs *et al.*, 2013; Boulton *et al.*, 2017). In this regard, it is observed that in family dairy production systems, feeding management is often inadequate and calves body development rates are commonly suboptimal from birth until weaning, negatively affecting the achievement of rearing objectives (Gutiérrez-Morales, 2014; Villaseñor-González *et al.*, 2022).

In this regard, the hypothesis proposed is that the limited body development of lactating calves may be influenced by the feeding protocols used. However, little has been explored in this respect within the family production system in Mexico. Therefore, the objective of the present study was to characterize the feeding protocols and costs used, as well as their relationship with the body development of lactating calves up to weaning in family milk-production units.

MATERIALS AND METHODS

Location of the Experimental Area

The study was conducted in the municipalities of Tepatitlán de Morelos, San Ignacio Cerro Gordo, and Valle de Guadalupe, which are part of the Los Altos dairy basin in the State of Jalisco, Mexico. These municipalities are located between 20° N and 102° W at an altitude ranging from 1680 to 2100 meters above sea level. The climate of the region is temperate sub-humid with an average temperature of 19.0 °C and an average annual precipitation of 753.0 mm between the months of June and September (CEAJ, 2023).

Experimental Units and Data Collection

A prospective cohort observational study was conducted, including 193 Holstein calves from 12 production units with characteristics of the family dairy production system (Montiel-Olguín *et al.*, 2019). Weekly visits were made to each cooperating production unit to record economic aspects and body development of the calves from birth until weaning.

Feeding Protocols and Costs

The type, quantity, and cost of each feed offered weekly to each calf were determined for the different feeding protocols used by each production unit. This was done based on records generated daily by the personnel in charge of the calves and the research team at each production unit, using field sheets. Additionally, during each visit by the research team, the consistency of the recorded data was verified, and direct evaluations of the amount of feed supplied (both liquid and solid) were conducted.

The quantity in liters of liquid feed (colostrum, whole milk, and milk replacer) offered was obtained from measurements taken in the containers (buckets) used to supply this type of feed. On the other hand, the quantity of solid feed (concentrate and forage) offered was estimated through weight measurements of the portions provided. Subsequently, the costs per type of feed and per feeding protocol offered to each calf during lactation were calculated, considering the combination of liquid and solid feed.

Body Development

The body development of the calves was determined through daily weight gain (DWG) and daily height gain (DHG) from the period of birth to weaning. For this purpose, each calf's birth weight (BW), birth height (BH), weaning weight (WW), and weaning height (WH) were recorded. Body weight was directly estimated through the thoracic perimeter, using measuring tapes specifically graduated for use with Holstein calves (Dairy Calf Tape, Coburn Co., Whitwater WI) and based on the methodology established by Heinrichs *et al.* (1992).

To estimate height, a stadiometer was used to measure the distance from the ground to the withers of the calves. To obtain the daily weight gain (DWG), the following formula was used:

$$DWG = (WW - BW) \,/\, Days\ in\ lactation\ (DL)$$

and to obtain the daily height gain (DHG), the following formula was used:

$$DHG = (WH - BH) \,/\, DL$$

This is based on the formula described by Villaseñor *et al.* (2022).

Statistical Analysis

Data on the type of liquid feed, type of solid feed, and the final feeding protocol offered to each calf were subjected to descriptive frequency statistics analysis. The variables of final feeding cost, DWG, and DHG were subjected to variance analysis, with the production unit included as an independent variable. In each statistical model to evaluate the final feeding cost, DWG, and DHG, DL, BW, and BH were included as covariates, respectively. As an example of each model:

$$Y_{ij} = \mu + \alpha_i + \beta\left(X_{ij} - \bar{X}\right) + \varepsilon_{ij}$$

where: Y_{ij}=*ij*-th observation of the response variable *Y*; μ=overall mean of the response variable; α_i=effect of the *i*-th treatment; β=regression coefficient between *X* and *Y*; *X*= *ij*-th observation of the covariate *X*; $\bar{X}$ =overall mean of the covariate *X*; ε_{ij}=random error of the *ij*-th observation.

For all analyses, version 9.3 of the SAS statistical software package was used, and in the variance analyses, the Generalized Linear Models procedure was employed (SAS, 2011). Probability values $\leq$0.05 and $>$0.05 up to $\leq$0.1 were considered significant or indicative of a statistical trend, respectively.

RESULTS AND DISCUSSION

Overall, the results support the hypothesis that the deficient body development observed in the calves is influenced by the feeding protocols implemented. In the present study, it was possible to identify the frequencies of liquid and solid feeding used from birth to weaning of calves in family milk-production units. Information was also obtained that allowed for the analysis of the relationship between feeding costs, lactation duration, and the body development of the heifers.

In Table 1, milk replacer was the most used type of liquid feed (46.1%), followed by whole milk (36.8%), and to a lesser extent, a combination of milk replacer and whole milk (17.1%). This pattern regarding the use of milk replacer is consistent with previous studies (Urie *et al.*, 2018a), where producers attempt to reduce costs by including milk replacer, although in many cases it negatively affects calf growth (Lee *et al.*, 2009). Regarding solid feed, starter concentrate was the most used type (49.2%), followed by a combination of starter concentrate and corn stover with grain (29.0%). However, it was observed that 21.8% of the calves received one of eight different types of solid feed (Table 1). This indicates that, while most production units use a starter concentrate designed for calves, low nutritional value forages such as corn stover without grain, which has a low protein content (NASEM, 2021), and concentrates designed for adult cattle in production are also used.

Regarding final feed, the use of milk replacer plus starter concentrate predominated (28.5%). Additionally, a similar percentage (around 14.0%) was found for the use of milk replacer plus starter concentrate plus corn stover with grain, whole milk plus starter concentrates, and whole milk plus starter concentrate plus corn stover with grain. In Table 2, it can be observed that 50% of the production units employed different final feeding protocols during the study period, with some cases using up to five types. These results indicate that the feeding process for calves is not technically designed or standardized in half of the family production units. This feeding management contrasts with what

Table 1. Types of feed and their usage percentages in the calves.

Type of feed	Percentage (Frequency)
Liquid feed	
Whole milk	36.8 (71/193)
Milk replacer	46.1 (89/193)
Whole milk+Milk replacer	17.1 (33/193)
Solid feed	
Starter concentrate	49.2 (95/193)
Starter concentrate+other concentrate*	2.1 (4/193)
Starter concentrate+CSWG	29.0 (56/193)
other concentrate+CSWG	7.3 (14/193)
Starter concentrate+alfalfa hay	6.2 (12/193)
Starter concentrate+other concentrate*+CSWG	2.1 (4/193)
Starter concentrate+CSiWG	0.5 (1/193)
Starter concentrate+other concentrate*+CSiWG	1.6 (3/193)
Starter concentrate+other concentrate*+alfalfa hay+CSiWG	1.0 (2/193)
Starter concentrate+CSWoG	1.0 (2/193)
Final Feed[&]	
1.- MR+starter concentrate	28.5 (55/193)
2.- MR+starter concentrate+CSWG	14.5 (28/193)
3.- WM+MR+starter concentrate+CSWoG	1.0 (2/193)
4.- WM+starter concentrate	14.0 (27/193)
5.- WM+starter concentrate+CSWG	14.0 (27/193)
6.- WM+MR+starter concentrate	7.3 (14/193)
7.- WM+MR+other concentrate*+CSWG	7.3 (14/193)
8.- MR+starter concentrate+alfalfa hay	4.7 (9/193)
9.- WM+starter concentrate+other concentrate*+CSWG	2.0 (4/193)
10.- WM+starter concentrate+CSiWG	0.5 (1/193)
11.- WM+starter concentrate+other concentrate*+CSiWG	1.6 (3/193)
12.- WM+starter concentrate+other concentrate*	2.1 (4/193)
13.- WM+starter concentrate+other concentrate*+alfalfa hay+CSiWG	1.0 (2/193)
14.- WM+starter concentrate+alfalfa hay	1.5 (3/193)

*Concentrate not specific for lactating calves. [&]Combination of liquid and solid feed provided. MR=Milk replacer; WM=Whole milk; CSWG=Corn stover with grain; CSWoG=Corn stover without grain; CSiWG=Corn silage with grain.

occurs in intensive production units, where it is recommended to follow a standardized feeding protocol for calves (Akins, 2016). For example, a survey conducted in U.S. dairies showed that pre-weaning feeding practices exhibit high similarity (Urie *et al.*, 2018a). Conventionally, it is recommended that calves consume starter concentrate containing 18 to 22% protein and high levels of fermentable carbohydrates (up to more than 35%), as well as high-quality forages such as alfalfa hay from the first weeks of life. This allows them to stimulate ruminal development and better adapt to changes in feeding (Akins, 2016; Machado and Ballou, 2022).

Additionally, it was observed that the initiation of starter concentrates and forage feeding for the calves was highly variable, with some dairies starting from the first week and most beginning after the third or fifth week of age. This management also contrasts with the conventional recommendation for Holstein calves, which suggests gradually integrating solid feed in increasing amounts throughout the lactation period (Machado and Ballou, 2022). Early provision of forage (from the first week of age) could compromise nutrient digestibility and calves' growth, compared to early feeding without hay or starting hay consumption from the second week (Xiao *et al.*, 2023). The results reflect the diversity in producers' criteria and the possible lack of technical guidance for managing feeding protocols, highlighting the need for improvement in this process. However, it is possible that these decisions are influenced by the availability and cost of different feeds at specific times throughout the year.

When analyzing the duration of the lactation period by production unit and type of feed, it was identified that calves remain in lactation for an average range of between 49 and 138 days, with variable times within the same production unit (Table 2). However, most production units had a lactation period between 60 and 90 days. The results regarding

Table 2. Types of final feed in each production unit and average days in lactation for each group of calves.

Production unit	Final feed (n)	Days at weaning
1	2.- MR+starter concentrate+CSWG (1/23)	64.0
1	4.- WM+starter concentrate (10/23)	68.0
1	5.- WM+starter concentrate+CSWG (9/23)	72.0
1	6.- WM+MR+starter concentrate (3/23)	70.3
2	1.- MR+starter concentrate (3/16)	65.7
2	3.- WM+MR+starter concentrate+CSWoG (2/16)	65.0
2	6.- WM+MR+starter concentrate (11/16)	62.3
3	4.- WM+starter concentrate (4/13)	99.5
3	10.- WM+starter concentrate+CSiWG (1/13)	84.0
3	11.- WM+starter concentrate+other concentrate*+CSiWG (3/13)	100.0
3	13.- WM+starter concentrate+other concentrate*+alfalfa hay+CSiWG (2/13)	138.0
3	14.- WM+starter concentrate+alfalfa hay (3/13)	78.3
4	2.- MR+starter concentrate+CSWG (27/27)	77.0
5	7.- WM+MR+other concentrate *+CSWG (14/14)	94.7
6	1.- MR+starter concentrate (17/17)	49.4
7	1.- MR+starter concentrate (14/14)	62.3
8	8.- MR+starter concentrate+alfalfa hay (4/4)	84.3
9	1.- MR+starter concentrate (7/12)	60.3
9	8.- MR+starter concentrate+alfalfa hay (5/12)	61.4
10	4.- WM+starter concentrate (13/29)	63.4
10	5.- WM+starter concentrate+CSWG (16/29)	66.9
11	5.- WM+starter concentrate+CSWG (2/10)	90.5
11	9.- WM+starter concentrate+other concentrate*+CSWG (4/10)	88.5
11	12.- WM+starter concentrate+other concentrate* (4/10)	89.5
12	1.- MR+starter concentrate (14/14)	62.3

*Concentrate not specific for lactating calves.
MR=Milk replacer; WM=Whole milk; CSWG=Corn stover with grain; CSWoG=Corn stover without grain; CSiWG=Corn silage with grain.

the duration of lactation observed in the present study are similar to those described in previous studies within this production system (Urie *et al.*, 2016a; Villaseñor-González *et al.*, 2022). It has been noted that lactation constitutes the stage of highest daily economic expenditure in calf rearing due to the costs of liquid feed (Heinrichs *et al.*, 2013). Indeed, in the present study, it was observed that liquid feed represented, on average, 80.2% (see Table 3) of the final feed, with a cost ranging from $589.5 to $3,776.6 Mexican pesos.

As shown in Table 3, another factor contributing to the increase in final feed cost was the duration of lactation, as weaning at 41 days cost $679.9 and $4,908.3 at 155 days. In contrast, other authors recommend that Holstein calves should be weaned at 60 days and consuming at least 700 g/day of concentrate for at least three consecutive days (Eckert *et al.*, 2015; Urie *et al.*, 2018b). This management practice helps to reduce costs during lactation and prevents potential growth setbacks in calves around weaning (Eckert *et al.*, 2015; Urie *et al.*, 2018b).

Significant statistical differences were found between production units ($P<0.01$) for both DGW and DHG, as well as for the cost of feeding (Table 4). Regarding calves' development, average development rates were below 600 g/day in 10 of the 12 evaluated production units, and in the other two units, the rates did not exceed 725 g/day. Similar results regarding DGW have been observed in previous studies (Gutiérrez-Morales, 2014; Villaseñor-González *et al.*, 2022), highlighting the need to pay more attention to the calf rearing process. It has been found that growth problems in the early stages of calf life can negatively affect their future productive and reproductive performance (Bazeley *et al.*, 2016; Van de Stroet *et al.*, 2016; Vam Eetvelde and Opsomer, 2017). Regarding DHG, similar results to those in the present study have also been described previously (Villaseñor-González *et al.*, 2022).

There was wide variation in feeding costs among the evaluated production units. It was observed that calves receiving the most expensive feeding protocol did not necessarily have the best weight or height gains (production units 3, 6, 9, and 10). On the other hand, calves that showed better body development received a feeding protocol with intermediate costs (production units 4 and 11). For example, calves in production unit 3 received an average of 0.84 kg day^{-1} of solid feed (>90% concentrate) and 3.6 liters/day of liquid feed (whole milk); meanwhile, calves in production unit 11 received 0.99 kg of solid feed (>90%

Table 3. Descriptive statistics of the cost (in Mexican pesos) of solid feed, liquid feed, and final feed for the total calves.

Descriptive Statistic	Solid Feed n=193	Liquid Feed n=193	Final Feed[&] n=193	Days at Weaning n=193
Mean	363.2	1470.1	1833.4	71.2
Minimum	40.1	589.5	679.9	41
First quartile	168.8	1250.0	1505.1	61
Second quartile	304.6	1438.4	1823.7	67
Third quartile	527.3	1655.6	2073.7	78
Maximum	1131.7	3776.6	4908.3	155

[&]Combination of liquid and solid feed provided.

Table 4. Effect of the production unit on the cost (in Mexican pesos) of feeding, daily weight gain (DGW), and daily height gain (DHG) of the calves.

Production Unit (n)	Feed Cost**	DGW Kg**	DHG Cm**
1 (23)	1955.5 ± 45.4^{c}	0.584 ± 0.03^{b}	0.187 ± 0.01^{bcd}
2 (16)	1513.8 ± 56.5^{e}	0.473 ± 0.03^{cdef}	0.166 ± 0.01^{cdef}
3 (13)	2395.8 ± 81.8^{a}	0.555 ± 0.04^{bc}	0.161 ± 0.01^{cdef}
4 (27)	1799.3 ± 43.3^{d}	0.721 ± 0.02^{a}	0.216 ± 0.01^{a}
5 (14)	1268.5 ± 74.0^{f}	0.511 ± 0.03^{bcd}	0.153 ± 0.01^{def}
6 (17)	2183.2 ± 67.9^{ab}	0.450 ± 0.03^{def}	0.156 ± 0.01^{def}
7 (14)	1825.0 ± 60.6^{d}	0.414 ± 0.03^{ef}	0.143 ± 0.01^{ef}
8 (4)	1172.3 ± 111.5^{f}	0.346 ± 0.06^{f}	0.114 ± 0.03^{f}
9 (12)	2070.2 ± 66.0^{bc}	0.519 ± 0.04^{bcd}	0.148 ± 0.02^{ef}
10 (29)	2099.3 ± 41.9^{b}	0.470 ± 0.02^{def}	0.170 ± 0.01^{cde}
11 (10)	1781.8 ± 77.2^{d}	0.705 ± 0.04^{a}	0.215 ± 0.02^{ab}
12 (14)	1162.0 ± 60.6^{f}	0.490 ± 0.03^{cde}	0.198 ± 0.01^{abc}

**$P<0.01$ level for the effect of the production unit; data presented as means ± standard error. [abcdef] Different letters among means within each response variable indicate significant statistical difference.

concentrate) and 3.4 L of liquid feed (whole milk). Additionally, not all types of low-cost feed resulted in the lowest body development in calves.

In the present study, the amount of liquid and solid feed provided was quantified; however, individual consumption and the nutritional contribution of the final feed could not be determined, which limits the ability to explain the results from this important aspect of calf' body development. These observations suggest an opportunity to improve nutritional management and obtain appropriate growth indicators at a lower cost. Other factors, such as housing conditions (Gutiérrez-Morales, 2014), maternal characteristics during the peripartum period such as body condition or having received a vaccination schedule (García-González, 2016), and colostrum consumption at birth (Villaseñor-González *et al.*, 2022), could also be associated with the observed body development. However, these variables were not recorded in this study.

CONCLUSIONS

In family milk-production units, there is a lack of standardization in feeding protocols. Although most units use feeds designed for lactating calves, some still utilize feeds of low nutritional value that are not suitable for this developmental stage. The increase in feeding costs is influenced by the level of liquid feed used and the duration of the calf's lactation. The body development of calves in most production units is suboptimal and is influenced by the implemented feeding protocol. Higher feeding costs do not necessarily result in better body development rates for calves, highlighting the need for actions aimed at improving feeding practices and achieving adequate calf's development at a lower cost.

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