Journal of Animal and Feed Sciences, 34, 3, 2025, xxx–xxx, https://doi.org/10.22358/jafs/200673/2025
The Kielanowski Institute of Animal Physiology and Nutrition, Polish Academy of Sciences, Jabłonna

ARTICLE IN PRESS

REVIEW

Growth performance and rumen development of Jersey calves fed high milk levels in a 60-day lactation program

L.A. Lourenço[1], V.I. Fioreze[1], J. Schafhäuser Júnior[2], A.C. Fluck[1,*], O.A.D. Costa[1], G. Fiorentini[1], F.A. Rizzo[3], P.P. da Rosa[1], A.S. Varela Júnior[4] and R.D. Jardim[4]

[1] Federal University of Pelotas-Eliseu Maciel College – Campus Capão do Leão, 96160-000 Capão do Leão, RS, Brazil
[2] Brazilian Agricultural Research Company (Embrapa) – Temperate Climate Station, 96160-000 Pelotas, RS, Brazil
[3] University of Caxias do Sul, 95070-560 Caxias do Sul, RS, Brazil
[4] Federal University of Rio Grande – Institute of Biological Sciences, 96203-900 Rio Grande, RS, Brazil

KEY WORDS: calf, dairy cattle, development, whole milk feeding

Received: 5 November 2024
Revised: 30 January 2025
Accepted: 31 January 2025

* Corresponding author:
e-mail: anacarolinafluck@yahoo.com.br

ABSTRACT. The study evaluated the effects of supplying whole milk at three different rates (15, 20 and 25% according to live weight at birth) in the diet of Jersey calves during the first 60 days after calving. Twenty-four animals (12 females and 12 males), with an average birth weight of 26.17 ± 2.94 kg, were randomly assigned to treatments consisting of four males and four females per group. Weekly assessments included body weight measurement, estimations of milk and concentrate intake, and measurements of morphometric parameters, including croup height, croup width, chest circumference, and height at withers. After 60 days, only males were slaughtered to evaluate the development and volume of gastric compartments and histological development. The Gompertz unipartite model with discrete latency was used to measure the growth curve behaviour over the 60-day evaluation period. Preliminary data visualization involved examining the spatial distribution on a Cartesian plane. Both lactation feeding level and sex of the calves influenced dry matter intake, with higher consumption and earlier onset observed in the treatment with lower milk amounts. The amount of milk also affected weight at the end of the lactation period and croup height, although male rumen development was not influenced by the rates of milk supplied.

Introduction

The dairy sector has presented a worrisome scenario in 2023 with the departure of medium- and small-scale producers and the consequent reduction in herd size. This trend has been observed in several countries, including Brazil, Argentina, New Zealand as well as the members of the European Union (EC, 2023; Embrapa, 2023). However, the remaining production systems have become more efficient, maintaining stable milk production despite a smaller herd. This shift reflects a focus on improving animal productivity, optimising or reducing production costs, and achieving higher profitability.

The growth begins at birth and continues through the lactation phase. However, a common perception among producers is that feeding milk to calves represents a loss, as it cannot be sold. This belief often leads to lower milk supply, as it is more expensive than solid feed. Consequently, calves may be transitioned to solid feed earlier to reduce feeding costs (Eckert et al., 2015). Soberon et al. (2012) investigated the relationship between pre-weaning nutrient intake and future milk production using a standard 305-day milk production mathematical modelling and concluded that the lifetime performance of dairy cows was influenced by early-life development. They emphasised that dairy producers could manipulate this programming early in life through appropriate nutrition. Furthermore, the latter authors also suggested that dietary manipulation in calves should start immediately after birth and continue for at least 5 weeks through liquid feeding, as this approach positively influences the animals' performance throughout their lives.

It is not widely known that variations in the liquid diet, depending on different nutritional levels, can cause structural changes in the digestive system, leading to distinct physiological responses. At birth, the pre-stomachs of cattle are rudimentary in terms of shape and function, with milk being the basal diet. Several studies have focused on the effects of *ad libitum* lactation feeding or providing whole milk at levels equal to or greater than 20% of birth weight (Welboren et al., 2019; Berends et al., 2020; Echeverry-Munera et al., 2021), demonstrating positive results in pre-weaning gains (Rosenberger et al., 2017; Ockenden et al., 2023). However, in practice, many dairy producers continue to follow traditional lactation practices, supplying only 8–10% of the calves' live weight in milk.

Another important consideration is that a restrictive milk supply to calves results in low energy intake, leading to reduced performance, slower growth (Broucek et al., 2020; Ockenden et al., 2023) and an increased incidence of illnesses and diarrhoea (van Niekerk et al., 2021). However, *ad libitum* lactation feeding can delay rumen fermentation and development of pre-stomachs by reducing dry matter intake during lactation (Huang et al., 2023). In addition, it can also cause other damage by exceeding the abomasum's capacity to process dairy nutrients. In this context, the objective of this study was to evaluate the effects of three different milk feeding levels on the initial intake, and body, rumen and papillary development of male and female Jersey calves during the first 60 days of lactation.

Material and methods

Ethics statement, location

The study was approved by the Animal Research and Experimentation Committee of the Federal University of Pelotas (case nos. 6390 and 6391). The experiment was conducted on the experimental farm of the Brazilian Agricultural Research Corporation (EMBRAPA) in Pelotas, Brazil (31°52′20″ S, 52°21′24″ W).

Animals, treatments, and experimental management

Twenty-four Jersey calves (12 males and 12 females), with an average birth weight of 26.17 ± 2.94 kg, were used in the study. The calves were born to healthy cows in their second and fourth lactation, all from the same herd. Detailed information about the animals used in the experiment is summarised in Table 1. The calves were housed individually in small wooden shelters with a mobility area of 12.5 m². After calving, they were separated from their cows and received 8 litres of colostrum within the first 48 h. On the third day, the animals were randomly assigned to treatments, maintaining a ratio of four males and four females per group. The treatments involved different milk feeding levels based on the fixed weight of each animal at birth: T1 – 15% milk body weight (BW); T2 – 20% milk BW; T3 – 25% milk bw, with 8 animals in each treatment group.

The experimental period began directly after colostrum intake within the first 36 h after birth and continued until weaning, which occurred 60 days after calving. Calves were bucket-fed twice a day at 7:00 and 18:00. The milk provided to the animals was analysed weekly to determine fat, protein, casein, total solids, lactose, urea and total bacterial count using infrared spectroscopy following the AOAC International, 1996 (method 972.16). The somatic cell count (SCC) was calculated using the equation of Shook (1993):

$$\text{Somatic cell score} = [\log_2(\text{SCC} / 100)] + 3$$

Milk supplied to the animals was collected directly from the lactation pipe with an average composition of 3.94% fat, 3.38% protein, 4.43% lactose, 12.71% total solids, a somatic cell count of 245 000 SCC/ml, and a total bacterial count of 112×10^3 CFU/ml at a temperature of 37.5 °C. From the third day, the animals also received a commercial laminated and pelleted feed suitable for lactating animals (20.91% crude protein, 22.85% neutral detergent fibre, 1.16% Ca and 0.6% P).

Leftover feed was removed and weighed daily in the morning. The animals were weighed at birth and weekly thereafter. Morphometric measurements included thoracic girth (measured as the circumference immediately caudal to the scapula passing through the sternum and the spinous processes of the thoracic vertebrae), height at withers (the distance from the ground to the withers, measured at 48 cm), croup height (the distance from the ground to the sacral tuberosity of the ilium, with the animals standing on a flat surface) and croup width (the

Table 1. Characteristics of Jersey calves used in the study

Gender	Date of calving	Treatment	Birth weight	Weaning	Slaughter date
Female	November 5th, 2014	15%	24.5	January 4th, 2015	–
Female	November 5th, 2014	15%	21.5	January 04th, 2015	–
Female	November 19th, 2014	15%	24.0	January 18th, 2015	–
Female	December 7th, 2014	15%	22.9	February 05th, 2015	–
Male	October 18th, 2014	15%	29.5	–	December 17th, 2014
Male	December 5th, 2014	15%	23.8	–	February 3rd, 2015
Male	December 30th, 2014	15%	28.0	–	February 28th, 2015
Male	January 28th, 2015	15%	28.7	–	March 29th, 2015
Female	October 21st, 2014	20%	23.5	December 20th, 2014	–
Female	December 5th, 2014	20%	20.0	February 03rd, 2015	–
Female	January 14th, 2015	20%	25.0	March 15th, 2015	–
Female	October 21st, 2014	20%	30.3	March 22nd, 2015	–
Male	November 24th, 2014	20%	31.4	–	January 23rd, 2015
Male	November 27th, 2014	20%	25.0	–	January 26th, 2015
Male	December 22nd, 2014	20%	26.0	–	February 20th, 2015
Male	January 3rd, 2015	20%	26.0	–	March 04th, 2015
Female	November 11th, 2014	25%	25.3	January 18th, 2015	–
Female	January 09th, 2015	25%	29.5	March 10th, 2015	–
Female	January 16th, 2015	25%	27.0	March 17th, 2015	–
Female	February 01st, 2015	25%	24.8	April 02nd, 2015	–
Male	November 04th, 2014	25%	28.8	–	January 3rd, 2015
Male	November 25th, 2014	25%	29.0	–	January 24th, 2015
Male	December 27th, 2014	25%	25.0	–	February 25th, 2015
Male	January 05th, 2015	25%	29.9	–	March 06th, 2015

distance between the sitting bones at the anterior part of the hindquarters) using a standard measuring tape (BOVITEC™, Santana, SP, Brazil). Additional width and height measurements were obtained using a hypometer. Total dry matter intake (DMI) was calculated by adding the daily intake of hay and concentrate feed, as well as including the dry matter content of the milk supplied.

At the end of the 60-day evaluation period, following weaning, the male calves were slaughtered while the female calves were moved to a paddock intended for newly weaned cows. The paddock had a forage canopy composed mainly of millet (*Pennisetum glaucum* (L.) R.) and some native species. The diet was supplemented with a commercial concentrate appropriate for the post-weaning period and mineral salt. No adaptation measures were required.

Laboratory assessments

Concentrate samples and leftovers were predried in a forced-air oven at 55 °C, and then ground in a Willey™ mill (Arthur H. Thomas, Chadds Ford, PA, USA) with a 1-mm screen. The samples were analysed for dry matter (DM) using method 967.03, crude protein (CP) by measuring N content according to methods 984.13 and 2001.11 (AOAC International, 2019), and neutral detergent insoluble fibre (NDF), with the addition of thermostable α-amylase and without sodium sulphite, according to the method of Van Soest et al. (1991). DMI was assessed based on the quantity of feed provided and dry matter remaining from the concentrate mixture.

Ruminal morphometry

On the 60th day of life, the males were euthanised through cerebral concussion followed by exsanguination (case no. 1000/2012 of the Federal Council of Veterinary Medicine; case no. 6391 – Federal University of Pelotas). Subsequently, the pre-stomachs were excised and dissected to remove the omental fat. The cavities were filled with water and their ends sealed with cotton thread and weighed. The organs were weighed together and separately, both in their full and empty states.

Ruminal wall samples, measuring approximately 2 cm² each, were collected at four specific locations: the caudoventral blind sac fundus, the right lateral wall (3 cm cranially and proximally from the right accessory pillar), the proximal region of the dorsal sac and the ventral sac (2 cm to the left side of the base of the cranial pillar) and fixed in a 10% formaldehyde solution. The thickness of the epithelium, submucosa and muscle layers was estimated based on photographs of histological slides of cross-sections of different rumen wall regions stained with haematoxylin and eosin using a BX 53 microscope with a high-resolution DP 72 digital camera (Olympus, Shinjuku-Tokyo, Japan). The thickness of the ruminal wall and the height of the papillae were analysed using an SZX 16 stereomicroscope and a DP 71 camera to capture transverse images of the formaldehyde-fixed ruminal tissue. All morphometric analyses of the images were performed using Image J™ software (National Institutes of Health, and the University of Wisconsin, WI, USA). For each sample, 10 measurements were taken in different areas of the tissue.

Statistical analysis

The data were subjected to a preliminary visual analysis, including the spatial distribution on a Cartesian plane. Growth analysis was performed using the Gompertz unicompartmental model with discrete latency, utilising the Proc Nlin procedure (SAS, 2018):

$$\mathrm{Y}t = \mathrm{A}f\exp\{-\exp[1 + ke(L - t)]\} + \varepsilon;$$

where: $\mathrm{Y}t$ – response variable as a function of time (t, d).

The model was applied to each experimental unit, and the parameters of the equation were subsequently organised and subjected to analysis of variance, similar to the other variables. A completely randomised design was adopted, using the mixed model methodology, incorporating fixed effects and random effects. Adjustment and selection of the mathematical model were based on the corrected Akaike information criterion (AICc) and its P-value (P = 0.05). The Glimmix procedure (SAS, 2018) was used to determine the best distribution and model fit according to the AICc.

Fixed effects (sex and lactation) and random effects (animal and time, if necessary) were included in the analysis of variance. When a significant effect of the fixed factors (sex, lactation and their interaction) was detected in the ANOVA (P = 0.05), means were compared using the F test or the Tukey-Kramer test. Statistical analysis was performed using SAS OnDemand.

Results

Intake and morphometric parameters

The level of milk supply positively affected dry matter intake (P = 0.025; Table 2), while sex had no significant effect on this variable (P = 0.811). Additionally, increased milk availability improved animal development as indicated by average daily gain (ADG) values. Except for the height at withers, morphometric characteristics were influenced by lactation feeding levels (P < 0.05). Male calves showed higher milk intake (Table 2) along with greater ADG and higher body weight (BW) at the end of the milk-feeding phase. Morphometric variables were significantly affected by milk supply levels, and an interaction between milk intake and sex was observed (P = 0.032).

Table 2. Influence of lactation feeding level and sex on dry matter intake, milk intake, total milk solids intake, and morphometric measurements of Jersey calves up to 60 days of age

Variables	Lactation feeding level 15%		20%		25%		*P*-value		
	female	male	female	male	female	male	A	S	A*S
Intake									
DMI, g	1604 ± 306.3§	2168 ± 414.0§	1115 ± 213.0	1029 ± 196.6	1302 ± 248.7	1170 ± 223.4	0.025	0.811	0.502
Milk intake, l	3.48 ± 0.053^{c}	4.05 ± 0.062^{bc}	4.94 ± 0.075^{b}	5.32 ± 0.081^{b}	6.44 ± 0.098^{ab}	7.04 ± 0.108^{a}	0.001	0.001	0.032
Milk solids, g/l of milk	440 ± 7.2	513 ± 8.4	626 ± 10.2	683 ± 11.1	816 ± 13.3§	897 ± 14.6§	0.001	0.001	0.086
Morphometric measurements (weaning)									
ADG, g	370 ± 21.4^{b}	425 ± 24.6^{b}	467 ± 27.0^{b}	479 ± 27.7^{b}	567 ± 32.8^{a§}	700 ± 40.5^{a§}	0.001	0.017	0.295
BW, kg	45.4 ± 2.05^{b}	53.0 ± 2.38^{b}	52.7 ± 2.37^{ab}	55.9 ± 2.51^{ab}	59.7 ± 2.69^{a§}	70.2 ± 3.16^{a§}	0.001	0.003	0.457
WH, cm	81.0 ± 1.21	82.7 ± 1.24	82.5 ± 1.23	82.4 ± 1.23	82.0 ± 1.23	86.0 ± 1.29	0.226	0.088	0.282
CG, cm	85.3 ± 1.46	87.8 ± 1.50	90.3 ± 1.54	90.1 ± 1.54	92.8 ± 1.59§	96.7 ± 1.65§	0.001	0.127	0.459
CH, cm	73.9 ± 1.31	74.5 ± 1.32	76.5 ± 1.35	75.2 ± 1.33	76.6 ± 1.36§	81.9 ± 1.45§	0.005	0.174	0.088
CW, cm	29.7 ± 0.75	30.7 ± 0.78	30.8 ± 0.78	31.8 ± 0.80	33.0 ± 0.83§	34.8 ± 0.88§	0.001	0.076	0.887

DMI – dry matter intake, BW – body weight, WH – wither height, CG – thoracic girth, CH – croup height, CW – croup width, A – animal effect, S – sex effect, A*S – animal × sex interaction; 15%, 20%, 25% – levels of whole milk in the diet means followed by different letters in the row differ due to the interaction between lactation feeding levels and calf gender – Tukey-Kramer's test (P < 0.05); § – differences between the lactation feeding levels – Tukey Kramer's test (P < 0.05); gender means were compared using the F test; data are presented as means ± SEM

A higher intake of accumulated dry matter was observed in the treatment with 25% whole milk inclusion (Table 2), with males starting consumption earlier than females. Among female calves, those in the treatment group receiving 20% whole milk had a higher DM intake rate compared to the 15% group (Table 3). Morphometric variables showed similar growth patterns, with no initial differences in magnitude, except for croup height, which showed an interaction between treatment factors. Males receiving 25% whole milk exhibited a more pronounced increase in croup height compared to those in the 15% milk treatment (Table 3).

Anatomical and histological parameters

Milk supply levels influenced the size of the digestive tract in males. Differences were observed in all parameters except for the total weight of the

Table 3. Influence of lactation feeding level and sex on dry matter intake, body weight and morphometric parameters of Jersey calves up to 60 days of age

	Lactation feeding level								
	15%		20%		25%		*P*-value		
Variables	female	male	female	male	female	male	A	S	A*S
Asymptotic values of growth parameters (A)									
DMI	509939§	22359§	43174	9577	19467	14867	0.013	0.007	0.081
BW	335 ± 28.5	457 ± 38.9	428 ± 29.7	405 ± 24.4	414 ± 25.0	511 ± 30.8	0.099	0.019	0.059
WH	1030 ± 24.4	1086 ± 29.7	1035 ± 28.3	1043 ± 24.7	1086 ± 29.6	1024 ± 24.2	0.770	0.962	0.123
TG	967 ± 21.6	1003 ± 22.4	954 ± 26.1	984 ± 19.0	1014 ± 22.7	993 ± 22.2	0.344	0.419	0.394
CH	341 ± 12.0	362 ± 11.0	343 ± 10.4	373 ± 13.1	357 ± 15.4	364 ± 12.8	0.745	0.083	0.656
CW	1020 ± 28.8	1076 ± 37.3	1065 ± 26.1	1084 ± 37.6	1096 ± 38.0	1110 ± 31.4	0.316	0.296	0.778
Growth rate (k)									
DMI	0.024 ± 0.0067[c]	0.151 ± 0.0517[a]	0.070 ± 0.0195[b]	0.071 ± 0.0197[b]	0.058 ± 0.0199[b]	0.057 ± 0.0275[b]	0.079	0.917	0.031
BW	0.0069	0.00707	0.00923	0.01335	0.01455§	0.01447§	0.034	0.539	0.708
WH	0.00293	0.00227	0.00263§	0.00307§	0.00224§	0.00416§	0.602	0.220	0.057
TG	0.0025[c]	0.00171[b]	0.00235[b]	0.00244[b]	0.00217[b]	0.00365[a]	0.196	0.670	0.049
CH	0.00441	0.00421	0.00523	0.0044	0.00597§	0.00642§	0.006	0.521	0.437
CW	0.00368	0.0039	0.00398	0.00353	0.00419	0.00427	0.392	0.851	0.618
Initial intake (L)									
DMI	19.8 ± 3.32	7.4 ± 1.23	14.4 ± 2.95	6.7 ± 1.37	7.4 ± 1.24	7.8 ± 2.26	0.133	0.009	0.091

DMI – dry matter intake, ADG – average daily gain, BW – body weight, WH – wither height, TG – thoracic girth, CH – croup height, CW – croup width, A – animal effect, S – sex effect, A*S – animal × sex interaction; 15%, 20%, 25% – levels of whole milk in the diet; means followed by different letters in the row differ due to the interaction between lactation levels and calf gender, Tukey-Kramer's test ($P < 0.05$); § – differences between the lactation feeding levels – Tukey-Kramer's test ($P < 0.05$); gender means were compared using the F test; data are presented as means ± SEM

Table 4. Weights of gastric compartments in male Jersey calves fed high whole milk levels and slaughtered at 60 days of age

Variables, kg	Lactation feeding level, %			*P*-value
	15	20	25	
Total full weight	14.1 ± 1.04[a]	13.4 ± 0.89[a]	14.9 ± 1.11[a]	0.555
Total empty weight	1.63 ± 0.120[a]	1.56 ± 0.102[a]	1.68 ± 0.143[a]	0.756
Full omasum	0.39 ± 0.035[a]	0.21 ± 0.017[b]	0.42 ± 0.043[a]	0.001
Empty omasum	0.190 ± 0.0093[b]	0.156 ± 0.0069[c]	0.212 ± 0.0105[a]	0.001
Full abomasum	4.36 ± 0.372[a]	4.97 ± 0.424[a]	5.86 ± 0.578[a]	0.103
Empty abomasum	0.427 ± 0.0187[a]	0.460 ± 0.0180[a]	0.470 ± 0.0206[a]	0.291
Full reticulum	0.767 ± 0.0744a	0.587 ± 0.0494[a]	0.467 ± 0.0453[a]	0.008
Empty reticulum	0.180 ± 0.0132[a]	0.156 ± 0.0103[a]	0.187 ± 0.0138[a]	0.161
Full rumen	9.76 ± 0.944[a]	7.03 ± 0.589[b]	7.38 ± 0.714[b]	0.049
Empty rumen	0.987 ± 0.0661[a]	0.722 ± 0.0483[b]	0.753 ± 0.0582[b]	0.008

15%, 20%, 25% – levels of whole milk in diet; data are presented as means ± SEM; means followed by different letters in the row differ significantly due to the interaction between lactation levels and calf gender – Tukey-Kramer's test ($P < 0.05$)

organs and the weight of the abomasum (Table 4). Lower milk supplementation resulted in greater weight and capacity of the rumen and reticulum. The weight of the omasum was 20% lower in this treatment, while histological parameters showed no significant differences ($P > 0.05$) with respect to the milk supply levels under study (Table 5).

and genetic differences. Nevertheless, when evaluating the effect of sex, we found that males had higher ADG and BW compared to females; however, other morphometric characteristics showed differences only with respect to the rate of whole milk addition. Furthermore, when applying the Gompertz model, it was observed that the initial magnitude of

Table 5. Development of rumen papillae in different rumen regions in male Jersey calves fed high levels of whole milk and slaughtered at 60 days of age

Rumen region	Lactation level, %	Rumen tissues				
		Papilla length	Wall thickness	Submucosal thickness	Epithelial thickness	Muscle thickness
Caudoventral blind sac	15	1790 ± 246.1	2125 ± 120.7	210 ± 51.3	60.5 ± 7.07	1668 ± 280.6
	20	1781 ± 244.8	1933 ± 109.7	314 ± 76.5	50.0 ± 5.84	1553 ± 261.3
	25	2078 ± 285.6	2023 ± 114.9	223 ± 54.4	48.0 ± 5.61	1429 ± 240.4
P-value		0.678	0.521	0.483	0.368	0.813
Left lateral wall	15	1876 ± 532.9	1751 ± 290.4	303 ± 50.5	52.2 ± 7.55	1032 ± 204.5
	20	1184 ± 336.5	1399 ± 231.9	229 ± 38.2	46.7 ± 6.75	836 ± 165.6
	25	1912 ± 543.1	1328 ± 220.2	254 ± 42.3	45.0 ± 6.50	706 ± 139.8
P-value		0.436	0.485	0.512	0.756	0.432
Dorsal sac	15	1172 ± 177.5	1750 ± 153.5	235 ± 38.5	48.2 ± 4.81	1333 ± 130.3
	20	1050 ± 159.0	1598 ± 140.4	256 ± 0.41.9	59.7 ± 5.95	1044 ± 102.1
	25	1329 ± 201.3	1369 ± 120.1	226 ± 37.0	60.2 ± 6.00	986 ± 96.4
P-value		0.565	0.191	0.864	0.255	0.122
Ventral sac	15	1039 ± 306.4	1890 ± 226.7	204 ± 50.2	44.7 ± 3.84	1521 ± 233.2
	20	953 ± 280.9	1681 ± 192.4	375 ± 92.3	52.5 ± 4.51	1302 ± 199.7
	25	1497 ± 441.4	1598 ± 182.9	166 ± 41.0	42.2 ± 3.63	1146 ± 175.7
P-value		0.539	0.419	0.104	0.234	0.458

15%, 20%, 25% – levels of whole milk in the diet; data are presented as means ± SEM; $P > 0.05$

Discussion

Intake and morphometric parameters

It was observed that increasing levels of milk supply were associated with reduced feed intake among animals, a finding supported by the results published by Rosenberger et al. (2017) and Broucek et al. (2020). Milk, in addition to being more palatable and easier to ingest due to its high nutritional and biological value, induces a quicker sensation of satiety compared to concentrate. Gelsinger et al. (2016) reported that increased ADG promoted by high milk consumption during the lactation period was directly related to high productivity in the first lactation of cows. However, weaning weight is often undervalued by producers, who prioritise early weaning to minimise production costs, which adversely affect the body development and production potential of these cows (Palczynski et al., 2020).

Bayou et al. (2015) have reported that males grow faster and achieve greater mature weight than females up to the post-weaning period, primarily due to hormonal, endocrinological, physiological, growth, i.e., the timepoint at which this factor becomes noticeable, showed an interaction between lactation level and sex for the rump height variable. This finding suggests that males begin growth earlier when provided with adequate nutrition. Nevertheless, few producers pay attention to raising males, particularly during this initial growth period, since the production profit is not considered a direct factor for these animals. However, characteristics such as cow's milk production are also influenced by the male. An animal lacking optimal growth conditions early in life may fail to express its full genetic potential, leading to its removal from the herd at the time of reproduction or negatively impacting the herd's productive capacity. Palczynski et al.(2020), evaluating pre-weaning calf feeding protocols on English dairy farms, observed that farmers who implemented changes to achieve optimal calf performance favoured feeding programs designed to promote accelerated growth, such as feeding higher whole milk doses, such as those recommended in this study.

Another relevant aspect indicated by the Gompertz model was that animals in the 15% milk supplementation group began consuming more dry matter before animals from the other treatments. However, the morphometric parameters evaluated in the present study were not affected by treatment levels, suggesting that the increased dry matter intake compensated for the lower milk supply (15%), effectively meeting the calves' nutritional requirements. However, it is important to anticipate that an early increase in dry matter intake, particularly before 60 days, when ruminal development is still incomplete, may reduce nutrient absorption and potentially negatively affect the initial allometric development of the mammary gland.

Considering these physiological parameters and the need to balance body development with adequate solid food intake, the 20% milk supply level appears to be the most appropriate. This finding was consistent with a study of Drackley (2008), who argued that the diet must support and accommodate the development of the calves' digestive functions from the pre-ruminant stage, ensuring they are fed liquids until the transition to a fully functional ruminant.

Boulton et al. (2015), in their evaluation of various practices in raising dairy calves from birth to weaning, observed that the initial growth rates directly influenced the age at first calving and the onset of milk production. Thus, our results clearly demonstrate that growth parameters depend not only on the level of milk supply but also on maintaining adequate dry matter intake and feed quality. These factors are essential to prevent any negative impact on the animal's development when lactation feeding level is reduced. Similarly, Jafari et al. (2020), in their study on the frequency of milk and solid food intake during the lactation period, concluded that calves did not benefit from the increased frequency of milk consumption. Although calves with lower milk supply had higher dry matter intake, their overall performance in terms of growth and development was comparable to those receiving more milk.

Anatomical and histological parameters

It was observed that lactation levels did not influence the weight or development of the pre-stomachs and stomachs. Traditionally, calves are provided with restricted milk quantities to encourage concentrate intake, optimise weight gain and, consequently, facilitate earlier weaning-aimed at reducing costs within the production system. Additionally, high levels of milk supply may hinder initial dry matter intake and delay the fermentation of carbohydrates to volatile fatty acids, which is crucial for the development of rumen papillae, typically beginning between the 3rd and 4th week of life. The primary stimulus for transforming the rumen into a functional organ is the chemical fermentation of soluble carbohydrates, releasing two volatile fatty acids: propionate and butyrate. Of the two, butyrate, plays a particularly vital role by exerting a mitotic effect and promoting cellular differentiation (Malhi et al., 2013), thereby initiating the formation of rumen papillae.

It was expected that the 15% milk supply group, which presented a higher and earlier concentrate intake compared to the other groups, as indicated by the Gompertz model, would also show some differences in the initial development of the gastric compartments. However, this did not occur, contrary to the findings of Elizondo-Salazar and Sánchez-Álvarez (2012), who evaluated the effect of liquid diets on rumen development and reported that calves with high milk intake during the lactation period showed reduced development of the rumen and papillae.

According to Cantor et al. (2019), intensive milk feeding can hinder ruminal development and complicate the transition to a solid diet, ultimately impairing performance after weaning. In the present study, the absence of differences between the intake of dry matter from solid feed likely contributed to favourable pre-gastric and gastric development. On the other hand, the lower intake of concentrate in the treatment with 25% whole milk inclusion did not cause morphophysiological damage.

Conclusions

Milk supply level and sex affected dry matter intake, with higher intake observed in treatments with lower milk supply. These factors also influenced weight at the end of lactation and croup height. However, no significant effects of different lactation feeding levels were observed on the remaining morphometric parameters. Furthermore, ruminal development did not differ between treatments, even with the increased concentrate intake observed in the lower milk supply group.

Based on these results, it can be inferred that an intensive and exclusive lactation feeding program using whole milk in the first days after calving can contribute to herd improvement. However, a high milk supply level, such as 25%, does not provide significant advantages compared to lower doses and results in higher costs and reduced milk availability for sale. We indicate that the 20% level appears to be more promising, as it supports consistent morphometric growth, weaning weight and ruminal parameter development. Although the 15% level resulted in satisfactory calf development, it promoted early and increased concentrate intake at a stage when the rumen was still developing and lacked full capacity to absorb nutrients from solid foods. It is important to emphasise that weekly monitoring, especially of calves' morphometric parameters, enables timely adjustments to the initial diet and selecting the optimal lactation feeding levels, which plays a crucial role in the development of these animals.

Conflicts of interest

The Authors declare that there is no conflict of interest.

References

AOAC International, 1996. Official methods of analysis of AOAC International. 15th edition. Official methods 967.03, 942.05, 954.05. Arlington, VA (USA). Cuniff P. (Editor)

AOAC International, 2019. Official methods of analysis of AOAC International. 21st edition. Washington, DC (USA)

Bayou E., Haile A., Gizaw S., Mekasha Y., 2015. Evaluation of non-genetic factors affecting calf growth, reproductive performance and milk yield of traditionally managed Sheko cattle in southwest Ethiopia. SpringerPlus 4, 568, https://doi.org/10.1186/s40064-015-1340-9

Berends H., van Laar H., Leal L.N., Gerrits W.J.J., Martín-Tereso J., 2020. Effects of exchanging lactose for fat in milk replacer on ad libitum feed intake and growth performance in dairy calves. J. Dairy Sci. 103, 4275–4287, https://doi.org/10.3168/jds.2019-17382

Boulton A.C., Rushton J., Wathes D.C., 2015. A study of dairy heifer rearing practices from birth to weaning and their associated costs on UK dairy farms. Open J. Anim. Sci. 5, 185–197, https://doi.org/10.4236/ojas.2015.52021

Broucek J., Uhrincat M., Kisac P., Hanus A., 2020. Effect of different rearing during the milk-feeding period on growth of dairy calves. Agriculture 10, 346, https://doi.org/10.3390/agriculture10080346

Cantor M.C., Neave H.W., Costa J.H.C., 2019. Current perspectives on the short- and long-term effects of conventional dairy calf raising systems: a comparison with the natural environment. Transl. Anim. Sci. 3, 549–563, https://doi.org/10.1093/tas/txy144

Drackley J.K., 2008. Calf nutrition from birth to breeding. Vet. Clin. N. Am. - Food Anim. Pract. 24, 55-86, https://doi.org/10.1016/j.cvfa.2008.01.001

EC, 2023. EU agricultural outlook for markets, 2023-2035. European Commission, DG Agriculture and Rural Development. Brussels (Belgium)

Echeverry-Munera J., Leal L.N., Wilms J.N., Berends H., Costa J.H.C., Steele M.A., Martin-Tereso J., 2021. Effect of partial exchange of lactose with fat in milk replacer on ad libitum feed intake and performance in dairy calves. J. Dairy Sci. 104, 5432–5444, https://doi.org/10.3168/jds.2020-19485

Eckert E., Brown H.E., Leslie K.E., DeVries T.J., Steele M.A., 2015. Weaning age affects growth, feed intake, gastrointestinal development, and behavior in Holstein calves fed an elevated plane of nutrition during the preweaning stage. J. Dairy Sci. 98, 6315–6326, https://doi.org/10.3168/jds.2014-9062

Elizondo-Salazar J.A., Sánchez-Álvarez M., 2012. Effect of liquid and solid diet intake on growth and rumen development of dairy calves (in Portuguese). Agron. Costarricense 36, 81–90, https://doi.org/10.15517/rac.v36i2.9823

Embrapa (Brazilian Agricultural Research Company), 2023. BRAZILIAN Milk report 2023: Low carbon milk. Juiz de Fora: Embrapa Gado de Leite. Curitiba, PN (Brazil), p. 120

Gelsinger S.L., Heinrichs A.J., Jones C.M., 2016. A meta-analysis of the effects of preweaned calf nutrition and growth on first-lactation performance. J. Dairy Sci. 99, 6206–6214, https://doi.org/10.3168/jds.2015-10744

Huang Y., Wang G., Zhang Q. et al., 2023. Effects of milk replacer feeding level on growth performance, rumen development and the ruminal bacterial community in lambs. Front. Microbiol. 13, https://doi.org/10.3389/fmicb.2022.1069964

Jafari A., Azarfar A., Ghorbani G.R., Mirzaei M., Khan M.A., Omidi-Mirzaei H., Pakdel A., Ghaffari M.H., 2020. Effects of physical forms of starter and milk allowance on growth performance, ruminal fermentation, and blood metabolites of Holstein dairy calves. J. Dairy Sci. 103, 11300–11313, https://doi.org/10.3168/jds.2021-104-2-2463

Malhi M., Gui H., Yao L., Aschenbach J.R., Gotthold G., Shen Z., 2013. Increased papillae growth and enhanced short-chain fatty acid absorption in the rumen of goats are associated with transient increases in cyclin D1 expression after ruminal butyrate infusion. J. Dairy Sci. 96, 7603–7616, https://doi.org/10.3168/jds.2013-6700

Ockenden E.M., Russo V.M., Leury B.J., Giri K., Wales W.J., 2023. Preweaning nutrition and its effects on the growth, immune competence and metabolic characteristics of the dairy calf. Animals (Basel) 13, 829, https://doi.org/10.3390/ani13050829

Palczynski L.J., Bleach E.C.L., Brennan M.L., Robinson P.A., 2020. Appropriate dairy calf feeding from birth to weaning: "It's an investment for the future". Animals (Basel) 10, 116, https://doi.org/10.3390/ani10010116

Rosenberger K., Costa J.H.C., Neave H.W., von Keyserlingk M.A.G., Weary D.M., 2017. The effect of milk allowance on behavior and weight gains in dairy calves. J. Dairy Sci. 100, 504–512, https://doi.org/10.3168/jds.2016-11195

SAS Institute Inc., 2018. SAS/STAT® 15.1 User's Guide: High-Performance Procedures. SAS Institute Inc. Cary, NC (USA)

Shook G.E., 1993. Genetic improvement of mastitis through selection on somatic cell count. Vet. Clin. N. Am. - Food Anim. Pract. 9, 563–577, https://doi.org/10.1016/S0749-0720(15)30622-8

Soberon F., Raffrenato E., Everett R.W., Van Amburgh M.E., 2012. Preweaning milk replacer intake and effects on long-term productivity of dairy calves. J. Dairy Sci. 95, 783–793, https://doi.org/10.3168/jds.2011-4391

van Niekerk J.K., Fischer-Tlustos A.J., Wilms J.N., Hare K.S., Welboren A.C., Lopez A.J., Yohe T.T., Cangiano L.R., Leal L.N., Steele M.A., 2021. ADSA Foundation Scholar Award: New frontiers in calf and heifer nutrition: From conception to puberty. J. Dairy Sci. 104, 8341–8362, https://doi.org/10.3168/jds.2020-20004

Van Soest P.J., Robertson J.B., Lewis B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74, 358–397, https://doi.org/10.3168/jds.S0022-0302(91)78551-2

Welboren C., Leal L.N., Steele M.A., Khan M.A., Martín-Tereso J., 2019. Performance of *ad libitum* fed dairy calves weaned using fixed and individual methods. Animal 13, 1891–1898, https://doi.org/10.1017/S1751731119000181