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Three ages at weaning in beef calves: Implications on performance and development

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ABSTRACT - We investigated the impact of weaning at 30, 75, and 180 days of age on performance, body measurements, and rumen development (using the β-hydroxybutyrate biomarker) of beef calves until 190 days of age. A total of 64 Brangus calves were assigned to three treatments: hyper-early (W30), weaned at 32±0.89 days of age (n = 22, 10 males and 12 females); early (W75), weaned at 77±0.95 days of age (n = 20, 12 males and eight females); and conventional (W180), weaned at 183±0.82 days of age (n = 22, 13 males and nine females). Body weight (BW), average daily gain (ADG), β-hydroxybutyrate (βHBA), and morphometric measurements were evaluated. These variables were influenced by an interaction between treatment and days and were not affected by the sex of calves. The W30 calves experienced weight loss from 30 to 40 days of age compared with the W75 and W180 calves. Consequently, at day 75, W30 animals were lighter and had lower body length, thoracic circumference, withers height, and croup height compared with the W75 and W180 calves. However, no significant differences in BW were observed among treatments at 85 days of age. Additionally, W30 calves exhibited higher ADG and a moderate correlation with βHBA levels. Weaning calves at 30 days of age may negatively affect their performance until the sixth week after weaning, but there is no impairment in performance at 190 days of age.

Keywords: animal production, beef cattle, Brangus, Kleiber ratio, rumen

1. Introduction

Early weaning refers to the definitive separation of cow-calf pairs before the calves reach 210 days of age. Typically, this practice is performed in beef calves that are older than 45 days (Rasby, 2007). Its primary objective is to restore the body condition score of cows that have experienced feed restrictions during lactation, ultimately improving the pregnancy rates (Houghton et al., 1990). The earlier the weaning occurs, the higher the probability of cows becoming pregnant within the first weeks of the breeding season (Alforma et al., 2023). However, the younger calves are weaned, the more difficult it is for them to cope with psychological, nutritional, physical (Lynch et al., 2019), and immunological challenges (Teixeira et al., 2021b).

The change in diet is one of the biggest challenges for young calves (Enríquez et al., 2011). Under natural conditions, calves gradually develop their stomach compartments, and it becomes ruminant around eight weeks of age (Church, 1974). However, early weaning can accelerate this process by promoting solid food intake, initiating rumen fermentation (Tamate et al., 1962), and inducing physical and metabolic changes in the rumen (Baldwin et al., 2004; Dong et al., 2019). If this process does not occur properly, it can impair the development of calves (Steele et al., 2016), resulting in poorer performance compared with calves weaned at conventional ages (Rasby, 2007).

Therefore, the most appropriate approach to assess weaning practices is by combining animal performance metrics (Taylor et al., 2020) with biochemical development parameters, such as β-hydroxybutyrate (Kazana et al., 2021). Increases in serum β-hydroxybutyrate are associated with an increase in feed intake (Deelen et al., 2016) and rumen development (Quigley et al., 1991; Suárez et al., 2006; Eckert et al., 2015), making it a suitable proxy for evaluating rumen development in calves (Deelen et al., 2016). Therefore, our objective was to investigate the impact of weaning at 30, 75, and 180 days of age on body measurements, ruminal development, and performance of beef calves assessed until 190 days of age. We hypothesized that weaning beef calves at 30 days of age would not have their development and performance impaired compared with those weaned at 75 and 180 days of age.

2. Material and Methods

2.1. Ethical note

Animal research was conducted according to the institutional committee on animal use (CEUA - no. 33439).

2.2. Animals and treatment groups

A total of 64 Brangus calves (35 males and 29 females) were randomly selected from the herd of an experimental farm located in Eldorado do Sul, Rio Grande do Sul, Brazil (latitude: 30°06'20.7" S; longitude: 51°41'21.9" W; and altitude 46 m). The dams were 4.3±0.23 years old (mean ± SE). The calves were born during the spring and exhibited similar birth weights across all treatments (34±1.33 kg). Subsequently, calves were distributed into three treatments according to weaning age: hyper-early (W30; n = 22, 10 males and 12 females) with an average weight of 53.45±1.10 kg and age of 32±0.89 days; early (W75; n = 20, 12 males and eight females) with an average weight of 84.63±2.05 kg and age of 77±0.95 days; and conventional (W180; n = 22, 13 males and nine females) with an average weight of 157.62±2.87 kg and age of 183±0.82 days. The W30 and W75 calves were weaned in December and February (summer), respectively, whereas the W180 calves were weaned in May (autumn).

On the day of weaning, cows and calves were transported to the management center for abrupt weaning, which is the most common weaning method in the beef industry (Rauch et al., 2019). Afterward, the cows were moved to a separate pasture located 2.6 km away from the area where the calves were allocated, avoiding any interaction between cows and calves.

Calves were moved to a drylot pen equipped with two feed troughs, one water trough, and a partially covered area made of polypropylene fabric (80% shade factor) that provided artificial shade immediately after processing and weaning. In total, two drylot pens with identical facilities were used, one for the W30 and another for the W75 animals, in a layout presented in Figure 1. Calves from the W30 treatment stayed in their pen for 78 days, and calves from the W75 treatment stayed in their pen for 33 days; both groups were moved to a pasture afterward. One of these pens was used for ten days to wean the W180 calves.

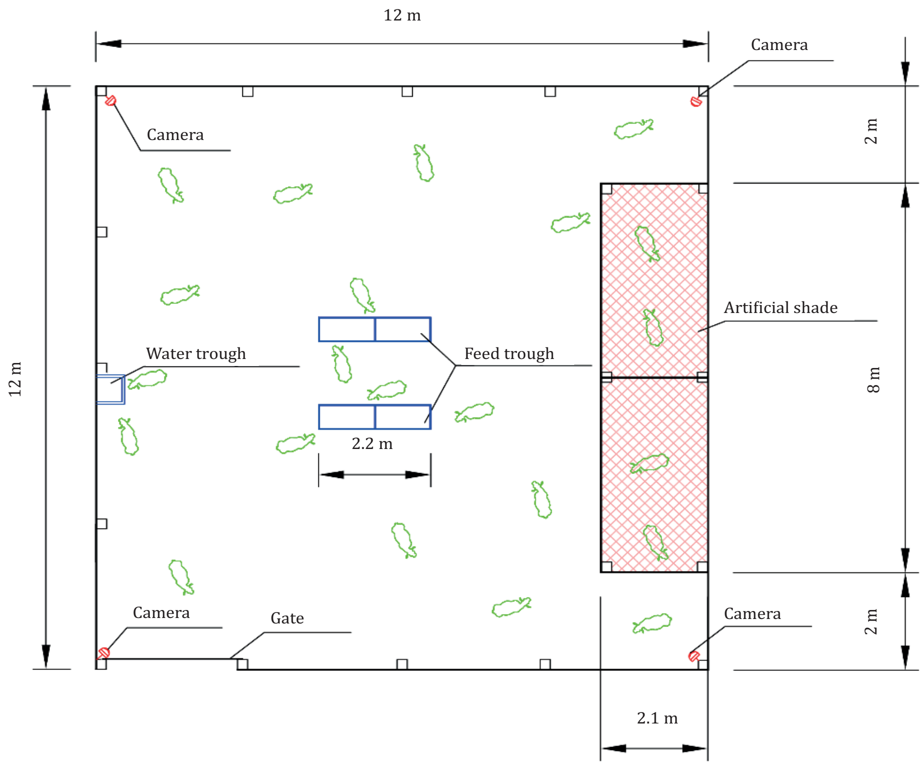


Figure 1 - Calf installations equipped with water troughs, feed troughs, and artificial shade.

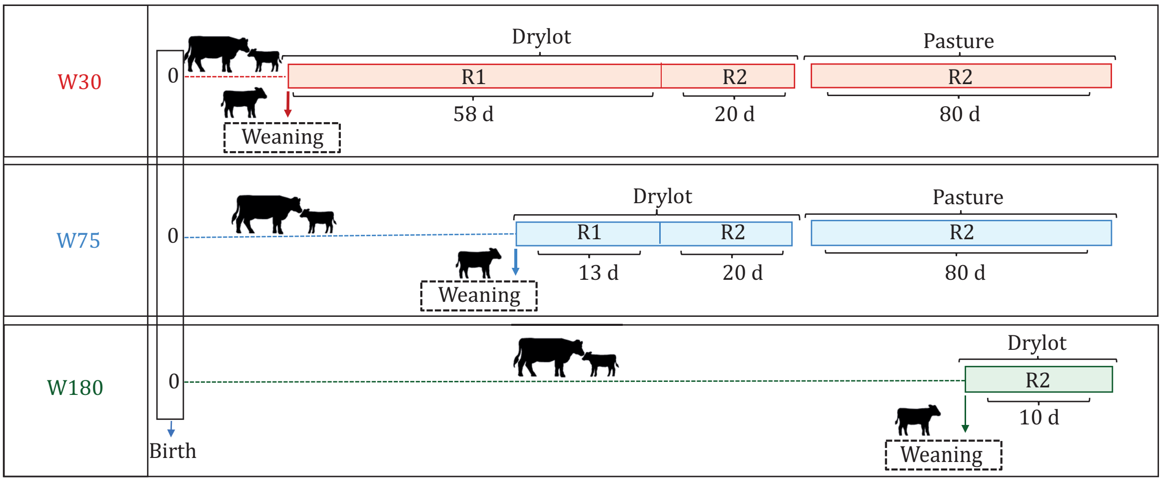
2.3. Nutritional and sanitary management

Before weaning, cow-calf pairs remained in the same area and were subjected to the same feeding management: a native pasture of 51.7 ha producing 2,200 kg dry matter (DM)/ha and a millet cultivated pasture (*Pennisetum americanum*) of 10.4 ha producing 1,830 kg DM/ha, as described by Alforma et al. (2023). No feed supplements were provided to calves at any time prior to weaning in any treatment. For this reason, alfalfa hay was introduced into their diet immediately after weaning to facilitate the adaptation to solid diet (Rasby, 2007; Orihuela and Galina, 2019).

The W30 calves were fed *ad libitum* after weaning, during the drylot period (Figure 2). Their diet consisted of pelleted initial ration 1 (Table 1) and alfalfa hay (167 g/kg of crude protein [CP] and 456 g/kg neutral detergent fiber [NDF]) during the 58 days after weaning. The average total intake of ration 1 was 1% of live weight (based on the DM) for the first 10 days after weaning and 2.3% for the following 48 days. For the next 20 days, calves received pelleted growth ration 2 (Table 1) and alfalfa hay, with an average total intake of 3.1% of live weight based on DM.

The W75 calves were weaned and fed *ad libitum* after weaning during the drylot period. For the first 13 days after weaning, they received ration 1 and alfalfa hay, with an average total intake of 1% of live weight. For the following 20 days, they received ration 2 and alfalfa hay, with an average total intake of 2.2% of live weight.

Calves from all treatments were fed twice daily during the first 10 days after weaning. From the 11th day after weaning until the end of the drylot period (at 110 days of age), W30 and W75 calves were fed thrice daily (08:00 h, 14:00 h, and 18:00 h). After the end of the drylot period (W30 = 78 days, W75 = 33 days), all calves from W30 and W75 treatments were moved to 3 ha of Brachiaria pasture (*B. decumbens* × *B. brizantha* × *B. ruziziensis*). The chemical composition of the pasture was 58 g/kg CP and 665 g/kg NDF, and a forage mass of 2,270 kg DM/ha. While in the pasture (from 110 days to 190 days of age), calves were fed ration 2 once a day at 08:00 h with an intake of 1.5% of live weight.



W30 - hyper-early weaning at 30 days of age; W75 - early weaning at 75 days of age; W180 - conventional weaning at 180 days of age.
W30 received ration 1 (R1) for 58 days and received ration 2 (R2) for 20 days in the drylot; W75 received R1 for 13 days and received R2 for 20 days in the drylot; calves from W30 and W75 were moved to the pasture with supplementation after the drylot period, receiving R2 for 80 days; W180 received R2 for 10 days after weaning in the drylot.

Figure 2 - Nutritional management before and after weaning.

Table 1 - Ingredient and chemical composition of the rations given to calves during the weaning

Item	Ration 1[1]	Ration 2[2]
Pellet composition (g/kg DM)		
Corn grain	331	300
Soybean meal	299	68
Defatted rice bran	212	210
Rice bran	100	180
Corn dried distillers' grains	0	140
Whole oat	0	60
Calcitic limestone	10	30
Mineral and vitamins premix	48	12
Final ration composition (g/kg DM)		
Pellet	785	1000
Flaked corn	96	0
Flaked soybean	77	0
Cane molasses	42	0
Chemical composition (g/kg)		
Dry matter	870	870
Crude protein	200	180
Mineral matter	80	100
Ethereal extract	30	40
Neutral detergent fiber	130	150
Acid detergent fiber	80	120
Total digestible nutrients	740	720

[1] Guarantee levels: calcium, 11 g/kg (minimum) – 13 g/kg (maximum); phosphorus, 7 g/kg (minimum); sulfur, 955 mg/kg (minimum); magnesium, 510 mg/kg (minimum); potassium, 147 mg/kg (minimum); cobalt, 0.69 mg/kg (minimum); copper, 20.5 mg/kg (minimum); iron, 30 mg/kg (minimum); iodine, 1.5 mg/kg (minimum); manganese, 72 mg/kg (minimum); selenium, 0.9 mg/kg (minimum); zinc, 109.5 mg/kg (minimum); vitamin A, 12,700 IU/kg (minimum); vitamin D3, 3,100 IU/kg (minimum); vitamin E, 43 IU/kg (minimum); folic acid, 0.4 mg/kg (minimum); nicotinic acid, 12.5 mg/kg (minimum); pantotenic acid, 6 mg/kg (minimum); biotin, 1.2 mg/kg (minimum); coline, 208 mg/kg (minimum); vitamin B1, 0.75 mg/kg; vitamin B12, 10 mcg/kg (minimum); vitamin B2, 2.5 mg/kg (minimum); vitamin B6, 1 mg/kg (minimum); vitamin K3, 0.25 mg/kg (minimum); lasalocid sodium, 80 mg/kg (minimum); *Bacillus cereus*, 2.5×10^8 cfu/kg (minimum); *Lactobacillus acidophilus*, 2×10^8 cfu/kg (minimum); *Ruminobacter amylophilum*, 2×10^8 cfu/kg (minimum); *Saccharomyces cerevisiae*, 2.3×10^6 cfu/kg (minimum).
[2] Guarantee levels: calcium, 11 g/kg (minimum) – 14 g/kg (maximum); phosphorus, 6 g/kg (minimum); sulfur, 955 mg/kg (minimum); magnesium, 510 mg/kg (minimum); potassium, 147 mg/kg (minimum); cobalt, 0.69 mg/kg (minimum); copper, 20.5 mg/kg (minimum); iron, 30 mg/kg (minimum); iodine, 1.5 mg/kg (minimum); manganese, 72 mg/kg (minimum); selenium, 0.7 mg/kg (minimum); zinc, 109.5 mg/kg (minimum); vitamin A, 8,700 IU/kg (minimum); vitamin D3, 2,100 IU/kg (minimum); vitamin E, 38 IU/kg (minimum); biotine, 1.2 mg/kg (minimum); lasalocid sodium, 40 mg/kg (minimum).

The W180 calves were weaned at 180 days of age and allocated to the drylot pen. They were fed pelleted growth ration 2 and alfalfa hay for 10 days, with an average total intake of 1.4% of live weight based on DM. Feed intake was measured by calculating the difference between the total weight of feed offered and the weight of leftovers the following day for all treatments. The leftover feed was weighted daily to adjust to the refusals rate of 5% (Teixeira et al., 2021b).

All calves were vaccinated against clostridial diseases at 40 days of age and received booster doses at 90 days of age. In addition, they were treated monthly for endoparasites and ectoparasites. The occurrence of nasal and ocular discharge and diarrhea was monitored daily, and the rectal temperature was measured when any abnormal behavior was observed.

2.4. Animal performance and growth

Body weight (BW) measurements were taken 24 h after birth and at 30, 40, 75, 85, 110, 150, 180, and 190 days of age. The average daily gain (ADG) was calculated for each weighing interval as well as for the 190 days. In addition, the Kleiber ratio ($KR = ADG \div BW^{0.75}$) was calculated over the entire study period to assess growth efficiency in grams per unit of metabolic size (g/UMS) (Kleiber, 1936).

Morphometric characteristics of calves were also measured (in cm) on the days corresponding to weaning for each experimental group (30, 75, and 180 days of age) using a graduated ruler and measuring tape. The measurements included: body length (distance from the lower tip of the shoulder to the tip of the ischium), thoracic circumference (circumference of the body in the chest region just behind the withers), withers height (distance between the withers and the ground surface), and, croup height (distance between the top of the sacrum region and the ground surface) (Menezes et al., 2008).

2.5. β-hydroxybutyrate

Blood samples from the jugular vein were collected in 10-mL vacutainer tubes containing a clot activator (BD, Franklin Lakes, NJ, EUA). Blood collections were performed at 08:00 h at six different time points (days 30, 37, 75, 82, 180, and 187, corresponding to the targeted weaning date of each group and seven days after the weaning date). Samples were centrifuged, stored in plastic vials, and frozen in liquid nitrogen (−196 °C) until further analysis. Concentrations of β-hydroxybutyrate were determined via Automatic Biochemical equipment (Lambax-Plenno-Labtest, MG, Brazil) using a commercial kinetic reaction kit (RANDOX Brazil Ltda, SP, Brazil).

2.6. Statistical analysis

All data were analyzed using the generalized linear model of repeated measures, treating each calf as a time-dependent sampling unit. The effect of treatment (weaning – W30, W75, and W180) and sex (male or female) of the calves were evaluated, considering the cow's age as a covariate. However, as no effect of calf sex was observed, the sex was removed from the final model. Therefore, the model analyzed the individual effects and the interaction between treatment and day, and comparisons of means were performed using the Least Significant Difference (LSD) method. The relationship between ADG and βHBA over the days was assessed using Pearson's correlation. All statistical analyses were conducted using the SPSS 20.0 software (IBM, 2011), with a significance level of 5%.

The generalized linear model can be expressed as follows:

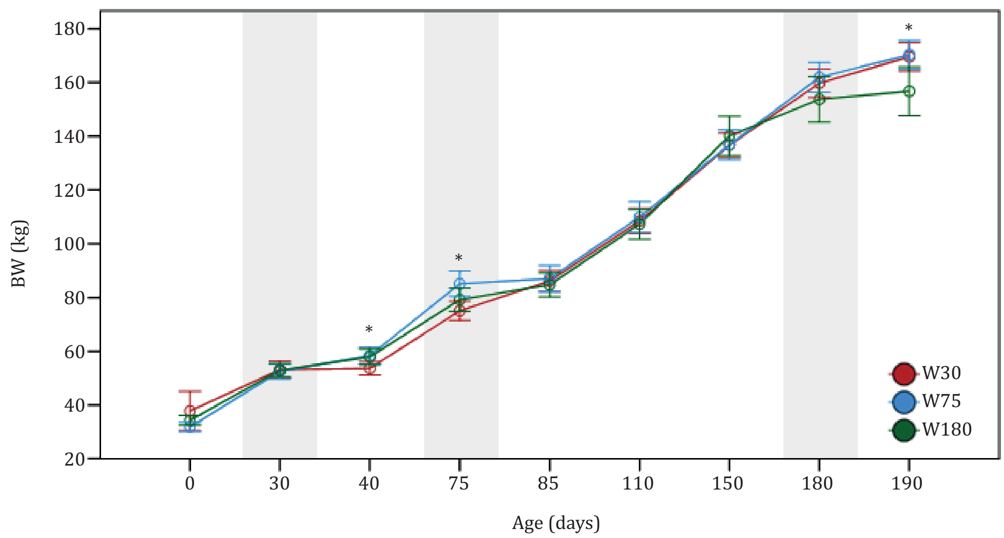
$$\Upsilon_{ijk} = \mu + \tau_j + \varphi_i(\tau_j) + \rho_k + (\tau^*\rho)_{jk} + \varepsilon_{ijk},$$

in which Υ_{ijk} = dependent variables; μ = mean of all observations; τ_j = effect of the *j*-th treatment; φ_i = repetition within the treatment (error a); ρ_k = effect of the *k*-th collection day; $(\tau^*\rho)_{jk}$ = interaction between the *j*-th treatment and *k*-th collection day; and ε_{ijk} = random error (error b).

3. Results

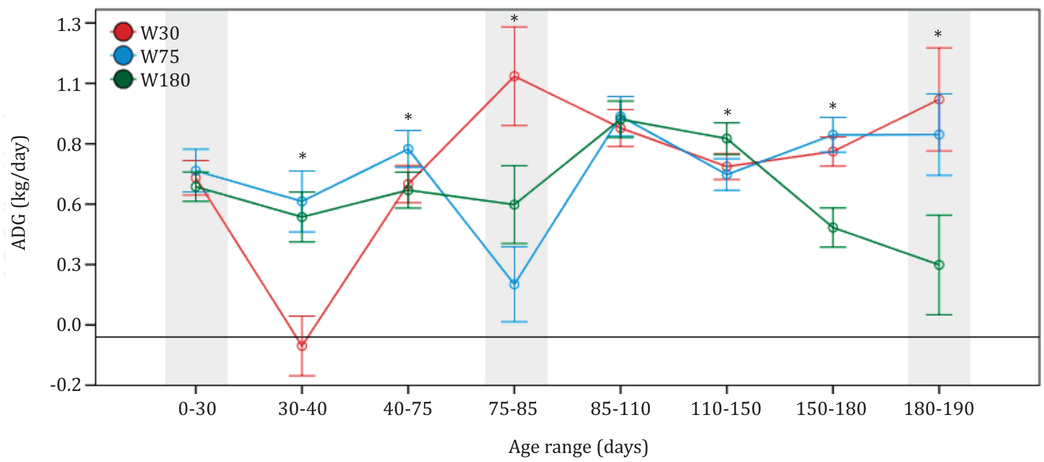
3.1. Animal performance

Weight and ADG were influenced by the treatment × day interaction ($P<0.001$) (Figures 3 and 4). During the period when all calves were nursed (from birth to 30 days old), there were no differences in weight and weight gain among treatments ($P>0.05$). Between 30-40 days of age, the W30 calves (weaned at 32±0.89 days of age) exhibited lower weight gain compared with W75 and W180 calves, which did not differ from each other ($P>0.05$). From 40-75 days, W75 calves (0.780±0.040 kg/d) had a



W30 - hyper-early weaning at 30 days of age; W75 - early weaning at 75 days of age; W180 - conventional weaning at 180 days of age.
* P<0.05.

Figure 3 - Average body weight (BW) of beef calves weaned at different ages.



W30 - hyper-early weaning at 30 days of age; W75 - early weaning at 75 days of age; W180 - conventional weaning at 180 days of age.
* P<0.05.

Figure 4 - Average daily weight gain (ADG) in beef calves weaned at different ages.

higher ADG than both W30 (0.630±0.040 kg/d) and W180 (0.610±0.040 kg/d) (P<0.001) calves, while no difference was observed between W30 and W180 groups. Consequently, W30 calves were lighter (75.860±1.510 kg) than W75 (85.110±2.340 kg) and W180 (79.230±2.130 kg) animals at the 75th day of age. However, between 75-85 days (period comprising the weaning of W75 calves, at 77±0.95 days of age), all treatments exhibited significant differences (P<0.05), with W30 presenting higher ADG followed by W180 and W75 calves. Therefore, the weight differences among treatments were compensated at 85 days of age.

Between 110-150 days, the ADG was lower for W30 (0.710±0.030 kg/d) and W75 (0.670±0.030 kg/d) compared with W180 calves (0.820±0.030 kg/d) (P<0.05). This period comprises the transfer of W30 and W75 calves from the drylot to the *Brachiaria* pasture at 110 days of age. Following the weaning at 180-190 days, calves in the W180 group exhibited lower ADG (0.300±0.100 kg/d) compared with W30 (0.980±0.110 kg/d) and W75 (0.840±0.080 kg/d), with no significant difference between W30 and W75 groups (P>0.05). As a result, the weight of W30 (169.550±2.670 kg) and W75 (170.300±2.680 kg) calves were greater than the weight of W180 (156.720±4.540 kg) at 190 days. The total weight gain (30-190 days) was higher for W30 (115.48±2.35 kg) and W75 (117.81±2.09 kg) calves compared with W180 animals (103.87±3.80 kg) (P<0.05).

During the ten days following the weaning of each group, only W30 calves exhibited negative weight gain (d 30-40: −0.040±0.060 kg/d). Both W75 (d 75-85: 0.220±0.080 kg/d) and W180 (d 180-190: 0.300±0.100 kg/d) calves experienced reductions in weight gain during the immediate periods after weaning, but they never exhibited negative ADG. The Kleiber ratio calculated over the 190 days was higher for W75 (21.49±0.28 g/UMS) and W30 (20.99±0.32 g/UMS) compared with W180 calves (19.71±0.40 g/UMS) (P<0.05). Furthermore, no mortality was observed in this experiment.

3.2. Animal growth measures

All treatments exhibited increasing growth measures over time (Table 2). On day 30, there were no significant differences in length, thoracic circumference, and withers height among treatments. However, the croup height was lower in W180 calves. On day 75, W30 calves exhibited lower values for all morphometric measures, while no difference was observed between W75 and W180 animals.

Table 2 - Morphometric measurements of beef calves weaned at three different time points

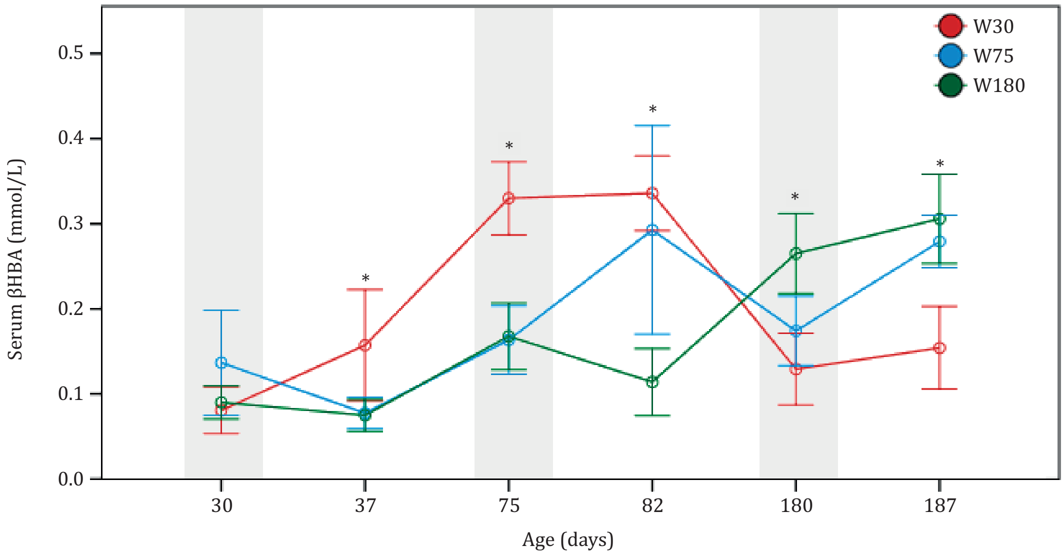
Day	Treatment[1]			P-value		
	W30	W75	W180	Treatment	Day	Treatment × day
		Animal length (cm)				
30	73.32±1.28Ac	76.95±0.98Ac	75.09±1.05Ac			
75	83.73±0.82Bb	89.55±0.96Ab	88.14±1.26Ab	0.035	<0.001	0.038
180	106.59±0.59Aa	110.05±1.00Aa	108.20±1.30Aa			
		Thoracic circumference (cm)				
30	88.64±0.89Ac	89.50±0.87Ac	88.23±0.81Ac			
75	97.73±1.05Bb	103.85±1.00Ab	102.00±1.01Ab	0.018	<0.001	0.001
180	123.41±0.86Aa	125.55±0.83Aa	123.48±1.38Aa			
		Withers height (cm)				
30	76.41±0.64Ac	76.85±0.41Ac	75.43±0.72Ac			
75	82.27±0.58Cb	86.55±0.43Ab	84.64±0.75Bb	0.016	<0.001	<0.001
180	96.41±0.87Ba	99.00±0.53Aa	99.14±0.92Aa			
		Croup height (cm)				
30	83.32±0.59Ac	83.15±0.41Ac	80.23±0.77Bc			
75	87.86±0.99Bb	93.30±0.58Ab	90.64±0.81Ab	0.036	<0.001	<0.001
180	103.55±0.88Ba	106.65±0.60Aa	107.00±1.02Aa			

[1] W30 - hyper-early weaning at 30 days of age; W75 - early weaning at 75 days of age; W180 - conventional weaning at 180 days of age.
A,B,C - Different letters in the rows represent statistical differences (P<0.05) per treatment.
a,b,c - Different letters in the columns represent statistical differences (P<0.05) per day.

Although the length and thoracic circumference of W30 calves did not differ (P>0.05) from W75 and W180 animals at 180 days of age, their withers and croup heights were lower.

3.3. β-hydroxybutyrate levels

Serum βHBA levels were influenced by the treatment × day interaction (P<0.001) (Figure 5). Its levels were greater on day 37 in W30 calves (0.16±0.03 mmol/L) compared with W75 and W180 calves (0.08±0.01 mmol/L). Similarly, on day 75, βHBA levels remained higher in W30 (0.33±0.02 mmol/L) compared with W75 (0.16±0.02 mmol/L) and W180 (0.17±0.02 mmol/L) calves. Moreover, a moderate positive correlation between βHBA levels and ADG was observed in W30 calves (r = 0.49; P = 0.003) at day 75. No differences were observed in βHBA levels between W75 and W180 calves on both days 37 and 75 (P>0.05). On day 82, there were no differences in βHBA levels between W30 and W75 calves (P>0.05), but both differed from W180, which exhibited the lowest βHBA values. However, βHBA levels increased in W180 calves at day 180, peaking on day 187.



W30 - hyper-early weaning at 30 days of age; W75 - early weaning at 75 days of age; W180 - conventional weaning at 180 days of age.
* P<0.05.

Figure 5 - Average β-hydroxybutyrate (βHBA) in beef calves weaned at different ages.

4. Discussion

Early weaning is a technique that aims at improving the probability of cows becoming pregnant by reducing their nutrient requirements, with minimal or absent weight loss in calves (Rasby, 2007). The benefits of this technique in enhancing pregnancy rates and calving distribution are well established. It has been found that the earlier weaning occurs, the greater the chances of the cows becoming pregnant early in the breeding season (Alforma et al., 2023). On the other hand, the earlier weaning occurs, the more stressful it is for the calves (Teixeira et al., 2021a). Therefore, the standard recommendation has been not to wean beef calves younger than 45 days of age (Rasby, 2007). However, the present study proved that it is possible to safely wean beef calves at 30 days of age, as evidenced by the absence of mortality throughout the experiment. Furthermore, both W30 and W75 animals ended the experiment with higher weights than W180.

Although it is possible to wean calves at 30 days of age with no mortality or impaired weight up to 190 days, this practice is time-demanding and requires a well-trained workforce to accomplish acceptable results. In the region where the present study was performed, both W30 and W75 treatments are recommended only in situations where a significant decrease in pregnancy rate is expected, such as during years of severe droughts, as they can help mitigate losses but not improve economic results (Camargo et al., 2022).

In our study, we observed a decrease in ADG following the weaning of W30 calves. This performance decline could be attributed to the adaptation of the calves' gastrointestinal tract to the new diet. It is expected that pre-ruminant calves, which have not yet developed the full physiological mechanisms to efficiently digest solid food, may exhibit weight loss during this transitional period (Church, 1974; Van Soest, 1994). Therefore, this period must be closely monitored to assess calves' adaptation to solid food (Drackley, 2008) and prevent drastic weight loss.

During the adaptation period, enzymatic activity for the digestion of solid feeds increases (Longenbach and Heinrichs, 1998), accompanied by the onset of ruminal fermentation processes (Baldwin et al., 2004). As the calf adapts to the solid diet, it transitions into becoming an effective ruminant and synthesizes most of its energy as short-chain fatty acids (Drackley, 2008). One of these acids is butyrate, the primary agent of the development of the gastrointestinal tract (Guilloteau et al., 2010). Butyrate promotes the elongation of ruminal papillae by stimulating the mitotic rate and reducing apoptosis (Mentschel et al., 2001). The ruminal mucosa absorbs butyrate, and approximately 77% is converted to βHBA (Pennington and Pfander, 1957). Therefore, elevated levels of βHBA indicate the activation and functioning of the gastrointestinal tract of ruminants (Meale et al., 2015).

This increase in βHBA was observed seven days after weaning in all treatments, indicating a progressive adaptation to the diet and rumen development. Similar findings were reported by Eckert et al. (2015) in a study on dairy calves weaned at six or eight weeks of age, in which a positive correlation between βHBA levels and stater intake was observed in calves weaned at six weeks of age. In our study, similar results were observed, with the highest βHBA levels occurring in W30 calves between 75 and 82 days of age, which coincided with their highest ADG. Subsequently, a decrease in both βHBA and ADG was observed, as a result of the change in the diet described in section 2.3. These findings further support the association between ADG, body weight, and the peak of βHBA. Consequently, they reinforce the importance of serum βHBA as a biomarker to evaluate the ruminal development of early-weaned calves (Deelen et al., 2016).

Another factor that may contribute to the initial decrease in ADG observed in W30 calves after weaning is their behavior in consequence to the stress of the weaning. In a parallel study conducted with the same animals, it was found that calves weaned at early ages (30 and 75 days old) exhibited increased activity compared with those weaned at conventional ages (Teixeira et al., 2021a). This increased activity was characterized by more time spent walking and vocalizing, as well as a decrease in feeding time (Teixeira et al., 2021a), which reduces feed intake and could help explain the initial variation in weight gain. These behavioural patterns are indicative of stress and may impact feed intake and weight gain (Price et al., 2003).

Stress levels can also be assessed by measuring cortisol levels, and it was found that W30 calves exhibited a 62% increase in cortisol levels on the first day after weaning (D0), which further increased to 205% on the second day after weaning (D1) compared with the W180 animals (Teixeira et al., 2021a). Elevated cortisol levels can affect glucose metabolism, leading to increased energy expenditure to recover homeostasis, which may impair other biological functions such as growth (Moberg, 2000), and help explain the differences observed in our study.

Although the weight was recovered in W30 calves, the delay in reestablishing postweaning feed intake had a negative impact on their morphometric growth at 180 days of age. These results are aligned with those of Curtis et al. (2018), who reported that low feed intake in young dairy calves temporarily affected their stature. Nonetheless, compensatory growth can be observed later (Curtis et al., 2018), as the skeletal system of calves continues to grow until they reach approximately 50% to 60% of their adult weight (Trenkle and Marple, 1983).

In our study, it was not possible to follow the development of the male calves after 190 days of age, owing to the management system of the experimental herd. However, a sequential study conducted by Lima et al. (2022) observed that weaning female calves at 30 days of age did not delay the onset of puberty or hinder their body development as heifers. This suggests that female calves can be weaned at 30 days of age without compromising their overall development, growth, and performance compared with those weaned at 75 and 180 days.

Moreover, previous studies have indicated that steers weaned at 80-90 days of age may produce better quality carcasses (Blanco et al., 2009; Waterman et al., 2012) with greater feed efficiency (Myers et al., 1999). Despite the lack of similar data for calves weaned at 30 days of age, the Kleiber ratio reported in our study indicates that W30 calves exhibited better efficiency of growth. This finding may encourage further investigation in this direction, exploring the potential benefits of early weaning in terms of growth efficiency.

5. Conclusions

Weaning beef calves at 30 days of age results in weight loss in the first ten days after weaning and negatively affects growth until 75 days of age. However, the early development of the rumen, facilitated by the ingestion of an adequate solid diet, and verified by the elevated levels of β-hydroxybutyrate, allow early-weaned calves to match the growth of calves weaned at a conventional age with better performance. Lastly, caution should be exercised when weaning beef calves at 30 days of age, and monitoring ruminal development through β-hydroxybutyrate measurements is recommended.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: Teixeira, O. S. and Barcellos, J. O. J. **Data curation:** Teixeira, O. S. and McManus, C. **Formal analysis:** Teixeira, O. S.; McManus, C. and Barcellos, J. O. J. **Funding acquisition:** Teixeira, O. S. and Barcellos, J. O. J. **Investigation:** Teixeira, O. S.; Camargo, V. A.; Rocha, M. K.; Alforma, A. M. P.; Sartori, E. D.; Rosa, Y. M. and Pérez-Atehortúa, M. **Methodology:** Teixeira, O. S.; Camargo, V. A.; Rocha, M. K.; Alforma, A. M. P.; Sartori, E. D.; Pérez-Atehortúa, M.; McManus, C. and Barcellos, J. O. J. **Project administration:** Barcellos, J. O. J. **Resources:** Barcellos, J. O. J. **Supervision:** Teixeira, O. S.; Rocha, M. K.; McManus, C. and Barcellos, J. O. J. **Visualization:** Teixeira, O. S. **Writing – original draft:** Teixeira, O. S.; Camargo, V. A.; Rocha, M. K.; Alforma, A. M. P.; Sartori, E. D.; Rosa, Y. M.; Pérez-Atehortúa, M. and McManus, C. **Writing – review & editing:** Teixeira, O. S.; Camargo, V. A.; Rocha, M. K.; Alforma, A. M. P.; Sartori, E. D.; Rosa, Y. M.; Pérez-Atehortúa, M.; McManus, C. and Barcellos, J. O. J.

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