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Extending the feeding period beyond 8.0 mm of subcutaneous fat reduces feed efficiency without improving meat colour and tenderness of non-implanted feedlot steers

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ABSTRACT. The effect of extending the pen-feeding period of non-implanted feedlot steers beyond the 8.0 mm fat thickness (FT) endpoint on performance, carcass and meat traits was evaluated. Sixty-four medium-sized British steers (308 ± 26 kg) were grouped into four blocks by weight and housed in 16 pens. Pens within each block were assigned to one of four finishing periods: 64, 91, 119 and 147 days on feed (DOF). The first harvest (64 DOF) was defined as the projected days to attain 8.0 mm FT. From the 8.0–13.8 mm FT endpoints (64 and 147 DOF, respectively), daily shrunk body weight (SBW) feed conversion increased from 9.98 to 15.76 kg/kg ($P < 0.001$), while daily carcass weight (CW) feed conversion increased from 15.34 to 18.27 kg/kg ($P < 0.001$). Carcass transfer (CW gain to SBW gain ratio) increased from 0.67 to 0.86 kg/kg. FT and marbling score increased at increasing rates during the finishing period ($P < 0.001$), whereas rib eye area increased at decreasing rates ($P < 0.001$). Extending the feeding period tended to improve meat tenderness at three days of ageing ($P = 0.066$), while there was no response at 14 days of ageing ($P > 0.10$). Overall, the 8.0 mm FT endpoint for non-implanted steers corresponded to proper performance and adequate meat quality.

Introduction

The feedlot feeding system is commonly used to achieve the animal endpoints and meat characteristics demanded by different markets. A minimum of 7.6 mm subcutaneous fat thickness (FT) is recommended to attain an adequate *post-mortem* muscle chilling rate to obtain the desired meat colour and tenderness (Page et al., 2001; Savell et al., 2005). Nonetheless, as some markets seek high marbling levels, animals are often kept on feed for longer periods. This increases meat marbling, but also other undesired fat deposits reducing feed efficiency on a body weight basis (Wilken et al., 2015; Volpi-Lagreca et al., 2021). However, as dressing percentage (DP) increases with the duration of the feeding period (Bruns et al., 2004; Vasconcelos et al., 2008), the reduction in feed efficiency is less significant when carcass weight (CW) is used instead of body weight (Wilken et al., 2015; Volpi-Lagreca et al., 2021).

It was suggested that if cattle were fed beyond the 7.6 mm subcutaneous FT endpoint, producers would maximize their profit by selling cattle based on CW rather than BW (Wilken et al., 2015; Bondurant et al., 2016). However, most previous studies were carried out in North America, where production systems usually use large-frame animals and frequently with steroidal implants that increase animal growth potential and improve feed efficiency (Maxwell et al., 2015). In this respect, the decrease in feed efficiency with increased feeding period may be steeper when feeding small- to medium-frame size steers with no implants (Hermesmeyer et al., 2000; Maxwell et al., 2015).

Another important aspect is the quality of the resulting product. As days on feed increase, FT grows linearly, while marbling score increases at a decreasing rate (May et al., 1992; Vasconcelos et al., 2008). An increase in marbling may improve meat tenderness (O´Quinn et al., 2018).

In this context, Volpi-Lagreca et al. (2021) suggested feeding non-implanted steers for 111 days, regardless of the feedlot placement weight. However, a recommendation based on days would not be as appropriate as one based on subcutaneous fat endpoints. The present study was conducted to assess the effects of extending the feeding period of steers without steroidal implants beyond the marketing endpoint of 8.0 mm ultrasound subcutaneous FT on steer performance, carcass characteristics, and meat tenderness.

Material and methods

Animals and diet

Animal management was approved by the Comité Institucional para el Cuidado y Uso de Animales de Experimentación (CICUAE – Protocol number: 174/2018, Balcarce, Argentina). The experiment was carried out from December 2018 to June 2019 at the Estación Experimental Agropecuaria Balcarce of the Instituto Nacional de Tecnología Agropecuaria (INTA), site on Balcarce, Argentina. Sixty-four small- to medium-sized British steers (Angus and Hereford × Angus, frame 4) were grouped into four blocks according to shrunk body weight (SBW) (308 ± 26 kg SBW; block I, 273 ± 8 kg SBW; block II, 299 ± 7 kg SBW; block III, 318 ± 7 kg SBW; block IV 342 ± 8 kg SBW) and housed in sixteen paved outdoor pens (4 animals/pen), with an area of 4.5 m^2/steer and 0.75 linear meters of feed bunk per steer. Selected steers were previously weaned at six to seven months of age and reared for eight months in mixed pastures (alfalfa, fescue, ryegrass and white clover) and corn silage supplementation during winter, resulting in an average daily body weight gain of 0.525 kg/day.

Four treatments were randomly assigned to pens in each block. The treatments consisted in four different extensions of the finishing period. The shortest time was defined as the projected days needed to achieve an ultrasound measurement of 8.0 mm FT between the 12th and 13th ribs on average, while the following harvests were performed consecutively at 28-day intervals. The projection was made using an FT ultrasound measurement at the beginning of the adaptation period (mean FT = 4.25 ± 0.65 mm) and an estimated post-adaptation fattening rate of 0.058 mm/day; hence, treatments lasted 64, 91, 119 and 147 days on feed (DOF). Day zero corresponded to the beginning of the final diet, which was started after an adaptation period of 19 days in which the proportion of corn grain in the diet was gradually increased. The final diet consisted in a typical finishing diet (Table 1). Each diet ingredient was sampled monthly and pooled for the entire experimental period. The pooled samples were dried at 60 °C for 48 h and milled to 1.0 mm for analysis. Each ingredient was assayed for the following parameters: crude protein, determined according to the method of Horneck and Miller (1998), neutral and acid detergent fibre according to Van Soest et al. (1991) using ANKOM 200 (ANKOM,

Table 1. Ingredients and chemical composition of diet

Diet ingredients, % in DM	
Dry milled corn	70.4
Corn silage	20.4
Sunflower expeller	6.2
Mineral supplement[1]	2.1
Urea	1.0
Chemical composition[2]	
crude protein,% in diet DM	11.5
neutral detergent fibre, % in diet DM	18.3
acid detergent fibre, % in diet DM	8.2
starch, % in diet DM	54.9
metabolisable energy, Mcal/kg DM	2.80

DM – dry matter; [1] supplement composition: %: calcium 15.7, phosphorus 0.6, magnesium 1.8, sulphur 1, salt 9.8; mg/kg: selenium 7.0, zinc 1254, manganese 1254, copper 352, cobalt 3.6, iodine 12, iron 800, monensin 1000; UI/kg: vit. A 104950, vit. D 3600, vit. E 130; [2] calculated from composition and *in vitro* digestibility of individual ingredients

Macedon, NY, USA), starch content according to MacRae and Armstrong (1968), and *in vitro* dry matter (DM) digestibility using a Daisy II incubator (ANKOM, Macedon, NY, USA).

Steers were fed once daily between 6:30 and 7:00 am during the summer, and between 8:00 and 8:30 am in the autumn. The amount of feed offered was adjusted daily to ensure access to feed *ad libitum*. The objective feed refusal was 0.2 kg DM per steer in the feed bunk before the next feeding. The diet was mixed and delivered using a vertical mixer (Metfer, Tres Arroyos, Buenos Aires, Argentina, capacity of 3 m^3) equipped with a scale (precision of 1.0 kg; Magris, Rufino, Santa Fe, Argentina), which was used to record the amount of feed distributed to each pen daily. Once a week, diet sample was taken and dried at 100 °C for 24 h to determine DM content. Refused feed was collected, weighted and sampled to determine DM content on a daily basis. Average steer DM intake (DMI) per pen was calculated daily as the difference between the feed offered and refused divided by the number of steers per pen. Since the feed bunks were uncovered, DMI from rainy days were removed from the analysis if refused feed could not be collected.

Steers were weighed at the end of the adaptation period (day zero), on day 28, and on each day of shipment to the slaughterhouse (days 64, 91, 119 and 147). Individual SBW were recorded using a Tru-Test 703 electronic scale (Tru-Test, San Antonio, TX, USA) between 8:00 and 9:00 am, after 18 h of feed access restriction. The fasting period was carried out for each weighing. Steers to be shipped were also weighed at the beginning of feed restriction to estimate shrinking percentage. Due to the restriction of feed imposed on the animals to obtain their SBW, and to prevent acidosis, the amount of feed offered was increased gradually to obtain the previous intake level within three days. These days were excluded from DMI estimations.

Real time carcass ultrasound measurements between the 12th and 13th ribs, comprising rib eye area (REA), marbling score and FT were performed at – 19, 28, 64, 91, 119 and 147 DOF, using an ExaGo ultrasound scanner (ECM, Angouleme, France). These measurements were carried out simultaneously with weighing to describe the evolution of these traits during the feeding period and to estimate the days needed to attain the 8.0 mm ultrasound FT endpoint.

After the final weighing of each slaughter group, the steers were kept without feed access until shipment at 1:00 pm. Then the steers were transported to the Azul Natural Beef commercial plant located in Azul, Buenos Aires, Argentina, 200 km from the experimental farm. The steers were slaughtered between 1:00 and 2:00 of the day after arrival.

Carcass characteristics and *longissimus thoracis* sampling

Hot CW was recorded for each animal, and individual DP was calculated by dividing hot CW by SBW from the day of shipping to the slaughterhouse. At 3 h *post-mortem*, *longissimus thoracis* pH and temperature were measured from the left side of each carcass between the 12th and 13th ribs, using a portable pH-meter (Sper Scientific model 850081, Scottsdale, AZ, USA). Approximately at 48 h *post-mortem*, pH and temperature were again recorded between the 12th and 13th ribs, and the section containing the 10th, 11th and 12th ribs was removed from the left side of each carcass. After 30 min of blooming, muscle and subcutaneous fat colour measures were obtained with a Minolta CR 310 Chroma meter (5 cm aperture diameter, D65-artificial, 10°angle, calibrated against a white plate; Minolta Corp., Ramsey, NJ, USA) from the caudal side of the collected sample. Marbling score (USDA, 2006), FT and REA were also determined from the same side. Carcass FT was measured at twothirds of the steak length using a gauge (Starrett, Athol Massachusetts, USA). REA was traced on acetate paper, scanned and calculated using the ImageJ software (Open scientific platform for image analysis; https://imagej.nih.gov/ij/).

Longissimus thoracis shear force and chemical analysis

The *longissimus thoracis* muscles obtained 48 h *post-mortem* were cut into two 2.5-cm-thick steaks, one 2.0-cm-thick steak and one 1.0-cm-thick steak. The 2.5-cm-thick steaks were aged at 5 °C in a vacuum package for a total of 3 and 14 days *post-mortem*, and subsequently stored at −20 °C. The 2.0-cm-thick steak was cut into cubes, vacuum-packaged, and stored at −20 °C three days *post-mortem*. The 1.0-cm-thick steak was chopped, vacuum-packaged, and stored immediately at −20°C.

Warner-Bratzler shear force of the *longissimus thoracis* muscle was measured for the two 2.5-cm-thick steaks, following the procedure described by Lucero-Borja et al. (2014). Sarcomere length in the 2.0-cm-thick steak, (using a 5-g sample) was estimated as described by Cross et al. (1981). The myofibrillar fragmentation index (MFI) was determined from the same steak based on a 0.5-g sample, following the procedure of Hopkins et al. (2004); sample protein concentration was determined using the Epoch Multi-Volume Spectrophotometer System (N°257878, BioTek Instruments Inc., Winooski, VT, USA).

Fat content of the *longissimus thoracis* muscle was estimated in the 1.0-cm-thick chopped steak by weight difference using petroleum ether with an XT10 Extractor (ANKON, Macedon, NY, USA).

Data analysis

Streeter et al. (2012) suggested that serial slaughter experiments should be tested with a regression approach to reduce the potential bias of period-based analysis. For the same purpose, Wilken et al. (2015) also incorporated intermediate measurements in their models.

In the present study, for traits with only one measurement at the time of slaughter (carcass and *longissimus thoracis* traits), linear mixed models were generated, including the block as a random effect and DOF divided into linear, quadratic, and cubic effects. For DP, the model was simplified to a first-order linear model, since no lack of fit was found.

In addition, for traits with repeated measurements through the feeding period (SBW, DMI and ultrasound measurements), linear mixed models were generated, including linear and quadratic effects of DOF as fixed effects (and cubic for DMI, since quadratic models showed lack of fit), and blocks and pens within blocks as random effects.

On the other hand, some variables were constructed from different models to estimate carcass transfer, SBW feed conversion and CW feed conversion. Changes in SBW gain and CW gain during the finishing period were calculated to estimate carcass transfer, i.e. the proportion of SBW gain that corresponded to CW gain. SBW gain rates were estimated using the derivatives of the second order linear mixed model SBW equations generated for each block, including pen as a random effect (since repeated SBW measurements were performed during the finishing period).

To estimate the CW gain changes during the finishing period, CW as a function of DOF was estimated by the product between the SBW model equation and the DP model equation of each block (for each block: CW (DOF) = SBW (DOF) × DP (DOF), with DOF between 64 and 147 days; Wilken et al., 2015). These DP models were generated as first order linear models for each block.

The evolution of CW gain during the finishing period was estimated by the derivative of the CW functions for each block. Similarly, carcass transfer was estimated by the ratio between CW gain and SBW gain. Estimates of the coefficients from each block equations were used to calculate the partial slopes of the equations with their deviations.

Daily SBW feed conversion and CW feed conversion were calculated by dividing the daily DMI measures of each pen by the estimates of daily SBW gain and CW gain using the equation of the corresponding block. Subsequently, third order linear mixed models for daily feed conversion were generated with DOF as fixed effects, and blocks and pens within blocks as random effects (as repeated measurements on the same experimental unit were performed throughout the finishing period). When the cubic effect was not significant, the model was simplified to a quadratic model.

To compare the evolution of SBW and CW feed conversion, mixed models were generated for two periods (64 to 119 and 119 to 147 DOF), including both feed conversions as different data subsets. These models included blocks and pens within block as random effects, DOF and the DOF* data subset interaction by including a dummy variable. The linear slopes of feed conversion were considered different if the DOF* data subset interaction was significant.

Statistical analyses were carried out using LME (mixed models) and LM (linear models) functions implemented in the R version 3.4.4 statistical software (R Core Team, 2018). ANOVA of these models were used to evaluate the effects, considered significant at $P < 0.05$ and as a tendency at $0.05 < P < 0.10$. For all statistical analyses, a pen was considered the experimental unit.

Results

Animal performance

SBW increased with DOF, but at a declining rate (linear and quadratic effect, $P < 0.001$; Figure 1A), while SBW gain decreased linearly with raising DOF ($P < 0.001$; Figure 2), from 1.623 kg/day on day zero to 0.653 kg/day on day 147 (60% decline). Shrinking percentage showed a quadratic response, reaching a maximum of 4.98% at 91 DOF (shrinking = 0.5921 (± 2.0623) + 0.1091 (± 0.0413) DOF − 0.0006 (± 0.0002) DOF^2, RSE = 0.593, R^2 = 0.683, linear: P = 0.087, quadratic: P = 0.016), while DP increased linearly with the extension of the feeding

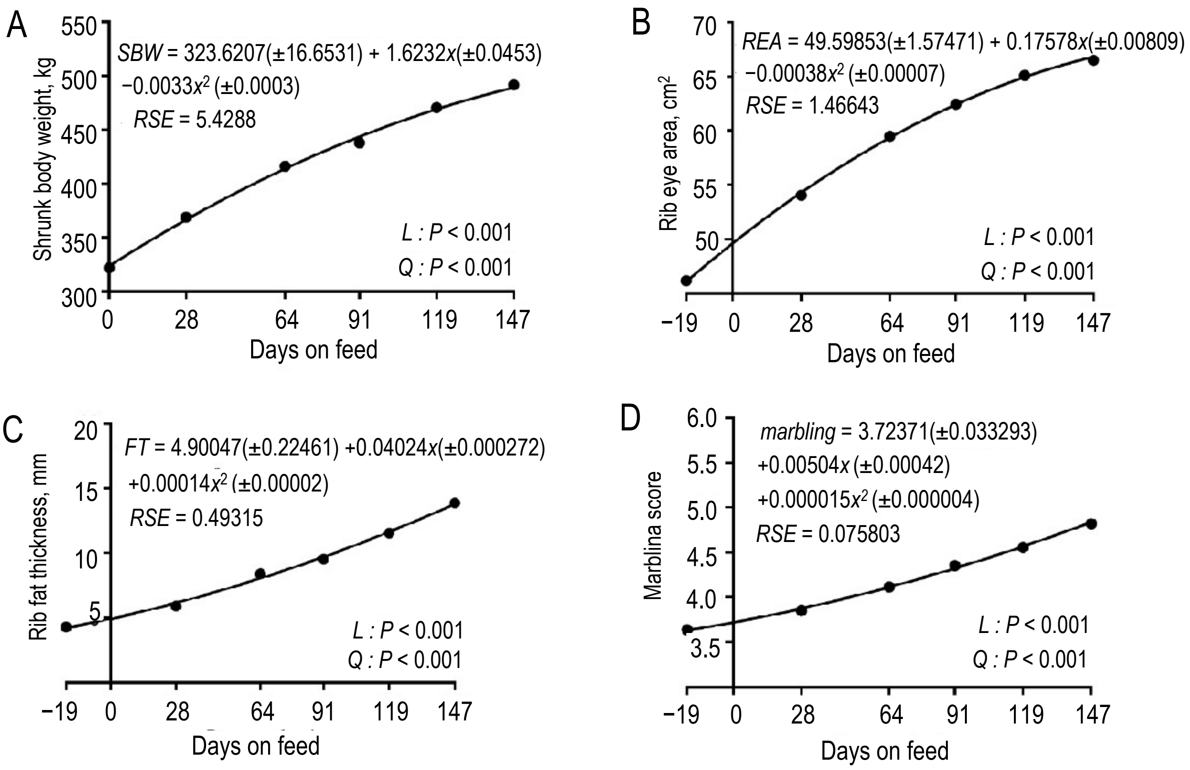

Figure 1. A) Shrunk body weight (SBW), B) Rib eye area (REA), C) Rib fat thickness (FT) and D) United States Department of Agriculture (USDA) marbling score (slight, 3.0; small, 4.0; modest, 5.0; moderate, 6.0) of feedlot steers during the feeding period. Day zero corresponds to the end of the adaptation period (19 days). Circles indicate mean values. RSE – model residual standard error. Significance of the linear (*L*) and quadratic (*Q*) effects of days on feed

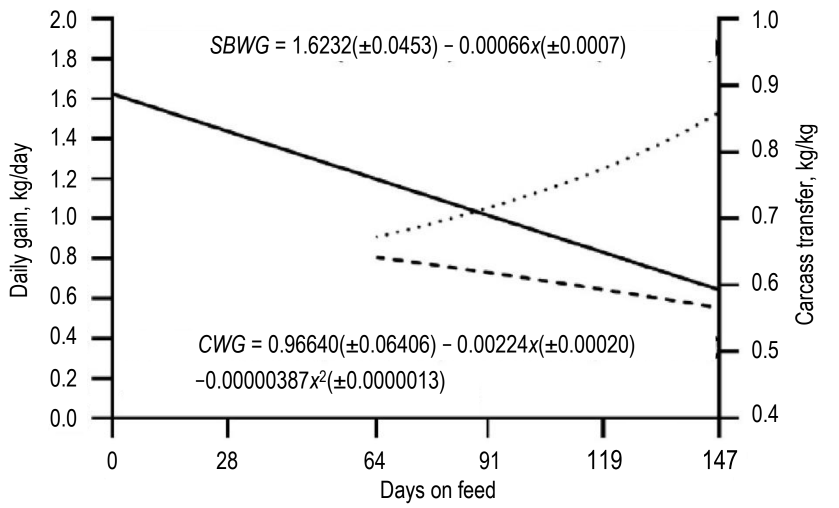

Figure 2. Shrunk body weight gain (SBWG, solid line), carcass weight gain (CWG, dashed line) and carcass transfer (CWG/SBWG ratio, dotted line) of feedlot steers during the feeding period. Day zero corresponds to the end of the adaptation period (19 days)

period, from 54.03% on day 64 to 57.23% on day 147 (DP = 51.814 (± 0.5328) + 0.0378 (± 0.0453) DOF, RSE = 0.541, $R^2 = 0.887$, $P < 0.001$). CW gain decreased at increasing DOF, but at a slower rate compared to SBW gain. Therefore, carcass transfer (CW gain/SBW gain ratio) increased at an increasing rate with longer feeding periods (Figure 2). Carcass transfer increased from 0.67 to 0.86 kg/kg from 64 to 147 DOF (28% increase).

DMI presented a cubic pattern of evolution throughout the feeding period (DMI = 9.95965 (± 0.2686) + 0.103544 (± 0.0047) DOF − 0.001401 (± 0.000079) DOF^2 + 0.000005 (± 0.00000038) DOF^3, RSE = 0.716, linear: $P < 0.001$, quadratic: $P < 0.001$, cubic: $P < 0.001$). The DMI peak was reached at 50 DOF (12.2 kg DM/day), after which it began to decline with a tendency to stabilize at 10.3 kg DM/day from 130 to 147 DOF.

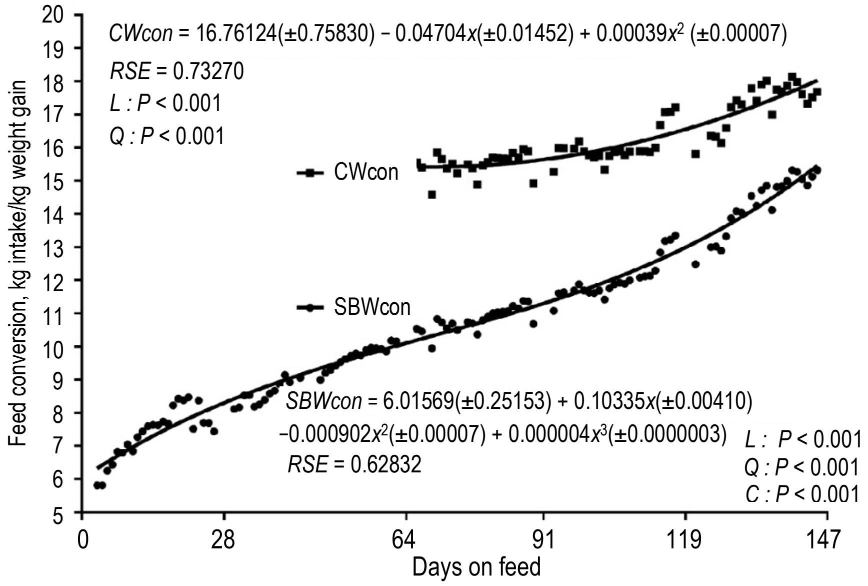

Figure 3. Feed conversion based on carcass weight (CWcon, squares) and shrunk body weight (SBWcon, circles) of feedlot steers during the feeding period. Squares and circles indicate daily mean CWcon and SBWcon, respectively. Day zero corresponds to the end of the adaptation period (19 days). RSE – model residual standard error. Significance of the linear (*L*), quadratic (Q) and cubic (*C*) effects of days on feed

Daily SBW feed conversion increased with the extension of the feeding period in a linear and cubic manner ($P < 0.001$; Figure 3). The inflection point was reached at day 69, where SBW feed conversion was 10.3 kg/kg. Beyond this feeding period (69 DOF), SBW feed conversion increased at an increasing rate. Daily CW feed conversion showed a linear and quadratic response ($P < 0.001$), remaining relatively stable from the first to the third harvest (64 to 119 DOF), between 15.3 and 16.7 kg/kg. Within this period, CW feed conversion increased at a lower rate than SBW feed conversion ($P < 0.001$), and after the third harvest (119 to 147 DOF) both increased at similar rates ($P = 0.061$).

Carcass characteristics

With the extension of the feeding period, the ultrasound model for REA showed a quadratic increase at a decreasing rate (Figure 1B), as the REA increase rate declined from 0.176 to 0.064 cm^2/day from 0 to 147 DOF (64% decline). The rate of REA growth relative to CW gain also decreased from 0.157 to 0.117 cm^2/kg from 64 to 147 DOF ($P < 0.001$). In contrast, both the FT and marbling score ultrasound models showed a quadratic increase, but at a rising rate (Figure 1C and 1d). The slope of the ultrasound FT model increased from 0.040 to 0.081 mm/day from 0 to 147 DOF (101% increase). The slope of the marbling score model in turn increased from 0.005 to 0.009 1/day from 0 to 147 DOF (87% increase).

Comparing the carcass data, REA, FT and marbling score increased linearly with longer finishing periods ($P < 0.05$; Table 2); only REA showed a trend of quadratic increase at a declining rate ($P = 0.070$). Carcass FT increased by 85% from the shortest to the longest finishing period, whereas REA and marbling score increased 14 and 16%, respectively. CW increased linearly ($P < 0.001$) and cubically ($P = 0.035$) from 226.4 to 281.3 kg from 64 to 147 DOF.

Extending the finishing period beyond the 8.0 mm ultrasound FT endpoint (64 DOF) increased the temperature of the *longissimus thoracis* muscle at 3 h *post-mortem* ($P < 0.001$), but did not affect muscle pH at this time point ($P > 0.15$; Table 2). Final *longissimus thoracis* pH and temperature showed a cubic response ($P < 0.001$), with pH ranging from 5.45 to 5.59, and temperature from 3.21 to 4.95 °C. Both muscle and fat colour parameters were affected by DOF ($P < 0.05$), except for the fat *b** value, which showed only a cubic trend ($P = 0.088$). The affected colour parameters exhibited a cubic response, with higher muscle values and lower fat values on day 119.

Longissimus thoracis shear force

Longissimus thoracis shear force of steaks aged for three days tended to decrease linearly ($P = 0.066$) with increasing DOF; however, shear force was not affected ($P \geq 0.206$) when steaks were aged for 14 days (Table 3).

Table 2. Effects of the extension of the feeding period of feedlot steers on carcass characteristics

	Days on feed				RSE	Significance[1]		
	64	91	119	147		*L*	*Q*	*C*
Carcass weight, kg	226.4	243.3	268.6	281.3	3.63	<0.001	0.198	0.035
REA, cm^2	57.6	62.6	66.3	65.8	2.74	0.001	0.070	0.679
FT, mm	7.1	7.4	11.1	13.2	1.38	<0.001	0.250	0.160
Marbling score[2]	4.17	4.50	5.09	4.85	0.32	0.005	0.099	0.166
pH-3 h	6.26	6.16	6.19	6.20	0.06	0.285	0.150	0.326
Temp-3 h, °C	19.5	26.0	26.0	32.2	0.97	<0.001	0.786	<0.001
pH-final	5.59	5.48	5.58	5.45	0.02	<0.001	0.601	<0.001
Temp-final, °C	3.88	4.49	3.21	4.95	0.12	<0.001	<0.001	<0.001
Muscle colour								
*L**	37.03	36.48	40.48	37.28	0.68	0.012	0.003	<0.001
*a**	14.9	15.11	17.25	15.8	0.91	0.042	0.094	0.026
*b**	13.48	13.41	15.37	13.72	0.56	0.059	0.017	0.001
Fat colour								
*L**	71.36	72.78	69.84	70.71	1.05	0.065	0.652	0.007
*a**	3.08	2.93	4.71	4.24	0.61	0.004	0.565	0.014
*b**	14.77	15.70	15.28	15.57	0.49	0.104	0.225	0.088

REA – rib eye area, FT – 12th rib fat thickness, RSE – residual standard error, *L** – lightness, from black (0) to white (100), *a** – redness, from green (negative values) to red (positive values), *b** – yellowness, from blue (negative values) to yellow (positive values); [1] significance of the linear (*L*), quadratic (*Q*) and cubic (*C*) effects of days on feed; [2] United States Department of Agriculture (USDA) marbling score (slight, 3.0; small, 4.0; modest, 5.0; moderate, 6.0)

Table 3. Effects of the extension of the feeding period of feedlot steers on *longissimus thoracis* shear force and fat conten

	Days on feed				RSE	Significance[1]		
	64	91	119	147		*L*	*Q*	*C*
Shear force, N								
3 days of ageing	49.1	43.4	44.0	38.0	6.97	0.066	0.965	0.425
14 days of ageing	34.6	32.9	31.8	32.1	3.19	0.271	0.544	0.929
Intramuscular fat, %	2.74	5.28	5.85	7.33	0.54	<0.001	0.073	0.037
Sarcomere length, μm	1.96	1.92	1.98	1.90	0.04	0.231	0.374	0.038
MFI	80.7	84.2	80.5	73.0	8.0	0.166	0.209	0.834

MFI – myofibrillar fragmentation index, RSE – residual standard error; [1] significance of the linear (*L*), quadratic (*Q*) and cubic (*C*) effects of days on feed

Sarcomere length showed a cubic response to lengthening the feeding period, but linear and quadratic effects were not significant (≥ 1.90 μm in all four slaughters).

The myofibrillar fragmentation index showed no response ($P \geq 0.166$) to the extension of the finishing period. Intramuscular fat content in the *longissimus thoracis* muscle increased linearly ($P < 0.001$) and cubically ($P = 0.037$) from 2.74 to 7.33% as DOF was extended from 64 to 147.

Discussion

Animal performance

The rate of SBW gain was expected to decrease linearly with increasing DOF ($P < 0.001$) and could be explained by an increase in maintenance energy costs with raising metabolic weight and energetic costs of gain (NRC, 1996). The latter increment was due to an increase in fat deposition and a reduction in lean tissue growth, as evidenced by a positive quadratic response of ultrasound subcutaneous FT and a negative quadratic response of ultrasound REA. In addition, a decrease in SBW gain with the extension of the feeding period occurred along with a reduction in DMI and hence energy intake. Thus, there was a reduction in net energy for growth (NRC, 1996).

The evolution of DMI during the feeding period was similar to the results published by Hicks et al. (1990). The reduction in feed consumption observed in this study could be attributed to an increase in leptin concentration associated with elevated carcass fatness (Foote et al., 2016), but also a reduction in lean tissue growth as a driver of intake (Webster, 1993). In this sense, Fox et al. (1988) suggested a 2.7% decrease in DMI per percentage point of empty body fat gain, between 21 to 32%. Similarly, DMI in the present study declined 2.2% per percentage point of increment of rib cut fat, between 21.5 and 28.3% (data not shown). In addition, beyond the 8.0 mm ultrasound FT endpoint, DMI declined 0.4 kg per mm increment in ultrasound FT (R^2 = 0.85).

The observed linear increase in DP with extended feeding time (0.0378% DP per day) was consistent with the observations of other authors (0.0229–0.0325% DP per day; Vasconcelos et al., 2008; Volpi-Lagreca et al., 2021). This rise in DP led to a higher carcass transfer with longer feeding periods. Carcass transfer was calculated using a regression approach, since period-based analysis may lead to a significant bias (Streeter et al., 2012). Wilken et al. (2015) reported that carcass transfer increased with a longer finishing period, reaching 0.90 kg/kg at the 12 mm FT endpoint. In the present study, the attained carcass transfer was 0.86 kg/kg at 13.2 mm FT.

The increase in carcass transfer suggested a reduction in gut fill and an allometric growth of carcass and non-carcass components of body weight (Streeter et al., 2012). In this aspect, Carstens et al. (1991) found that when steers were fed *ad libitum*, hot CW had a faster growth rate not only relative to full body weight, but also empty body weight. In contrast, non-carcass components showed a slower growth rate in relation to empty body weight. Accordingly, Volpi-Lagreca et al. (2021) found a reduction in liver, spleen, kidney, rumen, omasum and abomasum weights, as a percentage of body weight, when DOF increased.

In this study, similarly to previous works (Vasconcelos et al., 2008; Wilken et al., 2015; Bondurant et al., 2016), SBW feed conversion declined with the extension of the feeding period. As described above, the decrease in efficiency could be attributed to reduced SBW gain, increased maintenance energy costs and higher energetic cost of gain (NRC, 1996).

Volpi-Lagreca et al. (2021) reported no differences in SBW feed conversion between the 6.0 and 11.5 mm ultrasound FT endpoints (54 to 111 DOF), followed by an increase when animals where fed up to the 13.0 mm ultrasound FT endpoint (145 DOF). However, feed conversion was calculated from the beginning of the adaptation period to the harvest of each treatment. With this approach, extending the feeding period would dilute the lower weight gains obtained during the adaptation periods and, hence, the daily decrease in SBW gain would be underestimated.

CW feed conversion remained relatively stable as DOF increased from the 8.0 mm ultrasound FT endpoint (64 DOF) until approximately 119 DOF, where 11.7 mm ultrasound FT was reached. The stability in feed conversion based on CW could be mainly explained by the increase in carcass transfer. Volpi-Lagreca et al. (2021) reported that, even though CW feed conversion remained stable through the feeding period, it tended to be better for steers fed for 111 days than those fed for 145 days (11.5 and 13.0 mm ultrasound FT, respectively).

The deterioration of CW feed efficiency beyond the 11.7 mm ultrasound FT endpoint, despite the increase in carcass transfer, implicated that the higher energetic cost of gain (due to the increase in fat deposition) offset the effect of the increase in carcass transfer.

Although the feed conversion response was similar to that reported by Wilken et al. (2015), there were significant differences between the values obtained. Wilken et al. (2015) reported mean SBW feed conversion between 5.29 and 7.51 kg/kg, and mean CW feed conversion between 8.01 and 9.05 kg/kg, whereas in the present study, these values ranged from 6.02 to 15.76 kg/kg, and from 15.34 to 18.27 kg/kg, respectively.

The DMI value measured in the current work was 24.6% higher than the expected value that would cover the estimated requirements considering SBW and SBW gain parameters (NRC, 1996). This demonstrated a significant difference in the efficiency that could not be attributed to variations in ration composition, as all trials analysed by Wilken et al. (2015) also used high concentrate diets (ranging from 40 to 75% dry rolled or high moisture corn, and 0 to 40% corn milling by-product). Hence, the differences in efficiency could at least be partially attributed to the larger frame size and the application of steroidal implants in the studies analysed by Wilken et al. (2015). This indicated a significant loss in feed efficiency with extended DOF in production systems using small- to medium-frame steers without steroidal implants, which was in line with the study of Hermesmeyer et al. (2000).

Differences in growth potential, due to variation in frame and the use of steroidal implants (Maxwell et al., 2015) can be determined by comparing body weight at the same fat content. In previous studies, at the endpoint of 12 mm FT, mean body weights ranged from 510 to 532 kg when no steroidal implants were used (Bruns et al., 2004; Volpi-Lagreca et al., 2021) and between 529 and 625 kg when these implants were applied (Vasconcelos et al., 2008; Wilken et al., 2015; Bondurant et al., 2016). In the present study, the mean body weight was 470 kg at the 11.1 mm FT endpoint.

Carcass characteristics

The decreasing rate of REA growth was in line with the reports of Bondurant et al. (2016), who found that REA increase rates of 0.292 cm^2/day at the beginning of the finishing period were reduced to 0.053 cm^2/day at 185 DOF. However, the higher initial REA growth rates and maximum areas obtained in previous studies (76.6–99.1 cm^2; May et al., 1992; Bruns et al., 2004; Vasconcelos et al., 2008; Volpi-Lagreca et al., 2021) indicated a lower growth potential of steers used in the present study, as noted above.

Bondurant et al. (2016) also pointed out that FT grew at an increasing rate with an increasing finishing period. However, other authors (May et al., 1992; Vasconcelos et al., 2008) reported linear responses, but intermediate ultrasound measurements during the feeding period were not included in their models.

On the other hand, the linearly increasing marbling score was consistent with the results of Bondurant et al. (2016). Nevertheless, this response was not in line with the declining growth rate reported in earlier studies (May et al., 1992; Vasconcelos et al., 2008).

Chemical intramuscular fat is a more precise predictor than marbling score, as the latter is a subjective trait and, additionally, there are triglycerides and phospholipids that are not visible to the human eye. For this reason there is a moderate correlation between marbling and intramuscular fat (Stewart et al., 2021), which has been confirmed in the present study ($r^2 = 0.527$).

According to Pethick et al. (2004), intramuscular fat deposition occurs in three phases: an early stage where intramuscular fat remains low and nearly constant, a phase of linear increase, followed by a plateau in intramuscular fat deposition when mature body size is reached. The authors suggested that the linear increase occurred because intramuscular fat deposition relative to total fat content remained constant, while the muscle growth rate was reduced. In the present study, the extension of the feeding period beyond the 8.0 mm ultrasound FT endpoint remained within this linear phase, whereas the period before the first slaughter corresponded to the slow deposition phase, which would explain the positive quadratic response found when considering the entire finishing period.

The colour of muscle and fat are the main attributes that guide consumers in their purchasing decisions. In the present study, bright meat colour was attained in all feeding periods, according to the range of the *L** values suggested by Page et al. (2001).

As regards fat colour, the reduction in yellowness (*b**) during the finishing period is relevant for pasture-reared steers, as this colour is undesirable to consumers (Dunne et al., 2009). Typically, the *b** values obtained with concentrate feeding are lower than those acquired with pasture feeding (Dunne et al., 2009). In the present study, the mean *b** value (15.3) was lower than that reported by Melucci et al. (2012) for grazing steers in Argentina (19.2). On the other hand, extending the finishing period after 64 DOF in the current work did not affect fat yellowness. This suggests that 64 days on a high concentrate diet would be sufficient to reduce subcutaneous fat yellowness of pasture-reared young steers, which is consistent with Dunne et al. (2009).

Shear force

When steaks were aged for a short period of time (three days), shear force tended to decrease as the finishing period increased. As expected, the 8.0 mm ultrasound FT endpoint (64 DOF), where the mean carcass FT reached 7.1 mm, was sufficient to achieve an adequate *post-mortem* chilling rate of the *longissimus thoracis* muscle and an appropriate glycolytic rate (Savell et al., 2005). This in turn resulted in adequate sarcomere lengths. Despite the observed cubic effect for sarcomere length, as it was above 1.90 μm, no negative effect was expected with respect to shear force (Battaglia et al., 2019).

Consistently with the obtained final pH (pH < 5.80), appropriate for proteases activity (Lomiwes et al., 2014), no differences were observed in myofibrillar protein degradation at three days *post-mortem*. Hence, there were no differences in shear force that could be explained by myofibrillar degradation three days after death. Therefore, the tendency found for shear force with short ageing periods could be attributed to an increase in intramuscular fat content. Accordingly, O´Quinn et al. (2018) indicated that marbling score explained 15% of tenderness variation. Moreover, Nishimura (2015) suggested that intramuscular fat affected tenderness because its deposition between the muscle fibres packs weakened the structure of intramuscular connective tissue.

Conclusions

Overall, the 8.0 mm ultrasound FT endpoint for non-implanted feedlot steers is sufficient to achieve proper feed efficiency and to obtain bright and tender meat, especially if aged for 14 days. The economic response of extending the feeding period would depend on the current market and pricing conditions. However, considering the feed conversion values obtained, the cost of feeding cattle longer would exceed the economic value of SBW or CW increase, resulting in a negative economic impact for this type of systems.

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Conflict of interest

The Authors declare that there is no conflict of interest.

References

Battaglia C., Vilella G.F., Bernardo A.P.S., Gomes C.L., Biase A.G., Albertini T.Z., Pflanzer S.B., 2019. Comparison of methods for measuring shear force and sarcomere length and their relationship with sensorial tenderness of longissimus muscle in beef. J. Texture Stud. 1, 1–11, https://doi.org/10.1111/jtxs.12473

Bondurant R.G., MacDonald J.C., Erickson G.E., Brooks K., Funston R.N., Bruns, K.W., 2016. Carcass gain, efficiency, and profitability of steers at extended days on feed. Nebraska Beef Cattle Reports 859, 91–95, https://digitalcommons.unl.edu/animalscinbcr/859

Bruns K.W., Pritchard R.H., Boggs D.L., 2004. The relationships among body weight, body composition, and intramuscular fat content in steers. J. Anim. Sci. 82, 1315–1322, https://doi.org/10.2527/2004.8251315x

Carstens G.E., Johnson D.E., Ellenberger M.A., Tatum J.D., 1991. Physical and chemical components of the empty body during compensatory growth in beef steers. J. Anim. Sci. 69, 3251–3264, https://doi.org/10.2527/1991.6983251x

Cross H.R., West R.L., Dutson T.R., 1981. Comparison of methods for measuring sarcomere length in beef *semitendinosus* muscle. Meat Sci. 5, 261–266, https://doi.org/10.1016/0309-1740(81)90016-4

Dunne P.G., Monahan F.J., O'Mara F.P., Moloney A.P., 2009. Colour of bovine subcutaneous adipose tissue: A review of contributory factors, associations with carcass and meat quality and its potential utility in authentication of dietary history. Meat Sci. 81, 28–45, https://doi.org/10.1016/j.meatsci.2008.06.013

Foote A.P., Tait Junior R.G., Keisler D.H., Hales K.E., Freetly H.C., 2016. Leptin concentrations in finishing beef steers and heifers and their association with dry matter intake, average daily gain, feed efficiency, and body composition. Domest. Anim. Endocrinol. 55, 136–141, https://doi.org/10.1016/j.domaniend.2015.12.007

Fox D.G., Sniffen C.J., O'Connor J.D., 1988. Adjusting nutrient requirements of beef cattle for animal and environmental variations. J. Anim. Sci. 66, 1475–1495, https://doi.org/10.2527/jas1988.6661475x

Hermesmeyer G.N., Berger L.L., Nash T.G., Brandt R.T., 2000. Effects of energy intake implantation, and subcutaneous fat end point on feedlot steer performance and carcass composition. J. Anim. Sci. 78, 825–831, https://doi.org/10.2527/2000.784825x

Hicks R.B., Owens F.N., Gill D.R., Oltjen J.W., Lake R.P., 1990. Dry matter intake by feedlot beef steers: influence of initial weight, time on feed and season of the year received in yard. J. Anim. Sci. 68, 254–265, https://doi.org/10.1093/ansci/68.1.254

Hopkins D.L., Martin L., Gilmour A.R., 2004. The impact of homogenizer type and speed on the determination of myofibrillar fragmentation. Meat Sci. 67, 705–710, https://doi.org/10.1016/j.meatsci.2004.01.011

Horneck W.H., Miller R.O., 1998. Determination of total nitrogen in plant tissue. In: Y.P. Kalra (Editor). Handbook of reference methods for plant analysis. Soil and Plant Analysis Council, Inc. CRC Press. Boca Raton, FL (USA), pp. 75–83, https://doi.org/10.1201/9781420049398.ch9

Lomiwes D., Farouk M.M., Wu G., Young O.A., 2014. The development of meat tenderness is likely to be compartmentalised by ultimate pH. Meat Sci. 96, 646–651, https://doi.org/10.1016/j.meatsci.2013.08.022

Lucero-Borja J., Pouzo L.B., de la Torre M.S., Langman L., Carduza F., Corva P.M., Santini F.J., Pavan E., 2014. Slaughter weight, sex and age effects on beef shear force and tenderness. Livest. Sci. 163, 140–149, https://doi.org/10.1016/j.livsci.2014.02.003

MacRae J.E., Armstrong D.G., 1968. Enzyme method for determination of alpha-linked glucose polymers in biological materials. J. Sci. Food Agric. 19, 578–581, https://doi.org/10.1002/jsfa.2740191006

Maxwell C.L., Bernhard B.C., O'Neill C.F. et al., 2015. The effects of technology use in feedlot production systems on feedlot performance and carcass characteristics. J. Anim. Sci. 93, 1340–1349, https://doi.org/10.2527/jas.2014-8127

May S.G., Dolezal H.G., Gill D.R., Ray F.K., Buchanan D.S., 1992. Effects of days fed, carcass grade traits, and subcutaneous fat removal on post-mortem muscle characteristics and beef palatability. J. Anim. Sci. 70, 444–453, https://doi.org/10.2527/1992.702444x

Melucci L.M., Panarace M., Feula P. et al., 2012. Genetic and management factors affecting beef quality in grazing Hereford steers. Meat Sci. 92, 768–774, https://doi.org/10.1016/j.meatsci.2012.06.036

Nishimura T., 2015. Role of extracellular matrix in development of skeletal muscle and post-mortem aging of meat. Meat Sci. 109, 48–55, https://doi.org/10.1016/j.meatsci.2015.05.015

NRC (National Research Council), 1996. Nutrient requirements of beef cattle. National Academy Press. Washington, DC (USA)

O'Quinn T.G., Legako J.F., Brooks J.C., Miller M.F., 2018. Evaluation of the contribution of tenderness, juiciness, and flavour to the overall consumer beef eating experience. Transl. Anim. Sci. 2, 26–36, https://doi.org/10.1093/tas/txx008

Page J.K., Wulf D.M., Schwotzer T.R., 2001. A survey of beef muscle color and pH. J. Anim. Sci. 79, 678–687, https://doi.org/10.2527/2001.793678x

Pethick D.W., Harper G.S., Oddy V.H., 2004. Growth, development and nutritional manipulation of marbling in cattle: a review. Aust. J. Exp. Agric. 44, 705–715, https://doi.org/10.1071/EA02165

R Core Team, 2018. R: a language and environment for statistical computing. R Foundation for Statistical Computing. Vienna (Austria), https://www.r-project.org

Savell J.W., Mueller S.L., Baird B.E., 2005. The chilling of carcasses. Meat Sci. 70, 449–459, https://doi.org/10.1016/j.meatsci.2004.06.027

Stewart S.M., Gardner G.E., McGilchrist P., Pethick D.W., Polkinghorne R., Thompson M., Tarr G., 2021. Prediction of consumer palatability in beef using visual marbling scores and chemical intramuscular fat percentage. Meat Sci. 181, 108322, https://doi.org/10.1016/j.meatsci.2020.108322

Streeter M.N., Hutcheson J.P., Nichols W.T., Yates D.A., Hodgen J.M., Vander Pol K.J., Holland B.P., 2012. Review of large pen serial slaughter trials - growth, carcass characteristics, feeding economics. Proceedings of the 2012 Plains Nutrition Council Spring Conference. Amarillo, TX (USA), pp. 58–73

USDA (United States Department of Agriculture), 2006. Official United State standards for grades of carcass beef. Agricultural Marketing Service. Washington, DC (USA), pp. 1–4

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, 3583–3597, https://doi.org/10.3168/jds.S0022-0302(91)78551-2

Vasconcelos J.T., Rathmann R.J., Reuter R.R., Leibovich J., McMeniman J.P., Hales K.E., Covey T.L., Miller M.F., Nichols W.T., Galyean M.L., 2008. Effects of duration of zilpaterol hydrochloride feeding and days on the finishing diet on feedlot cattle performance and carcass traits. J. Anim. Sci. 86, 2005–2015, https://doi.org/10.2527/jas.2008-1032

Volpi-Lagreca G., Gelid L.F., Alende M., Bressan E.R., Pordomingo A.B., Pordomingo A.J., 2021. Effect of placement weight and days on feed on feedlot cattle performance and carcass traits. Livest. Sci. 244, 104392, https://doi.org/10.1016/j.livsci.2020.104392

Webster A.J.F., 1993. Energy partitioning, tissue growth and appetite control. Proc. Nutr. Soc. 52, 69–76, https://doi.org/10.1079/PNS19930038

Wilken M.F., MacDonald J.C., Erickson G.E., Klopfenstein T.J., Schneider C.J., Luebbe K.M., Kachman S.D., 2015. Marketing strategy influences optimum marketing date of steers in relation to corn price and days on feed. Prof. Anim. Sci. 31, 224-236, https://doi.org/10.15232/pas.2014-01325