

Timing of corn grain feeding during fattening: effects on animal performance, carcass characteristics, and meat quality

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ABSTRACT - The study evaluates the impact of feeding the same amount of corn grain at different times on animal production, carcass characteristics, and meat quality. At weaning, 60 steers (176 kg) were divided into six groups assigned to one of two dietary treatments ($n = 3$). In dietary treatment one (DT1), steers grazed an endophyte-free tall fescue pasture to 330 kg of LW and then (Phase-3) were fed a corn grain-based diet for 90 d before slaughter. In dietary treatment two (DT2), steers were fed a cracked corn grain-based diet for 90 d after weaning (Phase-1) and then grazed until slaughter, being supplemented with cracked corn grain in Phase-3. To reach the same total amount of grain intake in both treatments, in Phase-3, DT2 was supplemented with the amount of grain being fed to DT1 minus DT2 average grain intake in Phase-1. The average daily gain in DT1 was lower in Phase-1 than in DT2, but greater in Phase-2 and Phase-3. Final live weight, hot carcass weight, ribeye area and subcutaneous fat thickness were greater ($P < 0.05$) in DT1 than in DT2, but marbling score and intramuscular fat content did not differ ($P > 0.100$). Meat from DT1 had greater L^* , a^* , and b^* values than DT2 ($P < 0.05$), but the subcutaneous fat had a lower b^* -value ($P < 0.001$). The *longissimus dorsi* muscle shear-force did not differ ($P = 0.255$), and minor differences were observed in meat fatty acid composition. The n-6:n-3 ratio and C18:1 *trans*-10/*trans*-11 proportion were greater ($P < 0.050$), and the C20:5 proportion was lower ($P = 0.002$) in DT1 than in DT2. Thus, the corn grain feeding strategy during the fattening period did not affect meat marbling score or intramuscular fat content, shear force, or fatty acid profile, but did affect meat color as well as subcutaneous fat thickness and color.

Keywords: beef, color, grazing, intramuscular fat, marbling, shear-force

1. Introduction

In general, greater intramuscular fat (IMF) content in meat has been associated with greater meat palatability (Savell and Cross, 1988; Fořtová et al., 2022). This is the primary reason why IMF has been

included as a key quality indicator in the beef grading system of several countries (Polkinghorne and Thompson, 2010). However, consumer preferences for visible fat vary between countries (Testa et al., 2021; Fořtová et al., 2022). Nonetheless, a minimum of 3% IMF has been suggested as necessary to ensure beef palatability (Savell and Cross, 1988). Therefore, beef producers must understand how to manage animals effectively to achieve the desired IMF content.

Different studies have evaluated meat quality from cattle finished on concentrate or pasture diets (Realini et al., 2004; Duckett et al., 2007; Duckett et al., 2013). Others have examined the impact of grain supplementation on meat quality (Wright et al., 2015; Pavan and Duckett, 2019). The effects of feeding a highly concentrated diet at early weaning (Moisá et al., 2014; Scheffler et al., 2014) or at weaning (Koch et al., 2018) have also been evaluated. However, no studies have specifically assessed the effect of supplying a fixed amount of corn grain at different production phases on animal performance and meat quality characteristics.

In general, when comparing concentrate- and pasture-fed animals, those finished on concentrate diets exhibit greater fat content, brighter meat, and whiter subcutaneous fat color than pasture-fed counterparts (Duckett et al., 2007; Duckett et al., 2013; Pavan and Duckett, 2019). In these studies, meat shear force and tenderness outcomes varied, with some reporting lower shear force (greater tenderness) for concentrate-fed animals, while others found no significant differences. When pasture-fed animals were supplemented with 0.7% of their body weight (BW) with corn grain, meat characteristics were intermediate between those fed exclusively concentrate or pasture diets (Pavan and Duckett, 2019). Furthermore, when the phase of concentrate diet feeding (weaning or finishing) was evaluated, animals fed a concentrate diet at weaning took longer to reach slaughter weight and had thinner and yellower subcutaneous fat. However, animals fed the concentrate diet at weaning had similar IMF content, meat color, and shear force after 14 d of aging compared with animals fed the concentrate diet at finishing (Koch et al., 2018). In this study, steers fed the concentrate at weaning received a diet with 63% corn grain for 110 days, and steers fed the concentrate at finishing received a diet with 70% corn grain for 87 days.

Consumers consider meat and fat color when making purchasing decisions (Dunne et al., 2009). Yellow fat is generally associated with older animals and perceived negatively by consumers. However, different studies have shown that animals of similar age can have varying fat color based on their fresh forage intake (Duckett et al., 2007; Duckett et al., 2013; Pavan and Duckett, 2019). Extending the grazing period before finishing steers with a concentrate diet for 49 or 98 days did not impact the subcutaneous fat color, but extending the finishing period resulted in whiter fat (Pavan et al., 2023). Koch et al. (2018) reported that steers fed a corn grain diet at weaning and pasture at finishing exhibited similar fat color as steers that were always on pasture, but it was more yellow than that of steers fed pasture at weaning and a corn grain diet at finishing.

Different studies have evaluated the effect of feeding concentrate, pasture, or pasture plus supplement on meat fatty acid profile (Daley et al., 2010; Duckett et al., 2013; Wright et al., 2013; Pavan and Duckett, 2019). In general, it has been shown that as the proportion of concentrate or corn grain in the diet increases, the proportions of palmitic and monounsaturated fatty acids increase, whereas the proportion of stearic acid and the ratio of polyunsaturated n-6:n-3 decrease. Furthermore, these studies also reported that as the proportion of concentrate or corn grain in the diet increases, the proportions of two anticarcinogenic fatty acids (C18:1 *trans*-11 and C18:2 *cis*-9, *trans*-11) declined. Koch et al. (2018) evaluated the effect of feeding corn grain diets at weaning or finishing, obtaining similar results as those studies that evaluate finishing animals on pasture, pasture plus supplement, or concentrate diets. However, there is no report of the effect of offering the same amount of corn grain throughout the fattening period, but at different production phases.

It is hypothesized that a minimal impact on carcass and meat quality characteristics should be expected if the same amount of corn grain is fed at different times during the fattening period. Therefore, the present study aimed to evaluate the effects of feeding a fixed amount of cracked corn grain at different phases during the fattening period on animal performance, carcass characteristics, and meat quality.

2. Material and methods

The study was conducted at the experimental farm and the meat quality laboratory of INTA Balcarce, located in Balcarce, Buenos Aires, Argentina. Animal care and handling procedures were approved by the Institutional Animal Care and Use Committee (CICUAE #146/2018) of the National Institute of Agricultural Technology (INTA).

2.1. Animals and diets

Sixty British cross steers (Angus, Hereford) ($172 \text{ kg} \pm 15.6 \text{ kg}$ body weight; BW) from the same herd were blocked by BW in three blocks (light, medium, and heavy: 156 ± 8 , 169 ± 10 , $188 \pm 11 \text{ kg}$ BW, respectively) of 20 animals each. Then, animals within each block were randomly distributed to one of two dietary treatments (DT, 10 animals per treatment), resulting in three groups of 10 animals each per treatment, with the group as the experimental unit ($n = 3$). Treatments were defined by the phase in which the corn-based diet was offered. In one treatment (DT1), animals grazed during the rearing period (Phase-1 and Phase-2) and received a cracked corn grain-based diet during the finishing period (Phase-3). In the other treatment (DT2), animals were fed a cracked corn grain-based diet during the first 90 d (Phase-1) and then were kept grazing until slaughter (Phase-2 and Phase-3) but were supplemented with cracked corn grain in Phase-3 (Figure 1). The amount of corn grain supplemented to DT2 in Phase-3 was equivalent to the amount of corn grain fed to DT1 minus the average grain fed to DT2 during Phase-1. Therefore, the total amount of corn grain fed to DT1 and DT2 throughout the study was expected to be the same. Phase-1 lasted 90 d, and Phase-2 ended when animals reached an average BW of 330 kg. During Phase-1 and Phase-3 each block of a given treatment was assigned to a feeding pen or a pasture plot (10 animals each). In Phase-2 (120 d) all animals were rotationally grazed as a group. Throughout the study, animals grazed two pastures: one with *Medicago sativa* and *Festuca arundinacea*, and the other with *Festuca arundinacea*, *Trifolium repens*, and *Trifolium pratense*. Animals were moved to a new grazing paddock when the pasture height determined with a plate meter was 5 cm. The grain-based diets used in Phase-1 and Phase-3 were formulated to contain 13 and 11% of CP, respectively (Table 1).

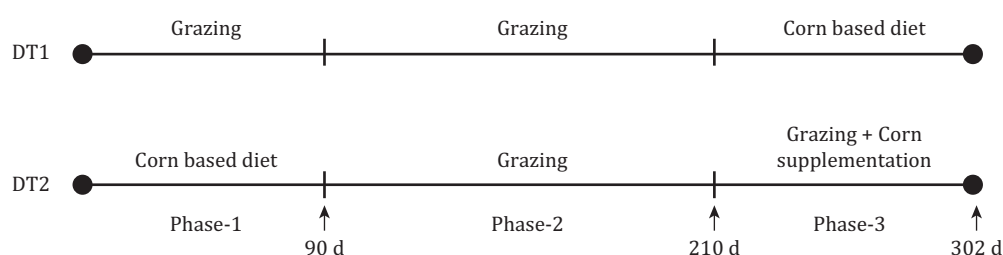


Figure 1 - Diagram of the distribution of diets throughout the trial for each of the treatments.

Table 1 - Concentrate composition used in Phase-1 and Phase-3 of the fattening period

	Phase 1	Phase 3
Concentrate ingredient composition (% DM)		
Cracked corn grain	68.67	70.02
Corn silage	17.25	20.87
Sunflower meal	11.25	-
Sunflower expeller	-	5.90
Urea	0.85	0.96
Mineral supplement ¹	1.98	2.25

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; IU/kg: vit. A 104950, vit. D 3600, vit. E 130.

Refusals of the corn grain diets were collected and measured daily. Feedstuffs and pasture samples were collected every 21 d to determine their dry matter (DM; oven dried at 60 °C for 48 h), crude protein (CP; Leco Corp., St. Joseph, MI), neutral and acid detergent fiber (NDF and ADF; Ankom 200 fiber extractor, Ankom Technologies, Fairport, NY) and starch (MacRae and Armstrong, 1968) content (Table 2). The total corn grain intake was 20.80 and 20.19 tons of DM for DT1 and DT2, respectively (Table 3).

The BW of each animal was recorded after an overnight feed withdrawal (16 h) at the beginning of the study (0 d) and at the end of each phase (90, 210, and 302 d). Additionally, the individual BW was determined every 21 d without feed withdrawal. At the end of each phase, individual ultrasound measurements were taken to estimate the intramuscular fat content (IMFu), the subcutaneous fat thickness (SFTu), and the ribeye area (REAu) in the region of the 12-13th rib of the left side of the animal using an ExaGo ultrasound instrument fitted with a 3.5-MHz probe (ExaGo, IMV Imaging, France). Images were analyzed using PowerEco software (ExaGo, IMV Imaging, France). At the end of the study, all animals were transported (200 km) to a commercial slaughterhouse on two consecutive days (302 and 306 d) and were harvested the following morning.

Table 2 - Feedstuffs and pastures dry matter (DM) content and chemical composition

	Pasture			Corn grain	Corn silage	SFM	SFE
	Phase 1	Phase 2	Phase 3				
Dry matter (g/100 g as fed)	23.5	25.20	29.16	85.72	35.54	88.58	92.33
Chemical composition (% DM)							
Crude protein	25.65	24.60	20.80	8.35	7.60	27.85	34.50
Neutral detergent fiber	42.45	44.30	38.30	14.90	33.00	33.50	38.10
Acid detergent fiber	21.40	19.60	20.60	4.20	17.80	23.40	26.30
Starch	-	-	-	66.50	34.90	-	-

SFM - sunflower meal; SFE - sunflower expeller.

Table 3 - Total, pasture, corn grain, and other dietary component diet dry matter intake (DMI) during the fattening period of steers fed corn grain in the finishing diet (DT1) or in the weaning diet and as a supplement during the finishing phase (DT2)

	DT1	DT2	SEM	P-value
Dry matter intake (kg/animal)				
Total	1877	1741	22	0.051
Pasture	868	850	15	0.474
Corn grain	717	712	15	0.820
Other dietary component	292	180	5	0.003

SEM - standard error of the mean.

2.2. Carcass quality measurements

The hot carcass weight (HCW) was recorded at harvest, and the muscle pH and temperature were measured (portable pH-meter, Sper Scientific) on the *longissimus thoracis* (LT) muscle between the 12th and 13th ribs from the left side of the carcass at 3 h postmortem (pH@3h and Temp@3h, respectively). The LT muscle's final pH was recorded from a similar position at 48 h postmortem (pHf). Then the left LT muscle was cut between the 12th and 13th ribs to determine the SFT, the REA, the marbling score (MS), and the meat color. The subcutaneous fat thickness (SFT) was measured with a manual caliper (Starrett®, Athol, Massachusetts, US), and the ribeye area (REA) was traced and

determined with ImageJ[®] software. Marbling was assessed using USDA beef marbling standards (200 = traces⁰⁰, 300 = slight⁰⁰, 400 = small⁰⁰, 500 = modest⁰⁰, 600 = moderate⁰⁰, 700 = slightly abundant⁰⁰) by a single trained evaluator. Meat color was recorded using a Minolta CR-700 with Spectra (Minolta Canada Inc., Mississauga, ON) to obtain values for L^* (measures darkness to lightness; lower L^* indicates a dark color), a^* (measures redness and greenness; greater a^* value indicates a redder color), and b^* (measures yellowness and blueness; greater b^* value indicates a more yellow color). The instrumental conditions were large area aperture (5 cm diameter), D65 illuminant, and 10° standard observation angle. The instrument was calibrated against a white plate. Samples were allowed to bloom for 30 min before color determination. The values from six scans were averaged for each color determination. At 48 h postmortem, the subcutaneous fat color was also determined following the same protocol as for the LT color determinations. Then, the loin section containing the 10th to 13th ribs was removed from each left carcass side and transported at 2–4 °C to the Meat Quality Laboratory at INTA Balcarce.

2.3. Sample preparation and chemical analysis

The LT muscle was obtained from each loin section, removing all external fat and connective tissues. Samples of LT muscle taken from the 13th rib were vacuum packaged and storage at –20 °C for the determination of moisture (weight loss after drying 1 g of fresh meat at 100 °C for 24 h), then were freeze-dried (FreeZone, Labconco, Missouri, USA) for the determination ether extract content with petroleum ether (Ankom XT10 extractor, ANKOM Technologies, Macedon, NY) and fatty acid profile (see 2.5). Two steaks (2.5 cm) from the 11th–12th rib were vacuum packaged and aged at 4 °C for a total of 4 d. Then, samples were stored at 20 °C for Warner-Bratzler shear force (WBSF) determination. A 2-cm steak from the 10th rib was chopped, vacuum-packed, and stored at –20 °C for later sarcomere length determination.

2.4. Warner-Bratzler shear force and sarcomere length

Warner-Bratzler shear force analysis was conducted according to AMSA guidelines (AMSA, 2016). Steaks were thawed at 4 °C for 24 h and cooked on a preheated open-hearth electric grill (Farberware, Bronx, New York) to an internal temperature of 71 °C. The internal temperature was controlled using a multi-scan digital thermometer (Scanning Thermometer, Digi-Sense, Cole-Palmer). Steaks were weighed before and after broiling to calculate cooking loss percentages. Steaks were cooled at 4 °C for 1 h before six cores (1.27 cm in diameter) were removed from each steak parallel to the muscle fiber orientation. Cores were sheared perpendicular long axis of the core using a Warner-Bratzler Shear Force machine (G-R Manufacturing, Manhattan, KS, US) with a digital dynamometer coupled (BFG 500N, Quantrol[™], Dillon/Quality Plus, Inc., Kansas City, MO, USA).

The sarcomere length was determined according to Cross et al. (1981) using a helium-neon laser (CVI Melles Giot). A total of 10 length readings per sample were recorded to calculate an average value.

2.5. Fatty acid profile

Fatty acid methyl esters from lyophilized feeds and LT samples were obtained by direct trans-methylation according to the method of Park and Goins (1994). Fatty acid methyl esters were analyzed with a Clarus 500 (Perkin-Elmer) gas chromatograph equipped with a capillary column CP-Select CB for FAME fused silica WCOT 100 m × 0.25 mm (Cat.no. CP7420; Varian, Inc.) according to the procedure of Duckett et al. (2002). The column oven temperature was increased from 150 °C to 160 °C at 1 °C/min, from 160 °C to 167 °C at 0.2 °C/min, from 167 to 225 °C at 1.5 °C/min, and then held at 250 °C for 16 min. The injector and detectors were maintained at 250 °C. The sample injection volume was 1 µL. Nitrogen was the carrier gas at a flow rate of 1 mL/min. Individual fatty acids were identified by comparison of retention times with standards (Sigma, St. Louis, MO; Supelco, Bellefonte, PA; Matreya, Pleasant Gap, PA). Fatty acids were quantified by incorporating an internal standard, methyl tricosanoic acid (C23:0), into each sample during methylation.

2.6. Statistical analysis

The BW, the average daily gain (ADG), and the ultrasound data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC; University Edition) as a complete randomized block (initial BW) design with repeated measures (days on trial). The type of covariance structure (compound symmetry, AR(1), Toeplitz, or Unstructured) with the smaller Bayesian Information Criteria (BIC) and the Subject=Pen options were included in the repeated statement (Littell et al., 2002). The mathematical model utilized for these variables was as follows:

$$Y_{ijk} = \mu + B_i + T_j + E_k + (TE)_{jk} + \varepsilon_{ijk}$$

in which Y_{ijk} = dependent variable, μ = overall mean, B_i = effect of block i (initial BW), T_j = effect of factor j (DT), E_k = effect of factor k (days on trial), $(TE)_{jk}$ = interaction effect between factor j and factor k , and ε_{ijk} = residual experimental error.

The carcass and meat quality variables were analyzed as a complete randomized block (initial BW and slaughter day) design with treatment in the model. The mathematical model utilized for these variables was as follows:

$$Y_{ijk} = \mu + B_i + SD_j + T_k + \varepsilon_{ijk}$$

in which Y_{ijk} = dependent variable, μ = overall mean, B_i = effect of block i (initial BW), SD_j = effect of block j (slaughter day), T_k = effect of factor k (DT), and ε_{ijk} = residual experimental error. Both dietary treatments had three experimental units (pen/plot). The Least squares means were computed and separated statistically using the test of Tukey ($\alpha = 0.05$).

3. Results

3.1. Total dry matter intake

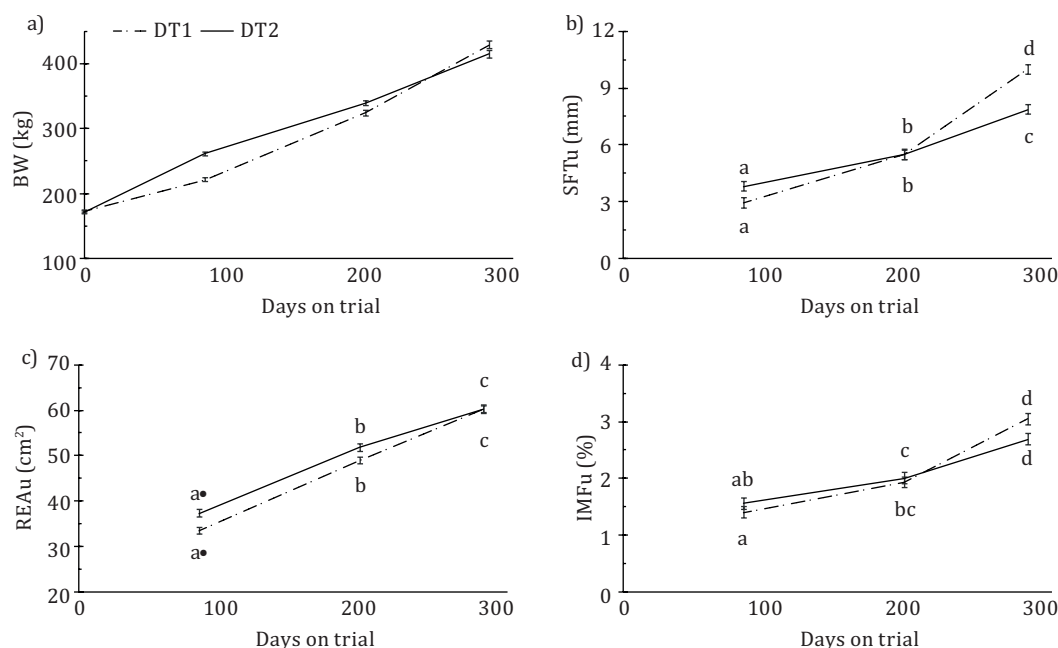
The objective of the study was to evaluate the effect of distributing the same amount of corn grain differently during the fattening period. Consequently, total corn grain dry matter intake (DMI) did not differ between dietary treatments ($P = 0.820$; 714 kg/animal). Total pasture DMI did not differ between dietary treatments either ($P = 0.474$; 858 kg/animal). Total DMI of the other components of the high-concentrate diet (corn silage, protein meal, and mineral supplement), excluding corn grain, was greater ($P = 0.003$) for DT1 than for DT2. Therefore, despite the similar overall corn grain DMI, total DMI tended to be 8% greater in DT1 than in DT2 ($P = 0.051$).

3.2. Animal performance and ultrasound measurements

An interaction was found between dietary treatments and days on trial for BW ($P < 0.001$), ADG ($P < 0.001$), SFTu ($P < 0.001$), and then REAu ($P = 0.004$), but not for IMFu ($P < 0.016$; Figure 2). Steers' BW increased throughout the feeding period, with no differences observed between dietary treatments on D0 (171 ± 2 kg), D210 (332 ± 2 kg), and D302 (427 ± 2 kg); however, at D90 (end of Phase-1), steers on DT1 were 41 ± 5 kg lighter than those on DT2 (220 and 261 kg, respectively). The ADGs were highest when animals were on the high-concentrate diets, Phase-3 of DT1, and in Phase-1 of DT2 (1.13 and 1.00 ± 0.03 kg/d); they were intermediate, without differences between treatments, in Phase-2 of DT1 and Phase-3 of DT2 (0.86 and 0.77 ± 0.03 kg/d); and lowest during the first grazing period of each treatment, Phase-1 of DT1 and Phase-2 of DT2 (0.54 and 0.66 ± 0.04 kg/d). The overall ADG was 8.6% greater in DT1 than in DT2 ($P = 0.014$; 0.88 and 0.81 ± 0.01 kg/d, respectively).

The SFTu, REAu, and the IMFu increased throughout the fattening period ($P < 0.001$), but in all three variables, the increase was affected by the dietary treatment applied (SFTu, $P < 0.001$; REAu, $P = 0.032$; IMFu, $P = 0.016$). The SFTu did not differ between the dietary treatments at the end of Phase-1 ($P = 0.103$; 3.4 ± 0.1 mm) and Phase-2 ($P = 1.00$; 5.5 ± 0.1 mm) but it was greater in DT1 than in DT2 at the end

of Phase-3 ($P < 0.001$; 10.0 and 7.9 ± 0.2 mm). The REAu tended to be lower in DT1 than in DT2 at the end of Phase-1 ($P = 0.074$; 33.4 and 37.3 ± 0.8 cm²), but did not differ at the end of Phase-2 and Phase-3 ($P > 0.100$; 50.4 and 60.2 ± 0.6 cm², respectively). The IMFu did not differ between the both the dietary treatments at the end of each phase, and increased at the end of each successive phase in both treatments (Phase-1: $P = 0.86$, $1.5 \pm 0.1\%$; Phase-2, $P = 0.989$, $2.0 \pm 0.1\%$; Phase-3, $P = 0.451$, $2.9 \pm 0.1\%$) although the IMFu from DT2 in Phase-1 and that from DT1 in Phase-2 did not differ.



DT1: Phase-1 (0-90 d), pasture; Phase-2 (91-210 d), pasture; Phase-3 (211-302 d), corn grain diet. DT2: Phase-1, corn grain diet; Phase-2, pasture; Phase-3, pasture + corn grain. BW, P-values: DT, 0.183; D, < 0.001 ; DT×D, < 0.001 . SFTu, P-values: DT, 0.230; D, < 0.001 ; DT×D, < 0.001 . REAu, P-values: DT, 0.0134; D, < 0.001 ; DT×D, 0.032. IMFu, P-values, DT, 0.713; D, < 0.001 ; DT×D, 0.016. Different letters (a-e) indicate statistically significant differences ($P < 0.05$), and a black dot (•) indicates a tendency for differences ($P < 0.10$).

Figure 2 - Effect of dietary treatments (DT) on the evolution of (a) body weight (BW), (b) the subcutaneous fat thickness (SFTu), (c) rib eye area (REAu) and (d) intramuscular fat content (IMFu) throughout the days on trial (D).

3.3. Carcass characteristics and meat quality traits

Hot carcass weight (HCW) was greater in DT1 than in DT2 ($P = 0.037$; 12 kg), but the carcass yield showed no differences ($P = 0.448$; 56.5%). The pH at 3 hours postmortem and final pH did not differ between treatments ($P = 0.056$; 6.05 ± 0.05 and $P = 0.465$; 5.49 ± 0.02). The temperature at 3 hours postmortem was 1.5 ± 0.3 °C greater in DT1 than in DT2 ($P = 0.003$).

Carcass subcutaneous fat thickness (SFT) was 2.5 ± 0.6 mm thicker ($P = 0.005$), and carcass ribeye area (REA), 2.9 ± 1.2 cm² larger ($P = 0.092$) in DT1 than in DT2. However, the marbling score showed no dietary treatment differences ($P = 0.284$; 415 ± 13).

The subcutaneous fat b^* -value (yellowness) was 2.1 ± 0.3 units greater for DT2 than for DT1 ($P < 0.001$). Conversely, the L^* , a^* and b^* values of the *longissimus thoracis* muscle were greater in DT1 than DT2 (L^* -value, $P = 0.033$, 1.3 ± 0.5 ; a^* -value, $P = 0.026$; 0.8 ± 0.2 ; b^* -value, $P = 0.040$, 0.9 ± 0.4 , Table 4).

Table 4 - Animal performance, and carcass and meat quality characteristics from steers fed corn grain in the finishing diet (DT1) or in the weaning diet and as supplement during the finishing phase (DT2)

	DT1	DT2	SEM	P-value
Hot carcass weight (kg)	247	235	3	0.037
Carcass yield (%)	57.2	57.6	3.4	0.448
pH@3 ¹	5.98	6.12	0.05	0.056
Temp@3 (°C) ²	24.4	22.9	0.2	0.003
pH Final ³	5.48	5.50	0.02	0.465
SFT (mm)	8.0	5.5	0.4	0.005
REA (cm ²)	62.31	59.44	0.84	0.048
Marbling score ⁴	426	405	13	0.284
Subcutaneous fat color ⁵				
<i>L</i> *	69.71	69.77	0.36	0.861
<i>a</i> *	6.45	7.09	0.16	0.026
<i>b</i> *	17.81	19.90	0.23	<0.001
<i>Longissimus thoracis</i>				
Moisture content (%)	73.20	74.00	0.27	0.074
Intramuscular fat (%)	3.17	3.15	0.28	0.918
Color ⁵				
<i>L</i> *	35.31	33.99	0.35	0.033
<i>a</i> *	15.99	15.18	0.20	0.025
<i>b</i> *	13.83	12.87	0.26	0.040
Warner Bratzler shear force (N)	44.31	41.17	1.70	0.255
Sarcomere length (μm)	1.90	1.89	0.01	0.596

SFT - subcutaneous fat thickness; REA - ribeye area; SEM - standard error of the mean.

¹ pH at 3 h postmortem.² Temperature at 3 h postmortem.³ Final pH.⁴ United States Department of Agriculture (USDA) marbling score (small, 400 - modest, 500).⁵ *L** - lightness (0 = black, 100 = white); *a** - redness (lower numbers = more green/less red, higher numbers = more red/less green); *b** - yellowness (lower numbers = more blue/less yellow, higher numbers = more yellow/less blue).

No treatment differences were obtained for the *longissimus thoracis* muscle moisture content ($P = 0.074$; $73.6 \pm 0.3\%$), intramuscular fat ($P = 0.918$; $3.2 \pm 0.3\%$), sarcomere length ($P = 0.596$; $1.89 \pm 0.01 \mu\text{m}$), or the Warner-Bratzler shear force ($P = 0.245$; $42.74 \pm 1.70 \text{ N}$).

No differences were observed between dietary treatments for the proportions of total saturated fatty acids (SFA; $P = 0.818$, $41.4 \pm 0.4\%$; Table 5), odd chain fatty acids (OCFA; $P = 0.354$, $1.5 \pm 0.04\%$), monounsaturated fatty acids (MUFA; $P = 0.397$, $41.2 \pm 0.2\%$) and polyunsaturated fatty acids (PUFA; $P = 0.730$, $6.3 \pm 0.2\%$). Only a few treatment differences were observed for individual fatty acids. Lower proportions of C12:0 ($P = 0.035$) and C20:5 n-3 ($P = 0.002$), and a greater proportion of C18:1 *trans*-11 ($P = 0.015$) were observed in DT1 than in DT2. The n-6:n-3 ratio was 8% greater in DT1 ($P = 0.027$).

4. Discussion

The intramuscular fat content is a crucial determinant of meat quality, influencing juiciness, flavor, and tenderness (Savell and Cross, 1988; Jeremiah et al., 2003; O'Quinn et al., 2012). Consequently, the marbling score has been established as a key parameter in the beef grading systems of different countries (Polkinghorne and Thompson, 2010). Strategies developed to increase intramuscular fat, such as prolonging time on concentrate diets or increasing slaughter weight, also tend to enhance fat deposition in less commercially valuable fat depots (Cianzio et al., 1982; Duckett et al., 1993; Zurbriggen et al., 2022). In concentrate-finished cattle, Scheffler et al. (2014) observed that feeding a concentrate diet during early weaning increases the marbling score without affecting subcutaneous

Table 5 - *Longissimus dorsi* fatty acid composition (%), and n-6:n-3 polyunsaturated fatty acid (PUFA) and polyunsaturated to saturated fatty acids (PUFA:SFA) ratios from steers fed corn grain in the finishing diet (DT1) or in the weaning diet and as a supplement during the finishing phase (DT2)

Fatty acids (%)	DT1	DT2	SEM	P-value
C8:0	0.12	0.08	0.03	0.304
C12:0	0.07	0.10	0.01	0.035
C14:0	2.55	2.68	0.08	0.277
C14:1	0.11	0.11	<0.01	0.433
C15:0	0.52	0.57	0.03	0.418
C16:0	24.00	24.04	0.21	0.811
C16:1	3.61	3.56	0.06	0.539
C17:0	0.93	0.97	0.04	0.413
C18:0	13.66	13.70	0.19	0.902
C18:1 <i>trans</i> -11	2.58	1.76	0.18	0.015
C18:1 <i>cis</i> -9	36.22	35.91	0.31	0.488
C18:1 <i>cis</i> -11	1.59	1.57	0.03	0.752
C18:2 <i>cis</i> -9, 12 (n-6)	3.37	3.57	0.16	0.421
C18:3 <i>cis</i> -8, 11, 14 (n-4)	0.04	0.04	<0.01	0.518
C18:3 <i>cis</i> -9, 12, 15 (n-3)	0.57	0.57	0.03	0.937
C18:2 <i>cis</i> -9, <i>trans</i> -11	0.32	0.35	0.01	0.084
C18:2 <i>trans</i> -10, <i>cis</i> -12	0.08	0.08	<0.01	0.339
C20:1 <i>cis</i> -11 (n-9)	0.16	0.15	<0.01	0.436
C20:2 <i>cis</i> -11, 14 (n-6)	0.10	0.10	0.01	0.911
C22:0	0.89	0.82	0.11	0.675
C20:4 <i>cis</i> -5, 8, 11, 14 (n-6)	1.15	0.94	0.09	0.168
C20:4 <i>cis</i> -8, 11, 14, 17 (n-3)	0.05	0.04	<0.01	0.679
C20:5 <i>cis</i> -5, 8, 11, 14, 17 (n-3)	0.29	0.38	0.01	0.002
C24:0	0.02	0.03	<0.01	0.166
C22:5 <i>cis</i> -7, 10, 13, 16, 19 (n-3)	0.61	0.63	0.03	0.624
C22:6 <i>cis</i> -5, 7, 10, 13, 16, 19 (n-3)	0.09	0.10	0.01	0.284
Total saturated fatty acids (SFA)	41.30	41.48	0.52	0.818
Total odd chain fatty acids (OCFA)	1.45	1.53	0.06	0.358
Total monounsaturated fatty acids (MUFA)	41.42	41.03	0.30	0.397
Total polyunsaturated fatty acids (PUFA)	6.25	6.37	0.23	0.730
n-6 PUFA	4.62	4.61	0.17	0.969
n-3 PUFA	1.59	1.72	0.07	0.227
Total no identified compounds	6.60	7.14	0.37	0.338
n-6:n-3 ratio	2.97	2.75	0.06	0.027
PUFA/SFA	0.15	0.16	0.01	0.798

SEM - standard error of the mean.

fat deposition. Similarly, Koch et al. (2018) observed that a grain diet fed at weaning rather than the finishing phase had a similar effect on carcass marbling scores but reduced the subcutaneous fat thickness. These findings agree with Du et al. (2010), who suggested that early starch supplementation promotes adipocyte differentiation in cattle.

In agreement with Koch et al. (2018), our findings indicate that similar marbling scores and reduced subcutaneous fat thickness can be achieved when steers receive the same total amount of corn but distributed differently; either as the main component of the weaning diet and as pasture supplement at finishing or as the main component of the finishing diet. This suggests that carcasses with equivalent intramuscular fat can be obtained through varied feeding strategies, providing flexibility to production systems according to their constraints, such as seasonal forage availability.

The lack of effect observed on the marbling score could be associated with the relatively low fat thickness of animals at slaughter or with the relatively short period that steers were on a concentrate diet. Roberts et al. (2009) did not observe any difference in marbling score when steers with 6.4 mm of fat thickness were slaughtered after being fed increasing levels of corn grain, and concluded that, as marbling is the last fat depot to be filled, a minimum degree of fatness would be required to generate marbling differences. Duckett et al. (1993) observed a significant marbling score change when steers were fed a concentrate diet between 84 and 112 days, and their fat thickness increased from 9.8 to 14.6 mm. In the current and the study by Koch et al. (2018) studies, despite the lack of treatment effects on intramuscular fat or marbling score, feeding the concentrate diet in the finishing rather than in the weaning period increased the fat thickness by 46% and 47%, respectively. Interestingly, in both studies, the highest levels were below the threshold suggested by Duckett et al. (1993). Sharman et al. (2013) concluded that marbling score is affected by animal body weight, which was not affected in the present study, and the subcutaneous fat thickness is affected by both animal body weight and energy intake. In the present study, the fat thickness was increased when the energy intake was greater, both in Phase-1 and Phase-3, but the intramuscular fat was not. The initial difference observed in the subcutaneous fat thickness at the end of Phase-1 disappeared after the common grazing period (Phase-2). During Phase-2 the subcutaneous fat thickness increased in both treatments, but more in steers that were already grazing in the previous phase (Phase-1). This agrees with results observed by Scheffler et al. (2014) and Koch et al. (2018) when animals were allowed to graze after receiving concentrate diets at early ages (early or normal weaning ages, respectively).

The greater ADGs observed when feeding concentrate diets in either early or late phases are consistent with previous findings (Schoonmaker et al., 2004; Duckett et al., 2009; Pordomingo et al., 2012; Scheffler et al., 2014; Koch et al., 2018; Fruet et al., 2019). Whereas the lower ADGs observed when both treatments were on pasture in Phase-2, in steers that received the concentrate diet in the previous phase, were also observed by Koch et al. (2018) and Scheffler et al. (2014). These lower ADGs may be attributed to steers' adaptation from a concentrate- to a forage-based diet, to compensatory growth in steers that were previously on pasture (Schumacher et al., 2022), or a combination of both factors.

The greater weight gains in DT1 during Phase-2 and Phase-3 resulted in slightly greater overall gains, but did not impact the final body weight, which remained similar between the treatments (427 ± 4 kg). Koch et al. (2018) also reported similar final body weights when steers were fed a concentrate diet at weaning or finishing. However, in their study, steers that received the concentrate at weaning consumed less total grain over the feeding period and required more time to reach the final weight.

Throughout the feeding period, ultrasound REA followed the changes in body weight. Similarly to the findings of Koch et al. (2018), ultrasound REA tended to be lower in DT1 after the first 90 days; however, this difference disappeared by the end of Phase-2, along with body weight differences. The heavier hot carcass weight observed in DT1 is consistent with its larger carcass REA and SFT compared to DT2.

As reported by Mallikarjunan and Mittal (1994), the lower fat thickness in steers finished on pasture with corn grain supplementation contributed to a faster muscle temperature decline, reflected in lower temperature at 3 h postmortem. However, this faster temperature decline did not affect the muscle pH decline within the first 24 h postmortem, the *longissimus thoracis* muscle contraction (sarcomere length), or shear force compared to the other treatment.

The similar shear force values observed between treatments after 7 d of aging contrast with the findings of Koch et al. (2018). They reported that the *longissimus thoracis* muscle from steers fed concentrate at weaning had lower shear force at 2 or 7 d of aging compared to those receiving concentrate at finishing, despite being older. However, they did not detect shear force differences after 14 d of aging. Koch et al. (2018) attributed the initial differences to variations in muscle fiber hypertrophy or connective tissue characteristics. In contrast, the present study did not observe differences after 7 d of aging.

Meat and subcutaneous fat color are two important drivers of meat purchase by consumers (Dunne et al., 2009; Testa et al., 2021). In general, consumers prefer a brighter meat color and a whiter fat color, traits more commonly observed in concentrate-fed than in pasture-fed animals (Duckett et al., 2007; Duckett et al., 2013). In agreement with that, in the present study, meat from concentrate-finished animals had greater L^* , a^* , and b^* -values than meat from animals finished on pasture with supplement. Despite observing similar L^* -values, Koch et al. (2018) also observed greater a^* and b^* -values in the *longissimus thoracis* muscle from steers that received the concentrate diet at finishing rather than at weaning.

The greater b^* -value in the subcutaneous fat of pasture-finished animals (DT2) compared to concentrate-finished animals (DT1) is likely to be attributable to the greater dietary carotenoid intake during the finishing period (pasture plus supplement vs. concentrate diet) and the lower subcutaneous fat deposition (Dunne et al., 2009). Similar results have been reported in studies comparing cattle fed concentrate at weaning or finishing (Koch et al., 2018), concentrate vs. pasture plus corn grain vs. pasture diets (Pavan and Duckett, 2019), and concentrate vs. pasture diets (Duckett et al., 2007; Duckett et al., 2013). It was observed that animals need to be fed a concentrate diet for more than 45 d, but not 60 d, to obtain a white fat color (Zurbruggen et al., 2022; Pavan et al., 2023).

Different studies have compared the effects of pasture, pasture plus grain supplementation, and concentrate feeding on the meat fatty acid profile (Daley et al., 2010; Duckett et al., 2013; Wright et al., 2015; Pavan and Duckett, 2019). However, none of these studies has specifically compared how different strategies for feeding the same amount of corn impact the fatty acid composition of meat. Koch et al. (2018) compared the fatty acid profile of steers fed a grain diet either after weaning or during finishing, but did not standardize total grain intake, as was done in the present study.

The results of the present study suggest that the timing of corn grain feeding during the fattening period (from weaning to slaughter) does not significantly alter the fatty acid profile of meat. Only minor differences were observed based on the timing of corn grain feeding. The slightly greater n-6:n-3 ratio and lower C20:5 n-3 proportion in the *longissimus dorsi* of steers finished on a high-concentrate diet (DT1) compared to those finished on pasture with corn grain supplementation (DT2) are consistent with previous studies (Duckett et al., 2009; Wright et al., 2015; Pavan and Duckett, 2019). It has been suggested that meat from concentrate-finished animals has greater proportions of C18:1 *trans*-10 and lower proportions of C18:1 *trans*-11 than meat from pasture-finished animals; thus the greater proportion of C18:1 *trans*-10/*trans*-11 in DT1 than in DT2 would be associated with an increase in the *trans*-10 isomer. Nonetheless, in the present study, although the total amount of grain fed was the same, DT1 animals were fed grains only half of the time that DT2 animals were.

5. Conclusions

Under the conditions of the present study, feeding the same amount of cracked corn grain but supplied at different times during the fattening period does not modify the meat marbling score or intramuscular fat content, it neither affects the main meat fatty acids proportions or its shear-force. Carcasses from steers finished with the cracked corn grain diet are slightly heavier and have greater subcutaneous fat thickness. Additionally, steers that received the cracked corn grain diet in the finishing period exhibited brighter meat color and whiter subcutaneous fat color.

Thus, except for its color attributes, both feeding strategies produce meat with similar characteristics, allowing producers to select the approach that best aligns with their production system. However, when determining the optimal fattening strategy to maximize returns, producers should consider consumer preferences for fat color.

Data availability

Data will be made available on request.

Author contributions

Conceptualization: Duckett, S. K. and Pavan, E. **Formal analysis:** Alonso Ramos, S.; Pouzo, L. B.; Testa, M. L. and Pavan, E. **Investigation:** Alonso Ramos, S.; Pouzo, L. B.; Maglietti, C. S.; Testa, M. L. and Pavan, E. **Methodology:** Pouzo, L. B.; Maglietti, C. S.; Testa, M. L.; Duckett, S. K. and Pavan, E. **Project administration:** Pavan, E. **Resources:** Pavan, E. **Supervision:** Pouzo, L. B.; Maglietti, C. S.; Testa, M. L. and Pavan, E. **Writing – original draft:** Alonso Ramos, S. **Writing – review & editing:** Pouzo, L. B.; Maglietti, C. S.; Testa, M. L.; Duckett, S. K. and Pavan, E.

Conflict of interest

The authors declare no conflict of interest.

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