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Effect of growth path on carcass and meat-quality traits of Hereford steers finished on pasture or in feedlot

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Abstract. The objective of this study was to evaluate the effect of nutritional management during rearing and finishing phases on beef fatty acid composition, and carcass and beef quality traits of Hereford cattle. The study used 240 castrated male calves weaned at 8 months of age, and with an average weight of 170 ± 17 kg. After weaning, the experiment was divided in to three phases in a 4×2 factorial design: a 93-day winter period with four treatment groups (on pasture or in feedlot and at high or low feeding levels); a 196-day compensatory-growth phase on pasture; and a finishing phase either on pasture or in feedlot. Animals were slaughtered when each group attained a mean liveweight of 500 kg. The winter growth × finishing management interaction significantly affected hot carcass weight ($P = 0.0029$). There was no differences observed for feedlot-finished steers, but for pasture-finished steers, those pasture-reared had higher hot carcass weight (kg) than those feedlot-reared (low pasture 256.30 ± 1.60, high pasture 253.72 ± 1.60, low feedlot 249.85 ± 1.66, high feedlot 247.60 ± 1.62). Feedlot-finished steers showed higher ($P < 0.05$) mean values than pasture-finished steers for ribeye area (55.61 ± 0.69 cm^2 vs 53.18 cm^2), backfat thickness (8.62 ± 0.32 mm vs 6.21 mm), marbling score (237.97 ± 13.06 vs 171.70) and final pH (5.53 ± 0.02 vs 5.48). Additionally, feedlot-finished steers raised in feedlot during the winter-growth period displayed the heaviest hindquarter cuts. Meat from pasture-finished steers had lower ($P < 0.05$) shear-force values than from feedlot-finished cattle (2.95 ± 0.18 vs 3.66 ± 0.17 kg), and when reared on either high or low pasture during winter-growth, they showed the highest ($P < 0.05$) conjugated linoleic acid (*cis*-9, *trans*-11) and n-3 polyunsaturated fatty acid concentrations. In conclusion, growing and finishing cattle on pasture improved the carcass yield of retail cuts because of low fat concentration, and improved the nutritional and health value of the beef fatty acid profile.

Additional keywords: carry-over effects, fatty-acid profile, finishing system, growth-out.

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Introduction

In most temperate regions of South America, beef-cattle rearing and fattening systems are mainly based on grazing with native or improved pastures as the primary feed source (i.e. a mix of cool-season grasses and legumes). Environmental conditions in winter in these regions are characterised by low temperature and short photoperiod, which limits the forage growth rate and, thereafter, cattle growth (Cozzolino *et al*. 1994). Hence, the effect of a winter nutrition restriction during rearing on subsequent finishing performance needs to be considered.

The impact of improving nutritional status immediately after weaning on animal performance, pattern of tissue deposition and feed-conversion ratio during the finishing phase has been widely described (Parks 1982; Owens *et al*. 1995; Dicker *et al*. 2001; Robinson *et al*. 2001; Purchas *et al*. 2002). Furthermore, differences in nutritional-management growth pathways before the fattening period are associated with different degrees of compensatory gain and fat deposition later in this phase (Drouillard and Kuhl 1999), as well as product quality (Brito *et al*. 2014).

Several studies employing different nutritional-management pathways have shown that animals finished on high-concentrate diets displayed heavier carcass and better beef quality in terms of tenderness, marbling, ribeye area (REA) and backfat thickness (BFT) than those finished on pasture (Mandell *et al.* 1998*a*; Realini *et al.* 2004; Duckett *et al.* 2013). On the other hand, pasture-finished animals produced beef with lower concentrations of fat and cholesterol, and a higher percentage of n-3 polyunsaturated fatty acids (PUFAs) and conjugated linoleic acid (CLA) than feedlot-finished animals (Aldai *et al.* 2011; Duckett *et al.* 2013).

Many studies have evaluated the nutritional impact of the finishing phase (pasture or feedlot) on beef and carcass quality traits (e.g. Realini *et al.* 2004; Duckett *et al.* 2013; Morales *et al.* 2015); however, fewer studies have assessed the effect of the rearing system or its interaction with the finishing phase on beef quality traits and beef fatty-acid profile (Dicker *et al.* 2001; Robinson *et al.* 2001; Loken *et al.* 2009; Brito *et al.* 2014; Gardine *et al.* 2018). Therefore, the objective of this study was to evaluate the interaction between nutritional management during the rearing phase and the finishing phase for effects on beef fatty-acid profile, and carcass and beef quality traits of Hereford cattle. This study encompassed the same dataset and experimental design as that published by Peripolli *et al.* (2017), which evaluated the effects of nutritional management during the rearing period on the performance and carcass traits of pasture- or feedlot-finished Hereford cattle.

Material and methods

The experiment was performed at the National Institute for Agricultural Research (INIA) Experimental Station 'La Estanzuela' (34°28′S, 57°51′W), Colonia, Uruguay, under the directives regarding the use of animals for experimentation of INIA Uruguay.

Details of the experimental design, animal weaning and handling, allocation, dietary treatments, and phases of the experiment were previously reported by Peripolli *et al.* (2017). Briefly, 240 castrated Hereford male calves weaned at ~8 months of age, and with an initial average liveweight (LW) of 170 ± 17 kg were used. After weaning, calves were kept together grazing native pastures (70 g protein/kg dry matter and 7.9 MJ metabolisable energy/kg dry matter), and were offered lucerne hay (*Medicago sativa*) for 25 days before the beginning of the experiment in May 2008.

The experiment was divided into three phases. The first phase was a winter-growth phase (93 days), in which calves were reared on pasture (P) or in feedlot (F) at either high (H) or low (L) feeding level, resulting in four management groups (HF, LF, HP, and LP). At the end of this phase, F groups were heavier than P groups, and H groups were heavier than L groups (Peripolli *et al.* 2017). The second phase was a 196-day compensatory-growth phase on pasture, after which weights did not differ between P and F groups but did between H and L groups. The third phase was a finishing phase, either on pasture or in feedlot, until each group attained an average LW of 500 kg, which occurred 3 months later for the pasture-finished than the feedlot-finished steers. The experimental design was a 4×2 factorial with four treatments in the first phase and two finishing regimes. See additional information in Peripolli *et al.* (2017).

Carcass data, sample collection, and analysis

Steers were slaughtered with a mean LW of 502.76 ± 5.07 kg in a commercial slaughterhouse, and in accordance with the Uruguayan Inspection Service procedures (Ministry of Livestock, Agriculture and Fishery, MGAP). According to Peripolli *et al.* (2017), no differences ($P > 0.05$) in LW at slaughter were observed between treatments. At 24 h post-mortem, the carcass length for each sample was measured in the left half-carcasses following the guidelines of De Boer *et al.* (1974). The carcass length was measured from the anterior edge of the *symphysis pubis* to the middle of the cranial edge of the visible part of the first rib. The left half-carcasses were cut between the 12th and 13th thoracic vertebrae to measure REA (cm^2) with a 1-cm^2 ribeye grid, and BFT (mm) with a 6-inch digital caliper. The carcasses were classified by qualified personnel into different groups of marbling score, from practically scarce to abundant, according to a photographic scale (USDA 1997).

Samples from the *longissimus dorsi* (LD) muscle were cut from the left half-carcasses from the 13th rib towards the head, and four steaks (2.5 cm thick) were collected from each sample. Samples were identified and vacuum-stored in polyethylene bags, and then aged for 7 days at 0°C. The Warner–Bratzler shear force measurement was performed in the aged LD according to AMSA (2005) guidelines. The steaks were thawed (4°C) for 24 h before the analysis and cooked in an electric oven at 180°C until the internal core temperature reached 71°C. The pH and meat colour (L^*, lightness; a^*, redness; b^*, yellowness) were also determined in the aged LD. Meat colour determination was performed with a MiniScan XE (HunterLab, Reston, VA, USA) with a 10° observer and illuminant D65, and it was expressed in CIE $L^*a^*b^*$ units. The hindquarter cut weight (HDQ), striploin, knuckle, rib plate flank on (last eight dorsal and six lumbar vertebrae, keeping the rib plate and flank), rump tail, rump, tenderloin and topside flat cuts were weighed and recorded separately, according to the guidelines of INAC (2014). Additional analyses were performed for the HDQ cut, including the percentage of fat (FT_{HDQ}), bone (B_{HDQ}) and beef retail (RB_{HDQ}).

Total lipid percentage was determined following the chloroform–methanol procedure of Folch *et al.* (1957), using a 10 : 1 chloroform : methanol ratio per sample. Samples from LD muscle were collected to determine the fatty-acid profile, which was determined for each sample by using the method described by Folch *et al.* (1957). The isolated lipids were then methylated and the methyl esters were formed according to Kramer *et al.* (1997). The fatty-acid profile was quantified by using gas chromatography (GC-2010 Plus with AOC 20i auto-injector; Shimadzu, Kyoto) with a SP-2560 capillary column (100 m × 0.25 mm internal diameter with 0.20 µm thickness; Supelco, Sigma-Aldrich Group, Bellefonte, PA, USA). The initial temperature was 70°C with a gradual warming (13°C/min) up to 175°C, followed by a 27-min holding time at this temperature, then a further increase in temperature up to 215°C (4°C/min), with a 31-min holding time for this last temperature. Hydrogen (H_2) was used as the carrier gas (40 cm^3/s). Fatty acids were identified by comparing the retention time of methyl esters of the samples with the standards C4–C24 (F.A.M.E Mix; Supelco), vaccenic acid *trans*-11 C18:1 (V038-1G; Sigma-Aldrich, St. Louis, MO, USA), CLA *trans*-10 *cis*-12 C18:2 (UC-61M 100 mg; Nu-Chek Prep, Elysian, MN, USA), CLA *cis*-9 *trans*-11 C18:2 (UC-60M 100 mg; Nu-Chek Prep), and tricosanoic acid (Sigma-Aldrich). Fatty acids were quantified by normalising the area under the curve of methyl esters, using GC Solution version 2.42 software (Shimazdu). Fatty acids are expressed as a percentage of the total fatty acid methyl ester quantified.

Statistical analyses

The experiment was a completely randomised design in a factorial arrangement (4 × 2) of four nutritional-management groups at winter-growing phase (HF, LF, HP, and LP) and two nutritional-management groups in the finishing phase (pasture or feedlot) (see additional information in Peripolli *et al*. 2017). For evaluation of beef and carcass traits, the experimental unit was the animal. The fixed effect of the nutritional-management groups at the winter-growing phase (HF, LF, HP, and LP) and finishing phase (feedlot or pasture), the interaction between management at the growing and finishing phases, and the covariable LW at the beginning of the finishing phase were included in the model. Only significant interactions ($P < 0.05$) were considered in the model. The Tukey test was applied to compare the least-square means ($P < 0.05$). Analyses were run using the SAS software version 9.3 (SAS Institute, Cary, NC, USA), applying the PROC MIXED procedure and the restricted maximum likelihood method.

Results and discussion

Carcass traits

Liveweights at the beginning of the finishing phase of each group (HF 362 ± 3 kg, LF 350 ± 3 kg, HP 364 ± 2 kg, and LP 351 ± 2 kg) were used as a covariate. The winter-growth × finishing management interaction significantly ($P = 0.0029$) affected hot carcass weight (HCW); there was no difference between feedlot-finished steers, but for pasture-finished steers, higher HCWs were obtained for pasture-rearing (LP 256.30 ± 1.60 kg, HP 253.72 ± 1.59 kg, LF 249.85 ± 1.65 kg and HF 247.60 ± 1.62 kg). There was no winter-growth × finishing management interaction ($P > 0.05$) for REA, BFT, and carcass length traits. The finishing phase significantly ($P < 0.05$) affected REA and BFT, with a positive and favourable effect of LW covariate on REA, carcass length, HCW and BFT (Table 1). Feedlot-finished steers displayed higher ($P < 0.05$) least-square means for REA and BFT than those finished on pasture, with no effects of the nutritional treatments during the winter-growth phase. The opposite effect was observed for carcass length (Table 1). Pasture-finished steers showed greater ($P < 0.05$) carcass length than feedlot-finished steers. Similarly, Keane and Allen (1998) evaluated three production systems (intensive, conventional and extensive) and described shorter hindquarter and leg lengths per kg carcass weight in the intensive production system.

Meat quality

Winter-growth and finishing nutritional-managements significantly ($P < 0.05$) affected beef shear force, however, no significant ($P > 0.05$) winter-growth × finishing management interaction was observed (Table 1). In the winter-growth phase, LP and LF groups showed lower beef shear force than the HP group, whereas HF displayed intermediate values. Considering the finishing phase, pasture-finished steers displayed lower beef shear force than feedlot-finished steers. Although there were significant differences in beef shear force for each nutritional phase, all treatment combination outcomes would have been considered acceptable by consumers, considering that the upper limit for tender meat was established to be 4.5 kg (Shackelford *et al.* 1991; Huffman *et al.* 1996).

Table 1. Least-square means and standard errors for carcass and meat quality traits according to winter-growth and finishing management
All values adjusted to a common liveweight (LW) at the start of the finishing phase; (+) or (–) indicate whether the LW effect was positive or negative. For winter-growth treatments: H and L are high and low LW gain, F and P are in feedlot and on pasture. Within parameters, means followed by the same lowercase letter (or no lowercase letter within a finishing phase) are not significantly different ($P > 0.05$): a, b compare within a finishing phase; x, y compare for winter-growth × finishing management interaction. Different uppercase letters are used to show significant difference ($P < 0.05$) between feedlot and pasture finishing managements (for mean of HF, LF, HP, LP)

Winter growth	Finishing	*n*	Hot carcass weight (kg)	Ribeye area (cm^2)	Backfat thickness (mm)	Carcass length (m)	Shear force at 7 days (kg)	Marbling score
HF	Feedlot (slaughtered ~23 months of age)	30	249.19 ± 1.62y	57.17 ± 0.69A	8.64 ± 0.32A	1.50 ± 0.01B	3.60 ± 0.17abA	280.37 ± 12.90aA
LF		30	247.76 ± 1.68y	55.28 ± 0.69	9.29 ± 0.32	1.51 ± 0.01	3.37 ± 0.17b	249.01 ± 12.88a
HP		30	247.04 ± 1.72y	55.43 ± 0.72	8.07 ± 0.33	1.51 ± 0.01	4.11 ± 0.18a	229.05 ± 13.37ab
LP		30	246.36 ± 1.71y	54.57 ± 0.70	8.49 ± 0.33	1.50 ± 0.01	3.58 ± 0.17b	193.46 ± 13.10b
HF	Pasture (slaughtered ~26 months of age)	30	247.60 ± 1.62y	53.02 ± 0.74B	6.19 ± 0.34B	1.52 ± 0.01A	2.95 ± 0.18abB	175.91 ± 13.81aB
LF		30	249.85 ± 1.65xy	52.92 ± 0.74	6.02 ± 0.34	1.53 ± 0.01	2.68 ± 0.18b	181.41 ± 13.88a
HP		30	253.72 ± 1.59xy	53.08 ± 0.73	6.28 ± 0.37	1.54 ± 0.01	3.30 ± 0.18a	180.45 ± 13.60ab
LP		30	256.30 ± 1.56x	53.72 ± 0.70	6.36 ± 0.36	1.55 ± 0.01	2.87 ± 0.17b	149.04 ± 13.09b
				P-value				
Winter growth			0.246	0.465	0.583	0.528	0.0021	0.0002
Finishing			0.0003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Winter growth × finishing			0.0029	0.142	0.145	0.122	0.974	0.0985
LW			<0.0001 (+)	<0.0001 (+)	0.0137 (+)	<0.0001 (+)	0.0311 (–)	0.7322

Beef tenderness is influenced by several factors such as diet, pre-slaughter growth rate, the animal's age, and the length of the finishing period (Strydom *et al*. 2000; Bonfatti *et al*. 2013). Finishing strategies in cattle have been extensively studied, with contradictory results regarding beef tenderness (Kerth *et al*. 2007; Moholisa *et al*. 2017). In agreement with our results, Realini *et al*. (2004), del Campo *et al*. (2008) and Morales *et al*. (2015) reported lower Warner–Bratzler shear force values for beef from pasture-finished cattle than from those finished on feedlot. However, all of these studies were performed under comparable experimental circumstances (i.e. similar diets and pasture condition). Mandell *et al*. (1998*b*) also observed lower Warner–Bratzler shear force values for Simmental cattle fed low-energy diets than those fed high-energy diets. Our findings may be associated with a modification in the muscle composition fibre types. For example, Seideman and Crouse (1986) observed a higher percentage of red fibres (oxidative fibres) in cattle submitted to 17% energy restriction than in unrestricted animals. Indeed, Moody *et al*. (1980) and Ockerman *et al*. (1984) reported a positive and significant correlation between red fibres and meat tenderness.

During the last 45–60 days before slaughter, pasture-finished steers displayed LW gain equal to or higher than that of feedlot-finished steers (results not shown). This finding could better explain the low beef shear force from pasture-finished steers. Animals with higher growth rate before slaughter have been associated with lower beef shear force than those with a slower growth rate (Fishell *et al*. 1985). Higher LW gain was shown to be associated with higher rates of protein turnover, resulting in higher concentrations of proteolytic enzymes and collagen solubility in the carcass tissue at slaughter (Miller *et al*. 1987).

Winter-growth and finishing nutritional-managements significantly ($P < 0.05$) affected the marbling score; however, no significant ($P > 0.05$) winter-growth × finishing management interaction was observed (Table 1). As expected, feedlot-finished steers showed higher marbling scores than pasture-finished steers, with HF and LF groups displaying the highest scores. Hedrick *et al*. (1983) and Dikeman *et al*. (1985) stated that cattle finished on a high-grain diet, following a nutritional restriction together with a lower growth rate, displayed less intramuscular fat than those reared at a higher growth rate. Compared with a forage-based diet, feedlot-finishing predisposes animals to increased fat deposition through high production of glucose precursors in the rumen, such as propionate, which improves metabolisable energy efficiency and then increases insulin activity and the fattening process (Gill *et al*. 1984; Sainz *et al*. 1995; Robinson *et al*. 2001).

There was no significant ($P > 0.05$) effect on L^* of winter-growth or finishing nutritional-management, or the interaction between them (Table 2). Significant ($P < 0.05$) differences for a^* were observed in relation to winter-growth and finishing nutritional managements. Feedlot-finished animals reared in LF and LP groups showed the highest a^* values. Vestergaard *et al*. (2000) reported that bulls finished under a range of conditions showed low a^* values due to the high concentration of heme pigment. Winter-growth management significantly ($P < 0.05$) affected b^* values, and steers in the HF group showed lower values than those in the LP group.

Finishing nutritional management affected ($P < 0.05$) pH values (Table 2), with feedlot-finished steers displaying higher pH values than pasture-fed steers. In an earlier study, high pH values were reported for pasture-fed animals (Young *et al*. 1999). Daly *et al*. (2002) found that animals fed high-energy diets displayed high muscle glycogen concentration at slaughter, resulting in a faster decline rate of pH and, consequently, low beef pH values. Considering that feedlot-finished and pasture-fed steers were fed a similar amount of energy (Peripolli *et al*. (2017), it is possible that the lower beef pH from pasture-fed steers was a result of their gregarious behaviour, providing a less stressful environment than the feedlot,. This behaviour most likely enhanced their ability to cope with pre-slaughter and slaughter stress compared with animals raised in pens (Jacques *et al.* 2017). In fact, in the present study,

Table 2. Least-square means and standard errors for meat colour and pH from aged (7 days) *longissimus dorsi* muscle according to winter-growth and finishing management

All values adjusted to a common liveweight (LW) at the start of the finishing phase. For winter-growth treatments: H and L are high and low LW gain, F and P are in feedlot and on pasture. Within parameters, means followed by the same lowercase letter (or no lowercase letter) are not significantly different ($P > 0.05$) within a finishing phase; different uppercase letters are used to show significant difference ($P < 0.05$) between feedlot and pasture finishing managements (for mean of HF, LF, HP, LP)

Winter growth	Finishing	*n*	L^* (lightness)	a^* (redness)	b^* (yellowness)	Ultimate pH
HF	Feedlot	30	38.18 ± 0.44	17.47 ± 0.34abA	9.04 ± 0.24b	5.54 ± 0.02A
LF		30	38.88 ± 0.44	18.02 ± 0.34a	9.74 ± 0.24ab	5.51 ± 0.02
HP		30	37.06 ± 0.47	17.47 ± 0.36b	9.43 ± 0.25ab	5.54 ± 0.02
LP		30	37.26 ± 0.46	18.47 ± 0.35a	10.02 ± 0.25a	5.54 ± 0.02
HF	Pasture	30	37.27 ± 0.47	17.32 ± 0.37abB	9.42 ± 0.26b	5.47 ± 0.02B
LF		30	37.10 ± 0.48	17.71 ± 0.37a	9.59 ± 0.26ab	5.48 ± 0.02
HP		30	37.16 ± 0.47	16.38 ± 0.36b	9.39 ± 0.25ab	5.49 ± 0.02
LP		30	37.56 ± 0.45	17.38 ± 0.35a	9.90 ± 0.24a	5.48 ± 0.02
			P-value			
Winter growth			0.259	0.0208	0.0232	0.824
Finishing			0.0775	0.0089	0.904	0.0004
Winter growth × finishing			0.0856	0.396	0.685	0.817
LW			0.969	0.120	0.0516	0.330

pre-slaughter management was performed according to commercial practices. Animals from different treatments were mixed in groups of 30–40 animals for transportation and overnight resting at the slaughterhouse. Such mixing of unfamiliar animals is well documented to produce meat with higher ultimate pH (Devine *et al*. 1993). Regardless of the treatment differences here, the pH values were considered to be within the normal range. According to Hedrick *et al*. (1989) and Węglarz (2010), high-quality beef should display an ultimate pH ranging from 5.4 to 5.6.

There was no significant ($P > 0.05$) winter-growth × finishing management interaction for intramuscular fat concentration. The finishing phase significantly ($P < 0.05$) affected intramuscular fat concentration, with feedlot-finished steers having higher intramuscular fat percentage than did pasture-finished steers.

Fatty acid profile

Significant ($P < 0.05$) winter-growth × finishing management interaction effects were observed for myristic (C14:0), myristoleic (C14:1), arachidic (C20:0), and CLA (*cis*-9, *trans*-11) fatty acids (Table 3). Pasture-finished steers reared in the HF group displayed the highest concentration of myristic acid (2.54 ± 0.08%), whereas LF feedlot-finished steers had the lowest concentration (2.14 ± 0.07%). For myristoleic acid, feedlot-finished steers displayed the lowest concentration regardless of winter-growth nutritional management, whereas the LF pasture-finished steers showed the highest concentration. The HP and LP groups that were pasture-finished displayed higher CLA than the HF group also pasture-finished. In this way, when the steers were finished under pasture conditions, the winter-growth management affected CLA concentration. These results suggest a carryover effect from the winter-growth nutritional-management groups on the CLA concentration for pasture-finished steers. This is the first study reporting a residual effect of the rearing period on beef fatty-acid composition for animals finished under different nutritional-management conditions. According to Nuernberg *et al*. (2005), a forage-based diet tends to increase CLA concentration. French *et al*. (2000) reported that forage-based diets could induce ruminal conditions such as pH, available carbohydrates and ruminal flow that contribute to enhancing the production of *trans*-11 C18:1 as a precursor of CLA.

The winter-growth phase affected ($P < 0.05$) some fatty acids such as linolenic (n-3 C18:3), eicosapentaenoic (n-3 C20:5, EPA) and arachidonic (n-6 C20:4). Steers reared in the LP group presented the highest concentrations of linolenic and EPA fatty acids, whereas those reared in the LF group showed the highest levels of arachidonic acid. Finishing-phase management affected ($P < 0.05$) the fatty acid profile, especially for oleic (*cis*-9 C18:1), linoleic (n-6 C18:2), palmitic (16:0), palmitoleic (16:1), stearic (18:0), docosapentaenoic (n-3 C22:5, DPA), docosahexaenoic (n-3 C22:6, DHA), linolenic, arachidonic and EPA fatty acids (Table 3).

Feedlot-finished steers showed higher concentrations of oleic and linoleic fatty acids than pasture-finished steers. These results were expected because of the predominance of linoleic acid in seeds and ingredients of the diet supplied to feedlot-finished animals (Wood *et al*. 2004; 2008). Pasture-finished steers showed the highest concentrations of palmitic, palmitoleic, stearic, docosapentaenoic, DHA, linolenic, arachidonic and EPA fatty acids. The results for palmitic and palmitoleic fatty acid concentrations in forage-fed animals can be explained by the higher concentration of acetate in the rumen, which is the main precursor of palmitic acid (Palmquist 1972). Realini *et al*. (2004) also observed higher concentrations of stearic, linolenic, EPA, DPA and arachidonic fatty acids in forage-fed animals than in concentrate-fed ones. The difference observed between linoleic and linolenic fatty acid concentrations can be explained by the fatty-acid composition of the diet, whereby the linoleic acid is highly present in lipids of grains and linolenic acid in lipids of forages. Moreover, pasture-finished cattle showed higher concentrations of long-chain n-3 PUFAs: EPA, DPA and DHA. Interestingly, linolenic acid is the precursor of the omega-3 pathway (Daley *et al*. 2010; Kitessa *et al*. 2010; Koch *et al*. 2018). The increased concentration of these n-3 fatty acids occurs through activities of elongases, desaturases and β-oxidation responsible for the conversion of alfa linolenic acid (Brenna 2002; Burdge and Calder 2005; Kjær *et al*. 2016).

Carcass yield of retail cuts

A significant ($P < 0.05$) winter-growth × finishing management interaction was obtained for the traits measured from the HDQ cut (FT_{HDQ}, B_{HDQ}, RB_{HDQ} and $RB_{HDQ}:B_{HDQ}$ ratio) (Table 4). Feedlot-finished steers reared in HF and LF groups displayed the highest HDQ cut weight, and those reared in HP and LP groups the lowest. Pasture-finished animals presented intermediate values regardless of winter-growth management (mean of 53.26 ± 0.39%). Feedlot-finished steers displayed higher FT_{HDQ} and lower RB_{HDQ} percentages than pasture-finished steers. Higher values of $RB_{HDQ}:B_{HDQ}$ ratio were found in LP- and HP-reared pasture-finished steers, and LF- and HF-reared feedlot-finished steers. Additionally, although an interaction was observed for $RB_{HDQ}:B_{HDQ}$ ratio, these results were inconclusive because the treatment groups differed in HCW; consequently, the effects of HCW could not be distinguished from those of the treatments.

Despite feedlot-finished steers showing a high performance for muscle development, pasture-based nutritional-management at winter-growth and finishing phases improved the yield of retail cuts. Beef carcass retail yield (%) makes an important contribution to the efficiency of the beef industry.

The winter-growth × finishing management interaction significantly ($P < 0.05$) affected the weight of striploin, rib plate flank on, rump and tenderloin cuts (Table 5). The striploin cut was heavier for feedlot- and pastured-finished steers reared in the HF group than the HP- and LP-reared feedlot-finished steers. Feedlot-finished steers reared in HP and LP groups showed the lowest weight for the rib plate flank on cut. Pasture-finished steers reared in HP and LP groups showed the highest weights for the rump cut, and feedlot-finished steers reared in the HP group the lowest. Feedlot-finished steers reared in HP and LP groups showed the highest tenderloin weight. Nutritional management at winter-growth and finishing phases significantly ($P < 0.05$) affected the knuckle, rump tail and topside cuts, with pasture-finished steers displaying the heaviest cuts. In addition, steers

Table 3. Least-square means and standard errors for intramuscular fat (IMF, %) and meat fatty-acid profile (% of total fatty acids quantified) according to winter-growth and finishing management

All values adjusted to a common liveweight (LW) at the start of the finishing phase; (+) or (–) indicate whether the LW effect was positive or negative. For winter-growth treatments: H and L are high and low LW gain, F and P are in feedlot and on pasture. Fatty acids: CLA, conjugated linoleic; 14:0, myristic; 14:1, myristoleic; 16:0, palmitic; 16:1palmitoleic; 18:0, stearic; 18:1, oleic; 18:2, linoleic; 18:3, linolenic; 20:0, arachidic; 20:2 n-6, eicosadienoic *cis* 11,14 acid; 20:3 n-3, eicosatrienoic *cis* 11, 14, 17 acid; 20:3 n-6, dihomo-gamma-linolenic acid or eicosatrienoic *cis* 8,11,14 acid; 20:4, arachidonic; 20:5, eicosapentaenoic; 22:5, docosapentaenoic; 22:6, docosahexaenoic. Within parameters, means followed by the same lowercase letter (or no lowercase letter within a finishing phase) are not significantly different ($P > 0.05$): a, b, c compare within a finishing phase; x, y, z compare for winter-growth × finishing management interaction. Different uppercase letters are used to show significant difference ($P < 0.05$) between feedlot and pasture finishing managements (for mean of HF, LF, HP, LP)

Winter growth	IMF	14:0	14:1	16:0	16:1	18:0	18:1 *cis*-9	18:2 n-6	18:3 n-3	18:3 n-6	20:0	20:2 n-9	20:3 n-3	20:3 n-6	20:4 n-6	20:5 n-3	22:5 n-3	22:6 n-3	CLA
Feedlot finish																			
HF	4.48 ± 0.08A	2.32 ± 0.08xy	0.34 ± 0.02z	26.44 ± 0.26B	3.34 ± 0.20bB	16.13 ± 0.44B	44.65 ± 0.62A	3.78 ± 0.16A	0.37 ± 0.04bB	0.19 ± 0.06	0.0873 ± 0.0043x	0.0587 ± 0.0061y	0.270 ± 0.017	0.020 ± 0.021	1.10 ± 0.08abB	0.22 ± 0.04cB	0.36 ± 0.04B	0.048 ± 0.012B	0.0277 ± 0.0199z
LF	4.43 ± 0.08	2.14 ± 0.08y	0.35 ± 0.02z	26.23 ± 0.26	3.52 ± 0.20ab	15.39 ± 0.44	44.77 ± 0.62	4.20 ± 0.16	0.40 ± 0.04b	0.20 ± 0.06	0.0830 ± 0.0044xy	0.0689 ± 0.0061y	0.309 ± 0.020	0.076 ± 0.021	1.28 ± 0.08a	0.26 ± 0.04bc	0.42 ± 0.04	0.059 ± 0.012	0.287 ± 0.020z
HP	3.79 ± 0.07	2.31 ± 0.08xy	0.33 ± 0.02z	25.94 ± 0.28	3.62 ± 0.21ab	15.89 ± 0.47	45.12 ± 0.66	3.74 ± 0.17	0.39 ± 0.04ab	0.18 ± 0.06	0.0773 ± 0.0046xyz	0.0641 ± 0.0065y	0.253 ± 0.021	0.022 ± 0.022	1.00 ± 0.09b	0.28 ± 0.04ab	0.44 ± 0.04	0.059 ± 0.013	0.272 ± 0.021z
LP	3.71 ± 0.07	2.43 ± 0.08xy	0.35 ± 0.02z	26.33 ± 0.27	3.57 ± 0.20a	15.40 ± 0.46	44.16 ± 0.64	4.31 ± 0.17	0.47 ± 0.04a	0.18 ± 0.06	0.0863 ± 0.0045x	0.0633 ± 0.0063y	0.292 ± 0.020	0.051 ± 0.021	1.16 ± 0.09ab	0.33 ± 0.04a	0.48 ± 0.04	0.071 ± 0.013	0.279 ± 0.021z
Pasture finish																			
HF	2.92 ± 0.09B	2.54 ± 0.09x	0.47 ± 0.02xy	27.37 ± 0.32A	3.45 ± 0.23bA	17.15 ± 0.52A	40.22 ± 0.73B	3.54 ± 0.19B	1.32 ± 0.05bA	0.16 ± 0.07	0.0869 ± 0.0050x	0.126 ± 0.007xy	0.278 ± 0.023	0.049 ± 0.024	1.36 ± 0.10abA	0.52 ± 0.04cA	0.64 ± 0.04A	0.10 ± 0.01A	0.474 ± 0.023y
LF	2.85 ± 0.08	2.46 ± 0.09xy	0.51 ± 0.02x	27.02 ± 0.30	3.54 ± 0.22ab	16.94 ± 0.50	40.45 ± 0.70	3.47 ± 0.18	1.36 ± 0.05b	0.23 ± 0.06	0.0847 ± 0.0048xy	0.124 ± 0.007y	0.309 ± 0.022	0.046 ± 0.023	1.38 ± 0.09a	0.57 ± 0.04bc	0.67 ± 0.04	0.12 ± 0.01	0.548 ± 0.022xy
HP	2.78 ± 0.08	2.34 ± 0.08xy	0.46 ± 0.02xy	26.79 ± 0.28	3.89 ± 0.21ab	16.36 ± 0.48	41.35 ± 0.67	3.32 ± 0.17	1.44 ± 0.04ab	0.18 ± 0.06	0.0643 ± 0.0046yz	0.149 ± 0.007xy	0.303 ± 0.021	0.041 ± 0.022	1.11 ± 0.09b	0.68 ± 0.04ab	0.70 ± 0.04	0.13 ± 0.01	0.582 ± 0.021x
LP	2.76 ± 0.07	2.29 ± 0.08xy	0.44 ± 0.02y	26.67 ± 0.27	4.43 ± 0.20a	16.49 ± 0.46	40.46 ± 0.64	3.56 ± 0.17	1.52 ± 0.04a	0.32 ± 0.06	0.0638 ± 0.0044z	0.153 ± 0.006x	0.298 ± 0.020	0.046 ± 0.021	1.23 ± 0.09ab	0.74 ± 0.04a	0.72 ± 0.04	0.10 ± 0.01	0.605 ± 0.021x
P-value																			
Growth (G)	0.548	0.440	0.440	0.267	0.0204	0.509	0.512	0.0915	0.0052	0.560	0.0013	0.041	0.328	0.530	0.0194	<0.0001	0.0654	0.571	0.014
Finishing (F)	0.0089	0.058	0.058	0.0003	0.0325	0.0022	<0.0001	<0.0001	<0.0001	0.390	0.0088	<0.0001	0.270	0.835	0.0325	<0.0001	<0.0001	<0.0001	<0.0001
G × F	0.534	0.0243	0.0243	0.705	0.173	0.724	0.924	0.384	0.454	0.459	0.0269	0.0276	0.614	0.535	0.747	0.378	0.969	0.483	0.0118
LW	0.0464 (+)	0.0268 (+)	0.0268 (+)	0.131	0.192	0.0841	0.321	0.0851	0.121	0.988	0.0732	0.1441	0.226	0.459	0.0444 (–)	0.0558	0.0301 (+)	0.523	0.196

Table 4. Least-square means and standard errors for hindquarter cut weight (HDQ), percentages of fat trimming (FT_{HDQ}), bone (B_{HDQ}) and beef retail (RB_{HDQ}) and $RB_{HDQ}:B_{HDQ}$ ratio from HDQ according to winter-growth and finishing management

All values adjusted to a common liveweight (LW) at the start of the finishing phase; (+) or (–) indicate whether the LW effect was positive or negative. For winter-growth treatments: H and L are high and low LW gain, F and P are in feedlot and on pasture. Within parameters, means followed by the same letter are not significantly different ($P > 0.05$) for winter-growth × finishing management interaction

Winter growth	Finishing	*n*	HDQ (kg)	% FT_{HDQ}	% B_{HDQ}	% RB_{HDQ}	$RB_{HDQ}:B_{HDQ}$ ratio
HF	Feedlot	30	56.28 ± 0.37x	11.39 ± 0.17x	22.09 ± 0.18yz	65.07 ± 0.30z	3.59 ± 0.03xy
LF		30	55.66 ± 0.37x	10.82 ± 0.17x	22.45 ± 0.18yz	65.01 ± 0.30z	3.57 ± 0.03xy
HP		30	51.90 ± 0.38z	7.00 ± 0.18y	23.09 ± 0.19x	69.08 ± 0.32y	3.42 ± 0.03z
LP		30	51.55 ± 0.38z	6.60 ± 0.18y	23.03 ± 0.18x	70.20 ± 0.31y	3.44 ± 0.03z
HF	Pasture	30	52.69 ± 0.39y	5.02 ± 0.18z	22.47 ± 0.19xy	72.35 ± 0.32x	3.52 ± 0.03yz
LF		30	52.84 ± 0.40y	4.87 ± 0.18z	22.69 ± 0.19xy	72.20 ± 0.32x	3.47 ± 0.03z
HP		30	53.64 ± 0.39y	4.45 ± 0.18z	21.72 ± 0.19yz	73.58 ± 0.32x	3.63 ± 0.03xy
LP		30	53.89 ± 0.37y	4.84 ± 0.17z	21.46 ± 0.18yz	73.09 ± 0.30x	3.70 ± 0.03x
				P-value			
Winter growth			<0.0001	<0.0001	0.770	<0.0001	0.529
Finishing			0.0343	<0.0001	0.0200	<0.0001	0.0061
Winter growth × finishing			<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
LW			<0.0001 (+)	0.190	0.560	0.010 (+)	0.770

Table 5. Least-square means and standard errors for beef cuts (kg) according to winter-growth and finishing management

All values adjusted to a common liveweight (LW) at the start of the finishing phase; (+) or (–) indicate whether the LW effect was positive or negative. For winter-growth treatments: H and L are high and low LW gain, F and P are in feedlot and on pasture. Within parameters, means followed by the same lowercase letter are not significantly different ($P > 0.05$): a, b compare within a finishing phase; x, y, z, v, w compare for winter-growth × finishing management interaction. Different uppercase letters are used to show significant difference ($P < 0.05$) between feedlot and pasture finishing managements (for mean of HF, LF, HP, LP)

Winter growth	Finishing	*n*	Striploin	Knuckle	Rib plate flank on	Rump tail	Rump	Tenderloin	Topside
HF	Feedlot	30	5.16 ± 0.07x	4.69 ± 0.06abB	39.90 ± 0.31x	1.13 ± 0.02abB	4.91 ± 0.07yzw	1.95 ± 0.027y	7.05 ± 0.082bB
LF		30	4.93 ± 0.07xy	4.66 ± 0.06b	39.73 ± 0.31x	1.11 ± 0.02ab	4.80 ± 0.07zw	1.93 ± 0.027y	7.10 ± 0.082b
HP		30	4.67 ± 0.07y	4.76 ± 0.06ab	38.02 ± 0.33y	1.05 ± 0.02b	4.43 ± 0.07v	2.10 ± 0.029x	7.46 ± 0.087a
LP		30	4.67 ± 0.07y	4.80 ± 0.06a	37.84 ± 0.32y	1.17 ± 0.02a	4.62 ± 0.07vw	2.12 ± 0.028x	7.33 ± 0.085a
HF	Pasture	30	5.01 ± 0.07x	5.23 ± 0.06abA	38.80 ± 0.33xy	1.28 ± 0.02abA	5.05 ± 0.07xyz	2.02 ± 0.029xy	7.84 ± 0.088bA
LF		30	4.95 ± 0.07xy	5.22 ± 0.06b	38.83 ± 0.34xy	1.27 ± 0.02ab	5.17 ± 0.07xy	1.95 ± 0.029y	7.81 ± 0.088b
HP		30	4.91 ± 0.07xy	5.36 ± 0.06ab	39.82 ± 0.33x	1.29 ± 0.02b	5.29 ± 0.07x	1.94 ± 0.029y	8.10 ± 0.086a
LP		30	4.91 ± 0.07xy	5.40 ± 0.06a	40.12 ± 0.32x	1.33 ± 0.02a	5.29 ± 0.07x	1.97 ± 0.028y	8.19 ± 0.083a
					P-value				
Winter growth			<0.0001	0.0238	0.463	0.0117	0.234	0.0012	<0.0001
Finishing			0.0648	<0.0001	0.0238	<0.0001	<0.0001	0.0054	<0.0001
Winter growth × finishing			0.0095	0.939	<0.0001	0.168	<0.0001	<0.0001	0.582
LW			<0.0001 (+)	<0.0001 (+)	<0.0001 (+)	<0.0001 (+)	<0.0001 (+)	<0.0001 (+)	<0.0001 (+)

reared in the LP group had the heaviest knuckle and rump tail weights, whereas those reared in HP and LP groups had the heaviest topside.

The results obtained in this study demonstrate that when animals are slaughtered at similar weights, those reared or finished on pasture tend to display heavier HCW and cut yields than those from feedlot conditions. This pattern may be related to the high percentage of FT_{HDQ} and low percentage of RB_{HDQ} observed in feedlot-finished steers (Table 4). Consequently, carcasses from feedlot-finished steers might have undergone a stricter trimming process in which the excessive subcutaneous fat content is removed, explaining the higher beef cut yields observed in pasture-reared animals (Table 5). Butterfield (1974) reported that meat yield decreased as carcass weight increased, probably due to the high fat content observed in concentrate-fed animals. Harrison *et al*. (1978) found that long-fed cattle (98 days in drylot) exhibited heavier carcasses with a higher degree of marbling and quality grade than forage-fed cattle; however, they displayed lower cutability scores than carcasses from forage-fed steers. Schroeder *et al*. (1980) reported that carcass with low fat content from forage-fed cattle showed higher retail cut yields than heavier carcasses from grain-fed cattle.

The present study considers several productive scenarios common in rearing and finishing beef-cattle systems in temperate regions of South America, providing substantial information to support farmers, technicians and researchers in beef-cattle feeding and management. The results obtained in this study help to establish the interactions between nutritional management at different phases of animal growth, aiming to improve quality of beef products and sustainability of beef production.

Conclusion

The nutritional management of Hereford steers during the finishing phase affected meat quality and, particularly, the fatty acid composition. Pasture-reared and -finished steers displayed a healthier fatty-acid profile with a higher content of beef CLA (*cis*-9, *trans*-11), EPA, DHA and DPA than feedlot-based groups. Pasture-finished steers displayed carryover effects of nutritional management at first winter-growth (post-weaning period of 93 days) for beef fatty acids important for human health (such as CLA).

Although feedlot-finished steers displayed high performance for muscle development and fat composition indicator traits such as ribeye area, backfat thickness and marbling, pasture-based nutritional management at winter-growth and finishing phases improved the yield of retail cuts and beef shear force. Thus, the pasture production system satisfies consumer expectations by providing high quality and healthier products.

Conflicts of interest

The authors declare no conflicts of interest.

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