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Effects of feeding system and slaughter age on the growth and carcass characteristics of tropical-breed steers[1]

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ABSTRACT: This study aimed to compare the growth performances and carcass characteristics of tropical-breed steers reared in 2 contrasted feeding systems (indoor vs. pasture) and slaughtered at different ages (early vs. late). A total of 309 Creole steers (growing at an initial BW of 173 ± 3 kg and an initial age of 252 ± 4 d) were used over a continuous 12-yr study. Indoor steers were housed in a cattle shed, fed fresh-cut grass plus concentrate, and slaughtered at 14.5 or 17.1 ± 0.1 mo of age. Pasture steers were pasture grazed without supplemental feed, and slaughtered at 17.6 and 21.2 ± 0.1 mo of age. Indoor-fed steers had a greater ADG (786 vs. 517 ± 29 $g·d^{-1}$; $P < 0.0001$) and more carcass fat (164 vs. 145 ± 4.5 $g·kg^{-1}$; $P = 0.001$) than pasture-fed steers. Late-slaughtered steers had decreased ADG (630 vs. 673 ± 27 $g·d^{-1}$; $P = 0.001$) but greater dressing percentages (hot dressing percentage = 55.7 vs. 54.7 ± 0.34%; chilled dressing percentage = 54.5 vs. 53.4 ± 0.34%; $P < 0.0001$) than early-slaughtered steers. The interaction between feeding system and slaughter age was significant for carcass tissue composition. Whole-carcass muscle content was greater in late-slaughtered steers than early-slaughtered steers, especially in pasture-fed steers (720 vs. 698 ± 6.0 $g·kg^{-1}$; $P < 0.0001$), but less so in indoor-fed steers (707 vs. 700 ± 5.9 $g·kg^{-1}$; $P = 0.046$). Furthermore, increasing slaughter age had no effect on carcass fat in indoor-fed steers (162 vs. 166 ± 4.8 $g·kg^{-1}$; $P = 0.342$), but decreased carcass fat in pasture-fed steers (150 vs. 140 ± 5.0 $g·kg^{-1}$; $P = 0.014$). The results showed that slaughter age and feeding system are 2 major factors that independently affect most of the growth and carcass traits of tropical-breed steers but jointly influence tissue deposition. Our study found that in tropical-breed steers that are grazing, late slaughtering grazing steers increased carcass muscle content without extra fat, thus yielding a carcass quality better suited to consumer choices.

Key words: average daily gain, carcass traits, cattle, indoor, pasture, slaughter age

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INTRODUCTION

Grazing is the main mode of feeding ruminants in the tropics (Steinfeld et al., 2006). Nevertheless, grazing systems are generally associated with low performances, particularly in the tropics, due to the relatively poor nutritive value of available forage. In these regions, further strategies may improve efficiency of grazing systems. First, a suitable pasture system management strategy can improve the exploitation of offered biomass and increase feed intake at pasture (Boval and Dixon, 2012). Second, supplementing grazed forages with nutritious feed-like concentrate (Sales et al., 2011) or abundantly available local feeds (Archimede et al., 2010) may enhance DM and nutrient intakes and thereby improve performances at pasture. However, systems off-pasture with supplemental feeds have developed in these regions.

Feeding system is a major criterion in beef production and induces specific effects on growth and carcass characteristics on cattle (Esterhuizen et al., 2008;

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Menezes et al., 2010). Furthermore, previous studies have also reported that many important beef characteristics, including growth and meat quality and palatability, are influenced by slaughter age (Maltin et al., 1998; Kwon et al., 2009).

To our knowledge, there is a lack of studies comparing the effects of the 2 common feeding systems in tropical environments on growth and carcass characteristics of tropical-breed cattle reared in a tropical climate, which addresses a large portion of global beef production.

Therefore, this study was designed to quantify and assess growth performances and carcass characteristics in steers from a tropical beef breed reared in 2 contrasted feeding systems (housed indoors or grazed at pasture) and slaughtered at 2 ages. We tested the hypothesis that pasture-fed cattle could achieve similar final carcass weight but with leaner meat than indoor-fed cattle simply by modifying slaughter age.

MATERIALS AND METHODS

This experiment was conducted between 1998 and 2009 at the French National Agronomic Research Institute (**INRA**) experimental animal husbandry station in Gardel, Guadeloupe (16°16′ N, longitude 61°30′ W), in the French West Indies. Animal care and management was performed in compliance with the Certificate of Authorization to Experiment on Live Animals issued by the French Ministry of Agriculture, Fisheries and Foodstuffs.

Experimental Design

Over a 12-yr period, the experiment used a total of 309 purebred Creole steers raised with the mothers on pasture until weaning at age 7 mo. After a postweaning transition period of about 40 d, the steers (252 ± 4 d old, at an average BW of 173 ± 3 kg) were grown in 2 feeding systems: housed in a cattle shed or grazed at pasture. Each year, 1 group of steers was kept indoors and fed fresh-cut grass and concentrate whereas the other group was left outdoors to graze pasture without supplementation. Within each feeding system, the animals were slaughtered either early or late. For indoor-fed steers (n = 177), early and late slaughter occurred at 14.5 ± 0.1 mo (n = 98) and 17.1 ± 0.1 mo (n = 79), respectively, whereas for pasture-grazed steers (n = 132), early and late slaughter occurred at 17.6 ± 0.1 mo (n = 65) and 21.2 ± 0.1 mo (n = 67), respectively. These ages were chosen to reproduce the commercial BW usually observed in the beef sector in Guadeloupe.

Table 1. Chemical composition of Pangola grass (*Digitaria decumbens*) based on data reported by Archimede et al. (2000) and concentrate used

Chemical composition[1], g/kg DM	Pangola grass		
	Pasture	Indoor	Concentrate
OM	887	879	915
CP	79	57	379
NDF	777	790	185
ADF	429	441	112
Acid detergent lignin	74	78	34.9

[1]Mineral and vitamin composition of the concentrate used: Ca (0.53%), Na (0.04%), P (0.42%), Mn (51.12 mg/kg), Zn (183.4 mg/kg), Fe (59.99 mg/kg), I (0.50 mg/kg), Se (0.15 mg/kg), Co (0.25 mg/kg), Cu (9.79 mg/kg), vitamin A (11 International Unit/kg), vitamin D3 (2.20 International Unit/kg).

Animal Feeding and Management

An average of 15 steers each year were assigned to the indoor treatment (**IND**) where they were penned together and fed twice a day, at 0800 h and 1500 h, with fresh-cut grass (mostly *Digitaria decumbens*) aged at about 50 d of regrowth (Table 1). The steers had free access to a pelleted commercial concentrate delivered by an automatic feeder and received concentrate up to 60% of the estimated daily voluntary intake (57 g of concentrate on a DM basis per kilogram metabolic BW). Pellet composition was 68% maize, 22% wheat middling, 8% soya meal, and 2% vitamins and minerals (Table 1).

Steers assigned to the pasture treatment (**PAST**) were rotationally grazed on irrigated pastures (predominantly *Digitaria decumbens*) at 30-d intervals. Each year, an average of 11 steers was assigned to the pasture treatment where they were rotationally grazed on 3.05 ha of irrigated pasture at a stocking rate of 1.30 $t \cdot ha^{-1}$. No supplementary feed was offered and steers were kept at pasture throughout the day. The pastures were fertilized at a rate of 50 nitrogen unit/ha, using a 27–9–18 N–P–K fertilizer.

All animals had ad libitum access to fresh water and mineral–vitamin supplement. Steers were weighed on a full BW basis, first at the beginning of the experimental period and then at 14-d intervals and again just before slaughter. Overall ADG was calculated as the difference between initial and final BW.

For IND steers, early slaughter (**EARLY**) and late slaughter (**LATE**) occurred at 14.5 ± 0.1 mo and 17.1 ± 0.1 mo, respectively, whereas for PAST steers, EARLY and LATE slaughter occurred at 17.6 ± 0.1 mo and 21.2 ± 0.1 mo, respectively.

Slaughter and Carcass Measurements

The day before slaughter, steers were transported to the experimental slaughterhouse and fasted overnight.

On the day of slaughter, steers were weighed alive just before being slaughtered by captive bolt stunning and exsanguination. Carcass dressing followed a standardized protocol without electrical stimulation as recommended by the French Ministry of Agriculture. Hot carcass weight was recorded, and hot dressing percentage (**HDP**) was defined as (HCW/slaughter BW) × 100. The entire digestive tract was removed and weighed (total and empty digestive tract, stomach, and intestines separate). Internal fat (heart, kidneys, ruffle, and peritoneal fats) was also removed and weighed. The carcasses were then split longitudinally into 2 sides, with the tail attached on the left side of the carcass. Both the left and right sides of the carcasses were weighed. The carcasses were chilled and stored at 4°C in a cooler for 24 h until further measures.

At 24 h postmortem, the carcasses were taken out of the cooler, chilled carcass weight (**CCW**) was recorded, and chilled dressing percentage (**CDP**) was defined as the ratio of CCW to slaughter BW (× 100). Morphological measures were taken as described in Boer et al. (1974) on both the left and right sides of the carcass, and the 2 measures were averaged. Carcass length and external depth of chest were determined with a tape measure. Measures of sirloin thickness and thigh thickness were made with a sharpened metal rule. The left side of the carcasses was divided into fore- and hindquarters by cutting between the fifth and sixth ribs, with the plate attached to the forequarters (cut passing across the ribs at right angles to the first at a point slightly below the centre of the rib cage). Quarters were weighted separately.

The hindquarters were ribbed between the sixth and the 11th ribs, and the sixth and 11th thoracic rib joints were collected, weighed, and dissected into muscle, fat, and bone tissues. Whole-carcass composition was assessed from carcass measurements and rib composition using the procedure described by Robelin and Geay (1975) and then adapted to local Creole cattle in previous experiments (M. Naves, unpublished data).

Statistical Analyses

Statistics were computed using the MIXED procedure (SAS Inst. Inc., Cary, NC). The model included the main effects of feeding system (**FS**), slaughter age class (**SA**), year of birth (**YB**), and sire (**SR**), applying this equation:

$$y_{ijklm} = \mu + FS_i + SA_j + (FS_i \times SA_j) + SR_k + YB_l + (FS_i \times YB_l) + \alpha \times ILW + e_{ijklm},$$

in which y_{ijklm} = the observed values for the *m*th steer in feeding system FS_i, at slaughter age SA_j, born from sire SR_k, and included in repetition YB_l, μ = mean value common to all observations, FS_i = fixed effect of feeding system (2 levels: indoor fed vs. pasture fed), SA_j = fixed effect of slaughter age class (2 levels: early vs. late), $FS_i \times SA_j$ = interaction between feeding system FS_i and slaughter age SA_j, SR_k = random effect of sire (26 sires), YB_l = random effect of year of birth (12 yr), $FS_i \times YB_l$ = random effect of the interaction between feeding system FS_i × year of birth YB_l, ILW = initial BW, as a general covariate, and e_{ijklm} = the error term.

According to this split-plot design, the effect of FS was tested as a "block" factor over year of birth considered as experimental unit whereas the other effects were tested over a general residual using the animal as experimental unit. Other interactions were tested in previous runs but discarded in the final model as not significant ($P > 0.05$). Results are given as least square means ± SEM and level of significance set at $P < 0.05$.

RESULTS

Growth Performance and Slaughter Characteristics

The mean growth curves of IND and PAST steers were linear ($y = 21.44x + 174.88$ and $y = 15.80x + 163.35$, $P < 0.001$, for IND and PAST steers, respectively) over the course of the experiment (Fig. 1). An average BW of 350 kg was reached after about 8 mo indoor and 11.5 mo at pasture. Growth under the indoor treatment was relatively uniform whatever the year of birth whereas growth under the pasture treatment was more heterogeneous, with 4 yr that differed greatly from the overall growth curve.

We found no interactions between feeding system and slaughter age on these variables (Table 2). Feeding system affected overall ADG ($P < 0.0001$): indoor steers gained an average 268 ± 29.7 g·d^{-1} more BW than PAST steers. Feeding system had no effect on final BW ($P = 0.385$), slaughter BW ($P = 0.397$), or HCW ($P = 0.106$).

Slaughter age also affected overall ADG ($P = 0.001$), final BW, and slaughter BW and HCW ($P < 0.0001$). Late-slaughtered steers had a reduced ADG than EARLY-slaughtered steers ($P = 0.001$), and despite starting with a lower initial BW ($P < 0.0001$), they showed heavier final BW ($P < 0.0001$), slaughter BW ($P < 0.0001$), and HCW ($P < 0.0001$).

Sire effect only affected final BW ($P = 0.039$) and ADG ($P = 0.035$) whereas year of birth had no effect on these variables. The interaction between year of birth and feeding system affected all the variables studied ($P < 0.03$).

Carcass Characteristics

Feeding system affected all carcass characteristics except CCW ($P = 0.094$) and the estimated muscle percentage of the entire carcass ($P = 0.253$; see Table 3).

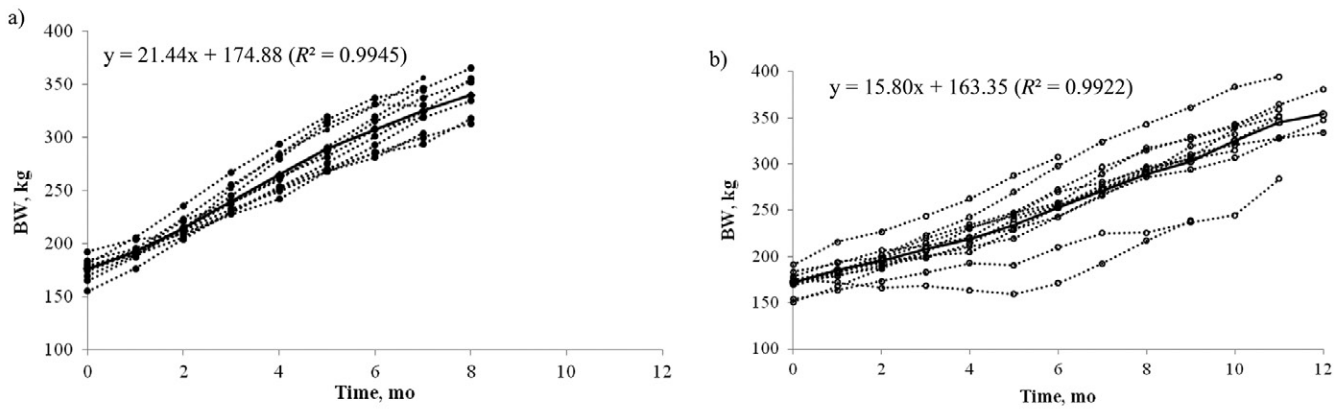

Figure 1. Plot of the mean growth curves (BW, kg) over time (month) of Creole steers raised indoors (a) or at pasture (b). Each dotted curve represents a contemporary group of steers, and the bold curve represents the overall growth curve in each treatment.

Indoor steer carcasses showed greater HDP ($P = 0.0002$), CDP ($P = 0.0002$), and fat deposition than PAST steer carcasses and less bone and less muscle in both sixth and 11th ribs than PAST steer carcasses.

Slaughter age affected HDP, CDP, CCW and total carcass muscle ($P < 0.0001$) and affected bone percentage in the sixth rib ($P = 0.002$) and in the whole carcass ($P < 0.0001$). Late-slaughtered steers showed greater HDP, CDP, CCW, and muscle percentage of the entire carcass compared with EARLY steers ($P < 0.0001$). However, bone deposits were lighter in LATE steer carcasses ($P < 0.0001$).

The interaction between feeding system and slaughter age affected fat ($P = 0.004$) and bone ($P = 0.002$) proportions of the 11th rib of the carcasses, muscle ($P = 0.007$), and fat ($P = 0.011$) proportions of the entire carcass as well as internal fat ($P = 0.001$). Steers raised on pasture, whether slaughtered EARLY or LATE, had less fat deposits ($P = 0.004$) in the 11th rib and in the whole carcass ($P = 0.011$) and less internal fat ($P = 0.001$) than IND steers (Fig. 2a, 2c, and 2e). Within the pasture-fed treatment, LATE-slaughtered steers (**PAST-LATE**) had less carcass fat content ($P = 0.011$) than EARLY-slaughtered steers (**PAST-EARLY**). Within the indoor-fed treatment, EARLY-slaughtered steers (**IND-EARLY**) had less fat deposits in the 11th rib ($P = 0.004$) and less internal fat ($P = 0.001$) than LATE-slaughtered steers (**IND-LATE**). Indoor steers late slaughtered had less bone deposits in the 11th rib ($P = 0.002$) than all other steers, which did not show between-treatment differences (Fig.2b). Muscle content of the whole carcass was equivalent in IND-EARLY and IND-PAST steers but was greater for LATE steers, especially PAST-LATE steers (Fig. 2d).

There was a sire effect on dressing percentages ($P = 0.022$) and muscle ($P = 0.018$) and fat ($P = 0.036$) percentages of the carcass. Year of birth affected muscle percentage of the entire carcass ($P = 0.072$). The interaction between year of birth and feeding system affected CCW ($P = 0.018$), CDP ($P = 0.043$), fat percentage of the sixth ($P = 0.042$) and 11th ribs ($P = 0.048$), and bone percentage of the entire carcass ($P = 0.018$).

Table 2. Effects of feeding system (FS) and slaughter age (SA) on Creole steer growth and slaughter characteristics

	Feeding system[1]			Slaughter age[2]			*P*-value						
Item	IND	PAST	SEM	EARLY	LATE	SEM	FS	SA	FS × SA	SR[3]	YB[4]	YB × FS	ILW[5]
Initial BW, kg	174	172	3.0	182	165	3.1	0.594	<0.0001	0.445	0.059	0.189	–	–
Initial age, d	249	256	4.1	250	254	3.5	0.138	0.071	0.344	0.087	0.176	0.028	–
Final BW, kg	349	341	7.7	324	365	6.4	0.385	<0.0001	0.881	0.039	0.221	0.020	<0.0001
ADG, $g \cdot d^{-1}$	786	517	29	673	630	27	<0.0001	0.001	0.233	0.035	0.061	0.028	0.620
Slaughter BW, kg	324	316	7.0	301.	339	5.6	0.397	<0.0001	0.768	0.055	0.355	0.019	<0.0001
HCW, kg	183	172	4.9	165	189	4.0	0.106	<0.0001	0.845	0.066	0.265	0.018	<0.0001

[1]IND = indoor fed; PAST = pasture grazing.

[2]EARLY = early slaughter; LATE = late slaughter.

[3]SR = sire.

[4]YB = year of birth.

[5]ILW = initial live weight.

Table 3. Effects of feeding system (FS) and slaughter age (SA) on Creole steer carcass characteristics

	Feeding system[1]			Slaughter age[2]			*P*-value						
Item	IND	PAST	SEM	EARLY	LATE	SEM	FS	SA	FS × SA	SR[3]	YB[4]	YB × FS	ILW[5]
HDP,[6] %	56.2	54.2	0.37	54.7	55.7	0.34	0.0002	<0.0001	0.822	0.022	0.107	0.052	0.002
CCW,[7] kg	179	168	4.8	161	185	3.9	0.094	<0.0001	0.749	0.063	0.270	0.018	<0.0001
CDP,[8] %	55.0	52.9	0.38	53.4	54.5	0.34	0.0002	<0.0001	0.923	0.022	0.136	0.043	0.001
Sixth rib composition, $g \cdot kg^{-1}$ of the sixth rib													
Muscle	698	723	5.5	709	713	4.9	0.002	0.389	0.355	0.025	0.369	0.083	0.473
Fat	145	107	5.6	123	129	4.7	0.0003	0.089	0.155	0.059	0.427	0.042	0.341
Bone	157	169	4.6	168	158	4.1	0.040	0.002	0.646	0.138	0.171	0.066	0.989
11th rib composition, $g \cdot kg^{-1}$ of the 11th rib													
Muscle	636	683	8.9	657	661	8.4	0.0001	0.486	0.529	0.022	0.072	0.087	0.672
Fat	185	127	8.0	154	158	7.1	<0.0001	0.411	0.004	0.032	0.195	0.048	0.870
Bone	178	190	4.3	187	181	4.3	0.006	0.086	0.002	0.432	0.035	–	0.680
Estimated carcass composition, $g \cdot kg^{-1}$ of CCW													
Muscle	704	709	5.6	699	714	5.3	0.253	<0.0001	0.007	0.018	0.049	0.058	<0.0001
Fat	164	145	4.5	156	153	4.3	0.001	0.227	0.011	0.036	0.077	0.084	0.016
Bone	132	146	3.0	144	133	2.4	0.006	<0.0001	0.582	0.183	0.310	0.018	<0.0001
Internal fat[9]	33.1	23.6	1.4	28.2	28.5	1.3	<0.0001	0.704	0.001	0.059	0.058	0.100	0.496

[1]IND = indoor fed; PAST = pasture grazing.

[2]EARLY = early slaughter; LATE = late slaughter.

[3]SR = sire.

[4]YB = year of birth.

[5]ILW = initial live weight.

[6]HDP = hot dressing percentage.

[7]CCW = chilled carcass weight.

[8]CDP = chilled dressing percentage.

[9]Internal fat relative to HCW.

Carcass Measurements, Conformation, and Noncarcass Components

The interaction between feeding system and slaughter age affected digestive tract traits. Digestive tract content was heavier for LATE steers, particularly PAST-LATE steers (37.6 vs. 32.0 ± 1.28 kg; $P = 0.033$). Relative to slaughter BW, LATE slaughter decreased intestine weight, especially in PAST-LATE carcasses (24.7 vs. 28.4 ± 0.68 $g \cdot kg^{-1}$; $P = 0.046$; Fig. 2f). Carcass measurements are presented in linear units as well as relative to BW, as they reflect developmental and conformational changes.

Feeding system affected all carcass measurements ($P < 0.001$) except carcass length ($P = 0.390$), thigh thickness ($P = 0.060$), and external depth of chest ($P = 0.771$; Table 4). In millimeters, PAST steers had thicker sirloin than IND steers ($P = 0.0003$). Relative to CCW, all measurements except thigh thickness were less in IND steers than PAST steers.

In absolute weight or relative to CCW, feeding system had no effect on fore- and hindquarters ($P > 0.05$). Indoor steers showed better carcass ($P = 0.026$) and leg ($P = 0.001$) compactness indexes. Feeding system affected all digestive tract measures ($P < 0.0001$). Indoor steers had lighter digestive tract contents than PAST steers in absolute weight and related to slaughter BW.

Slaughter age affected all the linear carcass measurements ($P < 0.0001$). Increasing slaughter age increased all carcass measurements except external depth of chest, but when expressed as a function of CCW, EARLY steers yielded greater carcass measurements than LATE steers. Late-slaughtered steers had heavier fore- and hindquarters that EARLY steers but lighter hindquarters than EARLY steers when expressed as percentage of CCW ($P < 0.0001$). Late-slaughtered steers had greater carcass and leg compactness indexes than EARLY-slaughtered steers ($P < 0.0001$). Increasing slaughter age led to a heavier weight of digestive tract organs but to a lower weight of digestive tract organs when expressed relative to slaughter BW ($P < 0.0001$).

The sire factor mostly affected carcass measurements when expressed in absolute values, carcass conformation relative to CCW, and weight of digestive tract traits. Year of birth affected weight of empty digestive tract ($P = 0.048$) and intestines ($P = 0.026$) and empty digestive tract ($P = 0.042$) and stomach ($P = 0.031$) when expressed relative to slaughter BW. The interaction between year of birth and feeding system affected all the variables tested except sirloin thickness ($P = 0.187$) and

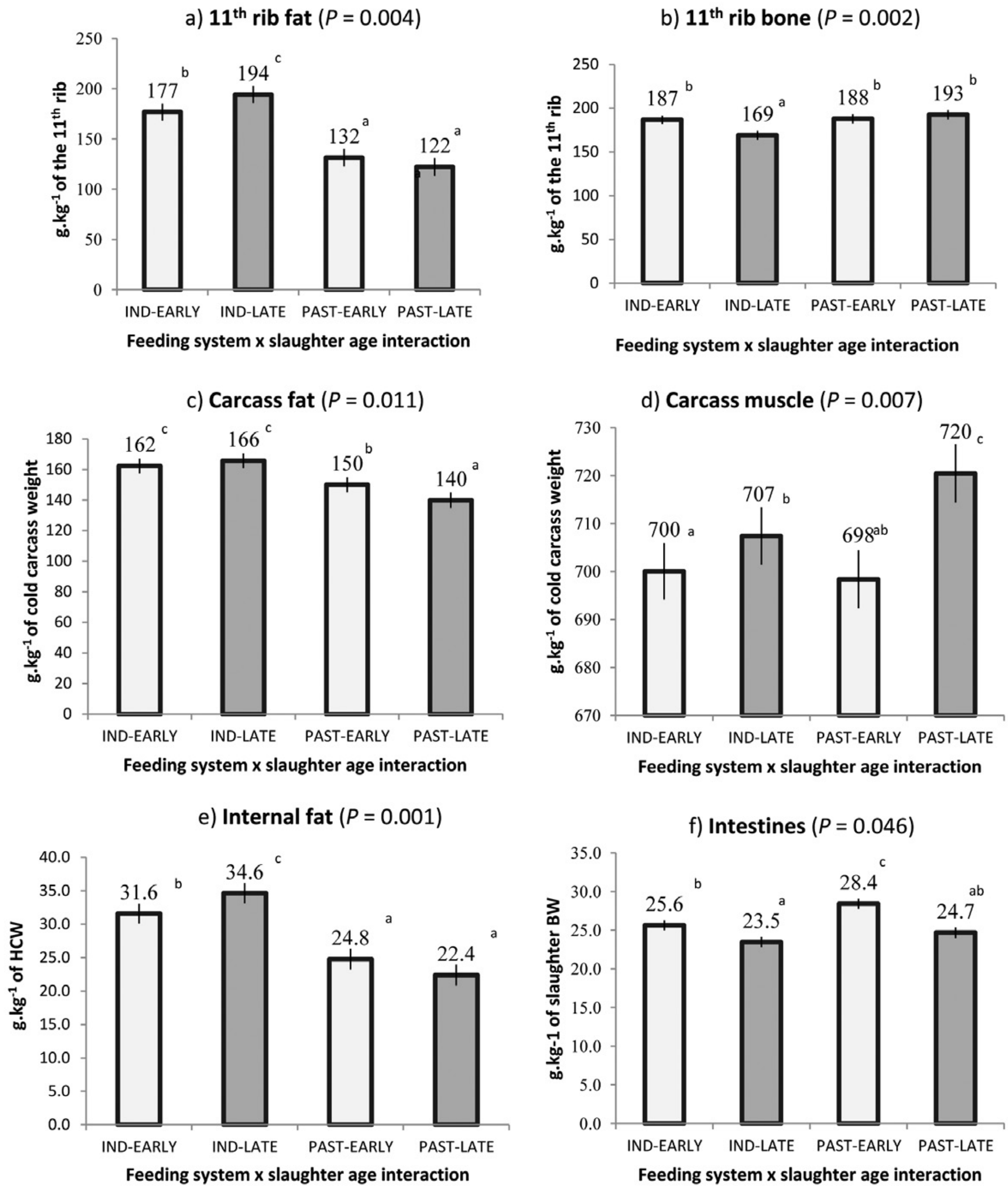

Figure 2. Effects of the interaction between feeding system (IND: indoor fed; PAST: pasture grazing) and slaughter age (EARLY: early slaughtered; LATE: late slaughtered) on (a) 11th rib fat, (b) 11th rib bone, in grams per kilogram of the 11th rib, (c) carcass fat, (d) carcass muscle in grams per kilogram of cold carcass weight, (e) internal fat in grams per kilogram of HCW, and (f) intestines in grams per kilogram of slaughter BW. Means with different superscripts are significantly different; $P < 0.05$.

empty digestive tract weight ($P = 0.058$) and intestines and stomach weight relative to slaughter BW ($P > 0.05$).

DISCUSSION

Feeding system and slaughter age are 2 important factors that appear independent for their effects on growth and carcass characteristics in tropical beef production systems. Indeed, although the interaction between feeding system and slaughter age was nonsignificant for most of the parameters measured, it did affect carcass tissue composition, which is a key criterion for beef production due to its effects on meat quality. Considering this major criterion, it emerges from our results that it is more efficient to use an early slaughter age for stall-fed cattle, particularly if they receive added concentrate, but not for pasture-fed steers. Our experimental design enabled a comparison of the carcass characteristics for steers fed exclusively on pasture and slaughtered at either 17 or 21 mo, which is seldom the case in other studies where feed-

Table 4. Effects of feeding system (FS) and slaughter age (SA) on Creole steer carcass conformation and digestive tract traits

	FS[1]			SA[2]			*P*-value						
Item	IND	PAST	SEM	EARLY	LATE	SEM	FS	SA	FS × SA	SR[3]	YB[4]	YB × FS	ILW[5]
Carcass measurements													
Carcass length, cm	116.5	117.3	0.93	115.3	118.5	0.84	0.390	<0.0001	0.896	0.137	0.079	0.033	<0.0001
Thigh thickness, cm	21.0	20.3	0.30	20.1	21.2	0.26	0.060	<0.0001	0.288	0.036	0.139	0.026	<0.0001
External depth of chest, cm	64.3	64.1	0.68	62.9	25.5	0.61	0.771	<0.0001	0.877	0.047	0.121	0.038	<0.0001
Sirloin thickness, mm	74.4	76.1	0.31	74.5	76.1	0.29	0.0003	<0.0001	0.828	0.006	0.297	0.187	<0.0001
Carcass measurements, kg^{-1} CCW[6]													
Carcass length	0.65	0.70	0.015	0.70	0.63	0.012	0.022	<0.0001	0.934	0.149	0.239	0.020	<0.0001
Thigh thickness	0.119	0.123	0.002	0.126	0.116	0.002	0.111	<0.0001	0.261	0.220	0.167	0.030	<0.0001
External depth of chest	0.36	0.39	0.011	0.40	0.36	0.010	0.033	<0.0001	0.910	0.012	0.075	0.020	<0.0001
Sirloin thickness	0.42	0.46	0.011	0.47	0.42	0.010	0.017	<0.0001	0.927	0.230	0.246	0.018	<0.0001
Carcass conformation, kg													
Forequarters	44.8	41.2	1.67	39.5	46.5	1.41	0.088	<0.0001	0.558	0.107	0.145	0.016	<0.0001
Hindquarters	39.3	37.1	1.00	36.0	40.4	0.82	0.110	<0.0001	0.900	0.017	0.298	0.018	<0.0001
Carcass conformation, % of CCW													
Hindquarters	46.8	47.6	0.39	47.9	46.6	0.35	0.057	<0.0001	0.091	0.019	0.076	0.035	0.0001
Leg compactness index[7]	0.282	0.266	0.003	0.270	0.278	0.003	0.001	<0.0001	0.347	0.029	0.115	0.042	0 0.0004
Carcass compactness index[8]	1.53	1.42	0.032	1.40	1.56	0.026	0.026	<0.0001	0.628	0.081	0.297	0.019	<.0001
Digestive tract traits, kg													
Empty digestive tract	16.6	17.9	0.41	16.8	17.6	0.38	0.004	0.0002	0.573	0.049	0.048	0.058	<0.0001
Digestive tract content	27.4	34.8	1.12	29.1	33.1	0.95	0.0004	<0.0001	0.033	0.021	–	0.015	0.001
Intestines	7.91	8.31	0.19	8.14	8.09	0.19	0.015	0.748	0.019	0.191	0.026	0.318	<0.0001
Stomach	8.67	9.55	0.25	8.70	9.52	0.23	0.004	<0.0001	0.198	0.027	0.079	0.039	<0.0001
Digestive tract traits, g·kg^{-1} slaughter BW													
Empty digestive tract	51.3	56.9	1.11	55.92	52.28	1.03	0.0001	<0.0001	0.510	–	0.042	0.047	<0.0001
Digestive tract content	84.7	110.7	3.56	96.7	98.8	2.88	0.0002	0.378	0.045	0.053	–	0.007	0.359
Intestines	24.5	26.5	0.60	27.0	24.0	0.56	0.008	<0.0001	0.046	0.359	0.074	0.081	0.0004
Stomach	26.7	30.3	0.65	28.9	28.2	0.62	<0.0001	0.030	0.148	0.238	0.031	0.060	0.0003

[1]IND = Indoor fed; PAST = pasture grazed.
[2]EARLY = early slaughter; LATE = late slaughter.
[3]SR = sire.
[4]YB = year of birth.
[5]ILW = initial live weight.
[6]CCW, chilled carcass weight.
[7]Thigh thickness/hock-to-symphysis distance.
[8]Chilled carcass weight/carcass length

ing systems and slaughter ages are confounded and where the authors generally practice early slaughter for housed animals fed a mixed diet and late slaughter for grazing animals to compensate for their decreased ADG (Brown et al., 2005). Here, we highlighted that it is advantageous to keep pasture-fed cattle alive for a longer time to get a carcass that is not only heavier but also leaner and more muscled and thus of greater quality, because this type of carcass is better suited to current consumer requirements, as reported by Grunert (1997).

Interaction between Feeding System and Slaughter Age Effects

There was generally no interaction between feeding system and slaughter age for most of the variables measured except for fat and bone percentages of the 11th rib and for entire carcass composition. Late slaughtering decreased carcass fat in pasture-fed steers but not indoor-fed steers. Humada et al. (2012), in a similarly structured study on Tudanca bulls reared indoors and fed concentrates for ad libitum intake or reared in semi-extensive conditions at pasture with concentrates and then slaughtered at 12 and 14 mo, found different interaction between feeding system and slaughter age on carcass fatness. In their conditions, younger semi-intensively farmed steers had lower carcass fatness than steers in the other treatments, which showed no between-group differences. Our different finding may be explained by the fact that Humada et al. (2012) used concentrate for both indoor-fed and pasture-fed steers.

Feeding System Effects

As expected, indoor-fed steers showed a greater ADG than pasture-fed counterparts. For indoor-fed Creole steers, we found greater ADG values than Itavo et al. (2007) had reported for Beefalo-Nellore steers slaughtered at 9 mo in tropical areas of Brazil after receiving roughage and concentrate for ad libitum intake. For pasture-fed Creole steers, our ADG values are greater than the 270 $g \cdot d^{-1}$ reported by Asizua et al. (2009) for Ankole purebred bulls or crossbred with Boran or Friesian and the 390 and 371 $g \cdot d^{-1}$ reported for zebu cattle at pasture by Mekasha et al. (2011) and Sales et al. (2011), respectively. Compared with these results from the literature, the ADG measured indoors or at pasture in our study appear relatively good for local breeds reared in tropical conditions.

There are very few studies comparing ADG between steers reared in indoor vs. pasture systems in tropical areas. Nevertheless, the ADG differential between the 2 feeding systems, which was approximately 268 $g \cdot d^{-1}$ in favor of indoor-fed steers, is consistent with Naves (2003) who found 787 and 420 $g \cdot d^{-1}$ for penned (forage plus supplement) and grazed Creole steers, respectively, from 9 to 14 mo of age. The differences in ADG between these feeding systems could be related to the use of feed supplement (Moore et al., 1999) and to different energy expenditures due to the greater exercise levels (Kaufmann et al., 2011) of grazing steers that increased energy requirements. Indeed, direct climatic effects may interfere directly on grazing steer performances. Under tropical conditions, seasonal variation has a marked influence on both the quantity and quality of forage mass available and thus on animal performances. This factor is even more critical when no supplementation is offered, as was the case in the current study. However, the growth curves in our study showed minimal seasonal fluctuations, as the pasture land used was irrigated and fertilized. The growth curve was more heterogeneous for pasture-fed steers than indoor-fed steers, with 4 yr that differed greatly from the mean, probably due to environmental conditions, but it remained linear across growth periods.

Indoor-fed steers had greater HDP and CDP than pasture-fed steers (+3.7 and +3.9%, respectively). For housed steers, HDP was greater than the 52% reported for grain-fed cattle by Maggioni et al. (2010) in young pen-reared bulls fed forage and concentrate and by Montero-Lagunes et al. (2011) in crossbred Zebu steers finished in feedlot conditions and fed forage and concentrate. For pasture-fed steers, HDP was similar to values reported by Rodas-González et al. (2006) and Montero-Lagunes et al. (2011) in almost identical conditions. Comparing indoor vs. pasture systems, the 3.7% difference found here was considerably less than the 11% reported by Montero-Lagunes et al. (2011) for European and zebu cattle fed a concentrate-rich supplementation. These differences in dressing percentage may also be linked to differences in empty digestive tract and digestive content mass, which were greater in pasture-fed steers than indoor-fed steers and were partly offset by the reduced internal fat content in grazing steers.

According to our set of fatness indicators, indoor-fed steers were "fatter" than pasture-fed steers. Carcass fat of indoor-fed steers reached 164 $g \cdot kg^{-1}$, which is lower than the 215 $g \cdot kg^{-1}$ reported in Brazil by Maggioni et al. (2010) for feedlot-finished Nellore cattle and crossed bulls. Carcass fat of pasture-fed steers was 145 $g \cdot kg^{-1}$, which is within the range of 80 $g \cdot kg^{-1}$ reported by Rodas-González et al. (2006) in Criollo-Limonero steers and 245 $g \cdot kg^{-1}$ reported by Ribeiro et al. (2008) in zebu cattle grazing without supplementation in tropical areas.

The roughly 13% difference in fat content between the 2 feeding systems contrasts with Menezes et al. (2010) who did not find any difference between fat percentages in grazing steers and confined steers, probably because their experiment lasted only 3 mo. It is well known that the amount of carcass fat is positively correlated with energy intake, as was the case for housed steers fed a mixed diet (Danner et al., 1980). Bines and Hart (1982) showed that concentrates tend to contain more starch, which induces greater levels of ruminal propionate, leading to an increase in fat synthesis. In a study on lambs, Priolo et al. (2002) suggested that animals raised on forage-based diets have a more developed digestive tract due to a greater forage DMI intake and therefore a greater rumination activity compared with grain-fed animals. The greater fatness in indoor-fed steer carcasses could also be linked to their reduced physical activity compared with outdoor rearing, as physical activity increases the mobilization of body lipid reserves to form muscle. Furthermore, as we observed here in indoor-fed animals, fatness values increased with increasing slaughter BW (Steen and Kilpatrick, 1995; Bruns et al., 2004). Moreover, shade may also enhance carcass fatness, as Mitlöhner et al. (2001) reported more fat for shaded heifers than unshaded heifers.

In summary, indoor feeding induced greater ADG, greater dressing percentages, and more carcass fat than outdoor grazing. These results are mainly explained by the greater energy intake, lower physical activity, and greater shade for housed cattle.

Slaughter Age Effects

Comparison of the 2 slaughter ages showed that late-slaughtered steers had 6.7% less ADG than early-slaughtered steers, whatever the feeding system. This observation is consistent with other findings (Kirkland et al., 2007), and the decreased ADG for late-slaughtered steers may be linked to a deterioration of feed conversion ratio as slaughter age and BW increase (Jurie et al., 2005). However, this difference in ADG at the 2 slaughter ages is not reflected in slaughter BW or carcass weight and is offset by the duration of the growth period.

The relatively greater HDP for late-slaughtered steers recorded in this study (+ 1.8%) is less than the 2.9% differential reported by Kirkland et al. (2007) for Holstein-Friesian steers fed in pens with silage and concentrate and slaughtered at 16 vs. 26 mo. The greater HDP found here for late-slaughtered steers could be due to their relatively lighter digestive tract and visceral mass.

Late slaughtering induced a reduced bone percentage, whatever the feeding system. Comparing carcass bone proportions of early vs. late-slaughtered steers, early-slaughtered steers had 8.2% more bone than late-slaughtered steers, which is a better figure than the average difference in bone mass (5.3%) described by Jurie et al. (2005) for French-breed bulls reared in stalls, fed with silage, hay, and concentrate, and slaughtered at 15 vs. 19 mo. Late-slaughtered steers showed reduced bone development, as evidenced by a decreased bone percentage and a reduced carcass length:carcass weight ratio. Bone growth is considered more a function of age than nutrition, as bone is an early-developing tissue (Field et al., 1990; Shahin and Berg, 1985). Moreover, carcass maturity increased with increasing slaughter age (Field et al., 1990).

Overall, late slaughtering resulted in reduced ADG, reduced bone percentage, and lighter carcasses relative to HCW. This trend may be linked to a deterioration of feed conversion ratio and bone percentage as slaughter age increases. Furthermore, slaughter age and slaughter BW are often confounded, as slaughter age is frequently dependent on the targeted slaughter BW.

Conclusion

Our results showed that feeding system and especially slaughter age are 2 major factors that appear independent in terms of assessing growth and carcass characteristics. However, as housing system and feeding strategy were confounded in this study, further research is needed to partition the specific individual effects of these 2 major factors on cattle performances.

The interaction between feeding system and slaughter age was nonsignificant for most of the variables measured except for carcass tissue composition, which is a key criterion for beef production. Bearing in mind this major criterion, it seems more advantageous to slaughter grazing cattle at a later age to get carcasses that are not only heavier but also leaner and more muscled and thus better suited to current consumer requirements. These findings will be of interest to beef producers in the tropics where grazing is the main mode of feeding ruminants.

Slaughtering late (21 mo) at pasture should be more profitable than indoor rearing with concentrates, especially as overall performances at pasture can be improved with appropriate pasture management and supplemental feeds. Further research is needed to compare the economic results and ecological impacts of these 2 production systems.

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