Archivos Latinoamericanos de Producción Animal. 2022. 30 (3)
www.doi.org/10.53588/alpa.300304

Influence of different feeding strategies on carcass and meat quality of grass-fed cull cows

Ximena Lagomarsino [1, 2] Fiorella Cazzuli
Maria Font-i-Furnols [3] Santiago Luzardo Fabio Montossi
INIA, Instituto Nacional de Investigación Agropecuaria,
Ruta 5, km 386, Tacuarembó 45000, Uruguay.

Abstract. Animal performance, carcass and meat quality characteristics of beef cull cows under different feeding strategies were compared. Cows were assigned to one of four grazing treatments combining different levels of forage allowance (FA) and supplementation rate (% of body weight, BW) using rice bran (RB): T1= FA 2 % + RB0, T2 = FA 4 % + RB0, T3= FA 2 % + RB 0.8 % and T4 = FA 2 % + RB 1.6 %. Cows from T1 presented lower (P < 0.05) slaughter weight (SW) than the other three treatments. Additionally, T1 presented lower body weight (P < 0.05) for rump and loin, striploin, sirloin, inside round and tri-tip, compared to T2, T3 and T4. Intramuscular fat (IMF), pH (48 h), Warner-Bratzler shear force (WBSF; aged for 7 or 21 days), lean colour, saturated fatty acid (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) concentrations did not differ among treatments (P > 0.05). Nonetheless, differences between treatments were found in n-6 and n-3 fatty acid contents (P < 0.05). The strategic use of low supplementation rates using rice bran on an oats forage crop improved certain meat and carcass quality traits of cull cows.

Key words: beef cattle; supplementation; grass-based feeding systems; valuable cuts and fatty acids.

Influencia de diferentes estrategias de nutrición sobre la calidad de la canal y de la carne de vacas de descarte alimentadas con pasto

Resumen. Se comparó la producción, las características de la canal y la calidad de la carne de vacas de descarte bajo diferentes estrategias de alimentación fueran evaluadas. Las vacas fueron asignadas a uno de cuatro tratamientos que combinaban diferentes niveles de asignación de forraje (AF) y suplementación con afrechillo de arroz (AA), según el peso vivo (% PV): T1 = AF 2 %, T2 = FA 4 %, T3 = AF 2 % + AA 0.8 % y T4 = FA 2 % + AA 1.6 %. Las vacas de T1 presentaron menor (P < 0.05) peso de faena que los restantes tratamientos. A su vez, T1 presentó menor peso (P < 0.05) para el lomo, bife, nalga de adentro y colita de cuadril, en comparación con T2, T3 y T4. La grasa intramuscular, pH (48 h), fuerza de corte Warner-Bratzler (con periodos de maduración de 7 o 21 días), color de la carne y concentración de ácidos grasos (AG) saturados (AGS), monoinsaturados (AGM) y poliinsaturados (AGP) no difirieron entre tratamientos (P > 0.05). Sin embargo, se observaron diferencias en el contenido de los ácidos grasos n-6 y n-3 (P < 0.05). El uso estratégico de un bajo nivel de suplementación de AA en un verdeo de avena mejoró ciertas características de calidad de la canal y la carne de las vacas de descarte.

Palabras clave: ganado vacuno; suplementación; sistemas de alimentación forrajeros; cortes valiosos y ácidos grasos.

Influência de diferentes estratégias de alimentação na qualidade da carcaça e qualidade da carne de vacas de descarte alimentadas com pastagem

Resumo. O desempenho animal, as características de carcaça e a qualidade da carne de vacas de corte (refugo) sob diferentes estratégias de alimentação foram avaliados. As vacas foram distribuídas em um dos quatro tratamentos de pastoreio direto combinando com diferentes níveis de oferta de forragem (FA) e taxa de suplementação (% do peso vivo, PC) usando farelo de arroz (RB): T1 = FA2 % + RB0, T2 = FA 4 % + RB0, T3 = FA 2 % + RB 0.8 % e T4 = FA 2 % + RB 1.6 %. As vacas do T1 apresentaram menor (P < 0.05) peso de abate (PS) do que os outros três

Recibido: 2021-07-23. Aceptado: 2022-03-17
[1]Corresponding author: ximena.lagomarsino@gmail.com
[2]FCA-UDE, Facultad de Ciencias Agrarias, Universidad de la Empresa, Luis Alberto de Herrera 2890, Montevideo, Uruguay.
[3]IRTA – Food Quality and Technology, Finca Camps i Armet, 17121 Monells, Girona, Spain.

tratamentos. Além disso, T1 apresentou menor peso (P < 0.05) para alcatra e lombo, contrafilé, pernil e tripa, em comparação com T2, T3 e T4. A gordura intramuscular (IMF), o pH (48 h), a força de cisalhamento Warner-Bratzler (WBSF; envelhecido por 7 ou 21 dias), a cor da carne, a quantidade de ácido graxo saturado (SFA),monoinsaturados (MUFA) e poliinsaturados (PUFA) não diferiram entre os tratamentos (P > 0.05). No entanto, foram encontradas diferenças entre os tratamentos nos teores de ácidos graxos n-6 e n-3 (P < 0.05). O uso estratégico de baixas taxas de suplementação com farelo de arroz em uma cultura forrageira de aveia melhorou algumas características de qualidade da carne e carcaça de vacas de descarte.

Palavras-Chave: bovinos de corte; suplementação; sistemas de alimentação baseados em capim; cortes valiosos e ácidos graxos.

Introduction

The Uruguayan beef supply chain is one of the most important economic activities in the country. During the last 10 years, approximately 2 million cattle heads were slaughtered per annum, of which 38 % have been cull cows with 6 to 8 permanent incisors (INAC, 2018). Thus, the importance of cull cows is clear for the meat industry, but also for cattle farmers in terms of income, particularly in the cow-calf operations when cows are diagnosed as non-pregnant (Montossi et al., 2014).

Increasing energy intake in semi-extensive and extensive beef production systems has a positive effect on the carcass (Rodríguez et al., 2014) and meat quality (Luzardo et al., 2008), and also on the fatty acid profile of intramuscular fat (Pouzo et al., 2015). An increase in quantity and/or quality of forage or the inclusion of supplementation increase live weight gain (Poppi et al., 1987; Ramírez-Barboza et al., 2016), which in turn, improves carcass quality in terms of conformation and degree of finishing (Brito et al., 2008; Pouzo et al., 2015). Animal feeding systems with greater energy supply improve the consumer´s acceptance in terms of lean and fat colour when compared to exclusively grass-fed animals (Realini et al., 2004; Ramírez-Barboza et al., 2016). According to Henchion et al. (2017), increasing the nutritive value of the diet of ruminants corresponds with the consumers´ preferences overall, since this has important influences on human health and wellbeing in terms of the fatty acid composition of meat.

Grass-fed beef production systems present a more beneficial omega6/omega3 ratio, and a greater polyunsaturated fatty acids / monounsaturated fatty acids (PUFA/MUFA) ratio in the intramuscular fat (IMF) compared to animals fattened in high-concentrate diets (Realini et al., 2004; Descalzo et al., 2005; Zea et al., 2007). Realini et al. (2009) reported that meat from grazing cattle supplemented with concentrates presented a greater acceptance from European consumers than those from exclusively grass-fed animals. According to a literature review carried out by Lagomarsino (2019), most of the research on the productivity and product quality of beef cull cows come from studies mainly associated with intensive feeding systems rather than grass-based diets.

We hypothesised that improvements in the nutrition of cull cows – either through greater forage allowances and/or with the restricted use of concentrate supplementation – enhance carcass and meat quality characteristics. The objective of this study was to evaluate the effect of different combinations of forage allowances of oat pasture and supplementation on animal performance, carcass, and meat quality of Hereford cull cows.

Materials and Methods

The experiment was carried out according to the recommendations of the Animal Experimentation Honorary Committee of Uruguay (CHEA) and aligned with the EU directions on animal experimentation (2010/63/EU).

Location and duration

This study was carried out during late autumn-winter for 130 days at "Glencoe" Experimental Station of the National Institute of Agricultural Research (INIA Uruguay) - located at 32 º 00' 24'' S, 57 º 08 ' 01 ''O and 124 m above sea level. After the fattening phase, cull cows were slaughtered in a commercial abattoir.

Experimental design and treatments

The experiment was analysed as a completely randomized block design. Forty Hereford cull cows were assigned to four treatments (n = 10 per treatment; n = 5 per plot) according to body weight (BW). At the

beginning of the experiment the average BW was 480.2 ± 48.5 kg and cows had mostly 6 permanent incisors. The treatments were generated by combining two forage allowances (FA; 2 and 4 % of BW) and three supplementation rates (0.8 and 1.6 % of BW) of whole rice bran (RB), as follows: T1 = FA 2 % + 0 % RB, T2 = FA 4 % + 0 % RB, T3 = FA 2 % + 0.8 % RB y T4 = FA 2 % + 1.6 % RB.

Pasture and supplementation

An annual forage crop of Avena byzantina (cv. INIA Halley) was used for direct grazing. Average forage biomass and height was 1608 kg DM/ha and 19.8 cm, respectively. The crude protein (CP) content of the forage crop was estimated according to AOAC (1990) (KJELTEC 2200 FOSS distiller), while acid detergent fibre (ADF) and neutral detergent fibre (NDF) were estimated according to the methodology described by Van Soest (1982) (ANKOM A 2000I). The nutritional value of the pre-grazing is presented on Table 1.

Table 1. Average nutritional value of the pre-grazing forage dry matter

Variable	%
Crude protein	12.8
Acid detergent fibre	25.3
Neutral detergent acid	45.1
Ash	10.8

Prior to the experiment, T3 and T4 animals had an adaptation period to RB supplementation for 10 days, in which the supplementation rate increased gradually until the target rate was reached (0.8 and 1.6 % BW, respectively). Rice bran supplementation was provided daily early in the morning by using one trough per supplemented group. Every 14 days the supplementation rate was adjusted according to the BW of each supplemented group. No leftovers of RB were observed throughout the experimental period. The nutritional value of RB was: 69.5 % DM digestibility, 17.3 % of CP, 11.1 % acid detergent fibre (ADF), 30.3 % NDF and 11.6 % ashes.

Animals from all treatments had access to fresh water and mineral blocks ad libitum. Mineral blocks presented the following composition: P: 5.9 %, Ca: 13.5 %, Mg: 1.0 %, NaCl: 47 %, Fe: 2500 mg/kg, Cu: 200 mg/kg, Co: 8 mg/kg, I: 40 mg/kg, Zn: 470 mg/kg, Se: 15 mg/kg, molasses: 5 %, vitamin A: 20000 IU/kg, vitamin D3: 2000 IU/kg, and vitamin E: 20 IU/kg.

Feeding treatments estimations

Total dry matter intake (DMI), animal require-ments, CP and net energy (NE) balance were estimated for each group of cows considering forage biomass and quality and using the assumption of an oat daily growth rate of 10 kg DM/ha/day (Millot, 1981), plus the addition of RB intake for T3 and T4. Based on the finishing beef cattle requirements from Nutritional Research Council (NRC, 2001), CP requirements (g/animal/day) were established, considering each group´s average daily gain (ADG) and BW. As for NE requirements, the following equations were used (AFRC, 1993):

(1) NE basal maintenance (NEbm) (Mcal/d) = $(0.53*(BW/1.08)^{0.67})/4.184$

(2) NE weight gain (NEg) = Energetic value of weight gain (EVg, Mcal/kg)*ADG (kg/d), where:

EVg = C2 $(4.1+0.0332BW - 0.000009BW^2)/(1-C3*0.1475ADG)$

C2: corrected by adult animal frame, breed and sex = 1, C3 = 1 (ADG > 0).

(3) EN grazing (ENgz) (Mcal/d) = C*DMI*(0.9-D) + 0.05T/ (GMA+3))*BW/4.184, where:

C = constant 0.006, DMI = dry matter intake, D = pasture, dry matter digestibility, T = Ground topography (1, flat), and GMA = green dry matter availability.

o D (Dry matter digestibility, %) was estimated following Osítis et al. (2003) as 88.9 - 0.779 x ADF %

Animal, carcass and meat quality determinations

Initial and final BW was recorded at the beginning of the trial, every 14 days. At the end of the experimental period, ADG was estimated for each treatment, as presented in Lagomarsino et al. (2020). During the slaughter process, carcasses were cut in halves, and hot carcass weight (HCW) was registered. After 48 hours, carcasses were ribbed between the 10th and 11th rib, and the ultimate pH was measured on the Longissimus thoracis muscle of each left half carcass using a pHmeter (Hanna 9125, Cluj-Napoca, Romania) previously calibrated. Next, half carcasses were quartered between the 10th and 11th, and the pistola cut from the left half-carcass was weighed and subsequently deboned. The weights of tenderloin, striploin, sirloin, outside round, inside, tri-tip, knuckle heel muscle, shank and flank on, fat and meat trimmings and bones were registered.

A 7-10 cm sample was taken from the Longissimus thoracis (from the 10th and 11th rib, following cranial direction) of each left half-carcass and which were vacuum-packaged and transported to the meat laboratory. Each meat sample was divided into two steaks of 2.54 cm thickness that were aged at 2- 4 ^{o}C for 7 or 21 days, plus one cm steak was taken for fatty acid analysis. After aging, instrumental lean colour (CIE L*: lightness, a*: redness and b*: yellowness) was

blooming with a Minolta chromameter CR-400 (Konica Minolta Sensing Inc., Japan) using a C illuminant, a 2° standard observer angle and 8 mm aperture size and calibrated with a white tile before use. Furthermore, according to the American Meat Science Association guidelines, Warner-Bratzler shear force (WBSF; model D2000- WB, G&R Electric Manufacturing Co Co, Manhattan, KS) was assessed (AMSA, 2016). Each steak was packed into polyethylene bags and cooked in a water bath until an internal temperature of 70 °C was reached. After cooking, six cores (1.27 cm diameter) were removed from each steak parallel to the longitudinal orientation of muscle fibers. Individual shear force (SF) values were averaged to assign a mean peak WBSF value to each sample.

Intramuscular fat (IMF) content was determined gravimetrically. Lipids were extracted using a mixture of chloroform-methanol according to Bligh and Dyer (1959) procedure. For the fatty acid determination, 0.03 g of fat were taken and dissolved with 2 mL of hexane, and afterwards 1 mL of a saturated solution of KOH in methanol was added and shaken for 2 min and then left to rest for 30 min (IUPAC, 1987). An aliquot was extracted from the upper layer for the subsequent determination of fatty acids. Fatty acid methyl esters were analyzed by gas chromatography coupled with a flame ionization detector (GC-FID; Konik HRGC 4000B, Konik Group, Barcelona, Spain) using a 90 % cyanopropyl polysilphenylene-siloxan capillary column (SGE BPX90 GC Column; 30 m, 0.25 mm i.d., and 0.25 µm film thickness; Trajan Scientific Australia Pty Ltd., Melbourne, Australia). Nitrogen was used as the gas carrier with 1 mL/min flow. The chromatographic conditions were: injection volume of 1 µL, the initial temperature of 80 °C for 0.5 min, increasing 3 °C/min until it reach 165 °C and held for 10 min, then increased at 10 °C/min to 180 °C and kept for 2 min, and finally increasing 15 °C/min to reach 250 °C and held for 13 min. Identification of fatty acid methyl esters (FAME) was performed by comparing their retention times with those of the standards (Supelco® 37 Component FAME Mix). Fatty acids were expressed as a percentage of the total fatty acids identified.

Statistical analysis

The experiment was analysed as a completely randomized block design. Body weight and ADG were analysed using the PROC MIXED procedure from the Statistical Analysis System software (SAS Institute Inc., Cary, NC, USA, version 9.4) as a repeated measures analysis considering: feeding treatments, time and its interaction as fixed effects and the animal as a random effect. The best covariance structure was selected based on the Akaike Information Criterion (AIC).

Carcass traits (HCW, pistola cut and other cuts weights), pH WBSF and instrumental colour variables and fatty acid composition were analysed considering feeding treatment as the fixed effect using the GLM procedure. Normality of the data was formally tested for all variables using the Shapiro Wilks test. When data were not normally distributed, they were normalized by choosing the proper transformation method for normal distribution.

For the statical analyses of HCW, CCW and meat cuts, the covariates BW, HCW were used. After ANOVA, least squares means were calculated for treatment comparisons with a significance level of $\alpha = 0.05$, using the PDIFF option of LSMEANS adjusted by Tukey, when F-tests were significant ($P < 0.05$). For the association analyses between WBSF (expressed in kgF, using a 4.5 kgF threshold) and the two maturing periods (7 and 21 days), contingency tables were used, and the contrasts were carried out using Pearsons´ chi-square test.

Results

The nutritional value of the post-grazing pasture is presented in Table 2.

Table 2. Average nutritional value of the post-grazing forage.

Variable	T_1	T_2	T_3	T_4	P-value
Dry matter biomass (kg/ha)	821.0^{b}	1009.7^{a}	964.2^{ab}	924.3^{ab}	0.0138
Height (cm)	6.2^{c}	8.1^{a}	6.9^{b}	6.7^{b1}	< 0.0001
Crude protein (%)	11.7	12.3	10.7	11.5	0.8245
Acid detergent fiber (%)	32.5	31.9	33.2	32.7	0.9429
Neutral detergent fiber (%)	56.6	56.5	58.1	59.1	0.6974
Ash (%)	14.4	13.6	13.2	13.5	0.7536

$^{a, b, c}$: different letters within the same parameter indicated significant ($P < 0.05$) differences among treatments.

Estimations of DMI, requirements, and balance of CP and NE for each treatment are presented in Table 3.

Table 3. Estimated dry matter intake, requirements, and balance of crude protein and net energy by feeding treatment.

Treatments		T_1	T_2	T_3	T_4	SEM[6]	P-Value
Estimated intake	CP[1]	1387.9[d]	2267.9[b]	1974.1[c]	2643.3[a]	23.2	< 0.0001
	NE[2]	27.8[d]	43.8[b]	38.4[c]	50.6[a]	0.4	< 0.0001
Requirements	CP[1]	941.4[b]	1457.3[a]	900.1[c]	899.6[c]	7.7	< 0.0001
	NE[2]	23.1[b]	36.9[a]	35.4[a]	39.5[a]	1.9	< 0.0001
	Nebm[3]	7.6	7.9	7.9	8.0	0.2	0.3023
	NEwg[4]	10.6[c]	20.8[b]	22.5[ab]	26.4[a]	1.7	< 0.0001
	NEg[5]	4.9[b]	8.2[a]	5.1[b]	5.1[b]	0.2	0.0008
Balance	PC[1]	446.4[d]	810.6[c]	1074.0[b]	1743.7[a]	26.9	< 0.0001
	NE[2]	4.6[b]	6.9[ab]	3.0[b]	11.2[a]	1.7	0.0100

[1]CP: crude protein (g/a/d); [2]NE: net energy (Mcal/a/d); bm[3]: basal metabolism; wg[4]: weight gain; g[5]: grazing; [6]SEM: standard error of the means. [a, b, c:] different letters within the same parameter indicated significant (P < 0.05) differences among treatments.

Greatest NE and CP intakes (P < 0.05) were observed in those treatments with the greatest FA (T2) and supplementation rate (T4), while the opposite was observed in the treatment with the lowest FA and not supplemented (T1). Requirements presented similar trends between treatments. Estimated intakes were above requirements for both CP and NE in all treatments, resulting in a positive balance.

Table 4. Initial and final body weight (BW) and average daily gain (ADG) by treatment.

Treatments	T_1	T_2	T_3	T_4	SEM[1]	P-value
Initial BW (kg)	480.3	480.6	480.5	479.5	16.0	0.9999
Final BW (kg)	539.3[b]	605.2[a]	608.4[a]	620.8[a]	17.9	0.0131
ADG (kg/a/d)	0.455[b]	0.958[a]	0.984[a]	1.087[a]	0.074	< 0.0001

[1]SEM: standard error of the means. [a, b, c:] different letters within the same parameter indicated significant (P < 0.05) differences among treatments.

No significant differences (P > 0.05) were observed in the initial BW among treatments (Table 4; 480.2 ± 48.5 kg). However, the final BW was lower (P < 0.05) in T1 compared with the other three treatments (Table 4). Supplemented treatments (T3 and T4) presented 12 % and 15 % greater BW compared to T1 at the end of the experiment. Cows from T1 presented an ADG 52-58 % lower (P < 0.05) than the other three treatments, which did not differ among them.

T2, T3 and T4 presented a greater (P < 0.05) HCW and pistola cut weight compared to T1 (Table 5). In addition, cows from T1 had lower (P < 0.05) weights of the most valuable beef cuts represented by rump and loin, striploin and sirloin, and also the inside round, tri-tip, and flank. Nonetheless, these differences were canceled out when corrected by final BW as a co-variate, indicating that they were not explained by the effect of treatments (data not shown). The rest of the cuts, fat trimmings, and bones registered no differences among treatments (P > 0.05).

Ultimate pH (48 h post-mortem) and WBSF after aging for 7 and 21 days did not present (P > 0.05) significant differences among treatments (Table 6).

On the other hand, considering a 4.5 kgF value proposed by Miller et al. (2001) as threshold criteria for WBSF consumer´s tenderness acceptance, 90 to 100 % of meat samples had values below 4.5 kgF in all treatments after 21 days of aging (Table 7).

Lean colour (CIE L*, a* and b*) and WBSF are also presented by aging time over experimental treatments (Table 8).

No significant interaction (P > 0.05) was found between treatment and aging for WBSF and lean colour (data not shown). However, differences (P < 0.05) were found when comparing the two aging periods with lower values of WBSF when meat was aged for 21 d (Table 8). In addition, both L* (lightness) and b* (yellowness) values were greater (P < 0.05) for 21 d than 7 d, but no differences (P > 0.05) were found for a* (redness) between both aging periods.

The IMF content and fatty acid composition by feeding treatment are shown in Table 9.

There were no significant differences (P < 0.05) in IMF content among treatments (4 % on average). The main fatty acids in all treatments were palmitic (16:0), stearic (18:0) and oleic (18:1), which represented

approximately 89 % (average across treatments) of total fatty acids identified. Their concentrations did not present significant differences (P > 0.05) among treatments, and neither did myristiroleic (C14:1), palmitoleic (C18:1), eicosadienoic (C20:2), eicosatrienoic (C20:3-n3) and dihomo-γ-linolenic (C20:3-n6). Fatty acids linoleic (C18:2) and linolenic (C18:3) acids presented significant differences (P < 0.05) among treatments, presenting the IMF from cows supplemented with RB (T3 and T4) with greater concentrations (P < 0.05) of linoleic acid. In contrast, linolenic acid was present in greater proportion in the cows fed exclusively in grass(T1 and T2). Concentrations of arachidic (C20:0), arachidonic (C20:4), eicosapentaenoic – EPA (C20:5) and docosapentaenoic – DPA (C22:5) acids were different among treatments with greater (P < 0.05) concentrations in cows from T1. The CLA proportion was greater (P < 0.05) in exclusively grass-fed animals (T1 and T2) compared to T4. Concentrations of SFA, MUFA and PUFA did not present differences among treatments. Feeding treatments resulted in greater (P < 0.05) concentrations of n-6 fatty acids in cows from T1, T3 and T4 than T2, and n-3 concentration was greater (P < 0.05) in T1 compared to the other three treatments. The PUFA:SFA ratio did not present significant differences (P > 0.05) among treatments. Lastly, a greater (P < 0.05) n-6/n-3 ratio was observed in T3 and T4 compared with T1 and T2.

Table 5. Carcass and cuts weights (kg) by feeding treatment.

Treatment	T_1	T_2	T_3	T_4	SEM[1]	P-value
Hot carcass weight (kg)	266.2[b]	292.0[ab]	295.8[a]	309.3[a]	9.2	0.0172
Pistola cut (kg)	62.4[b]	68.7a	68.4[a]	71.2[a]	2.0	0.0318
Rump & loin (kg)	12.4[b]	13.9[a]	13.9[a]	14.6a	0.5	0.0239
Tenderloin (kg)	2.1	2.2	2.1	2.3	0.1	0.4720
Striploin (kg)	4.9[b]	5.7a	5.7[a]	6.1[a]	0.3	0.0239
Sirloin (kg)	5.4[b]	6.1[a]	6.1[a]	6.3[a]	0.2	0.0265
Inside round (kg)	7.7[b]	8.1[a]	8.2[a]	8.6[a]	0.3	0.0139
Outside round (kg)	7.1	7.7	7.6	7.9	0.3	0.1857
Knuckle (kg)	5.0	5.1	5.1	5.3	0.2	0.7786
Tri-tip (kg)	1.2[b]	1.4[a]	1.5[a]	1.5[a]	0.1	0.0087
Heel muscle (kg)	2.0	2.1	2.2	2.2	0.1	0.3256
Shank (kg)	1.8	1.9	2.0	2.0	0.1	0.2607
Flank on (kg)	3.9[b]	5.1[a]	4.8[ab]	5.2[a]	0.2	0.0015
Meat trimmings (kg)	3.5	3.5	3.6	4.1	0.2	0.1996
Fat trimmings (kg)	4.4	5.5	5.6	6.0	0.5	0.1020
Bones (kg)	12.1	12.9	12.8	13.1	0.4	0.2163
Meat trimmings (% 2)	1.3	1.2	1.2	1.3	0.1	0.5659
Fat trimmings (% 2)	8.9	11.4	11.6	12.1	1.0	0.1239
Bones (% 2)	9.5	9.2	9.0	8.9	0.2	0.0707

[1]SEM: standard means error. [2] Hot carcass weight = 100 %. [a,b:]different letters within the same parameter indicated significant (P < 0.05) differences between treatments.

Table 6. Meat quality characteristics by feeding treatment.

Treatments	T_1	T_2	T_3	T_4	SEM[1]	P-value
Ultimate pH (units)	5.63	5.65	5.63	5.61	0.01	0.4658
L* (lightness) 7 d	33.93	34.40	34.78	34.69	0.53	0.6744
a* (redness) 7 d	17.27	17.52	17.28	17.91	0.44	0.7081
b* (yellowness) 7 d	9.16	9.42	9.57	9.48	0.28	0.7630
L* (lightness) 21 d	35.94	37.00	36.33	36.71	0.57	0.5835
a* (redness) 21 d	17.22	16.66	16.44	17.41	0.71	0.7427
b* (yellowness) 21 d	10.05	9.89	9.93	10.10	0.29	0.9459
WBSF2 7 d (kgF)	4.77	4.66	5.61	4.86	0.42	0.3440
WBSF2 21 d (kgF)	3.54	3.47	3.65	3.63	0.21	0.9101

[1]SEM:standard error of the means. [2]WBSF: Warner-Bratzler shear force

Table 7. Proportion (%) of meat samples with WBSF values lower than 4.5 kgF for each feeding treatment at two aging times (7 and 21 days).

Treatments	T_1	T_2	T_3	T_4	P-value
7 d	40	40	40	30	0.9562
21 d	100	100	90	90	0.4108

Table 8. Warner-Braztler shear force and instrumental lean color (L*, a*, and b*) by aging period (7 and 21 days) across treatments.

Ageing period (days)	7	21	SEM[1]	P-value
WBSF (kgF)[2]	5.0[b]	3.6[a]	0.2	< 0.0001
L* (lightness)	34.5[b]	36.5[a]	0.3	< 0.0001
a* (redness)	17.5	17.2	0.3	0.1773
b* (yellowness)	9.4[b]	10.0[a]	0.1	0.0036

[1]SEM: Standard error of the means. [2]Warner-Bratzler shear force. [a, b:] different letters within the same parameter indicated significant (P < 0.05)

Table 9. Fatty acid composition (%) by feeding treatment.

Treatments	T_1	T_2	T_3	T_4	SEM[1]	P-value
Intramuscular fat (%)	3.5	4.7	4.6	4.1	0.4	0.1380
C 14:0 (Myristic)	2.1^{b}	2.6^{a}	2.3^{ab}	2.1^{b}	0.1	0.0270
C 14:1 (Myristoleic)	0.35	0.40	0.40	0.30	0.04	0.1585
C 16:0 (Palmitic)	27.5	28.6	27.7	27.4	0.4	0.1166
C 16:1 (Palmitoleic)	3.8	4.0	4.0	3.4	0.2	0.1083
C 18:0 (Stearic)	16.2	15.7	15.7	17.1	0.6	0.2993
C 18:1n-9 (Oleic)	45.0	45.0	45.6	44.8	0.7	0.8678
C 18:2n-6 (Linoleic)	2.0^{bc}	1.7^{c}	2.3^{ab}	2.7^{a}	0.2	0.0006
C 18:3n-3 (Linolenic)	0.72^{a}	0.56^{ab}	0.42^{b}	0.41^{b}	0.05	0.0001
C 18:2 c9, t11	0.50^{a}	0.46^{a}	0.45^{ab}	0.37^{b}	0.03	0.0318
C 20:0 (Arachidic)	0.08^{a}	0.05 ^{b}	0.03^{b}	0.05^{b}	0.01	0.0183
C 20:2 n-6 (Eicosadienoic)	0.03	0.02	0.02	0.02	0.00	0.0892
C 20:3 n-3 (Eicosatrienoic)	0.14	0.08	0.13	0.14	0.02	0.0877
C 20:3 n-6 (Dihomo-γ-linolenic)	0.05	0.04	0.03	0.05	0.01	0.2339
C 20:4 n-6 (Arachidonic)	0.76^{a}	0.41^{b}	0.47^{b}	0.56^{ab}	0.08	0.0248
C 20:5 n (Eicosapentaenoic)	0.27^{a}	0.19^{b}	0.12^{b}	0.13^{b}	0.03	0.0004
C 22:5 n-3 (Docosapentaenoic)	0.34^{a}	0.23^{b}	0.15^{b}	0.19^{b}	0.0	0.0019
C 22:6 n-3 (Docosahexaenoic)	0.09	0.08	0.06	0.05	0.01	0.0813
Saturated fatty acids (SFA)	46.0	46.9	45.8	46.7	0.7	0.5942
Monounsaturated fatty acids (MUFA)	49.1	49.3	50.0	48.6	0.7	0.5931
Polyunsaturated fatty acids (PUFA)	4.5	3.4	3.8	4.3	0.3	0.0557
n-6	2.9^{a}	2.2^{b}	2.9^{a}	3.4^{a}	0.2	0.0055
n-3	1.6^{a}	1.1^{ab}	0.9^{b}	0.9^{b}	0.1	0.0003
PUFA/SFA	0.10	0.07	0.08	0.09	0.01	0.0053
n-6/n-3	1.9^{b}	2.0^{b}	3.5^{a}	3.7^{a}	0.2	0.0001

[1]SEM: standard error of the means. $^{a, b:}$ Different letters within the same parameter indicated significant ($P < 0.05$) differences between treatments.

Discussion

Overall, diets with greater energy supply resulted in greater animal performance and, consequently, greater slaughter weight, carcass weight, and valuable cuts´ weights. Additionally, meat quality was positively affected and modified the fatty acid profile, potentially benefiting human health.

As observed in our experiment, previous studies with cull cows (Restle et al., 2000; 2001; Aranha et al., 2018) and steers (Coppo et al., 2002; Beretta et al., 2006; Pouzo et al., 2015; Aranha et al., 2018) have reported that greater FA or the use of concentrate supplementation under grazing conditions on improved pastures or rangelands resulted in greater ADG and therefore, resulted in greater final BW. The carcass variables followed a similar response to the final BW. Greater final BW was achieved by cows from the greatest herbage allowance or supplemented rate used, which generated greater HCW, CCW, pistola cut weight and high-value individual cut weights. Similar findings were reported by del Campo et al. (2008) in steers, where the inclusion of concentrate supplementation or FA above 2 % of BW increased carcass weights compared to steers fed exclusively on pastures at 2 % of FA or not supplemented. Realini et al. (2004) also observed heavier carcasses on steers grazing improved pastures with additional use of concentrate supplements when compared to animals fed exclusively on pastures. Other research studies on cull cows (Restle et al., 2000, 2001; Stelzleni et al., 2007), reported similar animal responses, specifically when considering individual cut weights within the pistol cut considered, indicating that as diet quantity and quality improves, so does slaughter BW, HCW and main high value cut weights.

In the present study, the final pH did not present differences among treatments with pH < 5.7, a threshold value below which the probability of the occurrence of dark, firm, and dry (DFD) cuts is reduced (McNally and Warriss, 1996). As for the values of NE of each feeding treatment, all of them presented a positive balance between dry matter intake and NE/CP requirements, which positively impacted on the final pH, reaching the desired range values (Immonen et al., 2000). The Uruguayan Meat Quality Audits have shown that an important proportion of the nationwide slaughter of cull cows (16.3 %) presented pH values above 5.8 (Correa and Brito, 2017). However, unlike the cows of the present experiment, these animals come from different finishing and management conditions, which could affect pH values. All animals were handled under a controlled nutritional status and good management practices during the experimental

period, preventing animals from being exposed to ante-mortem stress factors.

Tenderness is considered the most important palatability trait in meat, affecting consumer acceptance (Dikeman, 1987; Miller et al., 1995; Boleman et al., 1997). WBSF values did not differ among treatments for both aging periods (7 and 21 days) in this study. This finding agrees with Realini et al. (2004), Duckett et al. (2007) and Latimori et al. (2008) research studies, which did not find any differences in young steers on WBSF values when comparing different feeding treatments (concentrate and pasture). Schnell et al. (1997) evaluated different feeding periods using cull cows fed on high energy diets and did not find differences in meat shear force when comparing concentrate supply duration. Couvreur et al. (2019) observed that the shear force of cull cow's meat was not affected when comparing different types of finishing diets. Meat tenderness is mainly affected by the amount and solubility of connective tissue, the composition and contractile state of muscle fibers, and the extent of postmortem proteolysis (Joo et al., 2013) and depends on various factors such as breed, gender, age and slaughter and maturation conditions (Silva et al., 2010). As an animal matures, the stability of collagen cross-linking between molecules increases and partly explains the increase in meat toughness observed in old animals (Bailey, 1989; McCormick, 1994; Andreas et al., 1995). Several authors have established WBSF threshold values below which meat would be considered tender (Shackelford et al., 1995; Huffman et al., 1996; Miller et al., 2001; Platter et at., 2003; Rodas-González et al., 2009) which were not reached by any feeding treatment when meat was aged for 7 days. However, lengthening the meat aging period to 21 days allowed for extending the tenderization process, and WBSF values of all treatments were below 3.7 kgF. The decrease of WBSF values as the aging period increases agrees with the findings of Realini et al. (2004), working with Hereford steers and with that of Matulis et al. (1987), studying British breed 8-year-old cull cows finished in the high-concentrate diet. Similar results were observed by Kuss et al. (2005) working with Charolais and Nellore breeds animals and by Stelzleni et al. (2007) studying Angus x Brahman crossbreeds. In addition, Mandell et al. (2006) concluded that longer aging periods of 28 days were needed to reach acceptable WBSF values on meat from cull cows. The findings of the present study showed that 7 days of meat ageing are not enough to attain acceptable WBSF values in cull cows. However, Meilgaard et al. (1999) pointed out that some experts question the validity of using sensory "thresholds" values because they are ill-defined in theory but may not reproduce results well, and may not even exist.

Lean color is one of the most relevant meat characteristics affecting consumer´s purchase decisions (Faustman and Cassens, 1990). Usually, grass-fed beef is darker in appearance than cattle fed on high-concentrate diets (Muir et al., 1998; Vestergaard, et al., 2000; Realini et al., 2004; Couvreur et al., 2019). In our study, L*, a* and b* values did not differ among treatments in both aging times, indicating no effect of concentrate supplementation even at 1.6 % of BW. These results were similar to those reported by del Campo et al. (2008) and Luzardo et al. (2008) using steers in comparable feeding and management conditions as in this study, but also similar to those of the experiments carried out by Stelzleni et al. (2007) with concentrate-fed cull cows. On the other hand, Couvrer et al. (2019) found a trend in greater b* for cows grazing pastures exclusively compared to similar groups of animals that were also being supplemented. Dark lean beef is often confused with dark-cutting beef due to glycogen depletion due to pre-slaughter stress (Tarrant, 1981).

The results of the present study showed a normal ultimate pH (pH ≤ 5.65) in all treatments which would indicate enough glycogen levels in muscle prior to slaughter. Darker meat colour from grass-fed cattle may be a consequence of more oxidative metabolism rather than a stress-related ante-mortem event, since greater myoglobin content and enzymes associated with oxidative metabolism have been observed on meat from grass-fed animals (Apaoblaza et al., 2020). If we extrapolate consumer benchmark values referred to meat colour lightness (L*) for lamb (Khliji et al., 2010) to beef, the L* values of all treatments would be very close to 34, the minimum value from which on average consumers would consider the meat lightness acceptable. However, Holman et al. (2017) reported that the redness (a*) provided the most simple and robust prediction of beef colour acceptability and when its value was equal to or above 14.5, where beef colour was considered acceptable (with 95 % acceptance) by consumers. In our study, a* values in all treatments were above the mentioned threshold regardless of the aging period. Other authors also studied the relationship between instrumental and visual appraisal of colour (Goñi et al., 2008; Ripoll et al., 2012), however more research is needed to achieve conclusive findings.

Even though the diet has less influence in ruminants than in monogastric species on IMF fatty acid composition (Scollan et al., 2006), both feed and energetic intake affect ruminant carcass fat deposition and fatty acid composition of subcutaneous and

intramuscular fat (Mir et al., 2000). In our study, IMF content did not present differences among treatments. Similar results were observed in steers by Realini et al. (2004), Descalzo et al. (2005), Brito et al. (2008), Latimori et al. (2008). Grass-fed steers have shown greater n-3 PUFA concentrations on IMF, while grain-based systems increased the proportion of MUFA (French et al., 2003; Realini et al., 2004; Descalzo et al., 2005). However, scientific literature related to the effects of feeding systems on cull cow's meat fatty acid composition is scarce. Noci et al. (2005) found that PUFA and n-3 contents increased linearly in heifer´s meat when the grazing period was longer (0, 40, 99, and 158 days) within the overall fattening process. The results observed for total n-6 and n-3 PUFA concentrations agree with those reported by Duckett et al. (2007) on steers, Noci et al. (2005) on heifers, and Stelzleni et al. (2008) on cull cows. It may be concluded that even within grass-based production systems, some differences may be found in fatty acids composition, depending on the level of supplementation, the type of supplement, genetics and animal age. Greater PUFA/SFA ratios were observed in both supplemented treatments and in the treatment with the lowest FA. Regardless of these differences, the ratio was always above the recommended threshold of 0.45 (UK Health Department, 1994).

The results of this experiment are consistent with studies in heifers in different grazing periods (Noci et al., 2005) and in finished steers in grazing regimes or in combinations of pastures with concentrates (Realini et al., 2004; Zea et al., 2007; Brito et al., 2008), who observed PUFA / SFA ratios below 0.45. In terms of n-6/n-3 fatty acids ratio, despite those greater values being observed in the RB supplemented treatments (T3 and T4), all treatments presented values within the recommendations of the UK Health Department (1994). De la Fuente et al. (2009) compared the fatty acid profile of steers fed on grass from Uruguay with similar animals from the UK (grass based and supplement) and from Spain and Garmany (feedlotted) and observed that the Uruguayan samples presented greater omega 3 levels and better om6/om3 ratios, compared to the other 3 production systems. These findings showed the beneficial effects of meat consumption from grass-fed ruminants (Wood et al., 2004) on human health. A human diet with a high n-6:n-3 PUFA ratio promotes the pathogenesis of many chronic diseases, such as cardiovascular disease (Simopoulos, 2008). The optimal n-6:n-3 fatty acid ratio varies from 1:1 to 4:1 depending on the disease under consideration (Simopoulos, 2002).

The main source of conjugated linoleic acid (CLA) in the human diet is animal products such as dairy and ruminant meat (Chin et al., 1992). In the current experiment, CLA concentrations presented differences among treatments, being the lowest when the diet included the highest supplement level. The greater CLA production with pasture-based diets would be associated with the impact on the ruminal bacteria population and their biohydrogenation capacity, which would result in greater CLA concentrations in meat. Thus, our results agree with Camfield et al., 1999; French et al., 2003; Realini et al., 2004, and Scollan et al., 2006.

Conclusions

The combination of greater forage allowances and/or supplementation resulted in heavier high-value cuts (e.g. rump and loin cuts). It is important to note that a 21 days-aging period was necessary to reach WBSF values for cull cows´ meat to be considered acceptable in terms of tenderness. Despite the scarcity of scientific literature available for cull cows, the results of the present study suggest that grass-based production systems with null or low use of supplements in British breeds produce acceptable carcasses, and meat quality traits and would associate with a healthy meat fatty acid profile.

Acknowledgments

We would like to thank INIA Tacuarembó´s staff, to Yovana Martínez, Sergio Bottero, Julio Frugoni, América Mederos, Beatriz Carracelas, Wilfredo Zamit, Mauro Bentancur, Gustavo Brito, Roberto San Julián, Guillermo de Souza and Julio Costales. CERCA for the Generalitat de Catalunya is also acknowledged.

Contributors' statement

Conceptualization: X. Lagomarsino and F. Montossi; Data curation: X. Lagomarsino and F. Cazzuli, Formal Analysis: X. Lagomarsino and F. Cazzuli; Funding acquisition: F. Montossi; Investigation and writing: X. Lagomarsino, F. Montossi, F. Cazzuli, S. Luzardo, M. Font; Methodology: X. Lagomarsino, F. Montossi; Project administration: F. Montossi.

Funding: This work was funded by the National Institute for Agricultural Research (INIA Uruguay).

Literature Cited

AFRC. 1993. Energy and Protein Requirements of Ruminants. An Advisory Manual Prepared by the Agricultural Food and Research Council Technical Committee on Responses to Nutrients. CAB International, Wallingford, UK.

AMSA. 2016. Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of meat. 2 ed. American Meat Sciense Association, Champaign, IL, USA.

AOAC. 1990. ´Official Methods of Analysis´. 15th ed. Association of Official Analytical Chemist, Arlington, VA.

Andreas, B., Carsten, M., Hans, S., Manfred, K., and Frieder, J.S. 1995. Pyridinoline crosslinks in bovine muscle collagen. Journal Food Science, 60(5): 953−958. https://doi.org/10.1111/j.1365-2621.1995.tb06269.x

Apaoblaza, A., Gerrard, S.D., Matarneh, S.K., Wicks, J.C., Kirkpatrick, L., England, E.M., Scheffler, T.L., Duckett, S.K., Shi, H., Silva, S.L., Grant, A.L., and Gerrard, D.E. 2020. Muscle from grass- and grain-fed cattle differs energetically. Meat Science, 161: 107996. doi.org/10.1016/j.meatsci.2019.107996.

Aranha, A.S., Andrighetto, C., Lupatini, G.C., Mateus, G.P., Ducatti, C., Roça, R.O., Martins, M.B., Santos, J.A.A., Luz, P.A.C., Utsunomiya, A.T.H., and Athayde, N.B. 2018. Performance carcass and meat characteristics of two cattle categories finished on pasture during the dry season with supplementation in different forage allowance. Arquivo Brasileiro de Medicina. Veterinaria e Zootecnia, 70(2): 517-524. https://doi.org/10.1590/1678-4162-9576

Bailey, A.J. 1989. The chemistry of collagen cross-links and their role in meat texture. Reciprocal Meat Conference Proceedings. American Meat Science Association, 127−135.

Beretta, V., Simeone, A., Elizalde, J.C., and Baldi, F. 2006. Performance of growing cattle grazing moderate quality legume-grass temperate pastures when offered varying forage allowance with or without grain supplementation. Australian Journal of Experimental Agriculture, 46: 793−797. doi.org/10.1071/EA05331.

Bligh, E., and Dyer, W. 1959. A rapid method for total lipid extraction and purification. Canadian Journal Biochemistry and Physiolgy, 37(8): 911−917. doi.org/10.1139/o59-099.

Boleman, S.J., Boleman, S.L., Miller, R.K., Taylor, J.F., Cross, H.R., Wheeler, T.L., Koohmaraie, M., Shackelford, S.D., Miller, M.F., West, R.L., Johnson, D.D., and Savell, J.W. 1997. Consumer evaluation of beef of known categories of tenderness. Journal of Animal Science, 75(6): 1521−1524. doi.org/10.2527/1997.7561521x.

Brito, G., Lagomarsino, X., Olivera, J., Trindade, G., Arrieta, G., Pittaluga, O., del Campo, M., Soares de Lima, J., San Julián, R., Luzardo, S., and Montossi, F. 2008. Effect of different feeding systems (pasture and supplementation) on carcass and meat quality of Hereford and Braford steers in Uruguay. International Congress of Meat Science and Technology 54th (ICoMST). 10−15 August 2008. Cape Town, South Africa.

Camfield, P., Brown, A., Johnson, Z., Brown, C., Lewis, P., and Rakes, L. 1999. Effects of growth type on carcass traits of pasture or feedlot-development steers. Journal of Animal Science, 77: 2437−2443. https://doi.org/10.2527/1999.7792437x

Chin, S.F., Liu, W., Storkson, J.M., Ha, Y.L., and Pariza, M.W. 1992. Dietary sources of conjugated dienoic isomers of linoleic acid, a newly recognized class of anticarcinogens. Journal of Food Composition and Analysis, 5(3): 185−197. https://doi.org/10.1016/0889-1575(92)90037-K .

Coppo, J., Coppo, N., Revidatti, M., Capellari, A., Navamuel, J., and Fioranelli, S. 2002. Fresh citrus pulp supplementation effects on weight gain and plasma protein of wintering cows. Analecta Veterinaria, 22(2): 15−21. http://sedici.unlp.edu.ar/bitstream/handle/10915/11144/Documento_completo.pdf?sequence=1

Correa, D., and Brito, G. 2017. Fase II: Trabajo en plantas frigoríficas. In: Brito. G., Correa. D., San Julián. R. (Eds). Tercera auditoria de calidad de carne vacuna del Uruguay. Instituto Nacional de Investigación Agropecuaria (INIA). Serie Técnica 229. Montevideo. Uruguay. 3−34.

Couvreur, S., Le Bec, G., Micol, D., and Picard, B. 2019. Relationships Between cull beef cow characteristics, finishing practices and meat quality traits of *Longissimus thoracis* and *Rectus abdominis*. Foods, 8(4): 141. https://doi.org/10.3390/foods8040141

De la Fuente, J., Díaz, M.T., Álvarez, I., Oliver, M.A., Font i Furnols, M., Sañudo, C., Campo, M.M., Montossi, F., Nute, G.R., Cañeque, V. 2009. Fatty

acid and vitamin E composition of intramuscular fat in cattle reared in different production systems. Meat Science, 82(3):331. https://doi.org/10.1016/j.meatsci.2009.02.002

Del Campo, M., Brito, G., Soares de Lima, J.M., Vaz Martins, D., Sañudo, D., San Julián, R., Hernandez, P., and Montossi, F. 2008. Effects of feeding strategies including different proportion of pasture and concentrate. on carcass and meat quality traits in Uruguayan steers. Meat Science, 80 (3): 753−760. https://doi.org/10.1016/j.meatsci.2008.03.026

Descalzo, A., Insani, E.M., Biolatto, A., Sancho, A.M., Garcıa, P.T., Pensel, N.A., and Josifovich, J.A. 2005. Influence of pasture or grain-based diets supplemented with vitamin E on antioxidant/oxidative balance of Argentine beef. Meat Science, 70: 35−44. doi.org/10.1016/j.meatsci.2004.11.018.

Dikeman, M.E. 1987. Fat reduction in animals and the effects on palatability and consumer acceptance of meat products. In: Proceedings of the 40th Annual Reciprocal Meat Conference. 28 June - 1 July 1987, Chicago, IL. 93–103.

Duckett, S. K., Neel, J. P. S., Sonon, R. N. Jr., Fontenot, J. J. P., Clapham, W. M., and Scaglia, G. 2007. Effects of winter stocker growth rate and finishing system on: II. Ninth tenth eleventh-rib composition muscle color and palatability. Journal of Animal Science, 85: 2691–2698. doi.org/10.2527/jas.2006-734.

Faustman, C., Cassens, R.G., 1990. The biochemical basis for discoloration in fresh meat: a review. Journal of Muscle Foods, 1: 217–243. https://doi.org/10.1111/j.1745-4573.1990.tb00366.x

French, P., O´Riordan, E., Monahan, F., Caffrey, P., and Moloney, A. 2003. Fatty acid composition of intra-muscular triacilglyceroles of steers fed autumn grass and concentrates. Livestock Production Science, 81: 307−317. doi.org/10.1016/S0301-6226(02)00253-1.

Goñi, V., Indurain, G., Hernandez, B., and Beriain, M. J. 2008. Measuring muscle color in beef using an instrumental method versus visual color scales. Journal of Muscle Foods, 19: 209–221. https://doi.org/10.1111/j.1745-4573.2008.00106.x

Henchion, M., McCarthy, M., and Resconi, V. 2017. Beef quality attributes: A systematic review of consumer perspectives. Meat Science, 128: 1−7. doi.org/10.1016/j.meatsci.2017.01.006

Holman B.W., van de Ven R.J., Mao Y., Coombs C.E., and Hopkins D.L. 2017. Using instrumental (CIE and reflectance) measures to predict consumers' acceptance of beef colour. Meat Science, 127:57−62. https://doi.org/10.1016/j.meatsci.2017.01.005

Huffman K.L., Miller M.F., Hoover L.C., Wu C.K., Brittin H.C., and Ramsey C.B. 1996. Effect of beef tenderness on consumer satisfaction with steaks consumed in the home and restaurant. Journal of Animal Science, 74(1): 91−7. https://doi.org/10.2527/1996.74191x

Immonen, K., Ruusunen, M., Hissa, K., and Puolanne, E. 2000. Bovine muscle glycogen concentration in relation to finishing diet. slaughter and ultimate pH. Meat Science, 55: 25–3. doi.org/10.1016/S0309-1740(99)00121-7

INAC (Instituto Nacional de Carnes). 2018. Anuario estadístico. Montevideo. Uruguay. 136 p.

IUPAC. 1987. Standard Method 2.301, Preparation of of Fatty Acid Methyl Ester, in Standard Methods for Analysis of Oils, Fats and Derivatives. 7th Edition, Blackwell, Oxford.

Joo, S.T., Kimb. G.D., Hwanga, Y.H., and Ryub, Y.C. 2013. Control of fresh meat quality through manipulation of muscle fiber characteristics. Meat Science, 95 (4): 828−836. https://doi.org/10.1016/j.meatsci.2013.04.044

Khliji S., van de Ven R., Lamb T.A., Lanza M., and Hopkins D.L. 2010. Relationship between consumer ranking of lamb colour and objective measures of colour. Meat Science, 85: 224−229. https://doi.org/10.1016/j.meatsci.2010.01.002

Kuss, F., Restle, J., Brondani, I., Álves, D., Perottoni, J., Missio, R., and do Amaral, G. 2005. Características da carcaça de vacas de descarte de diferentes grupos genéticos terminadas em confinamento com distintos pesos. Revista Brasileira de Zootecnia, 34(4): 1285−1296. https://doi.org/10.1590/S1516-35982005000300025

Lagomarsino, X. 2019. Engorde de vacas de descarte en regiones ganaderas extensivas: producción, calidad de canal y carne. Tesis Magister. Montevideo. Universidad de la República. Facultad de Agronomía, 138 pp.

Lagomarsino, X., Cazzuli, F., and Montossi, F. 2020. Finishing strategies for cull cows undergrass-based production systems in Uruguay. Agrosur, 48(3): 1−11.

Latimori, N.J., Kloster, A.M., García, P.T., Carduza, F.J., Grigioni, G., and Pensel, N.A. 2008. Diet and genotype effects on the quality index of beef produced in the Argentine Pampeana region. Meat Science, 79 (3): 463−469. doi.org/10.1016/j.meatsci.2007.10.008

Luzardo, S., Montossi, F., San Julián, R., Cuadro, R., Risso, D., and Brito, G. 2008. Effect of feeding regimes on the performance. carcass and meat quality of Hereford steers in Uruguay. International Congress of Meat Sci. and Technology 54th

(ICoMST). 10 – 15 August 2008. Cape Town. South Africa.

Mandell, I., Campbell, C., Quinton, V., and Wilton, J. 2006. Effects of skeletal separation method and postmortem ageing on carcass traits and shear force in cull cow beef. Canadian Journal of Animal Science, 83(3): 351–361. doi.org/10.4141/A05-039

Matulis, R.J., Mckeith, F.K., Faulkner, D.B., Berger, L.L., and George, P. 1987. Growth and carcass characteristics of cull cows after different times-on-fed. Journal of Animal Science, 65(3): 669−674. doi.org/10.2527/jas1987.653669x

McCormick, R. J. 1994. The flexibility of the collagen compartment of muscle. Meat Science, 36(1–2): 79−91. https://doi.org/10.1016/0309-1740(94)90035-3

McNally, P.W., and Warriss, P.D. 1996. Recent bruising in cattle at abattoirs. The Veterinary Record, 138: 126−128. https://doi.org/10.1136/vr.138.6.126

Meilgaard, M. C., Civille, G. V., and Carr, B.T. 1999. Determining thresholds. In Sensory Evaluation Techniques. 3rd ed. CRC Press LLC, Boca Raton, FL. 123–132.

Miller, M.F., Huffman, K.L., Gilbert, S.Y., Hamman, L.L., and Ramsey, C.B., 1995. Retail consumer acceptance of beef tenderized with calcium chloride. Journal of Animal Science, 73: 2308–2314. https://doi.org/10.2527/1995.7382308x

Miller, M., Carr, M., Ramsey, C., Crockett, K., and Hoover, L. 2001. Consumer thresholds for establishing the value of beef tenderness. Journal of Animal Science, 79(12): 3062−3068. doi.org/10.2527/2001.79123062x

Millot, J. 1981. Avena. Ministerio de Agicultura y Pesca. Centro de Investigaciones agrícolas "Alberto Boerger" (CIAAB). Miscelánea, 36. 30 pp.

Mir, Z., Paterson, L. J., and Mir, P. S. 2000. Fatty acid composition and conjugated linoleic content of intramuscular fat in crossbred with or without Wagyu genetics fed a barley-based diet. Canadian Journal of Animal Science, 80: 195–197. doi.org/10.4141/A98-113

Montossi, F., Soares De Lima, J., Brito, G., and Berretta, E. 2014. Impacto en lo productivo y económico de las diferentes orientaciones productivas y tecnologías propuestas para la región del basalto. in: Alternativas tecnológicas para los sistemas ganaderos del basalto. Instituto Nacional de Investigación Agropecuaria (INIA). Serie Técnica 217. Montevideo. Uruguay. pp. 557 – 568.

Muir, P., Deaker, J., and Bown, M. 1998. Effects of forage-and grain-based feeding systems on beef quality: A review. New Zealand Journal of Agricultural Research, 41(4): 623–635. https://doi.org/10.1080/00288233.1998.9513346

Noci, F., Monahan, F.J., French, P., and Moloney, P. 2005. The fatty acid composition of muscle fat and subcutaneous adipose tisuue of pasture-fed beef heifers: Influence of the duration of grazing. Journal of Animal Science, 83(5): 1167−1178. doi.org/10.2527/2005.8351167x

NRC. 2001. Nutrient requirements of beef cattle. Seventh revised edition. 2001. Washington. D. C.: National Academy Press.

Osítis, U., S. Strikauska, and A. Grundmane. 2003. Lopbarības Analīžu Rezultātu Apkopojums. (Summary of Feed Analysis Results) LLU, SIA Jelgavas tipogrāfija. 62, 1.

Platter W.J., Tatum J.D., Belk K.E., Chapman P.L., Scanga J.A., and Smith G. C. 2003. Relationships of consumer sensory ratings, marbling score, and shear force value to consumer acceptance of beef strip loin steaks. Journal of Animal Science, 81(11):2741−50. doi: 10.2527/2003.81112741x.

Poppi, D., Hughes, T., and L´Hullier, P. 1987. Intake of pasture by grazing ruminants. Livestock Feeding on Pasture. New Zealand Society of Animal Production (Occasional Publications 10), 55−63.

Pouzo, L., Fanego, N., Santini, F.J., Descalzo, A., and Pavan, E. 2015. Animal performance. carcass characteristics and beef acid profile of grazing steers supplemented with corn grain and increasing amounts of flaxseed at two animal weights during finishing. Livestock Science, 178: 140−149. doi.org/10.1016/j.livsci.2015.05.034

Ramírez-Barboza, J., Valverde Abarca, A., and Rojas Bourillón, A. 2016. Efecto de la raza y niveles de energía en la finalización de novillos en pastoreo. Agronomía Mesoamericana, 28(1):

Realini, C., Duckett, S., Brito. G., Dalla Rizza, M., and De Mattos, D. 2004. Effect of pasture vs. concentrate feeding with or without antioxidants on carcass characteristics, fatty acid composition, and quality of Uruguayan beef. Meat Science, 66: 657−577. doi.org/10.1016/S0309-1740(03)00160-8

Realini, C.E., Font i Furnols, M., Guerrero, L., Montossi, F., Campo. M.M., Sañudo, C., Nute, G.R., Alvarez, I., Cañeque, V., Brito, G., and Oliver, M.A. 2009. Effect of finishing diet on consumer acceptability of Uruguayan beef in the European market. Meat Science, 81: 499–506. doi.org/10.1016/j.meatsci.2008.10.005

Restle, J., Roso, C., Oliveira, A., Alves, D., Pascoal, L., and Rosa, J. 2000. Suplementação energética para vacas de descarte de diferentes idades em terminação em pastagem cultivada de estação fria sob pastejo horário. Revista Brasileira de Zootecnia, 29(4): 1216−1222. doi.org/10.1590/S1516-35982000000400036

Restle, J., Vaz. F., Celestino, D., Filho, A., Pascoal, L., Oliveira, A., and Arboitte, M. 2001. Efeito da Suplementação energética sobre a carcaça de vacas de diferentes idades terminadas em pastagem cultivada de estação fria sob pastejo horário. Revista Brasileira de Zootecnia., 30(3): 1076−1083. doi.org/10.1590/S1516-35982001000400023

Ripoll, G., Panea, B., and Alberti, P. 2012. Visual appraisal of beef and its relationship with the CIELab colour space. Informacion Tecnica Economica Agraria, 108: 222–232.

Rodas-González A., Huerta-Leidenz N., Jerez-Timaure N., and Miller M.F. 2009. Establishing tenderness thresholds of Venezuelan beef steaks using consumer and trained sensory panels. Meat Science, 83(2):218−223.

Rodríguez, J., Unruh, J., Villarreal, M., Murillo, O., Rojas, S., Camacho, J., Jaeger, J., and Reinhardt, C. 2014. Carcass and meat quality characteristics of brahman cross bulls and steers finished on tropical pastures in Costa Rica. Meat Science, 96: 1340−1344. doi.org/10.1016/j.meatsci.2013.10.024

Schnell, T.D., Belk, K.E., Tatum, J.D., Miller, R.K., and Smith, G.C. 1997. Performance, carcass, and palatability traits for cull cows fed high-energy concentrate diets for 0, 14, 28, 42, or 56 days. Journal of Animal Sience, 75(5):1195−1202. doi.org/10.2527/1997.7551195x

Scollan, N., Hocquette, J., Nuernberg, K., Dannenberger, D., Richardson, I., and Moloney, A. 2006. Innovations in beef production systems that enhance the nutritional and health value of beef lipids and their relationship with meat quality. Meat Science, 74: 17−33. doi.org/10.1016/j.meatsci.2006.05.002

Shackelford, S.D. Wheeler, T.L., and Koohmaraie, M. 1995. Relationship Between Shear Force and Trained Sensory Panel Tenderness Ratings of 10 Major Muscles from Bos indicus and Bos taurus Cattle. Journal of Animal Science, 73: 3333−3340. doi.org/10.2527/1995.73113333x

Silva, C.C.G., Rego, O.A., Simões, E.R.E., and Rosa, H.J.D. 2010. Consumption of high energy maize diets is associated with increased soluble collagen in muscle of Holstein bulls. Meat Science, 86(3): 753−757. doi.org/10.1016/j.meatsci.2010.06.017.

Simopoulos, A. P. 2002. The importance of the ratio of omega-6/omega-3 essential fatty acids. Biomed. Pharmacother, 56: 365−379. doi:10.1016/S0753-3322(02)00253-6

Simopoulos, A. P. 2008. The omega-6/omega-3 fatty acid ratio, genetic variation, and cardiovascular disease. Asia Pacific Journal of Cinical Nutrition, 17(1): 131−134.

Stelzleni, A., Patten, L., Johnson, D., Calkins, C., and Gwartney, B. 2007. Benchmarking carcass characteristics and muscles from commercially identified beef and dairy cull cow carcasses for Warner-Bratzler shear force and sensory attributes. Journal of Animal Science, 85(10): 2631−2638. doi.org/10.2527/jas.2006-794

Stelzleni, A., Johnson, D., and Thrift, T. 2008. Effects of days on concentrate and postmortem aging on carcass and palatability characteristics of selected muscles from cull beef cows. The Professional Animal Scientist, 24: 334–341. doi.org/10.15232/S1080-7446(15)30864-0

Tarrant, P.V.1981. The Occurrence, Causes and Economic Consequences of Dark-Cutting in Beef — A Survey of Current Information. In: Hood D.E., Tarrant P.V. (eds) The Problem of Dark-Cutting in Beef. Leiden, Boston: Martinus Nijhoff Publishers, 3–36.

UK Healt Department. 1994. Report of health and social subject. Nutritional aspects of cardiovascular disease. London: United Kingdom, 46: 186.

Van Soest, P. 1982. Nutritional Ecology of the Ruminant. New York, Cornell University.

Vestergaard, M., Oksbjerg, N., and Henckel, P. 2000. Influence of feeding intensity, grazing and finishing feeding on muscle fibre characteristics and meat colour of semitendinosus, longissimus dorsi and supraspinatus muscles of young bulls. Meat Science, 54(2): 177–185.

Wood, J., Richardson, R., Nute, G., Fisher, A., Campo, M., Kasapidou, E., Sheard, P., and Enser, M. 2004. Effects of fatty acids on meats quality: a review. Meat Science, 66: 21−32. doi.org/10.1016/S0309-1740(03)00022-6

Zea, J., Díaz, M., and Carballo, J. 2007. El efecto del sistema de producción y del sexo en la calidad de la carne de vacuno joven. Archivos de Zootecnia, 56(216): 817−828.