Meat and Muscle Biology™

Residual Feed Intake in Hereford Steers: Is It Associated with Carcass and Meat Quality Characteristics?

Santiago Luzardo[1]*, Guillermo de Souza[1], Gustavo Brito[1], Pablo Peraza[2], and Elly A. Navajas[2]

[1]Instituto Nacional de Investigación Agropecuaria (INIA), Estación Experimental Tacuarembó, Tacuarembó 45000, Uruguay
[2]Instituto Nacional de Investigación Agropecuaria (INIA), Estación Experimental Las Brujas, Rincón del Colorado 90200, Uruguay
*Corresponding author. Email: sluzardo@inia.org.uy (Santiago Luzardo)

Abstract: Carcass and meat quality traits were evaluated on 136 Hereford steers categorized according to their residual feed intake (RFI): high RFI (HRFI), medium RFI (MRFI), and low RFI (LRFI). Steers from the 3 groups of RFI did not differ ($P > 0.05$) on final live weight, hot carcass weight, carcass yield, marbling scores, ribeye area, and subcutaneous fat thickness. No differences ($P > 0.05$) were observed in the weights of tenderloin, strip loin, bottom round, knuckle, and tri-tip among RFI groups; however, steers from LRFI and MRFI had heavier ($P < 0.05$) top sirloins than HRFI animals and inside rounds from more efficient animals (LRFI) were heavier ($P < 0.05$) than HRFI steers. Steers from HRFI showed a greater ($P < 0.05$) proportion of intramuscular fat (IMF) than LRFI animals. *Longissimus* muscles from HRFI steers presented greater ($P < 0.05$) concentrations of saturated (SFA), monounsaturated, and polyunsaturated fatty acids (PUFA) than those from MRFI and LRFI animals. The PUFA/SFA ratio of IMF did not differ ($P > 0.05$) between LRFI and HRFI steers and neither between LRFI and MRFI. In addition, the omega 6:omega 3 fatty acids ratio did not differ ($P > 0.05$) among the 3 RFI groups. Consumer´s panel acceptability scores for tenderness, flavor, and overall liking were not significantly different ($P > 0.05$) among meat samples from LRFI, MRFI, and HRFI steers. Our findings indicated that RFI would not be associated with carcass traits and meat quality of Hereford steers, except for the IMF content and fatty acids concentrations. Therefore, end-product quality would be only marginally affected when RFI characteristic is included in a Hereford breeding program.

Key words: steers, residual feed intake, carcass, meat quality
Meat and Muscle Biology 8(1): 18391, 1–10 (2024) **doi:10.22175/mmb.18391**
Submitted 2 October 2024 Accepted 30 October 2024

Introduction

Improving feed efficiency is a key factor in livestock systems to reduce feeding costs and enhance profitability (Baker et al., 2006), and it is also associated with beef production sustainability (Kenny et al., 2018). Residual feed intake (RFI) is one of the traits used to assess feed efficiency of both growing and finishing beef cattle, which is defined as the difference between actual and expected feed intake of an animal based on its level of production (Koch et al., 1963). The moderate heritability of RFI and its independence of performance traits, in comparison with other feed efficiency metrics, has contributed to becoming a trait of preference for improving feed efficiency by genetic selection (Herd and Bishop, 2000; Arthur et al., 2001; Pravia et al., 2022). This trait has been incorporated into the genetic evaluation of the Uruguayan Hereford breed, and the expected phenotypic independence was also confirmed at the genetic level in Hereford, in which non or negligible unfavorable phenotypic and genetic correlations were found with growth performance traits (Pravia et al., 2022). Comparisons of efficient and inefficient animals

indicate significantly lower feed intake in efficient individuals with a difference of around 15% to 20% during growing and fattening at similar levels of performance (McGee et al., 2014; Kenny et al., 2018; Pravia et al., 2018, Silveira, 2023). This implies important savings in terms of feed costs and a favorable effect on profitability if carcass and meat quality are not negatively affected. Thus, it is pivotal to know the relationship between RFI and carcass and meat quality characteristics. Previous studies have not shown consistent evidence about the phenotypic association between RFI and meat quality characteristics, (Herd and Bishop, 2000; Baker et al., 2006; Cruz et al., 2010; Zorzi et al., 2013; Herd et al., 2014; Nascimento et al., 2016; Pravia et al., 2018) most likely because different populations respond distinctly to classification for RFI (Meale et al., 2021).

The aim of the present study was to evaluate the association between RFI at finishing and carcass and beef quality traits of Hereford steers.

Materials and Methods

Experimental treatments

Residual feed intake was measured in 136 Hereford steers with an average age of 590 d in two different years ($n = 67$ in 2022 and $n = 69$ in 2023) at the Central de Pruebas de Kiyú, San José, Uruguay. All methods and procedures used in live animals were approved by the Committee for the Ethical Use of Animals of the National Agricultural Research Institute, Uruguay (Protocol number 2018-11). Steers were fattened in a confinement system and daily feed intake of each animal was recorded for 70 d using a GrowSafe™ automated system (GrowSafe Systems Ltd., Alberta, Canada). Feed intake was adjusted by the dry matter percentage to determine the dry matter feed intake. Steers were fed with a total mixed ration and composition of the diets are described in Table 1.

Phenotypic RFI was calculated as the residual (e) of the regression model used to predict dry matter intake (DMI), shown as follows:

$$\text{DMI} = b_0 + b_1\text{*MTW} + b_2\text{*ADG} + b_3\text{*FAT} + \text{Test} + e \quad (1)$$

DMI is the average dry matter intake (kg/d) during the test period, MTW is the metabolic weight (kg) at the mid-term experimental period, ADG is the average daily gain (kg/d), FAT is the backfat thickness (mm) measured at the 12th rib by ultrasound at the end of the test period; b_0 represents the intercept, b_1, b_2, and b_3 are the partial regression coefficients of each variable on DMI, and e is the residual of the regression that denotes the RFI. The model used for the estimation of RFI at finishing follows the same used at the growing phase, described by Pravia et al. (2022), which is used for the estimation of breeding values for RFI in the Uruguayan Hereford genetic evaluation (Pravia et al., 2023).

Steers were categorized into 3 groups: high RFI (HRFI; > 0.5 SD above the RFI mean; $n = 44$), medium RFI (MRFI; RFI mean ± 0.5 SD; $n = 55$), and low RFI (LRFI; < 0.5 SD below the RFI mean; $n = 37$). Average RFI values (kg of DMI per d) and standard deviations were: 0.853 ± 0.318 for HRFI, 0.030 ± 0.226 for MRFI and −1.059 ± 0.549 for LRFI.

Table 1. Ingredients and chemical composition of the fattening diets during the experimental period

Item	Year 2022	Year 2023
Ingredient (% of Dry Matter)		
Corn silage		38.46
Sorghum silage	30.50	
Corn grain	59.90	51.28
Corn Dried Distillers Grains with Solubles	7.47	8.77
Calcium carbonate	1.14	0.85
Urea	0.78	0.40
Salt	0.12	0.15
Mycotoxin binder[1]	0.04	0.04
Monensin[2]	0.01	0.01
Minerals and vitamins premix[3]	0.04	0.04
Chemical composition (%)		
Dry matter (% as fed)	61.74	58.75
Crude protein	12.58	13.82
Acid detergent fiber	11.30	11.73
Neutral detergent fiber	21.77	26.43
Ether extract	1.92	4.54
Ash	4.65	5.26

[1]Mycosorb® A$^+$ (ALLTECH).

[2]Rumensin® (ELANCO).

[3]Rovimix® (DSM).

Carcass evaluation

Steers were humanely slaughtered in a commercial meat packing plant according to the Uruguayan legislation. At slaughter, hot carcass weight (HCW) was recorded and carcass yield (dressing percentage) was calculated (CYd = (HCW/final live weight)*100). After slaughter, carcasses were kept in a cooler for 24 h at 2–4°C. Thereafter, the sides of the carcasses were quartered, and ribeye area (REA, cm^2) and

subcutaneous fat thickness (FAT, mm) were measured between the 10th and 11th ribs. Subsequently, the left "pistola" cut (prepared from a hindquarter by the removal of the thin flank, lateral portion ribs and a portion of the navel end brisket) was weighed and deboned, and the weights of 7 cuts (tenderloin [IMPS 190], strip loin [IMPS 180], top sirloin [IMPS 184], inside round [IMPS 169], bottom round [IMPS 171A], knuckle [IMPS 167], and tri-tip [IMPS 185C]), lean trimmings, fat, and total bone were recorded. All cuts were trimmed to 5 mm of external fat.

Sample preparation, meat color, cooking losses, and shear force determinations

A 2.5-cm *longissimus thoracis* steak at the 11th rib was collected, transported under refrigerated conditions to the Meat laboratory of the National Agricultural Research Institute, and then aged for 5 d at 0 to 2°C. After aging, instrumental meat color (CIE L^*: lightness, a^*: redness, and b^*: yellowness) was measured after 30 min blooming on each steak in triplicate with a Minolta chromameter CR-400 (Konica Minolta Sensing Inc., Japan) using a C illuminant, a 2° standard observer angle, and an 8-mm aperture size, and was calibrated with a white tile before use. Thereafter, steaks were weighed using an electronic scale (EP-41KA, A&D Company, Tokyo, Japan) before cooking in a preheated clam shell style grill (GRP100 The Next Grilleration, Spectrum Brands, Inc., Miami, FL, USA) until reaching 71°C measured with a digital probe thermometer (Comark N9094, Norwich, Norfolk, UK) in the geometric center (AMSA, 2016). After cooking, the steaks' surface moisture and fat were slightly blotted, cooled to room temperature, and then weighed again to determine the cooking losses (CL) as: [(raw weight − cooked weight)/raw weight]*100. Subsequently, 6 cores (1.27-cm diameter) were removed from each sample parallel to the longitudinal orientation of muscle fibers and shear force was assessed with a TA.XT Plus texturometer (Stable Micro Systems, Godalming, Surrey, UK) fitted with a Warner-Bratzler V-shaped blade. Individual Warner-Bratzler shear force (WBSF) values were averaged to assign a mean peak WBSF value to each sample (AMSA, 2016).

A second 2.54-cm-thick steak was collected from the *longissimus thoracis* muscle and frozen until the sensory consumer panel assessment. An additional 1.5-cm steak of the *longissimus thoracis* muscle was also collected for IMF and fatty acid composition.

IMF and fatty acid composition

Subcutaneous fat and connective tissue were removed from each steak and then each steak was cut into small pieces to be subsequently frozen at −80°C. Afterward, samples were pulverized using a Robot Coupe R2 (Robot Coupe®, Montceau-les-Mines, France), packed in individual sterile whirl-pack bags (Nasco, Fort Atkinson, WI, USA), and placed into a −80°C freezer until analysis was performed. Intramuscular fat content was determined gravimetrically using the chloroform–methanol method described by Bligh and Dyer (1959). Fatty acids were cold methylated with methanolic potash (IUPAC, 1987) and the analysis was performed with a gas chromatograph (Shimadzu Nexis GC 2030, Tokyo, Japan) fitted with a 60-m SH-Rt-WAX capillary column (0.25-mm internal diameter and 0.25-µm-thick film, Shimadzu, Columbia, Maryland, USA). Nitrogen was used as a carrier gas at 1 ml/min flow. Chromatographic conditions were an initial temperature of 100°C for 0.5 min, then increased 10°C/min until reaching 120°C for 2 min, and subsequently increased 10°C/min until achieving 220°C for 15 min, totaling 29.5 min per sample. The injection volume was 1 µl and a flame ionization detector was used which was kept at 260°C while the injector was 230°C. Fatty acids were identified by comparing retention times with those of a standard mixture of 37 FAME Supelco™ 37 compounds (Sigma, St. Louis, USA); meanwhile, conjugated linoleic acid (CLA; *c*9, *t*11-18:2) was identified using octadecadienoic acid, conjugated, methyl ester standard (No. O5632, Sigma, St. Louis, USA). Saturated (SFA), monounsaturated (MUFA), and polyunsaturated (PUFA) fatty acids were reported in mg/100 g of meat using methyl heneicosanoate (C21:0) as an internal standard.

Consumer sensory panel

A consumer sensory panel ($n = 100$) was performed with meat samples from steers slaughtered in 2023. The consumer panel was conducted according to the guidelines of the Declaration of Helsinki (The Code of Ethics of the World Medical Association) for experiments involving humans.

Steak samples were thawed at 2°C for 24 h on the days prior to the consumer panel sessions. Steaks intended for sensory assessment were wrapped with aluminum foil and then grilled as previously described to reach an internal temperature of 71°C. After cooking, external fat and connective tissue were removed, and samples were cut into 10 cubes that were wrapped

Table 2. Characteristics of the consumers participating in the sensory panel ($n = 100$)

Gender	Percentage
Male	58
Female	42
Age	
<30 y	41
31-50 y	50
>50 y	9

	Frequency of Consumption (%)			
Meat	Less Than Once a Month	Once a Month	Every 2 Weeks	Every Week
Beef	2	8	2	78
Chicken	4	8	33	55
Pork	36	43	14	7
Sheep	21	33	27	19

with aluminum foil, coded with a 3-digit random number, and held in a heated oven for no more than 10 min until testing. Consumers scored the sensory acceptability of beef aged for 5 d from the 3 groups of RFI following the procedures designed to reduce the effects of order of presentation and first order carry-over effects (Macfie et al., 1989). Each consumer was asked to assess tenderness, flavor, and overall liking acceptability on 9-point hedonic scales: (1) dislike extremely, (2) dislike very much, (3) dislike moderately, (4) dislike slightly, (5) neither like nor dislike, (6) like slightly, (7) like moderately, (8) like very much, and (9) like extremely. Unsalted crackers and still drinking water were available for consumers to cleanse their palate between samples. Consumers' characteristics (gender, age, and frequency of meat consumption) are presented in Table 2.

Statistical analysis

Data analysis was performed considering a mixed model using the MIXED procedure of the Statistical Analysis System (version 9.4, SAS Institute, Cary, NC, USA). The model included the RFI group as a fixed effect, whereas the year and its interaction with RFI group were considered as random effects. Individual animals represented the experimental units. Plots of residuals and the W-statistic (Shapiro and Wilk, 1965) were evaluated to assess homogeneity of variance and studentized residuals were calculated to determine outliers for all data. Hot carcass weight was adjusted by slaughter weight (SW), and pistola cut was used as a covariate for the weight of the valuable cuts. Data from the consumer sensory panel were analyzed in a model in which the RFI group was considered as fixed effect, consumer as random effect, and session as a blocking effect. After analysis of variance, least-squares means were calculated for RFI group comparisons with a significance level of $\alpha = 0.05$, using the PDIFF option of LSMEANS adjusted by Tukey, when F-tests were significant ($P < 0.05$).

Results

The three groups of steers did not differ ($P > 0.05$) in SW, HCW, carcass yield, marbling scores, REA, and FAT (Table 3). In addition, no differences ($P > 0.05$) were observed in meat quality attributes: meat color (L^*, a^*, and b^*), CL, and WBSF among HRFI, MRFI, and LRFI steers (Table 3). A significant ($P < 0.05$) year effect was found in almost all the carcass and meat quality characteristics that could be associated with different diets between years during the experimental period. Regardless, there were no significant ($P > 0.05$) interactions between year and RFI group for any of the carcass and meat quality traits. There were only significant differences ($P < 0.05$) among RFI groups for the top sirloin and the inside round; all other valuable cuts were similar ($P > 0.05$) among RFI groups. Steers from LRFI and MRFI had heavier ($P < 0.05$) top sirloins than HRFI animals. Inside round from more efficient animals (LRFI) were heavier ($P < 0.05$) than HRFI steers (Table 4). As observed for carcass and meat quality traits, there was a significant effect of year on the weight of most cuts; however, there was not a significant interaction of year × RFI for any of the evaluated cuts (Table 4).

Steers from HRFI showed a greater ($P < 0.05$) proportion of IMF than LRFI animals (Table 5). When significant differences ($P < 0.05$) were observed in the fatty acid concentrations, greater ($P < 0.05$) contents were found in meat from HRFI than in LRFI steers, except for C14:0 and C22:6-n3. *Longissimus* muscles from HRFI steers presented greater ($P < 0.05$) concentrations of SFA, MUFA, and PUFA than those from MRFI and LRFI animals. The PUFA/SFA ratio of IMF did not differ ($P > 0.05$) between LRFI and HRFI steers and neither between LRFI and MRFI. In addition, the omega 6:omega 3 fatty acids ratio was similar ($P > 0.05$) among the 3 RFI groups (Table 5).

Tenderness, flavor, and overall liking acceptability mean scores were not significantly different ($P > 0.05$)

Table 3. Least-squares means ± standard error of carcassand meat quality characteristics for HRFI, MRFI, and LRFI groups of steers

	RFI Group[1]			*P*-Values		
Traits	HRFI	MRFI	LRFI	RFI	Year	RFI*Year
SW[2] (kg)	543.6 ± 5.0	532.2 ± 4.4	534.8 ± 5.3	0.218	0.211	0.935
HCW[3] (kg)	290.7 ± 1.0	290.2 ± 0.9	290.5 ± 1.0	0.924	0.0001	0.074
CYd[4] (%)	54.1 ± 0.2	54.4 ± 0.2	54.3 ± 0.2	0.686	<0.0001	0.070
Marbling[5]	499 ± 7.3	497 ± 6.5	483 ± 7.8	0.289	0.075	0.196
REA[6] (cm^2)	63.3 ± 0.9	64.3 ± 0.8	66.2 ± 1.0	0.108	0.0002	0.214
Fat thickness (mm)	14.7 ± 0.6	14.9 ± 0.5	14.8 ± 0.6	0.961	<0.0001	0.138
Meat quality traits - 5 d aging						
Lean color						
*L** (Lightness)	38.1 ± 0.4	38.3 ± 0.4	38.5 ± 0.4	0.808	0.020	0.369
*a** (Redness)	22.4 ± 0.2	22.3 ± 0.2	22.3 ± 0.3	0.938	0.0003	0.497
*b** (Yellowness)	11.1 ± 0.2	11.1 ± 0.1	10.9 ± 0.2	0.743	0.0008	0.737
CL[7] (%)	20.4 ± 0.4	20.8 ± 0.4	20.8 ± 0.4	0.769	<0.0001	0.052
WBSF[8] (kg)	3.59 ± 0.15	3.73 ± 0.13	3.45 ± 0.16	0.392	0.548	0.066

[1] HRFI: high residual feed intake; MRFI: medium residual feed intake; LRFI: low residual feed intake.

[2] SW: slaughter weight.

[3] HCW: hot carcass weight adjusted by final live weight.

[4] CYd: carcass yield = (HCW/slaughter weight) × 100.

[5] United States Department of Agriculture marbling scores were encodedas follows: slight = 300 to 399, small = 400to 499.

[6] REA: ribeye area adjusted by HCW.

[7] CL: cooking losses = [(raw weight − cooked weight)/raw weight] × 100.

[8] WBSF: Warner-Bratzler shear force.

Table 4. Least-squares means ± standard error of valuablemeat cuts, lean trimmings, fat, and bones for HRFI, MRFI, and LRFI groups of steers

	RFI group[1]			*P*-Values		
Item	HRFI	MRFI	LRFI	RFI	Year	RFI*Year
Pistola[2] (kg)	58.7 ± 0.2	59.1 ± 0.2	59.0 ± 0.2	0.440	<0.0001	0.298
Subprimal cut[3] (kg)						
Tenderloin	1.99 ± 0.023	2.03 ± 0.020	2.03 ± 0.024	0.372	<0.0001	0.676
Strip loin	5.95 ± 0.059	5.87 ± 0.051	5.81 ± 0.062	0.266	0.0003	0.855
Top sirloin	5.21^{b} ± 0.060	5.38^{a} ± 0.053	5.40^{a} ± 0.063	0.045	<0.0001	0.705
Inside round	7.72^{b} ± 0.057	7.83^{ab} ± 0.061	7.95^{a} ± 0.061	0.002	0.126	0.326
Bottom round	7.51 ± 0.060	7.50 ± 0.053	7.53 ± 0.064	0.906	<0.0001	0.522
Knuckle	4.97 ± 0.036	5.00 ± 0.032	5.09 ± 0.039	0.077	0.007	0.436
Tri-tip	1.20 ± 0.016	1.23 ± 0.014	1.21 ± 0.017	0.393	0.001	0.824
Trimmings[3]	4.11 ± 0.091	3.93 ± 0.081	3.87 ± 0.097	0.166	<0.0001	0.650
Fat[3]	4.28 ± 0.117	4.30 ± 0.103	4.04 ± 0.124	0.241	<0.0001	0.748
Bones[3]	11.60 ± 0.080	11.60 ± 0.071	11.59 ± 0.085	0.995	<0.0001	0.567

[a,b]Least-squares means with different superscripts in the same rowdiffer significantly ($P < 0.05$).

[1]HRFI: high residual feed intake; MRFI: medium residual feed intake;LRFI: low residual feed intake.

[2]Pistola cut is prepared from a hindquarter by the removal of thethin flank, lateral portion ribs, and a portion of the navel end brisket.

[3]Weights adjusted by the weight of the pistola cut.

among meat samples from LRFI, MRFI, and HRFI steers (Table 6). It is important to highlight that the 3 groups of RFI were scored positively (i.e., at least "I like slightly") for the 3 attributes.

Discussion

As reported in previous studies carcass characteristics such as HCW, carcass yield, marbling scores,

Table 5. Least-squares means ± standard error of IMF content and fatty acids composition (mg fatty acid/100 g of meat) of *longissimus* muscle from HRFI, MRFI, and LRFI groups of steers

	RFI Group[1]			*P* Values		
Item	HRFI	MRFI	LRFI	RFI	Year	RFI*Year
IMF (%)	4.61^{a} ± 0.18	4.26^{ab} ± 0.16	3.85^{b} ± 0.19	0.018	0.0003	0.644
Fatty acids (mg/100g muscle)						
C14:0 (myristic)	92.6^{a} ± 4.78	76.7^{b} ± 4.25	78.6^{ab} ± 5.10	0.037	0.008	0.519
C14:1 (myristoleic)	18.3 ± 1.08	15.1 ± 0.95	16.2 ± 1.15	0.090	0.018	0.277
C16:0 (palmitic)	1036.9^{a} ± 49.06	877.4^{b} ± 43.61	875.3^{b} ± 52.27	0.029	0.0001	0.357
C16:1 (palmitoleic)	101.7^{a} ± 5.15	88.12^{ab} ± 4.54	83.84^{b} ± 5.64	0.046	0.006	0.336
C18:0 (stearic)	641.2^{a} ± 30.62	533.1^{b} ± 27.22	506.8^{b} ± 32.63	0.006	0.001	0.427
C18:1-n9 (oleic)	1614.5^{a} ± 79.58	1345.8^{b} ± 70.26	1324.0^{b} ± 84.79	0.017	<0.0001	0.488
C18:2-n6 (linoleic)	126.7^{a} ± 4.28	109.2^{b} ± 3.85	111.2^{b} ± 4.56	0.007	0.013	0.208
C18:3-n6 (linolenic)	2.52 ± 0.13	2.14 ± 0.12	2.14 ± 0.14	0.064	0.007	0.599
C18:3-n3 (linolenic)	8.14 ± 0.34	7.20 ± 0.31	7.18 ± 0.37	0.078	0.0004	0.208
CLA (conjugated linoleic)	10.21^{a} ± 0.53	8.58^{b} ± 0.48	8.38^{b} ± 0.57	0.032	0.827	0.394
C20:0 (arachidic)	4.43 ± 0.27	3.78 ± 0.23	4.04 ± 0.28	0.187	0.098	0.889
C20:2-n6 (eicosadienoic)	3.69^{a} ± 0.17	3.06^{b} ± 0.15	3.01^{b} ± 0.18	0.006	0.035	0.433
C20:3-n3 (eicosatrienoic)	3.93^{a} ± 0.22	3.03^{b} ± 0.19	3.04^{b} ± 0.23	0.003	<0.0001	0.703
C20:3-n6 (DGLA)[2]	1.77 ± 0.13	1.87 ± 0.12	1.90 ± 0.15	0.786	0.396	0.165
C20:4-n6 (arachidonic)	27.6 ± 0.88	25.2 ± 0.79	26.7 ± 0.94	0.118	0.542	0.816
C20:5-n3 (EPA)[3]	3.30 ± 0.88	3.18 ± 0.14	3.52 ± 0.17	0.299	0.003	0.440
C22:5-n3 (DPA)[4]	7.71 ± 0.27	6.98 ± 0.24	7.30 ± 0.29	0.132	0.114	0.432
C22:6-n3 (DHA)[5]	1.53^{a} ± 0.07	1.20^{b} ± 0.06	1.37^{ab} ± 0.07	0.002	0.978	0.590
SFA[6]	1775.2^{a} ± 83.0	1491.0^{b} ± 73.7	1464.9^{b} ± 88.4	0.015	0.0003	0.387
MUFA[7]	1734.4^{a} ± 85.4	1449.0^{b} ± 75.4	1430.2^{b} ± 91.0	0.020	<0.0001	0.483
PUFA[8]	198.3^{a} ± 6.1	173.8^{b} ± 5.5	175.7^{b} ± 6.6	0.007	0.052	0.651
PUFA/SFA	0.11^{b} ± 0.004	0.13^{a} ± 0.004	0.12^{ab} ± 0.003	0.030	<0.0001	0.829
Omega 6:omega 3	7.01 ± 0.11	7.02 ± 0.09	6.69 ± 0.11	0.062	<0.0001	0.500

^{a,b}Least-squares means with different superscripts in the same row differ significantly ($P < 0.05$).

[1]HRFI: high residual feed intake; MRFI: medium residual feed intake; LRFI: low residual feed intake.

[2]DGLA: dihomo-gamma-linolenic acid.

[3]EPA: eicosapentaenoic acid.

[4]DPA: docosapentaenoic acid.

[5]DHA: docosahexaenoica acid.

[6]SFA: saturated fatty acids, Σ C14:0 + C16:0 + C18:0 + C20:0.

[7]MUFA: monounsaturated fatty acids, Σ C14:1 + C16:1 + C18:1n9.

[8]PUFA: monounsaturated fatty acids, Σ C18:2n6 + C18:3n6 + C18:3n3 + CLA + C20:2n6 + C20:3n3 + C20:3n6 + C20:4n6 + C20:5n3 + C22:5n3 + C22:6n3. n-6: omega 6 fatty acids, Σ C18:2n6 + C18:3n6 + C20:2n6 + C20:3n6 + C20:4n6. n-3: omega 3 fatty acids, Σ C18:3n3 + C20:3n3 + C20:5n3 + C22:5n3 + C22:6n3.

Table 6. Least-squares means ± standard error for tenderness, flavor, and overall liking scores of beef samples from HRFI, MRFI, and LRFI groups of steers evaluated by a consumer panel ($n = 100$) in 2023

	RFI Group[1]			
Variable	HRFI	MRFI	LRFI	*P*-Values
Tenderness[2]	6.69 ± 0.28	7.00 ± 0.28	7.28 ± 0.28	0.318
Flavor[2]	6.71 ± 0.16	6.84 ± 0.16	6.89 ± 0.16	0.652
Overall liking[2]	6.60 ± 0.19	6.90 ± 0.19	7.05 ± 0.19	0.227

[1]HRFI: high residual feed intake; MRFI: medium residual feed intake; LRFI: low residual feed intake.

[2]9-point category scales: (1) dislike extremely, (2) dislike very much, (3) dislike moderately, (4) dislike slightly, (5) neither like nor dislike, (6) like slightly, (7) like moderately, (8) like very much, and (9) like extremely.

REA, and fat thickness were not affected by RFI (Baker et al., 2006; Castro Bulle et al., 2007; Cruz et al., 2010; Gomes et al., 2012; Zorzi et al., 2013; Pravia et al., 2018). Nevertheless, Robinson and Oddy (2004) reported that selection for reduced RFI is likely to decrease subcutaneous fat thickness. Herd et al. (2014) found that HRFI steers had a greater depth of subcutaneous rib fat than LRFI. These authors indicated that fat deposition pattern changes in LRFI animals toward more intermuscular fat and less subcutaneous fat; however, our results do not support these findings. Heavier top sirloin and inside round were found in LRFI steers than in HRFI animals, but no differences were observed in the weights of any of the other cuts. Zorzi et al. (2013), when working with Nellore bulls, did not find differences in the weights of the strip loin, tenderloin, and complete rump between high and low RFI animals. Bonilha et al. (2013) reported no differences in the percentage of edible part of carcass between low and high RFI Nellore bulls. Results from the present study showed that significant differences among RFI groups were found just for the weight of two cuts whose magnitude (less than 4% difference) lacks practical relevance for the meat industry. Selection for more efficient animals (LRFI) would not have any detrimental effect on the weights of retail cuts.

Tenderness is considered the most relevant attribute influencing consumer satisfaction and beef palatability (Dikeman, 1987; Miller et al., 1995; Maltin et al., 2003; Van Wezemael et al., 2014). It has been suggested that selection for more efficient animals could be negatively associated with meat tenderness (Herd and Pitchford, 2011) and may be related to a lesser degradation of myofibrillar proteins (Gomes et al., 2012). Some studies have shown greater shear force values on aged (Zorzi et al., 2013) and non-aged meat (Herd et al., 2014; Nascimento et al., 2016) from more efficient (low RFI) animals; however, in our study, meat shear force was not affected by RFI, which agrees with previous research (Baker et al., 2006; Ahola et al., 2011; Gomes et al., 2012; Blank et al., 2017; Pravia et al., 2018). It is important to note that all shear force values of meat, even those aged for 5 d, were below 4.1 kg, indicating that it was tender beef that would guarantee high acceptability by consumers (Huffman et al., 1996). This was confirmed to some extent by consumers since the mean tenderness scores of the three RFI groups were at least "I like slightly." Cooking losses were not different across RFI groups, which were in agreement with the findings of previous studies (Ahola et al., 2011; Herd et al., 2014; Blank et al., 2017). Beef color represents the most important factor that affects consumers purchase decision (Faustman and Cassens, 1990; Mancini and Hunt, 2005). Lack of beef cherry-red color or discoloration may reduce consumer's willingness to purchase. Values of L^*, a^*, and b^* coordinates of meat color were not different among RFI groups in our study and similar results were also found in unaged (Perkins et al., 2014) and aged meat for 7 and 14 d (Nascimento et al., 2016). However, Baker et al. (2006) found greater b^* (yellowness) values of lean color in high compared to mid- and low-RFI steers. In addition, Herd et al. (2014) observed greater L^*, a^*, and b^* values on meat aged for 7 d in high compared with low-RFI Angus steers, although those differences were small in magnitude. We could infer that inconsistencies in objective meat color measurements would indicate no clear association between RFI and beef color.

Intramuscular fat content is a relevant characteristic that influences meat tenderness, juiciness, and flavor, affecting beef palatability (Smith et al., 1985; O'Quinn et al., 2012; Emerson et al., 2013; Corbin et al., 2015; Frank et al., 2016). Furthermore, there is growing interest in the nutritional aspects and health implications of meat consumption, particularly associated with its fat content (Daley et al., 2010). In our study, even though no differences were observed in the marbling scores across RFI groups, inefficient steers (HRFI) presented a greater IMF content than LRFI animals, which agrees with the findings of Nascimento et al. (2016) in Nellore steers. Nevertheless, some studies did not find differences in the IMF content across RFI groups of *Bos taurus* (McDonagh et al., 2001) and *Bos indicus* (Gomes et al., 2012) steers. Previous studies that evaluated the relationship between RFI and IMF seem to be inconclusive (Welch et al., 2012). Regarding fatty acid composition, meat from HRFI steers showed greater concentrations of SFA, MUFA, and PUFA than LRFI, which was related to the greater IMF content. Rauw et al. (2012) worked with barrows, and they observed that the correlations between RFI and fatty acid profile became non-significant after correction for IMF. In Japanese Black cattle, Inoue et al. (2011) found that RFI has less of an effect than feed conversion ratio on the fatty acid composition of intramuscular fat. These authors reported positive but low genetic correlations (0.06 to 0.17) of oleic acid (C18:1), MUFA, and the SFA to MUFA ratio with RFI.

Evaluating meat-eating quality is of primary relevance to understanding the acceptance of meat products and in this scenario, consumer sensory studies are

increasingly used (Miller, 2020). Tenderness, juiciness, and flavor are the 3 attributes influencing cooked meat palatability and are linked to consumer satisfaction (Garmyn, 2020). In the present study, consumer panel scores for tenderness, flavor, and overall liking of steaks did not differ across RFI groups. Ahola et al. (2011) reported an absence of a relationship between RFI, and tenderness, juiciness, flavor, off-flavor, and overall acceptability of steaks from Angus steers evaluated by a trained sensory panel. In the same line, Baker et al. (2006) did not find differences in tenderness and flavor of steaks from Angus steers across RFI groups scored by trained panelists. Therefore, our findings and previous studies with British breeds have not found any relationship between RFI and sensory attributes.

Conclusions

The findings of the present research indicate that RFI would not be related to carcass traits and meat quality of Hereford steers. The current study detected differences in the IMF content and fatty acids concentrations, but those differences did not affect palatability attributes scored by consumers. The inclusion of RFI in genetic selection programs would have a positive impact on reducing feed costs, among others, with minor or no detrimental effect on end-product quality.

Acknowledgments

The authors would like to thank the Uruguayan Hereford Breeders' Society for enabling us to carry out the present study using their facilities at the Central de Pruebas de Kiyú (San José, Uruguay). Authors also wish to thank MARFRIG Tacuarembó S.A. and MARFRIG Establecimientos Colonia S.A. meat packing plants for their support in the work carried out at their facilities.

Literature Cited

Ahola, J. K., T. A. Skow, C. W. Hunt, and R. A. Hill. 2011. Relationship between residual feed intake and end product palatability in longissimus steaks from steers sired by Angus bulls divergent for intramuscular fat expected progeny difference. The Professional Animal Scientist 27:109–115. https://doi.org/10.15232/S1080-7446(15)30456-3

American Meat Science Association (AMSA). 2016. Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of meat. American Meat Science Association, Champaign, IL.

Arthur, P. F., J. A. Archer, D. J. Johnston, R. M. Herd, E. C. Richardson, and P. F. Parnell. 2001. Genetic and phenotypic variance and covariance components for feed intake, feed efficiency, and other postweaning traits in Angus cattle. J. Anim. Sci. 79:2805–2811. https://doi.org/10.2527/2001.79112805x

Baker, S. D., J. I. Szasz, T. A. Klein, P. S. Kuber, C. W. Hunt, J. B. Glaze Jr., D. Falk, R. Richard, J. C. Miller, R. A. Battaglia, and R. A. Hill. 2006. Residual feed intake of purebred Angus steers: effects on meat quality and palatability. J. Anim. Sci. 84: 938–945. https://doi.org/10.2527/2006.844938x

Blank, C. P., J. Russell, S. M. Lonergan, and S. L. Hansen. 2017. Influence of feed efficiency classification and growing and finishing diet type on meat tenderness attributes of beef steers. J. Anim. Sci. 95:2986–2992. https://doi.org/10.2527/jas.2016.1312

Bligh, E. G., and W. J. Dyer. 1959. A rapid method of total lipid extraction and purification. Can. J. Biochem. Phys. 37:911–917. https://doi.org/10.1139/o59-099

Bonilha, E. F. M., R. H. Branco, S. F. M. Bonilha, F. L. Araujo, E. Magnani, and M. E. Z. Mercadante. 2013. Body chemical composition of Nellore bulls with different residual feed intakes. J. Anim. Sci. 93:3457–3464. https://doi.org/10.2527/jas.2012-5437

Castro Bulle, F. C. P., P. V. Paulino, A. C. Sanches, and R. D. Sainz. 2007. Growth, carcass quality, and protein and energy metabolism in beef cattle with different growth potentials and residual feed intakes. J Anim Sci. 85:928–936. https://doi.org/10.2527/jas.2006-373

Corbin, C. H., T. G. O´Quinn, A. J. Garmyn, J. F. Legako, M. R. Hunt, T. T. N. Dinh, R. J. Rathmann, J. C. Brooks, and M. F. Miller. 2015. Sensory evaluation of tender beef strip loin steaks of varying marbling levels and quality treatments. Meat Sci. 100:24–31. https://doi.org/10.1016/j.meatsci.2014.09.009

Cruz, G. D., J. A. Rodríguez-Sánchez, J. W. Oltjen, and R. D. Sainz. 2010. Performance, residual feed intake, digestibility, carcass traits, and profitability of Angus-Hereford steers housed in individual or group pens. J. Anim. Sci. 88:324–329. https://doi.org/10.2527/jas.2009-1932

Daley, C. A., A. Abbot, P. S. Doyle, G. A. Nader, and S. Larson. 2010. A review of fatty acid profiles and antioxidant content in grass-fed and grain-fed beef. Nutr. J. 9:10. https://doi.org/10.1186/1475-2891-9-10

Dikeman, M. E. 1987. Fat reduction in animals and the effects on palatability and consumer acceptance of meat products. 40th Recip. Meat Conf. Proc., St. Paul, MN. p. 93–103.

Emerson, M. R., D. R. Woerner, K. E. Belk, and J. D. Tatum. 2013. Effectiveness of USDA instrument-based marbling measurements for categorizing beef carcasses according to differences in longissimus muscle sensory attributes. J. Anim. Sci. 91:1024–34. https://doi.org/10.2527/jas.2012-5514

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

Frank, D., S. T. Joo, and R. Warner. 2016. Consumer acceptability of intramuscular fat. Korean J. Food Sci. An. 36:699–708. https://doi.org/10.5851/kosfa.2016.36.6.699

Garmyn, A. 2020. Consumer preferences and acceptance of meat products. Foods 9:708. https://doi.org/10.3390/foods9060708

Gomes, R. C., R. D. Sainz, S. L. Silva, M. C. César, M. N. Bonin, and P. R. Leme. 2012. Feedlot performance, feed efficiency reranking, carcass traits, body composition, energy requirements, meat quality and calpain system activity in Nellore steers with low and high residual feed intake. Livest. Sci. 150: 265–273. https://doi.org/10.1016/j.livsci.2012.09.012

Herd, R. M., and S. C. Bishop. 2000. Genetic variation in residual feed intake and its association with other production traits in British Hereford cattle. Livest. Prod. Sci. 63:111–119. https://doi.org/10.1016/S0301-6226(99)00122-0

Herd, R. M., and W. S. Pitchford. 2011. Residual feed intake selection makes cattle leaner and more efficient. In: P. Cronje, editor, Recent advances in animal nutrition in Australia. Univ. of New England, Armidale, Australia. p. 45–58.

Herd, R. M., P. F. Arthur, C. D. K. Bottema, A. R. Egarr, G. H. Geesink, D. S. Lines, S. Piper, J. P. Siddell, J. M. Thompson, and W. S. Pitchford. 2014. Genetic divergence in residual feed intake affects growth, feed efficiency, carcass and meat quality characteristics of Angus steers in a large commercial feedlot. Anim. Prod. Sci. 58:164–174. https://doi.org/10.1071/AN13065

Huffman, K. L., M. F. Miller, L. C. Hoover, C. K. Wu, H. C. Brittin, and C. B. Ramsey. 1996. Effect of beef tenderness on consumer satisfaction with steaks consumed in the home and restaurant. J. Anim. Sci. 74:91–97. https://doi.org/10.2527/1996.74191x

Inoue, K., M. Kobayashi, N. Shoji, and K. Kato. 2011. Genetic parameters for fatty acid composition and feed efficiency traits in Japanese Black cattle. Animal 5:987–994. https://doi.org/10.1017/S1751731111000012

IUPAC. 1987. Preparation of fatty acid methyl ester. In: A. Dieffenbacher, W. D. Pocklington, editors, Standard methods for analysis of oils, fats and derivatives. 7th ed. Blackwell Scientific Publications, Oxford, UK.

Kenny, D. A., C. Fitzsimons, S. M. Waters, and M. McGee. 2018. Invited review: Improving feed efficiency of beef cattle - the current state of the art and future challenges. Animal 12:1815–1826. https://doi.org/10.1017/S1751731118000976

Koch, R. M., L. A. Swiger, D. Chambers, and K. E. Gregory. 1963. Efficiency of feed use in beef cattle. J. Anim. Sci. 22:486–494. https://doi.org/10.2527/jas1963.222486x

Macfie, H. J., N. Bratchell, K. Greenhoff, and L. V. Vallis. 1989. Designs to balance the effect of order of presentation and first order carry-over effects in hall tests. J. Sens. Stud. 4:129–148. https://doi.org/10.1111/j.1745-459X.1989.tb00463.x

Maltin, C., D. Balcerzak, R. Tilley, and M. Delday. 2003. Determinants of meat quality: Tenderness. P. Nutr. Soc. 62:337–347. https://doi.org/10.1079/pns2003248

Mancini, R. A., and M. C. Hunt. 2005. Current research in meat color. Meat Sci. 71:100–121. https://doi.org/10.1016/j.meatsci.2005.03.003

McDonagh, M. B., R. M. Herd, E. C. Richardson, V. H. Oddy, J. A. Archer, and P. F. Arthur. 2001. Meat quality and the calpain system of feedlot steers following a single generation of divergent selection for residual feed intake. Aust. J. Exp. Agr. 41:1013–1021. https://doi.org/10.1071/EA00024

McGee, M., C. M. Welch, J. A. Ramirez, G. E. Carstens, W. J. Price, J. B. Hall, and R. A. Hill. 2014. Relationships of feeding behaviors with average daily gain, dry matter intake, and residual feed intake in Red Angus–sired cattle. J. Anim. Sci. 92: 5214–5221. https://doi.org/10.2527/jas.2014-8036

Meale, S. J., A. L. Ruiz-Sanchez, E. Dervishi, B. C. Roy, F. Paradis, M. Juárez, J. Aalhus, Ó. López-Campos, C. Das, C. Li, H. Block, M. G. Colazo, C. Straathof, H. L. Bruce, and C. Fitzsimmons. 2021. Impact of genetic potential for residual feed intake and diet fed during early- to mid-gestation in beef heifers on carcass characteristics and meat quality attributes of their castrated male offspring. Meat Sci. 182:108637. https://doi.org/10.1016/j.meatsci.2021.108637

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

Miller, R. 2020. Drivers of consumer liking for beef, pork, and lamb: A review. Foods 9:428. https://doi.org/10.3390/foods9040428

Nascimento, M. L., A. R. D. L. Souza, A. S. Chaves, A. S. M. Cesar, R. R. Tullio, S. R. Medeiros, G. B. Mourão, A. N. Rosa, G. L. D. Feijó, M. M. Alencar, and D. P. D. Lanna. 2016. Feed efficiency indexes and their relationships with carcass, non-carcass and meat quality traits in Nellore steers. Meat Sci. 116:78–85. https://doi.org/10.1016/j.meatsci.2016.01.012

O'Quinn, T. G., J. C. Brooks, R. J. Polkinghorne, A. J. Garmyn, B. J. Johnson, J. D. Starkey, R. J. Rathmann, and M. F. Miller. 2012. Consumer assessment of beef strip loin steaks of varying fat levels. J. Anim. Sci. 90:626–634. https://doi.org/10.2527/jas.2011-4282

Perkins, S. D., C. N. Key, Garrett, M. N. Marvin, C. F. Garrett, C. D. Foradori, C. L. Bratcher, L. A. Kriese-Anderson, and T. D. Brandebourg. 2014. Effect of residual feed intake on hypothalamic gene expression and meat quality in Angus-sired cattle grown during hot season. J. Anim. Sci. 92:1451–1461. https://doi.org/10.2527/jas.2013-7020

Pravia, M. I., E. A. Navajas, F. L. Macedo, J. Clariget, and Luzardo, S. 2018. Association between feed efficiency and carcass and meat quality traits in Hereford steers. Proceedings of 11th World Congress on Genetics Applied to Livestock Production, Auckland, New Zealand, 11–16 February 2019. p. 604.

Pravia, M. I., E. A. Navajas, I. Aguilar, and O. Ravagnolo. 2022. Evaluation of feed efficiency traits in different Hereford populations and their effect on variance component estimation. Anim. Prod. Sci. 62:1652–1660. https://doi.org/10.1071/AN21420

Pravia, M. I., E. A. Navajas, I. Aguilar, and O. Ravagnolo. 2023. Prediction ability of an alternative multi-trait genomic evaluation for residual feed intake. J. Anim. Breed Genet. 140:508–518. https://doi.org/10.1111/jbg.12775

Rauw, W. M., I. Diaz, F. Francés, D. Corella, J. Soler, J. Tibau, and L. Gomez-Raya. 2012. The relationship between feed intake behaviour with intramuscular fat, cholesterol and fatty acid composition in pork. J. Anim. Breed Genet. 129:289–297. https://doi.org/10.1111/j.1439-0388.2011.00978.x

Robinson, D. L., and V. H. Oddy. 2004. Genetic parameters for feed efficiency, fatness, muscle area and feeding behaviour of

feedlot finished beef cattle. Livest. Sci. 90:255–270. https://doi.org/10.1016/j.livprodsci.2004.06.011

Shapiro, S. S., and M. B. Wilk. 1965. An analysis of variance test for normality (complete samples). Biometrika 52:591–611. https://doi.org/10.2307/2333709

Silveira, M. 2023. Asociación de eficiencia de conversión del alimento con otras características de importancia económica y ambiental en la producción de carne. M.S. thesis, University of the Republic, Montevideo, Uruguay. (https://hdl.handle.net/20.500.12008/43700)

Smith, G. C., Z. L. Carpenter, H. R. Cross, C. E. Murphey, H. C. Abraham, J. W. Savell, G. W. Davies, B. W. Berry, and F. C. Parrish Jr. 1985. Relationship of USDA marbling groups to palatability of cooked meat. J. Food Quality 7:289–308. https://doi.org/10.1111/j.1745-4557.1985.tb01061.x

Van Wezemael, L., S. De Smet, Ø. Ueland, and W. Verbeke. 2014. Relationships between sensory evaluations of beef tenderness, shear force measurements and consumer characteristics. Meat Sci. 97:310–315. https://doi.org/10.1016/j.meatsci.2013.07.029

Welch, C. M., J. K. Ahola, J. B. Hall, G. K. Murdoch, D. H. Crews, L. C. Davis, M. E. Doumit, W. J. Price, L. D. Keenan, and R. A. Hill. 2012. Relationships among performance, residual feed intake, and product quality of progeny from Red Angus sires divergent for maintenance energy EPD. J. Anim. Sci. 90:5107–5117. https://doi.org/10.2527/jas.2012-5184

Zorzi, K., S. F. Bonilha, A. C. Queiroz, R. H. Branco, T. L. Sobrinho, and M. S. Duarte. 2013. Meat quality of young Nellore bulls with low and high residual feed intake. Meat Sci. 93: 593–599. https://doi.org/10.1016/j.meatsci.2012.11.030