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Feed efficiency and its correlations with carcass traits measured by ultrasound in Nellore bulls

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ABSTRACT

Forty-six Nellore bulls were individually fed for 84 days and evaluated for residual feed intake (RFI) and feed conversion ratio (FCR) with the objective to correlate RFI_1 (usual), RFI_2 (adjusted for final rump fat thickness) and FCR with carcass composition traits measured by ultrasound and to verify differences between RFI groups (classified by standard deviation) in performance and carcass traits. Carcass traits were evaluated by ultrasound at the beginning and at the end of the test and the gain over the test period was calculated for ribeye area (REA), backfat thickness on the 12–13th ribs (BFT) and rump fat thickness on the *Biceps femoris* muscle (RFT). The RFI_1 was positively correlated ($P<0.05$) with the final RFT ($r=0.34$) and with the gain in RFT ($r=0.36$) and also there were differences ($P<0.05$) in these traits and also in dry matter intake (DMI) between groups, in which the most efficient animals had lower values of DMI, final RFT, and gain in RFT. For the RFI_2, there were no differences ($P>0.05$) between groups and neither were there significant correlations between those with the carcass traits, only for FCR, feed efficiency and DMI. FCR was correlated with the gain in REA and BFT ($r=-0.43$ and $r=-0.31$, respectively) and with the initial BFT ($r=0.31$). The positive correlation between residual feed intake and subcutaneous fat of Nellore bulls' may cause some concern, because with the selection of more efficient individuals (with negative RFI), carcasses which are too lean will be produced. Adjustments in the estimation of RFI including carcass traits may override this undesirable effect.

1. Introduction

Traditional genetic improvement programs that include weight gain as the main trait can compromise the feed efficiency of the beef cattle (Almeida, 2005). This happens because steers selected only by weight gain also increase their feed intake. Sometimes this increase in feed expenses will not be compensated by an increase in weight. Thus to improve livestock profitability, it is important to take into account feed efficiency traits when selecting steers.

Beef cattle feed efficiency is usually described by the gross feed efficiency (GFE) or the feed conversion ratio (FCR). These traits have limitations as selection criteria due to their correlations with live body weight and average daily gain. As a long-term concern, this could compromise the productive efficiency in grazing systems by over-increasing the female's mature size therefore increasing their nutritional requirements for maintenance. A feed efficiency trait that can be used and is not correlated with live body weight and average daily gain is the residual feed intake (RFI) that measures feed intake independent from mature size or growth (Arthur et al., 2001; Richardson and Herd, 2004).

Richardson et al. (2004) observed, in a unique selection generation of *Bos taurus* against RFI (higher efficiency), a

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reduction in carcass fat content in its progeny. It is necessary to investigate if this effect also occurs in *Bos indicus* cattle, mainly in the Nellore breed. Also, if a body composition adjustment in the RFI estimate can avoid any compromise in the performance or in the carcass traits.

According to Lanna and Almeida (2004) the lower subcutaneous fat deposition by the most efficient animals could be overdone by predicting feed intake not only by the body weight and average daily gain, but also by the body composition, which can be partly evaluated *in vivo* by ultrasound. The carcass traits obtained by ultrasound allow a better adjustment of the predicted intake and, consequently, more accurate RFI values (Almeida, 2005).

The objective of this study was to estimate the correlations between RFI (adjusted or non-adjusted to subcutaneous fat) and FCR with productive traits (average daily gain, daily feed intake, live body weight, and gross feed efficiency). In addition, to estimate the correlations of RFI and FCR with carcass traits (ribeye area, subcutaneous fat thickness over the 12th to the 13th ribs, and *Biceps femoris* muscle fat thickness). Furthermore for evaluating the possible differences across these traits for the RFI groups (high, medium, and low) in Nellore bulls.

2. Material and methods

2.1. Animals and facilities

The trial was conducted in Guapirama, in the north of Paraná State (south of Brazil), between December 22nd and March 16th, 2009 in an experimental feedlot with 15 m long × 2 m wide individual pens. Forty-six Nellore bulls were evaluated, coming from 10 different breeders with an average starting age of 22 ± 2 months and live body weight of 409 ± 49 kg, and all were registered in Associação Brasileira dos Criadores de Zebu (ABCZ).

2.2. Experimental diet and management

All young bulls were adapted by grazing *Panicum maximum* pasture for 45 days to avoid eventual compensatory effects from original farms. Subsequently, these animals were housed in the experimental feedlot, and were allowed to adapt to the diets and facility for 14 days.

The bulls were individually fed twice a day with a total mixed ratio diet (Table 1) with 70% total digestible nutrients (%TDN) estimated by the Weiss et al. (1992) equation and 15.2% crude protein. Sugarcane silage and concentrate were added to the 50:50 proportion, on a dry matter (DM) basis. No feed additives or hormonal implants were used.

The chemical composition of the sugarcane silage and feed refusals was obtained by weekly samples that were analyzed in the Laboratório de Nutrição Animal of Universidade Federal do Paraná (UFPR). Daily sub-samples of the silage and feed refusals were collected and at the end of each week those sub-samples were homogenized to obtain the weekly sample. Table 2 shows the average silage chemical composition during the 12-week experiment. The diet average dry matter was 34.37 ± 5.55%DM.

2.3. Data collection

All bulls were weighed five times on days 0, 21, 42, 63, and 84 of the experimental feedlot period, after being deprived of feed (but not water) by 16 h. The average daily gain (ADG) was measured by linear regression of individual BW measurements on day of trial.

The observed dry matter intake (DMI_{obs}) was obtained through the subtraction of the daily feed offered minus the daily feed refusals (both DM-adjusted). Residual feed intake (RFI_1) was calculated as the difference between actual and predicted feed intake by regressing DMI on mid-test $BW^{0.75}$ and ADG (Koch et al., 1963) using the REG procedure of SAS, whereas RFI_2 also included ultrasound fat thickness over the *Biceps femoris* muscle at the end of trial (RFTf). The model for predicting DMI of the RFI_1 was:

$$DMI_{est} = 0.15463 + \left(0.07619 \times BW^{0.75}\right) + (0.85989 \times ADG) \quad \left(R^2 = 0.56\right)$$

For the RFI_2 the equation to get the DMI_{est} was:

$$DMI_{est} = 0.16748 + \left(0.06749 \times BW^{0.75}\right) + (0.82585 \times ADG) + (0.15305 \times RFTf) \quad \left(R^2 = 0.62\right)$$

After determining the RFI, young bulls were classified into high (less efficient; > 0.5 SD above the mean), medium (mid; ± 0.5 SD from the mean), and low (more efficient;

Table 1
Ingredient composition of the experimental diet.

Ingredients	% (DM)
Sugarcane silage	50.00
Corn grain cracked	20.22
Soybean meal 49%	20.43
Wheat meal	7.37
Limestone	1.26
Sodium chloride (NaCl)	0.40
Dicalcium phosphate	0.10
Premix mineral[a]	0.22

[a] Mineral premix: P = 14 (g/kg); Ca = 45 (g/kg); Mg = 3 (g/kg); S = 16 (g/kg); Na = 10 (g/kg); Zn = 530 (mg/kg); Cu = 160 (mg/kg); Mg = 140 (mg/kg); Co = 16 (mg/kg); I = 50 (mg/kg); Se = 5 (mg/kg).

Table 2
Chemical composition of sugarcane silage.

Nutrient	%
Dry matter	25.52
Crude protein (% DM)	8.48
Ether extract (% DM)	1.12
Ash (% DM)	4.31
Acid detergent fiber (% DM)	44.52
Neutral detergent fiber (% DM)	69.97
Total digestible nutrients (%)	70.00
Digestible energy (Mcal/kg)[a]	3.09
Metabolizable energy (Mcal/kg)[a]	2.67
Calcium (% DM)	0.27
Phosphorus (% DM)	0.12

[a] NRC (2001).

<0.5 SD below the mean) RFI groups. The FCR was measured as the ratio of the DMI_{obs} over the ADG and the GFE by the inverse of FCR.

During the trial, ultrasound images (Aloka SSD500 equipped with 3.5 MHz linear transducer) of carcass composition traits [ribeye area (REA), 12th to 13th-rib fat thickness (BFT; backfat), and subcutaneous fat over the *Biceps femoris* muscle (RFT; rump fat)] were collected at the beginning and end of the trial. Gain in REA, BFT, and RFT was also calculated.

2.4. Statistic analysis

The correlation coefficients between RFI_1, RFI_2 and the FCR with carcass traits, performance and dry matter intake variables were computed by the CORR procedure from SAS (Statistical Analysis System, 1998). Simple Pearson correlations were estimated and considered as significant if probabilities were lower than 5%. The RFI group effect was analyzed by analysis of variance using the GLM procedure of SAS and the means were compared with the Tukey–Kramer test. The results were interpreted as statistically significant with a 5% probability level.

3. Results and discussion

3.1. Productive traits and feed efficiency

The multiple linear regression analysis has shown that the mid-test $BW^{0.75}$ and ADG variables accounted for 51% and 5%, respectively, of the total variation in the DMI_{est} on the prediction of RFI_1. For the RFI_2, the mid-test $BW^{0.75}$, ADG and RFTf have contributed 51%, 5%, and 6% respectively in the DMI_{est} variation. Therefore, the inclusion of the RFTf has raised the R^2 of the multiple regressions 6%, from 56% to 62%.

According to Basarab et al. (2003), the R^2 of prediction equation of feed intake can be increased by the inclusion of other variables in the model, as the gain of rump fat and marbling, measured by ultrasound, which increased the R^2 in 4%. Almeida (2005) also found an increase of 4% in R^2 with the inclusion of fat thickness in Nellore bulls.

Table 3 shows the descriptive statistics of the performance, feed intake and efficiency traits as well as its correlations with RFI_1, RFI_2 and FCR during the 84-d experimental period. The obtained standard deviation values for both RFI estimates in this study were similar to others with *B. indicus* studies such as Almeida (2005) with ±0.41 kg of DM/day or even *B. taurus* animals as Carstens et al. (2002) with ±0.82 kg of DM/day and Basarab et al. (2003) with ±0.66 kg of DM/day. There were no significant correlations ($P>0.05$) between the feed conversion ratio and the RFI estimates, in agreement with the results of Basarab et al. (2003).

Unlike FCR, the selection for RFI seems to choose lower intake animals and lower maintenance demands, without changing the adult size or weight gain (Basarab et al., 2003). This trend was also observed in this study, in which the correlations between RFI_1 and RFI_2 with DMI estimates (kg DM/day, %BW and $BW^{0.75}$) were significant ($P<0.05$), whereas the correlations with ADG and BW were not ($P>0.05$). These correlations were expected because RFI is a trait based on the feed intake; so the ADG and BW would not be influenced by a selection for RFI.

In contrast to the lack of correlations between RFI and growth rate, the FCR was strongly correlated with ADG ($P<0.05$), corroborating the results from Basarab et al. (2003), which found a strong correlation between FCR and ADG of 0.61. Therefore, using FCR as a trait to select for feed efficiency in growing cattle will eventually lead to increases in cow mature body size. Feed conversion ratio was not correlated with the DMI estimates; so an improvement in FCR would not reduce feed intake. As the FCR and the GFE are direct ratios of the same variables (ADG and DMI) there was a significant ($P<0.05$) and high correlation between them.

To further examine the relationships between RFI and performance traits, 46 young bulls were ranked by RFI and separated into low (16 bulls or 35%), medium (17 bulls or 37%), and high (13 bulls or 28%) groups. Differences in intake, performance, and feed efficiency traits between RFI groups, non-adjusted for subcutaneous fat thickness over the *Biceps femoris* muscle, are presented in Table 4. When the animals were separated into different RFI groups adjusted also for subcutaneous fat thickness over the *Biceps femoris* muscle, a new distribution of young bulls was observed: 10 bulls (22%) in the high RFI_2 class, 23 bulls (50%) in the medium RFI_2 class, and 13 animals (28%) in the low RFI_2 group. Differences in intake, performance, and feed efficiency traits among RFI groups, adjusted for subcutaneous fat thickness over the *Biceps femoris* muscle, are presented in Table 5.

Feed conversion ratio, GFE, BW, $BW^{0.75}$, and ADG did not differ ($P>0.05$) between the high-, medium-, and low-RFI_1 groups. Low-RFI_1 bulls consumed 14.7% less feed than their counterparts ranked as high RFI. These findings demonstrate

Table 3
Means and standard deviations for performance, feed intake, and feed efficiency traits in Nellore bulls, and correlations with feed efficiency traits.

Traits	Mean	SD	r_{RFI1}	r_{RFI2}	r_{FCR}
Body weight (kg)	456	49.35	0.00	0.00	0.35*
Body weight$^{0.75}$ (kg)	98.7	8.02	0.00	0.00	0.36*
Average daily gain (kg/day)	1.17	0.22	0.00	0.00	−0.85*
Dry matter intake$_{obs}$ (kg/day)	8.68	0.87	0.67*	0.62*	0.25
Dry matter intake (%BW)	1.91	0.15	0.82*	0.77*	0.20
Dry matter intake ($BW^{0.75}$)†	8.81	0.61	0.93*	0.87*	−0.07
Feed conversion ratio	8.03	1.64	0.28	0.28	
Gross feed efficiency	0.129	0.025	−0.32*	−0.29*	−0.97*
Residual feed intake$_1$ (kg DM/day)	0.00	0.58		0.93	0.28
Residual feed intake$_2$ (kg DM/day)	0.00	0.54	0.93		0.28

* Correlation coefficients are significantly different from zero ($P<0.05$).
† ($BW^{0.75}$ × DMI) / 100.

Table 4
Characterization of performance traits of Nellore young bulls with high, medium and low RFI_1.

Traits	RFI_1 group[1]			SEM[2]	P>F[3]
	High	Medium	Low		
Number of bulls	13	17	16		
Body weight (kg)	466	446	460	7.28	0.53
Body weight$^{0.75}$ (kg)	100	97	99	1.18	0.54
Average daily gain (kg/day)	1.22	1.15	1.16	0.03	0.67
Dry matter intake$_{obs}$ (kg/day)	9.56^a	8.50^b	8.15^b	0.13	<0.01
Dry matter intake (%BW)	2.06^a	1.92^b	1.78^c	0.02	<0.01
Dry matter intake (BW$^{0.75}$)†	9.54^a	8.79^b	8.22^c	0.09	<0.01
Gross feed efficiency	0.122	0.129	0.136	0.003	0.35
Feed conversion ratio	8.49	8.02	7.67	0.24	0.41
Residual feed intake (kg DM/day)	0.72^a	−0.01^b	−0.57^c	0.09	<0.01

[1]Least square means by Tukey–Kramer test within a row with different superscripts differ ($P<0.05$).
[2]Standard error of the mean.
[3]Error probability α.
† ($BW^{0.75} \times DMI$)/100.

that the RFI selects lower consumption animals without affecting ADG and the BW. The differences among low-, medium-, and high-RFI groups and other results observed in this study indicate that the RFI is phenotypically independent of body weight and the daily weight gain, because both compose the prediction model to estimate RFI. Probably the low correlations between RFI with GFE and FCR were the reason for the non-significant ($P>0.05$) differences among RFI groups.

When RFI was adjusted for the subcutaneous fat thickness over the *Biceps femoris* muscle, the most and the least efficient RFI_2 groups were different between themselves ($P<0.05$) for GFE, FCR and, as expected, DMI. These differences among RFI-groups are in agreement with other studies (Almeida et al., 2004; Basarab et al., 2003; Gomes 2009; Lancaster et al., 2009). The remaining characteristics of body size and performance did not differ ($P>0.05$) between groups because these variables are present in the RFI estimation model.

3.2. Carcass traits and feed efficiency

Means and standard deviations for the carcass traits and their correlations with RFI_1, RFI_2 and FCR are shown in Table 6. The ribeye area (initial, final and gain) traits were not phenotypically correlated ($P>0.05$) with RFI_1 and RFI_2 which agrees with Lancaster et al. (2009). These findings do not agree with Leme and Gomes' (2007) who found an association between RFI and REA in Zebu animals, with the more efficient animals showing larger ribeye areas. According to the present study, more efficient animals for RFI would not have lower lean meat yield in the carcass and therefore would not present any losses of the edible portion of the carcass. Higher ribeye areas are related to higher meat quantities in the carcass, which leads to lesser fixed costs of production.

In contrast, the correlations between FCR and the ribeye area (initial and gain) were significant ($P<0.05$), but the correlation direction was divergent for initial and gain traits. The negative correlation between FCR and the REA gain shows that the lower FCR (more efficient) the greater the gain in REA. The positive correlation between FCR and the initial REA can be explained by the fact that animals with higher initial weight are animals that were possibly in a more advanced stage of maturity, with lower deposition of muscle tissue hence the larger animals tend to have higher feed conversion (less efficient).

The RFI_1 was positively correlated ($P<0.05$) to the *Biceps femoris* subcutaneous fat thickness in the final evaluation (final RFT) and the gain in RFT, but this same trait measured at the beginning of the experiment was not related to RFI_1.

Table 5
Characterization of performance traits of Nellore young bulls with high, medium and low RFI_2.

Traits	RFI_2 group[1]			SEM[2]	P>F[3]
	High	Medium	Low		
Number of bulls	10	23	13		
Body weight (kg)	473	447	461	7.28	0.38
Body weight$^{0.75}$ (kg)	101	97	99	1.18	0.38
Average daily gain (kg/day)	1.14	1.19	1.17	0.03	0.81
Dry matter intake$_{obs}$ (kg/day)	9.60^a	8.55^b	8.20^b	0.13	<0.01
Dry matter intake (%BW)	2.04^a	1.92^b	1.79^c	0.02	<0.01
Dry matter intake (BW$^{0.75}$)†	9.49^a	8.81^b	8.26^c	0.09	<0.01
Gross feed efficiency	0.112^a	0.133^b	0.135^b	0.003	0.05
Feed conversion ratio	9.25^a	7.63^b	7.80^b	0.24	0.02
Residual feed intake (kg DM/day)	0.74^a	0.00^b	−0.56^c	0.09	<0.01

[1]Least square means by Tukey–Kramer test within a row with different superscripts differ ($P<0.05$).
[2]Standard error of the mean.
[3]Error probability α.
† ($BW^{0.75} \times DMI$)/100.

Table 6
Means and standard deviations of the carcass traits and their correlations with RFI (r_{RFI1} and r_{RFI2}) and FCR (r_{FCR}).

Traits	Mean	SD	r_{RFI1}	r_{RFI2}	r_{FCR}
Initial REA (cm^2)	49.70	5.02	−0.02	−0.05	0.32*
Final REA (cm^2)	71.37	5.84	0.09	0.03	−0.11
Gain REA (cm^2)	21.67	5.23	0.12	0.09	−0.43*
Initial BFT (mm)	1.69	0.53	0.17	0.11	0.31*
Final BFT (mm)	4.07	0.68	0.28	0.17	−0.11
Gain BFT (mm)	2.38	0.79	0.13	0.08	−0.31*
Initial RFT (mm)	1.95	0.47	0.09	−0.10	0.17
Final RFT (mm)	5.79	1.42	0.34*	0.00	0.13
Gain RFT (mm)	3.83	1.23	0.36*	0.04	0.08

REA — ribeye area, BFT — backfat thickness, RFT — rumpfat thickness.
* Correlation coefficients are significantly different from zero ($P<0.05$).

These positive correlations described above mean that more efficient animals (negative RFI) may have lower subcutaneous fat deposition in the carcass.

The analysis shows that the correlations of RFI_1 and RFI_2 with thickness of subcutaneous fat in *Longissimus* muscle were not significant at the beginning, and end of the experiment ($P>0.05$). This can be explained by the fact that fat tissue deposition follows simultaneously in the posterior–anterior and back–ventral directions (Batt, 1980), suggesting a higher variation between individuals for the rump fat deposit and a lower variation in the loin region.

Moreover, because the study was conducted with young Nellore bulls, the lower fat of *Longissimus* muscle is consistently lower than European-breed sires at the same age (Crouse et al., 1989). This variation can explain the fact that RFI_1 was only correlated with rump fat. For the same reasons, the two carcass fat traits evaluated at the beginning of the trial were not correlated to RFI_1, because the subcutaneous fat deposit was still too low (1.69 mm to the initial BFT and 1.95 mm to the initial RFT). However, FCR was negatively associated with BFT gain during the experiment, which means that the less efficient animals had lower fat deposition in the *Longissimus* muscle area.

The weak correlations estimated between RFI_1 and fat deposition in the *Longissimus* agree with the results from Almeida et al. (2004) and Carstens et al. (2002), but they disagree with the results obtained by Basarab et al. (2003) and Lancaster et al. (2009) who found genotypic and phenotypic correlations between these traits in *B. taurus* and Leme and Gomes (2007) who found significant differences for fat deposition in the *Longissimus* across RFI groups (high, medium and low) in Zebu animals.

Table 7
Carcass traits measured by ultrasound of Nellore bulls with high, medium and low RFI_1.

Traits	RFI_1 group[1]			SEM[2]	P>F[3]
	High	Medium	Low		
Initial REA (cm^2)	51.08	48.26	50.11	0.74	0.29
Final REA (cm^2)	72.49	70.98	70.87	0.86	0.72
Gain REA (cm^2)	21.41	22.72	20.76	0.77	0.56
Initial BFT (mm)	1.78	1.76	1.53	0.08	0.33
Final BFT (mm)	4.26	4.08	3.89	0.10	0.34
Gain BFT (mm)	2.48	2.32	2.36	0.12	0.87
Initial RFT (mm)	2.09	1.98	1.82	0.07	0.29
Final RFT (mm)	6.58[a]	5.71[ab]	5.23[b]	0.21	0.03
Gain RFT (mm)	4.48[a]	3.73[ab]	3.41[b]	0.18	0.05

REA — ribeye area, BFT — backfat thickness, RFT — rumpfat thickness.
[1]Least square means by Tukey–Kramer test within a row with different superscripts differ ($P<0.05$).
[2]Standard error of the mean.
[3]Error probability α.

Table 8
Carcass traits measured by ultrasound of Nellore bulls with high, medium and low RFI_2.

Traits	RFI_2 group[1]			SEM[2]	P>F[3]
	High	Medium	Low		
Initial REA (cm^2)	51.81[a]	47.87[b]	51.32[a]	0.74	0.04
Final REA (cm^2)	73.27	70.51	71.42	0.86	0.47
Gain REA (cm^2)	21.46	22.64	20.10	0.77	0.38
Initial BFT (mm)	1.88	1.59	1.70	0.08	0.36
Final BFT (mm)	4.39	3.97	3.98	0.10	0.23
Gain BFT (mm)	2.51	2.39	2.27	0.12	0.79
Initial RFT (mm)	2.00	1.89	2.04	0.07	0.62
Final RFT (mm)	6.02	5.55	6.02	0.21	0.54
Gain RFT (mm)	4.02	3.67	3.98	0.18	0.66

REA — ribeye area, BFT — backfat thickness, RFT — rumpfat thickness.
[1]Least square means by Tukey–Kramer test within a row with different superscripts differ ($P<0.05$).
[2]Standard error of the mean.
[3]Error probability α.

Most available data indicate that RFI is positively correlated with rate of fat deposition in the carcass and this was confirmed in this study, where more efficient animals (negative RFI) had a lower fat deposition in the carcass (Lancaster et al., 2009). The phenotypic correlation found in this study is in agreement with Carstens et al. (2002) who found genetic and phenotypic correlations between RFI and fat thickness in the *Biceps femoris* in *B. taurus* breeds. Likewise, such differences were also observed between RFI_1 groups (Table 7), in which the low RFI group (more efficient) had lower final RFT and gain in RFT when compared with high RFI animals (less efficient).

No difference between RFI_2 groups for the fat deposition traits was observed when adjusting the prediction model with the inclusion of the carcass fat RFT trait. A lower initial REA estimate in the medium group was only noticed, as presented in Table 8.

From the data presented in Table 7 it can be stated that the most efficient animals (low RFI_1) had final subcutaneous fat deposition in the *Biceps femoris* muscle 1.35 mm lower and they had gained 1.07 mm less in RFT than the least efficient animals (high RFI_1).

3.3. Implications

The subcutaneous fat of Zebu breeds is fundamental to the Brazilian beef production systems based on grazing. Steers with lower subcutaneous fat deposition in the carcass, theoretically will reach required fat deposition later, so they should remain on feed for a longer time which can lead to higher production costs (Leme and Gomes, 2007).

Moreover, the subcutaneous fat works as a thermal shield to the *rigor mortis* of the carcass cooling. When the subcutaneous fat is scarce, muscle temperature quickly cools down due to the lack of thermal shielding, the muscle fibers contract fast due to the depletion of adenosine triphosphate (glycolysis), leading to *cold-shortening*, which is characterized by dark, firm, and dry (DFD) meat (Sainz and Araujo, 2002). In this process, the sarcomere reduces its size, keeping a compact structure and generating meat hardening of slaughtered animals, causing serious economic losses to the beef industry. Brazilian slaughterhouses are penalized when carcasses are too thin due to reduced beef quality.

By analyzing the correlations obtained in the present study, the suggested model is to adjust the DMI_{est} including the *Biceps femoris* subcutaneous fat thickness in the final evaluation (RFTf), although it improves the multiple regressions R^2, but it is also shown that the RFI correlation with the adjustment is not significant for any carcass trait and the different RFI groups are not different between themselves for these carcass traits. Thus, the above described consequences would not limit the adoption of RFI as a selection trait in breeding programs. However, it is still fundamental to study the genotypic correlations after RFI selection with the objective of verifying whether the correlations behave similarly as this current study.

The correlations between traditional RFI and *Biceps femoris* muscle fat thickness are positive and significant and, therefore, when selecting animals with lower RFI (more efficient) it is possible to choose individuals that have lower subcutaneous fat deposition. For this reason it is suggested that the dry matter intake prediction model includes traits such as subcutaneous fat deposition in order to adjust the intake according to body composition.

Conflict of interest statement

The authors have nothing to disclose regarding relationships that could be viewed as a potential conflict of interests.

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References

Almeida, R., 2005. Consumo e eficiência alimentar de bovinos em crescimento. 181p. Tese (Doutorado), - Escola Superior de Agricultura "Luiz de Queiroz" /Universidade de São Paulo, Piracicaba-SP.

Almeida, R., Lanna, D.P.D., Leme, P.R., 2004. Consumo alimentar residual: um novo parâmetro para avaliar a eficiência alimentar de bovinos de corte. Reunião Anual da Sociedade Brasileira de Zootecnia, Anais…, 41, pp. 03–14.

Arthur, P.F., Archer, J.A., Johnston, D.J., 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.

Basarab, J.A., Price, M.A., Aalhus, J.L., Okine, E.K., Snelling, W.M., Lyle, K.L., 2003. Residual feed intake and body composition in young growing cattle. Can. J. Anim. Sci. 83, 189–204.

Batt, R.A.L., 1980. Studies in Biology no. 116. Influences on Animal Grown and Development. Camelot Press, London.

Carstens, G.E., Theis, C.M., White, M.B., Welsh Jr., T.H., Warrington, B.G., Miller, R.K. Randel, R.D., Forbes, T.D., Lippke, H., Greene, L.W., Lunt, D.K., 2002. Relationships between net feed intake and ultrasound measures of carcass composition in growing beef steers. Beef Cattle Research in Texas. Nutrition. P. 31–34.

Crouse, J.D., Cundiff, L.V., Koch, R.M., Koohmaraie, M., Seideman, S.C., 1989. Comparisons of *Bos indicus* and *Bos taurus* inheritance for carcass beef characteristics and meat palatability. J. Anim. Sci. 67, 2661–2668.

Gomes, R.C. Metabolismo proteico, composição corporal, características de carcaça e qualidade de carne de novilhos Nelore (*Bos indicus*) em função de seu consumo alimentar residual. 2009. 93 f. Tese (Doutorado) - Faculdade de Zootecnia e Engenharia de Alimentos, Universidade de São Paulo, Pirassununga.

Koch, R.M., Swiger, L.A., Chambers, D., Gregory, K.E., 1963. Efficiency of feed use in beef cattle. J. Anim. Sci. 22, 486–494.

Lancaster, P.A., Carstens, G.E., Crews Jr., D.H., Welsh Jr., T.H., Forbes, T.D.A., Forrest, D.W., Tedeschi, L.O., Randel, R.D., Rouquette, F.M., 2009. Phenotypic and genetic relationships of residual feed intake with performance and ultrasound carcass traits in Brangus heifers. J. Anim. Sci. 87, 3887–3896.

Lanna, D.P.D., Almeida, R., 2004. Exigências nutricionais e melhoramento genético para eficiência alimentar: experiências e lições para um projeto nacional. Reunião Anual da Sociedade Brasileira de Zootecnia, Anais…, 41, pp. 248–259.

Leme, P.R., Gomes, R.C., 2007. Características de carcaça de novilhos Nelore com diferente consumo alimentar residual. XX Reunión Asociación Latinoamericana de Producción Animal (ALPA). Anais da XX Reunión Asociación Latinoamericana de Producion Animal (ALPA), Cuzco, Perú.

National Research Council, 2001. Nutrient Requirements of Dairy Cattle, 7th rev. ed. Natl. Acad. Sci., Washington, D.C.

Richardson, E.C., Herd, R.M., 2004. Biological basis for variation in residual feed intake in beef cattle. 2. Synthesis of results following divergent selection. Aust. J. Exp. Agric. 44, 431–440.

Richardson, E.C., Herd, R.M., Archer, J.A., Arthur, P.F., 2004. Metabolic differences in Angus steers divergently selected for residual feed intake. Aust. J. Exp. Agric. 44, 441–452.

Sainz, R.D., Araujo, F.R.C., 2002. Uso de tecnologias de ultra-som no melhoramento do produto final carne. Anais…, 5° Congresso Brasileiro das Raças Zebuínas, Uberaba.

SAS Institute Inc., 1998. SAS/STAT ® 7.0 User's Guide Release. SAS Institute Inc., Cary, NC.

Weiss, W.P., Conrad, H.R., Pierre, N.R. St, 1992. A theoretical-based model for predicting total digestible nutrient values of forages and concentrates. Anim. Feed Sci. Technol. 57, 717–726.