

Maintenance energy requirements and support metabolism in tropical beef cattle: a meta-analysis of gender and genotype interactions

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ABSTRACT: Energy-demanding processes in animal production rise in tandem with increased nutritional intake. This meta-analysis aimed to quantify the metabolizable energy (ME) requirements for maintenance (kME_m) and metabolizable energy to support metabolism (HiEv), considering genotype and gender, in beef cattle under tropical conditions. A total of 273 individual records of comparative slaughter from seven studies (theses and dissertations) grouped by animal gender (intact males and castrated males), and genotype (Nellore or crossbred) were used in the current study. We estimated kME_m and HiEv based on the independent variables' ME intake and full body weight (FBW). The meta-analysis showed no effect of genotype on kME_m ($p = 0.66$). However, intact males exhibited a 34.41 % lower kME_m compared to castrated males ($p = 0.01$). Crossbred steers had a 61.33 % higher HiEv than Nellore steers ($p < 0.001$). Similarly, intact males had a 41.07 % higher energy support demand ($p = 0.05$) than castrated males. In addition, we observed positive correlations (medium to high) between body protein ($r = 0.67$; $p > 0.001$), body fat ($r = 0.59$; $p > 0.001$), and retained energy ($r = 0.71$; $p > 0.001$) and HiEv. Thus, the greater the deposition of protein (mainly), fat, and body energy, the greater the HiEv. In conclusion, the genotype of the animals did not affect the kME_m. Intact males had lower HiEv than castrated males. Both Nellore steers and intact males utilized HiEv more.

Keywords: gender, genetic, nutrient partitioning

Introduction

The transformation of food energy into animal products, as in any other energy transformation system, cannot occur without energy loss, since food energy is used for maintenance and production (Blaxter, 1966; Henrique et al., 2005). Losses observed in energy transformation processes must be addressed, especially those arising from heat energy (HE) (NRC, 1981; Baldwin, 1995). The heat produced by ruminant animals is created by chemical reactions in the animal's body, through fermentation in the digestive system, especially in the rumen (Kleiber, 1961; Czerkawski, 1980; van Lingem et al., 2016). However, partitioning HE into its metabolic components remains a complex aspect of feeding systems (NRC, 1981; NASEM, 2016). The definition of HE or metabolizable energy (ME) to support metabolism (HiEv) is the combination of heat emanating from product formation, digestion, absorption, and assimilation, waste formation and excretion, supplemented by heat from fermentation (NRC, 1981).

Processes that demand large amounts of energy (digestion, circulation, secretion, maintenance of concentration gradients, muscle tone, and dynamics of tissue renewal) are increased in animals in production (e.g., growth and lactating animals), to align with the increased nutritional plane (Turner and Taylor, 1983). The result of these increases was mainly an elevation of vital functions in the animal. The costs directly involved in tissue synthesis are inseparable aspects

of a single dynamic pool that cannot be partitioned (Armstrong and Blaxter, 1984).

Genetic and environmental factors, along with breed, gender, and castration status, affect cattle's maintenance energy requirements, with *Bos indicus* (Linnaeus, 1758) requiring 10 % less energy than *Bos taurus* (Linnaeus, 1758) (NRC, 1981). Castration impacts growth, carcass composition, and feed efficiency, and emphasizes the role of these factors in determining energy requirements and feed efficiency (Berg and Butterfield, 1976; ARC, 1980).

Thus, this study hypothesizes that metabolic support is correlated with the steers' genotype and gender. Thus, this meta-analysis aimed to quantify the metabolizable energy requirements for maintenance (kME_m) and HiEv, considering genotype and gender, in beef cattle under tropical conditions.

Materials and Methods

Data acquisition and selection

The database was acquired through searches for the keywords "body composition; gender; metabolizable energy intake (MEI); metabolizable energy for maintenance (MEM); Nellore; steers". The search was conducted in the Dissertations and Theses repository of the Universidade Federal de Viçosa LOCUS (<https://locus.ufv.br/handle/123456789/1>). The studies used in the meta-analysis are presented in Table 1.

The inclusion and exclusion criteria followed the guidelines established by Lean et al. (2014). To be included in this meta-analysis, studies had to meet the following criteria: 1) be comparative slaughter studies with animals maintained at a maintenance level (in this analysis, animals at maintenance level were considered as the baseline group, while others were classified as treatment), 2) clearly describe the comparability of treatment groups at the baseline of each trial, 3) provide actual measurements of the variables of interest for the meta-analysis, and 4) provide the sample size and variability of pertinent measures (e.g., standard deviation) for both the treatment and control groups. The variables of interest in meta-analysis include the kMEM (kJ kg⁻¹ full body weight [FBW]) and ME used for metabolic support (HiEv, MJ d⁻¹).

A total of eight studies (dissertations and theses) published between 2001 and 2010 were identified. However, seven studies (comprising 273 individual data points) met most of the selection

criteria, depending on the specific variable, and were included in the final database (Tables 1 and 2). The final dataset contained information on FBW (kg), MEI (MJ kg⁻¹ dry matter), body protein (kg), body fat (kg), retained energy (MJ), sample size (N), means, minimum and maximum values (data depth) for the groups, measures of variability (standard deviation), and skewness and kurtosis (measure of distribution of the dataset). The remaining studies were excluded because of they had insufficient replicates for the relevant variables.

Calculations

Maintenance Requirement Estimates

The definition of MEM is the amount of ME that maintains heat production without variation (loss or gain) in body composition in the animal that is in equilibrium regarding FBW (Williams and Jenkins, 2003). Based on this definition of MEM, we used data

Table 1 – Studies used in meta-analysis.

Study	Author/Year	Phase	Breed or crossbreed	Gender	Treatments
1	Silva (2001)	Steers and Bulls	Nellore	intact male	Levels of protein in diet (15 and 18 %) and levels of concentrate (0, 20, 40, 60, and 80 %)
2	Paulino (2002)	Steers	Nellore unselected	castrated male	Levels of concentrate (5, 35, and 65 %)
3	Moraes (2006)	Steers	Nellore unselected	intact male	Different supplementation strategy
4	Veloso (2001)	Steers	Nellore × Limousin	intact male	Levels of concentrate (25, 37.5, 50, 62.5, and 75 %)
5	Marcondes (2007)	Steers	Nellore	intact male; castrated male	Levels of concentrate (1 and 1.25 % body weight)
6	Chizzotti (2007)	Steers	Nellore × Red Angus	intact male; castrated	Levels of concentrate (0.75 and 1.5 % body weight)
7	Marcondes (2010)	Steers	Nellore; Nellore × Angus; Nellore × Simmental	castrated male	Levels of concentrate (1 and 2 % body weight)

Table 2 – Descriptive statistics of data used in meta-analysis.

Variable		Number of animals	Mean	Median	Standard deviation	Minimum	Maximum	Skewness	Kurtosis
General									
FBW (kg)		192	404	406	83	210	548	-0.31	-1.04
kMEM (kJ kg ⁻¹ BW)		192	177	178	47	82	336	0.19	-0.53
HiEv (MJ d ⁻¹)		190	15891	16548	5884	4372	27717	-0.28	-1.17
Genotype									
FBW (kg)	Nellore	97	357	357	61	210	484	-0.23	-0.57
	Crossbred	95	452	484	75	248	548	-1.35	0.66
kMEM (kJ kg ⁻¹ BW)	Nellore	97	192	201	46	82	336	-0.08	0.05
	Crossbred	95	161	151	42	94	250	0.40	-1.03
HiEv (MJ d ⁻¹)	Nellore	95	13545	12756	5276	4372	27717	0.42	-0.36
	Crossbred	95	18236	20548	5537	5019	25494	-1.16	-0.03
Gender									
FBW (kg)	Male	108	404.17	423	86.44	210.01	515.29	-0.38	-1.22
	Castrated	84	403.7	404.25	78.5	233.5	548	-0.18	-0.81
kMEM (kJ kg ⁻¹ BW)	Male	108	168.12	158.95	48.02	81.86	336.31	0.77	0.42
	Castrated	84	187.89	202.38	42.52	110.2	250.2	-0.64	-0.97
HiEv (MJ d ⁻¹)	Male	106	15781.16	16385.3	5862.69	4372.41	27716.77	-0.22	-1.27
	Castrated	84	16029.18	16600.47	5944.04	4778.76	25493.92	-0.36	-1.08

FBW = final full body weight; kMEM = metabolizable energy requirements for maintenance; BW = body weight; HiEv = metabolizable energy used for support metabolism. Crossbred utilized were: Nellore unselected; Nellore × Limousin; Nellore × Red Angus; Nellore × Angus; Nellore × Simmental.

from FBW and ME intake in this study to estimate the kME_m through Eq. (1):

$$kME_m = MEI / FBW \quad (1)$$

where kME_m represents the ME requirement for maintenance (kJ kg^{-1} FBW), MEI, the ME intake (MJ d^{-1}), and FBW, the full body weight.

Heat Production of Metabolic Support

Fasting metabolism (FPH) was calculated according to the equation described by ARC (1980):

$$FPH = C1 \times (0.53 \times [FBW / 1.08]^{0.67}) \quad (2)$$

where FPH is the fasting metabolism (MJ d^{-1}), FBW, the full body weight and C1, a constant based on the type of animal (1.15 for bulls and 1.0 for other cattle).

Maintenance multiples (MM) were calculated as a function of MEI and FPH according to Williams and Jenkins (2003):

$$MM = MEI / FPH \quad (3)$$

where MM is the maintenance multiples, MEI, the ME intake (MJ d^{-1}) and FPH, the fasting metabolism (MJ d^{-1}).

The ME estimate requirement for metabolic support by multiple ME intake was calculated according to Eq. (4):

$$kH_iE_v = FPH / (MM - 1) \quad (4)$$

where kH_iE_v is the ME requirement for support metabolism per multiple of ME intake (MJ kg^{-1} FBW), FPH is the fasting metabolism (MJ d^{-1}) and MM is the maintenance multiples.

The ME used for metabolic support was estimated according to Williams and Jenkins (2003):

$$H_iE_v = kH_iE_v \times (MM - 1) \times FBW \quad (5)$$

where H_iE_v is ME used for metabolic support (H_iE_v , MJ d^{-1}), kH_iE_v is the ME requirement for support metabolism per multiple of ME intake (MJ kg^{-1} FBW) and FBW the full body weight.

Meta-analytical procedure

Effect size was estimated in the meta-analysis using the standardized mean difference (SMD). This index quantifies the contrast between the treatment and control groups after adjusting for differences in their means and standard deviations. The SMD was calculated according to the procedure of Hedges (1981) for fixed effects, and that of DerSimonian and Laird (1986) for random effects. In addition to the

SMD, the raw mean difference (RMD) was obtained. This measure represents the direct difference between the treatment and control groups as described by Appuhamy et al. (2013).

The results of RMD for ME requirements relating to maintenance and metabolic support of steers were summarized in a forest plot. Each study included in the analysis was represented by a point on the plot, accompanied by its confidence interval. The pooled estimate of the effect size was also presented with its confidence interval. In this graphical representation, the relative contribution of each study to the combined effect size estimate was indicated by the size of the point, with larger points indicating greater weight. Thus, the forest plot simultaneously displayed the individual and overall effect sizes, as well as the weighted contributions of each study under both fixed- and random-effects models.

A random-effects meta-analysis was applied to estimate the variance between studies using a moment-based procedure, as described by DerSimonian and Laird (1986). This method assumes that the true effect size in each study (θ_i) can be expressed as:

$$\theta_i = \mu + \vartheta_i$$

where θ_i is the true effect size (RMD) in the i -th study, μ corresponds to the overall effect size, and ϑ_i is the deviation of each study from μ . The deviation is assumed to follow a normal distribution with mean zero and variance τ^2 [$\vartheta_i \sim N(0, \tau^2)$], which is unknown and estimated from the data. Consequently, the distribution of true effects was considered normal, with mean μ and variance τ^2 . The degree of heterogeneity (τ^2) was quantified using the I^2 statistic, which expresses the percentage of the total variation attributable to τ^2 and the sample variance.

When heterogeneity was substantial ($I^2 > 50\%$), models were constructed to investigate potential sources of variability. Following the methodology described by Appuhamy et al. (2013) and implemented in the 'metafor' package, meta-regression was performed. This approach assessed whether specific covariates explained part of the heterogeneity in treatment effects. Under fixed-effect analysis, a common effect was estimated, whereas random-effect analysis provided the mean of a distribution of effects. For significant covariates, bubble plots were created to illustrate the outcomes of the meta-regression. In this study, genetic group and gender were defined a priori as possible sources of variation in treatment response.

To evaluate publication bias, funnel plots were constructed. These plots visually represent the relationship between study size and the precision of the estimated effect. Smaller studies tended to show greater variability, whereas larger studies showed less variance. In the absence of publication bias, the funnel plot is expected to show approximate symmetry.

All statistical procedures for the meta-analysis were performed using the 'meta' package (version 4.6-0; Schwarzer, 2016) in R software (version 3.3.1). Additionally, Pearson correlation coefficients were calculated using PROC CORR in SAS to determine the strength of linear relationships between HiEv and body protein, body fat, and energy retention.

Results

In this study, we used the funnel plot to measure the accuracy of estimating the treatment effect and observed a slight right-sided asymmetry ($p < 0.001$) in the observed variables (Figure 1).

The meta-analysis showed no effect of genotype on kMEM ($p = 0.66$). Additionally, intact males exhibited a 34.41 % lower kMEM compared to castrated males [4.86 / 7.41] ($p = 0.01$) (Table 3). In terms of HiEv, crossbred steers had a 61.33 % greater energy support demand than Nellore steers ($p < 0.001$). Similarly, intact males had a 41.07 % higher energy support demand ($p = 0.05$) than castrated males (Table 3).

The forest plot shown in Figure 2A reveals a significant effect ($p = 0.01$) of intact males on kMEM. In contrast, Figure 2B shows no significant effect ($p = 0.66$) of Nellore steers vs. crossbred animals on kMEM. Analyzing Figure 3A, we observed that intact males exhibit a similar pattern for HiEv ($p = 0.05$) as they do for kMEM. However, crossbred steers show a significant effect ($p < 0.001$) compared to Nellore steers (Figure 3B).

To help explain the heterogeneity, we conducted a meta-regression analysis. Three exploratory variables were considered: genotype, gender, and FBW. The results indicated that intact animals had a lower kMEM ($-2.68 \text{ kJ kg}^{-1} \text{ body weight [BW]}$)

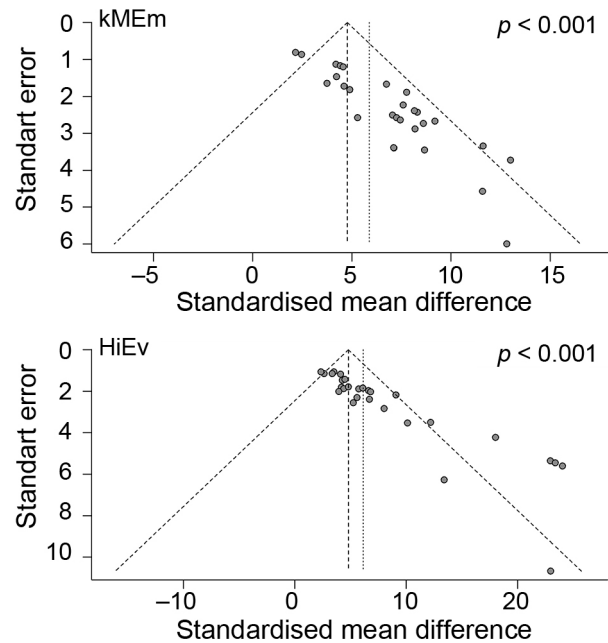


Figure 1 – Funnel plot of the effect of genetic group and gender on metabolizable energy requirements for maintenance (kMEM) and ME used for support metabolism (HiEv). Each point represents an individual randomized trial. The y-axis shows the standard error of the trials, while the x-axis represents the effect size. The dotted line indicates the weighted mean of effect sizes, and the dashed line represents the null effect line. Larger studies tend to cluster near the mean effect size at the top of the plot, whereas smaller studies appear towards the bottom. Study size is determined by their standard errors, as smaller studies have greater sampling error and greater variability in effect sizes. When publication bias occurs, asymmetry is expected, with more small studies showing positive results than negative ones. SMD = standardized mean difference.

Table 3 – Effect of gender and genotype on metabolizable energy requirement for maintenance (kMEM) and metabolizable energy used for support metabolism (HiEv) in steers.

Variables	n	Control (SD)	Means	RMD	ES	p-value	I^2	
kMEM (kJ kg⁻¹ BW)								
Genotype	Nellore	15	126	(9.95)	5.62	0	56 %	
	Crossbred	13	109	(3.48)	6.06	3.91	14 %	
	Total	28	118	(6.95)	5.87	1.33	48 %	
Gender	Male	15	111	(8.82)	4.86	0.72	44 %	
	Castrated	13	126	(4.78)	7.41	0.31	12 %	
	Total	28	118	(6.94)	5.87	1.09	0.01	48 %
HiEv (MJ d⁻¹)								
Genotype	Nellore	15	6479	(771.78)	4.04	1.54	0.45	0 %
	Crossbred	13	7833	(709.31)	11.38	0.29	0.01	74 %
	Total	28	7107	(742.78)	6.15	1.09	< 0.001	65 %
Gender	Male	15	6809	(784.73)	8.62	3.99	< 0.001	78 %
	Castrated	13	7451	(694.38)	5.08	0	0.32	12 %
	Total	28	7107	(742.78)	6.15	1.33	0.05	65 %

n = number of trials; SD = standard deviation; RMD = raw mean difference; ES = effect size; I^2 = statistic of estimated heterogeneity; BW = body weight. Crossbred utilized were: NeUn = Nellore unselected; NeLim = Nellore × Limousin; NeRed = Nellore × Red Angus; NeAng = Nellore × Angus; NeSim = Nellore × Simmental.

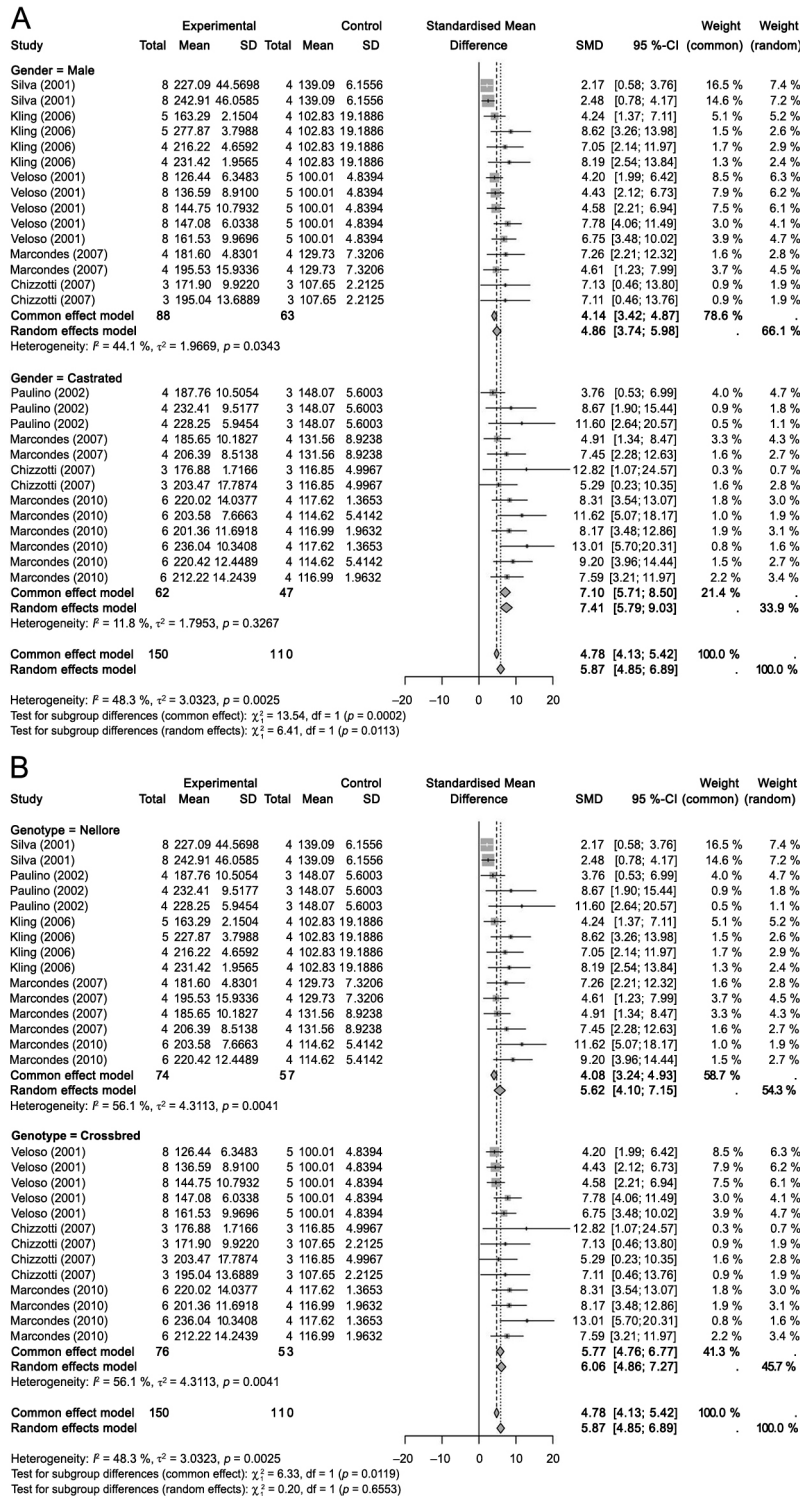


Figure 2 – Forest plot of the effect of A) gender and B) genetic group on metabolizable energy requirements for maintenance. The solid line along the x-axis represents the no-effect line, while the dotted lines show the estimated differences between the fixed and random models. Points to the left of the line indicate a reduction in the trait, while points to the right indicate an increase. Each square reflects the relative weight of a study in the overall estimate of effect size, with larger squares representing greater weight. The upper and lower edges of the squares indicate the 95 % confidence intervals for the effect size. The diamond at the bottom represents the 95 % confidence interval for the overall global estimate. SD = standard deviation; SMD = standardized mean difference; CI = confidence interval; I^2 = statistic of the estimated heterogeneity; τ^2 = degree of heterogeneity; df = degree of freedom.

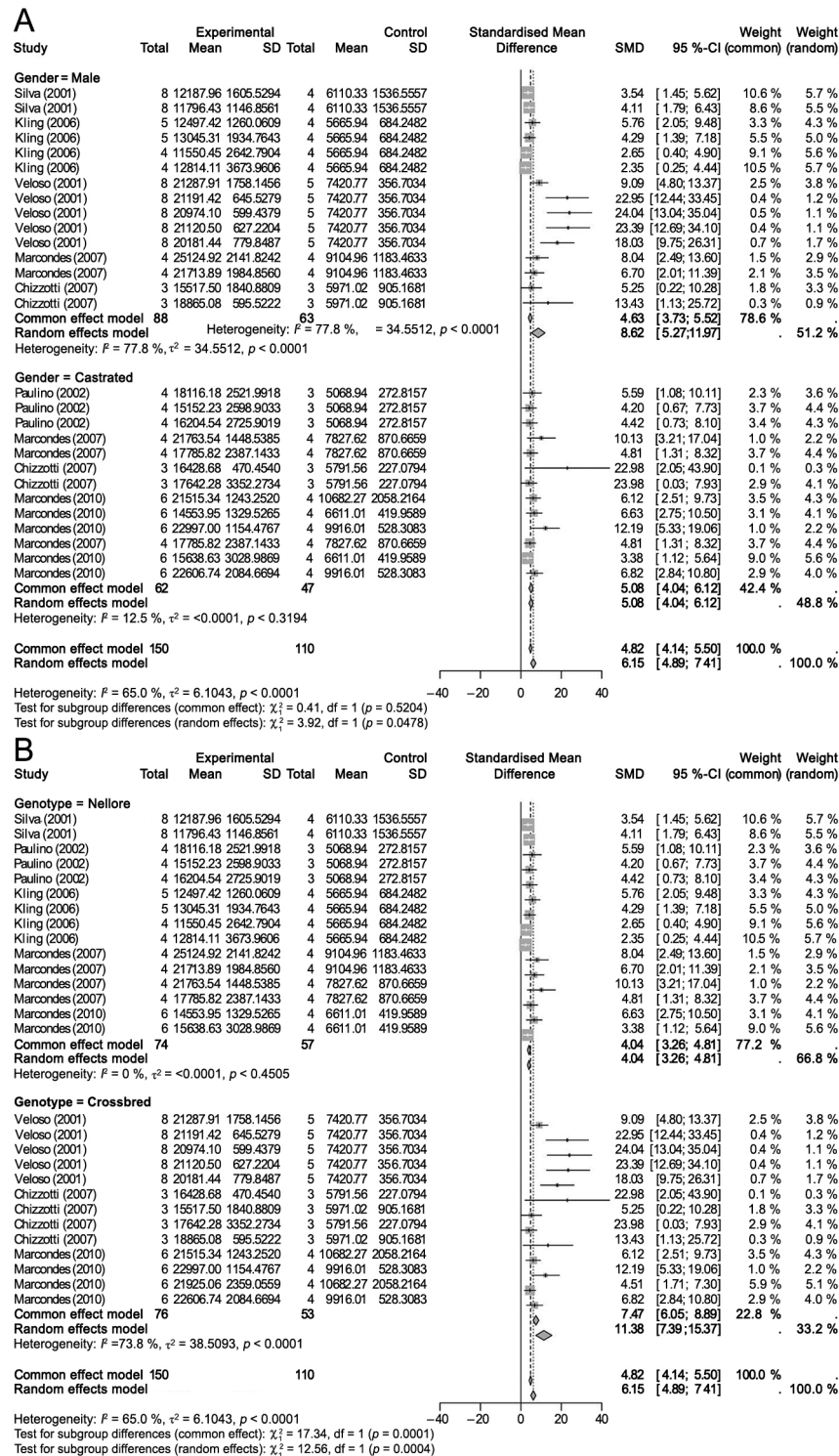


Figure 3 – Forest plot of the effect of A) gender and B) genetic group on metabolizable energy used for support metabolism. The solid line along the x-axis represents the no-effect line, while the dotted lines show the estimated differences between fixed and random models. Points to the left of the line indicate a reduction in the trait, while points to the right indicate an increase. Each square reflects the relative weight of a study in the overall estimate of effect size, with larger squares representing greater weight. The upper and lower edges of the squares indicate the 95 % confidence intervals for the effect size. The diamond at the bottom represents the 95 % confidence interval for the overall global estimate. SD = standard deviation; SMD = standardized mean difference; CI = confidence interval; I^2 = statistic of the estimated heterogeneity; τ^2 = degree of heterogeneity; df = degree of freedom.

compared to castrated animals, with heterogeneity reduced to zero (Table 4). The heterogeneity of 44 % accounts for the variation among studies within intact male group (Table 3). We also observed that kMEM increased with FBW at a rate of 0.035 kg (Table 4). As regards HiEv, Nellore steers demonstrated a lower energy demand (-3.98 MJ d^{-1}) compared to crossbred steers, with heterogeneity reduced to 45.2 (Table 4). The heterogeneity of 74 % accounts for the variation in studies within the group of crossbred steers (Table 3).

In addition, when analyzing correlations, we observed positive correlation correlations (medium to high) between body protein ($r = 0.67$; $p > 0.001$), body fat ($r = 0.59$; $p > 0.001$) and retained energy ($r = 0.71$; $p > 0.001$) with HiEv. However, the correlation between HiEv and MEI was low ($r = 0.18$; $p = 0.01$). Thus, the greater the deposition of protein (mainly), fat, and body energy, the greater the HiEv (Figure 4).

Discussion

The funnel plot showed a slight right-sided asymmetry (publishing studies with positive, significant results), which can indicate publication bias, according to Sterne et al. (2011). However, other possible explanations should be considered, such as funnel plot asymmetry, which may also result from between-study heterogeneity or methodological heterogeneity (Chamberlain et al., 2011).

The kMEM is influenced by several factors related to the animal, such as production level,

breed, body composition, gender, size, visceral organ mass, physiological state, health status, activity, and environment (Ferrell and Jenkins 1985; NASEM, 2016).

In this study, we observed that kMEM varied by animal gender (Table 3). This variation is related to the fact that intact males produce hormones such as testosterone, which can influence muscle growth and nutrient utilization efficiency, thereby improving metabolic efficiency (Wicks et al., 2019). Consequently, this leads to a greater proportion of muscle relative to fat, which can result in a lower energy requirement for maintenance, as active muscles consume more energy (support metabolism) (Wicks et al., 2019; Oliveira et al., 2021). Our study corroborates this finding, as intact males had a lower kMEM; however, HiEv was higher than in castrated animals (Table 3). Muscle and adipose tissues require an average of 21 % (15 to 26 %) of total energy (Caton et al., 2000; García-Aguilar et al., 2019). This energy is utilized to transport ions, proteins, renewal, and cell proliferation. These events are considered essential to regulating the energy in the metabolism of these tissues. The organs and viscera require about 55 % (45 to 65 %) of the total energy (Reynolds et al., 1991). Furthermore, we observed that kMEM is directly related to BW (Table 4). Heavier animals generally have a greater basal metabolic rate, meaning they require more energy to maintain basic body functions such as respiration, circulation, and temperature regulation (NRC, 1981).

Extra energy (ME used for support metabolism) can be utilized, and this caloric increase can be

Table 4 – Parameters of the meta-regression procedure with the outcome variables and raw mean difference in steers.

Item	β					Best Model		
	Genotype		Gender		FBW	I^2	R^2	AICc
	Nellore	Crossbred	Male	Castrated				
kMEM (kJ kg ⁻¹ BW)	-	-	-2.68*	-	0.035*	0.0	100	121.97
HiEv (MJ d ⁻¹)	-3.98*	-	-	-	-	45.2	53	158.47

β = meta-regression parameters; FBW = full body weight; I^2 = statistic of estimated heterogeneity; R^2 = coefficient of determination; AICc = corrected Akaike information criterion; kMEM = metabolizable energy requirements for maintenance; BW = body weight; HiEv = metabolizable energy used for support metabolism. Crossbred utilized were: Nellore unselected; Nellore \times Limousin; Nellore \times Red Angus; Nellore \times Angus; Nellore \times Simmental. * $p < 0.001$.

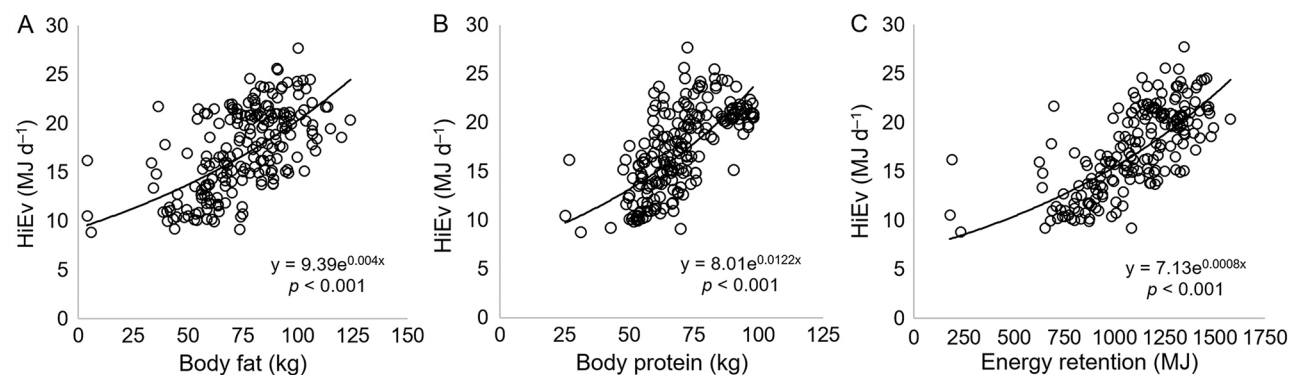


Figure 4 – Metabolizable energy to support metabolism (HiEv, MJ d⁻¹) in A) relationship with body fat, B) body protein, and C) energy retention.

attributed to the requirements of productive functions (e.g., tissue deposition) and energy expenditure processes that are not part of the pathways related to production (e.g., blood flow) (Williams and Jenkins, 2003). The primary source of heat increment is the metabolism of absorbed nutrients. The heat increment is not the heat produced when nutrients are metabolized (Blaxter, 1966; Kleiber, 1961; Ellis et al., 2006). It is, in fact, the difference between the utilization of absorbed nutrients and the utilization of stored nutrients for body functions, e.g., tissue deposition. Our study corroborates this finding because the increased deposition of fat (Figure 4A), protein (Figure 4B), and retained body energy (Figure 4C) are linked to increased HiEv. This fact explains the greater HiEv in crossbred steers (Tables 3 and 4).

In summary, the energy requirement for maintenance and the ME used to support metabolism can be influenced by several factors, as mentioned above. Although there are numerous studies evidencing this fact, the old and current models (AFRC (1993); CSIRO (2007); Valadares Filho (2016); NASEM (2016); INRA (2018)) were basically created from body weight or metabolic body weight ($BW^{0.75}$) to estimate kMEM, disregarding the multifactorial nature of kMEM and, consequently, HiEv.

The genotype of the animals did not affect the requirement for MEM. However, intact males had a lower kMEM compared to castrated males. Both Nellore steers and intact males utilized HiEv more.

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Conflict of interest

The authors declare that they have no financial, personal, or other relationships with individuals or organizations that could inappropriately influence or bias the research content.

Data availability statement

The entire dataset supporting the results is available upon request from the corresponding author.

Declaration of use of AI technologies

The authors declare that no AI technologies were used in the production of this paper.

Authors' Contributions

Conceptualization: Oliveira TS. **Data curation:** Muñeton LPG, Oliveira TS. **Formal analysis:** Oliveira TS, Muñeton LPG, Angeles-Hernandez JC. **Investigation:** Oliveira TS, Muñeton LPG, Angeles-Hernandez JC. **Methodology:** Meirelles Junior JR, Mozelli Filho E JL, Silva IN, Lima MT. **Writing-original draft:** Aniceto ES, Oliveira TS. **Writing-review & editing:** Oliveira TS, Angeles-Hernandez JC.

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