UNIVERSIDADE FEDERAL DE LAVRAS

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EXIGÊNCIAS NUTRICIONAIS E ESTUDO DA RELAÇÃO ENTRE A TERMOGRAFIA INFRAVERMELHA E A PRODUÇÃO DE CALOR DE TOUROS ANGUS E NELORE

LAVRAS - MG

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Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Zootecnia, área de concentração em produção e nutrição de ruminantes, para obtenção do título de Doutor.

Orientador

Dr. Mario Luiz Chizzotti

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OBRIGADO

RESUMO

Trinta e dois animais com peso corporal (PC) inicial de 380 ± 5,2 kg foram usados para se estudar as exigências nutricionais e a relação entre a termografia infravermelha e a produção de calor novilhos não-castrados da raça Nelore e Angus, usando a técnica do abate comparativo. Quatro animais de raça foram abatidos no início do experimento, para se estimar a composição corporal inicial dos demais. Os animais restantes foram alojados em baias individuais, onde oito animais de cada raça foram alimentados *ad libitum* com uma dieta de relação silagem:concentrado de 30:70 (300 g/kg de silagem e 700 g/kg de um concentrado à base de milho e farelo de soja, com base na MS). Outros 4 animais de cada raça foram alimentados com esta mesma dieta, porém com uma restrição alimentar de 55%, com base no consumo de matéria seca médio, ajustado para peso corporal metabólico dos animais que receberam a dieta sem restrição. O consumo foi medido diariamente e um ensaio de metabolismo foi realizado com a coleta total de fezes e urina. Estes dados foram usados para se estimar o consumo de energia metabolizável. Após 25, 50 e 75 dias, do início do experimento, fotografias em infravermelho foram tomadas da cabeça dos animais alimentados *ad libitum,* para se registrar as temperaturas da pele e superfície ocular. Após 84 dias de confinamento, os animais foram abatidos e a retenção de energia e a produção de calor foram calculadas. A análise estatística foi realizada, utilizando-se o pacote estatístico SAS. O cálculo das exigências foi feito utilizando-se os procedimentos GLM e NLIN. A relação entre a termografia infravermelha e a produção de calor foi estudada utilizando-se os procedimentos MIXED e REG, adotando-se nível de significância de 0,05. A exigência de energia líquida para mantença foi diferente entre touros Angus e Nelore: 98 versus 76 kcal/kg PC vazio$^{0,75}\cdot d^{-1}$, quando calculadas pelo modelo logaritmo e 100 versus 80 kcal/kg PC vazio$^{0,75}\cdot d^{-1}$, quando calculadas pelo modelo não linear. Não houve diferença entre as raças nas exigências nutricionais para o crescimento. Foram encontradas correlações significativas ($P \leq 0,005$) entre a produção de calor diária e as temperaturas da pele e superfície ocular ($r \geq 0,65$), registradas no 50º dia. Os resultados deste estudo reforçam que touros zebuínos possuem menores exigências líquidas para mantença que animais taurinos e que a termografia infravermelha é uma técnica com potencial uso nas estimativas de produção de calor de bovinos.

Palavras-chave: Angus. Energia. Exigências nutricionais. Nelore. Termografia infravermelha.

ABSTRACT

In this study, we used 32 animals with initial body weight (BW) of 380 ± 5.2 kg to determine the nutritional requirements of Nellore and Angus young bulls using the comparative slaughter technique. At the beginning of the experiment, four animals of each breed were slaughtered. The remainder were housed in individual stalls, in which eight animals of each breed were fed *ad libitum* a silage/concentrate (SC) diet (300 g/kg of silage and 700 g/kg of a concentrate based on corn and soybean meal, DM basis). Another 4 animals of each breed were fed the SC diet at 55% of dry matter intake adjusted for the metabolic BW of the animals that received the SC diet *ad libitum*. We measured daily intake, and conducted a metabolism trial with total collection of feces and urine. The data were used to estimate metabolizable energy intake. On the 25^{th}, 50^{th} and 75^{th} experimental days, infrared thermal images were taken of the faces of animals fed *ad libitum* to access skin and ocular surface temperatures. A metabolism trial was conducted to estimate metabolizable energy intake. After 84 experimental days, the cattle were harvested in order for us to calculate retained energy and heat production (HP). The data were analyzed using SAS. The nutritional requirements were calculate using GLM and NLIN procedures. The relation between infrared thermography and HP was studied using the MIXED and REG procedures. The net energy requirements for maintenance differed between Angus and Nellore, with 98 and 76 kcal/kg $EBW^{0.75}\cdot d^{-1}$, respectively, when calculated by logarithm model, and 100 and 80 kcal/kg $EBW^{0.75}\cdot d^{-1}$, respectively, when calculated by nonlinear model. There was no difference between breeds regarding nutritional requirements for growth. We found significant correlations ($P \leq 0.005$) between daily HP and maximum (r = 0.65) and average skin temperatures (r = 0.65) and maximum (r = 0.65) and average ocular surface (r = 0.69) temperatures recorded on d 50. The results indicate that Zebu bulls have lower net energy requirements for maintenance than *Bos taurus taurus* bulls and that Infrared thermography has potential for the evaluation of cattle HP.

Key words: Angus. Energy. Infrared thermography. Nellore. Nutritional requirements.

LISTA DE SIGLAS

ADFI	Average Daily Feed Intake
ADG	Average Daily Gain
AIC	Akaike Information Criterion
BW	Body Weight
CAR	Consumo Alimentar Residual
cDMI	centered Dry Matter Intake
CEM	Consumo de Energia Metabolizável
CP	Crude Protein
DEI	Digestible Energy Intake
DM	Dry Matter
DMI	Dry Matter Intake
EB	Energia Bruta
EBW	Empty Body Weight
ED	Energia Digestível
EE	Ether Extract
EL	Energia Líquida
EL_g	Exigências de energia líquida para ganho
EL_m	Exigências de energia líquida para mantença
EM	Energia Metabolizavel
ER	Energia Retida
FR	Feed Restriction diet
GE	Gross Energy
GEI	Gross Energy Intake
GIT	Gastrointestinal Tract
GPCV	Ganho em Peso de Corpo Vazio
HP	Heat Production
k_g	Eficiência de uso da energia metabolizável para ganho
k_m	Eficiência de uso de energia metabolizável para mantença
MEI	Metabolizable Energy Intake
ME_m	Metabolizable energy requirements for maintenance
NDF	Neutral Detergent Fiber
NE_g	Net energy requirements for growth
NE_m	Net energy requirements for maintenance
NFC	Non Fibrous Carbohydrate

NP_g	Net protein requirements for growth
OMD	Organic Matter Digestibility
PC	Peso Corporal
PCV	Peso de Corpo Vazio
PCVeq	Peso de Corpo Vazio equivalente
Rdf	Residual degrees of freedom
RE	Retained Energy
RMSE	Root Mean Square Error
RSS	Residual Sums of Squares
SBW	Shrunk Body Weight
SC	Silage/Concentrate diet

SUMÁRIO

CAPÍTULO I

Introdução geral

1 INTRODUÇÃO

Bovinos *Bos taurus indicus* e seus cruzamentos são comumente usados em sistemas pecuários tropicais ao redor do mundo. Essa subespécie compartilha um ancestral comum com *Bos taurus taurus* (LOTFUS et al., 1994). No entanto, ambas as subespécies evoluíram de forma separada por centenas de milhares de anos, e durante esse período, bovinos de raças zebuínas se adaptaram a ambientes rigorosos, de clima quente e úmido e se alimentando de forragem de baixa qualidade (TURNER, 1980).

Entre os fatores que afetam as exigências nutricionais de bovinos está o genótipo. O NRC (NATIONAL RESEARCH COUNCIL, 2000) e o CSIRO (COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANIZATION, 2007) assumem que as exigências de energia líquida para mantença (EL_m) de bovinos *B. taurus indicus* são, respectivamente, 10 e 17% inferiores do que *B. taurus taurus*. Outros autores, no entanto, não evidenciaram diferenças na EL_m entre taurinos e zebuínos puros e seus cruzamentos (FERREL; JENKINS, 1998; MARCONDES et al., 2013). Já com relação às exigências de energia líquida para ganho de peso (EL_g), que são estimadas através da quantidade de energia retida no corpo do animal, Chizzotti, Tedeschi e Valadares Filho (2008), reportam que elas tendem a ser diferentes entre zebuínos puros e cruzados, como resultado das diferenças na energia retida entre animais dos dois grupos genéticos, pois bovinos cruzados são mais precoces e alcançam o mesmo teor de gordura corporal com um menor peso do que zebuínos puros.

Para se estimar as exigências nutricionais de energia para mantença é necessário se determinar a produção de calor do animal, e tradicionalmente, ela é medida através da calorimetria ou da técnica de abate comparativo, ambos métodos dispendiosos e que requerem considerável infraestrutura. Uma potencial alternativa seria o uso da termografia infravermelha, técnica de medição da temperatura superficial de um objeto, não invasiva, que não requer contato direto com o animal, e que tem sido usada para se avaliar a eficiência alimentar, uma vez que os animais menos eficientes têm maior produção de calor e apresentariam maior temperatura de superfície corporal do que os animais mais eficientes (DIGIACOMO et al, 2014; MONTANHOLI et al., 2009a; MONTANHOLI et al., 2009b). Montanholi et al. (2008) encontraram uma forte correlação entre a produção de calor medida pela calorimetria indireta e a temperatura da superfície da pele registrada através da termografia infravermelha. No entanto, essa técnica ainda não foi avaliada em estudos de abate comparativo, onde a produção de calor é estimada como a diferença entre o consumo de energia metabolizável (CEM) e da energia retida (LOFGREEN; GARRET, 1968).

Esta tese será apresentada no formato de artigos científicos. O artigo científico 1 foi redigido de acordo com as normas do periódico Livestock Science e o artigo 2 foi redigido de acordo com as normas do Journal of Animal Science.

2 REFERENCIAL TEÓRICO

2.1 Exigências de energia

A energia utilizada pelos animais é proveniente da ingestão de alimentos e disponibilizada através de processos digestivos e metabólicos, que são energeticamente ineficientes devido a diversas perdas que ocorrem durante os processos de assimilação de nutrientes pelo organismo (VALADARES FILHO et al., 2010).

Energia bruta (EB) é o calor liberado pela combustão de amostras dos alimentos em uma bomba calorimétrica, representando a máxima produção de energia pela oxidação de todo o carbono a CO_2. Porém, somente uma fração da energia bruta no alimento pode ser aproveitada pelo organismo, uma vez que carboidratos, proteínas e lipídeos não são completamente digeridos pelo animal. A energia digestível (ED) absorvida pelo animal é a diferença entre a EB da dieta e das fezes.

A energia metabolizável (EM) é determinada subtraindo-se da ED das perdas energéticas pela excreção de urina e produção de metano. Perdas energéticas na urina são relacionadas à ingestão de proteína, ou mais precisamente, nitrogênio digestível, uma vez que a excreção de carbono na urina está relacionada ao principal produto de perda de nitrogênio em mamíferos, a ureia. Já a produção de metano depende do substrato fermentado e da comunidade de micro-organismos no rúmen (BARBOZA; PARKER; HUME, 2009).

A energia líquida (EL), determinada descontando-se a EM das perdas por calor, é a quantidade de energia disponível para os processos de mantença e síntese de tecidos. Processos de mantença incluem controle da temperatura corporal e do balanço de fluídos corporais, substituição de células e mecanismos relacionados à busca, ingestão e digestão de alimentos (NATIONAL RESEARCH COUNCIL, 2000). Todas as rotas metabólicas produzem calor porque todas as reações são ineficientes, e assim, animais perdem energia na forma de calor continuamente, sendo a produção de calor proporcional ao metabolismo (BARBOZA; PARKER; HUME, 2009).

Muitos fatores podem influenciar nas exigências de energia de bovinos, como por exemplo, o genótipo. O NRC (NATIONAL RESEARCH COUNCIL, 2000) apresenta uma série de resultados apontando considerável variação nas exigências de energia entre bovinos de diferentes raças, assumindo EL_m para animais taurinos de 77 kcal/kg peso corporal $(PC)^{0,75}$•dia^{-1}, valor encontrado por Lofgreen e Garret (1968), usando dados de 200 animais, entre machos castrados e novilhas da raça Angus. O mesmo comitê assume que bovinos de raças zebuínas possuem EL_m 10% inferiores a esse valor, baseando-se em uma série de estudos comparando animais das raças Africander, Barzona, Brahman e Sahiwal com bovinos de raças britânicas. Já o CSIRO (COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANIZATION, 2007), baseando-se nos estudos de Frisch e Vercoe (1977, 1984), considera a EL_m de taurinos 16% superior à de animais *B. taurus indicus*. Ambos os comitês consideram que animais, provenientes de cruzamentos *B. taurus taurus* x *B. taurus indicus,* possuem EL_m intermediárias entre os dois genótipos puros. No entanto, outros autores não observaram diferença nas exigências de energia para mantença entre animais puros e cruzados. Marcondes et al. (2013), em uma meta-análise envolvendo 26 estudos e totalizando 752 animais, não encontraram diferenças na EL_m entre bovinos Nelore puros ou cruzados com raças taurinas, relatando EL_m de 79 kcal/kg $PCV^{0,75}$•dia^{-1}, valor semelhante ao adotado pelo NRC (NATIONAL RESEARCH COUNCIL, 2000). Ferrel e Jenkins (1998), avaliando novilhos provenientes do cruzamento de touros Angus, Hereford, Boran, Brahman (essas duas, raças zebuínas) ou Tuli (raça taurina adaptada às condições tropicais) com vacas MARC III (raça composta, 1/4 Angus, Hereford, Pinzgauer e Red Poll) também não observaram diferença na EL_m (72 kcal/kg peso corporal $(PC)^{0,75}$•dia^{-1}) entre os genótipos, quando as exigências foram calculadas pelo modelo não linear.

O custo de mantença do corpo depende da energia gasta na manutenção da homeostase e turnover de células, que variam entre tecidos, mas são tipicamente altas no tecido nervoso e nos órgãos relacionados à digestão (SUMMERS; MCBRIDE; MILLIGAN, 1988). De acordo com o CSIRO (COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANIZATION, 2007), levando-se em consideração o consumo de oxigênio pelos tecidos, absorção e metabolismo dos nutrientes, intestinos e fígado são responsáveis por, aproximadamente, metade das exigências de mantença do animal. Pele, rins e tecido nervoso respondem por mais um terço das exigências, sendo o restante consumido pelos músculos. Variações no nível de atividade destes tecidos devido, por exemplo, ao genótipo e ao nível de alimentação, poderiam modificar as exigências de energia do animal. Estudos têm reportado que zebuínos tendem a apresentar menor peso de fígado e órgãos do trato gastrointestinal quando comparados a taurinos (MENEZES; RESTLE, 2005; PERON; FONTES; LANA, 1993).

No entanto, segundo Valadares Filho et al. (2010), o modelo proposto por Marcondes, Tedeschi e Valadares Filho et al. (2010) para se estimar a eficiência de uso de energia metabolizável para mantença (k_m; Eq. 1) introduz um novo conceito de como a eficiência de uso da energia influencia nas exigências de mantença. Este modelo sugere que a diferença entre zebuínos e taurinos pode não estar relacionada às exigências de energia para mantença, mas sim à k_m, onde zebuínos seriam mais eficientes em converter EM consumida em EL, quando comparados com animais Bos taurus.

$$k_m = 0{,}513 + 0{,}173 \times k_g + \alpha \times GPCV \qquad [Eq. 1]$$

onde k_m é a eficiência de uso de energia metabolizável para mantença; α é igual a 0,1 para animais Nelore e 0,073 para animais cruzados *B. taurus taurus* x *B. taurus indicus*; k_g a eficiência de uso da energia metabolizável para ganho; e GPCV é o ganho em peso do corpo vazio.

De acordo com Garret (1980), o turnover proteico pode ser responsável por parte da variação do k_m. De acordo com Oddy, Ball e Pleasants (1997), menores taxas de turnover relativo ao PC deveriam ser associados com reduzido gasto energético. No tecido muscular, que representa entre 30 e 40% do total do PC, as principais enzimas proteolíticas que controlam o turnover proteico são calpaínas, enquanto a calpastatina atua inibindo as calpainas. Portanto, maior atividade de calpastatina pode resultar em menores taxas de turnover proteico. Rubensam, Felicio e Termignoni (1998) e Whipple, Koohmaraie e Dikeman (1990) relataram que bovinos provenientes de cruzamentos entre raças zebuínas e taurinas apresentaram maior atividade de calpastatina quando comparada com animais taurinos puros, indicando que possivelmente bovinos de raças zebuínas apresentam menor turnover proteico e, por consequência, possivelmente maior k_m.

O estresse calórico também tem efeito na EL_m. Zebuínos evoluíram sob ambientes tropicais, o que tornou este genótipo mais tolerante ao calor do que bovinos *B. taurus taurus*, devido a adaptações morfofisiológicas que permitem a este genótipo uma melhor dissipação do calor (VALADARES FILHO et al., 2010). Sob altas temperaturas, o organismo aumenta a taxa metabólica e o “trabalho” para dissipar o calor (por exemplo, aumento da taxa de respiração) e, como consequência, a EL_m. Valente et al. (2013) observaram que a taxa de respiração dos animais Angus foi, em média, 146% maior do que Nelore (95,7 vs 38,9/min, em temperatura ambiente média de 28,5 ° C).

Além do genótipo, a condição sexual também pode afetar as exigências de energia. O uso de esteróides na pecuária de corte é proibido em vários países, então o uso de machos não castrados seria uma estratégia para tirar proveito dos efeitos anabólicos de hormônios sexuais endógenos, já que touros jovens apresentam maiores taxas de crescimento, carcaças mais pesadas e maior proporção de músculos e cortes comestíveis, quando comparados com animais castrados não implantados (PRADO et al., 2015; SILVA et al., 2008). Além disso, os consumidores têm se preocupado cada vez mais com o bem-estar animal, com um lobby de alguns setores da sociedade para reduzir a prática da castração. Ambos CSIRO (COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANIZATION, 2007) e NRC (NATIONAL RESEARCH COUNCIL, 2000) admitem que os machos não castrados têm EL_m 15% maior do que novilhos e novilhas. Os fatores responsáveis por essa diferença incluem uma maior concentração de proteína no corpo de touros e as diferenças de maturidade, quando os animais são comparados a um mesmo peso corporal (NATIONAL RESEARCH COUNCIL, 2007).

A EL_g é estimada através da quantidade de energia retida no corpo do animal (NATIONAL RESEARCH CONCIL, 1984). Logo, seria de se esperar que fatores que alteram a composição corporal, como a raça, também atuariam na EL_g. De acordo com Garrett (1980), a raça tem influência muito mais marcante sobre a composição corporal, a um mesmo PC ou peso de carcaça, que o nível de nutrição. Durante o crescimento, à medida que o peso do animal aproxima-se de seu peso adulto (ou peso de maturidade), a porcentagem de gordura no ganho de peso aumenta enquanto a de músculo diminui, sendo que raças precoces apresentam peso na maturidade inferior ao de raças tardias. De acordo com Chizzotti, Tedeschi e Valadares Filho (2008), bovinos Nelore poderiam apresentar um maior peso na maturidade do que animais cruzados com raças taurinas, sendo os novilhos cruzados mais precocemente e alcançando o mesmo teor de gordura corporal com um menor peso. Os mesmos autores reportaram que a EL_g de bovinos Nelore puros ou cruzados com raças taurinas tendem a ser diferentes, resultado das diferenças na energia retida entre animais dos dois grupos genéticos. No entanto, Valadares Filho et al. (2010), utilizando o PCV equivalente (PCVeq) em detrimento do PCV não observaram diferença na EL_g entre animais Nelore puros e cruzados (Eq. 2), e segundo os autores, a ausência de efeito de grupo genético é coerente, uma vez que a utilização do PCVeq ajusta a diferença no tamanho, na maturidade entre as raças sendo, portanto, efeito de grupo genético. O uso do PCVeq, inicialmente proposto pelo NRC (NATIONAL RESEARCH COUNCIL, 2000), tem o objetivo de corrigir o peso de animais de diferentes tamanhos corporais ou pesos na maturidade, já que a eficiência do uso de energia para ganho varia de acordo com o PC e taxas de ganho.

$$EL_g = \alpha \times PCVeq^{0,75} \times GPCV^{1,095} \qquad \text{Eq. 2}$$

Onde, EL_g são as exigências de exigências de energia líquida para ganho em peso (Mcal/dia); α é igual a 0,053 para machos não castrados, 0,064 para machos castrados e 0,072 para fêmeas; PCVeq é o peso de corpo vazio equivalente (kg) e o GPCV é o ganho em peso de corpo vazio (kg/dia).

O expoente de 1,095 é similar ao da equação utilizada pelo NRC (NATIONAL RESEARCH COUNCIL, 2000), desenvolvida como base em um banco de dados envolvendo 3500 animais de origem taurina britânica.

$$EL_g = 0{,}0635 \times PCVeq^{0,75} \times GPCV^{1,0977} \qquad \text{Eq. 3}$$

Onde, EL_g são as exigências de exigências de energia líquida para ganho em peso (Mcal/dia), PCVeq é o peso de corpo vazio equivalente (kg) e o GPCV é o ganho em peso de corpo vazio (kg/dia).

2.2 Termografia infravermelha

Imagens termográficas detectam a radiação infravermelha que é emitida por todos os objetos com temperatura acima do zero absoluto (-273 °C ou 0 °K; MCCAFFERTY, 2013). A câmera de imagens termográficas mede a radiação (R; W/m^2) e calcula a temperatura (°K) através da lei de Stefan Boltzmann (Eq. 4).

$$R = \varepsilon \times \sigma \times T^4 \qquad \text{Eq. 4}$$

Onde R é a radiação, W/m^2; ε é a emissividade da superfície; σ é 5,67 x 10^{-8} $W/m^2 \cdot K^{-4}$ (constate de Stefan Boltzmann); e T é a temperatura, °K.

Emissividade é definida como a habilidade de uma superfície para emitir e absorver radiação (MONTEITH; UNSWORTH, 1990), sendo considerada maior que 0,95 em tecidos biológicos (LUDWIG, 2013). A radiação infravermelha captada pela câmera é transformada, através de algoritmos, em uma imagem em escala de cinza, que pode ser convertida em uma imagem colorida (LUDWIG, 2013).

As primeiras câmeras de infravermelho foram desenvolvidas na Alemanha para uso militar, durante a segunda guerra mundial. Já entre as décadas de 50 e 60, alguns estudos demonstraram que câmeras de infravermelho poderiam ser usadas para detectar os estágios iniciais do câncer de mama, pois células cancerígenas possuem grande circulação sanguínea, criando um "hot spot" nas imagens térmicas (RICCA, 2013), e desde então, a termografia de infravermelho tem sido estudada na medicina humana e animal.

Processos fisiológicos afetam a temperatura dos tecidos biológicos pela mudança do fluxo sanguíneo, sendo que o calor gerado por processos inflamatórios é transferido para tecidos adjacentes, incluindo pele, via dilatação dos vasos capilares e é dissipado como energia infravermelha (KNIZKOVA et al., 2007). Sendo assim, imagens geradas por câmeras térmicas podem ser usadas para identificar mudanças de temperatura, informação que não revela a patologia, mas facilita a detecção e localização da inflamação ou lesão, através da mudança no padrão de temperatura (EDDY; HOOGMOED; SNYDER, 2001). Estudos com equinos (JOHNSON et al., 2011), cervídeos (DUNBAR et al., 2009) e carnívoros (DUNBAR; MACCARTHY, 2006) comprovaram a sensitividade de imagens termográficas em detectar diferenças nos padrões de temperatura em animais febris. Em bovinos, Schaefer et al. (2004) usaram imagens termográficas para identificar animais infectados com diarreia viral, observando significante mudança na temperatura da superfície ocular diversos dias antes dos bezerros manifestarem outros sinais clínicos da doença.

Porém, as aplicações da termografia de infravermelho no estudo com animais vão além da detecção de distúrbios patológicos, com potencial para ser usada na detecção de estro (HURNIK; WEBSTER; BOER, 1985), de gestação (DURRANT et al., 2006), no estudo de comportamento e estresse animal (COSTA, 2013), da termorregulação (MCCOARD et al., 2014) e da eficiência energética (MOTANHOLI et al., 2009b).

Montanholi et al. (2008) encontraram forte correlação (r = 0,88; P < 0,001) entre a temperatura dos pés e produção de calor de vacas em lactação, concluindo que a termografia infravermelha é uma técnica com potencial uso na determinação da eficiência alimentar em bovinos. A relação entre o CEM e a produção de calor é exponencial, uma vez que um aumento no consumo conduz a um incremento da atividade metabólica dos órgãos, causada por digestão, absorção e metabolismo dos nutrientes (CHIZZOTTI; TEDESCHI; VALADARES FILHO, 2008). A proporção da energia metabolizável ingerida convertida em produtos (carne, leite, lã, etc.) é inversamente relacionada com a quantidade de energia que não é retida e perdida pelo animal na forma de calor, em grande parte dissipado através da pele na forma de radiação (KLEIBER, 1961). Assim sendo, animais menos eficientes têm maior produção de calor e, consequentemente, apresentariam maior temperatura de superfície corporal do que os animais mais eficientes (MONTANHOLI et al., 2009a). Estudos comparando-se animais de alto e baixo consumo alimentar residual (CAR; animais menos eficientes e mais eficientes, respectivamente) demonstraram que a temperatura corporal obtida por meio de imagens termográficas refletem a eficiência alimentar. DiGiacomo et al. (2014) registraram imagens térmicas da superfície da pele de diferentes partes do corpo de vacas classificadas como eficientes e ineficientes, e observaram que a temperatura do pescoço e do ombro tenderam a ser maiores em animais ineficientes, enquanto a temperatura do úbere foi significativamente menor (0,9 °C) ,nas vacas classificadas com alto CAR. Os autores concluíram que as temperaturas encontradas por meio de imagens térmicas, tomadas nos pontos supracitados, refletem diferenças na eficiência alimentar. Em novilhos, Montanholi et al. (2009a) observaram correlação significantemente positiva entre o CAR e as temperaturas da superfície da pele e do globo ocular aferidas através de imagens térmicas, sendo que as superfícies do focinho e bochecha foram mais quentes em animais menos eficientes. Além disso, a temperatura da superfície corporal foi responsável por mais de 70% da variação do CAR explicada pelo consumo de matéria seca, ganho médio diário e conversão alimentar, o que indica uma aplicação importante desta tecnologia. Montanholi et al. (2009b) também observaram que animais com alto CAR apresentam temperatura de superfície corporal maiores que animais mais eficientes. No entanto, ao contrário do relatado pelos autores supracitados, Martello et al. (2016) observaram maior temperatura da fronte nos animais mais eficientes. De acordo com os autores, em um ambiente termoneutro, animais mais eficientes apresentariam menor temperatura de superfície de pele, um reflexo da menor produção de calor para exigências de mantença e por consequência, menor calor sendo dissipado por radiação. Contudo, mesmo sobre moderado estresse calórico, como ao que foi submetido os animais estudados (temperatura média de 26 °C, variando entre 19 e 30 °C, e umidade relativa de 40%), seria esperado que o organismo ativasse mecanismos termoregulatórios para alcançar equilíbrio da temperatura corporal. Assim, segundo os autores, a maior temperatura da fronte sugeriria uma maior capacidade dos bovinos de baixo CAR em dissipar calor e manter a temperatura corporal, ou seja, possuiriam termorregulação mais eficientes.

3 CONSIDERAÇÕES GERAIS

a) Apesar de ampla, a literatura sobre exigências nutricionais de bovinos carece de dados recentes, comparando animais puros de raças taurinas e zebuína.

b) Os exemplos acima indicam que a termografia infravermelha possui potencial para ser utilizada em sistemas pecuários, com destaque para pesquisas que envolvam o estudo do metabolismo e eficiência energética.

4 OBJETIVOS GERAIS

Diante do exposto, o presente trabalho foi conduzido objetivando-se:

a) estimar as exigências nutricionais de energia de novilhos Angus e Nelore, não castrados;

b) avaliar a relação entre a termografia infravermelha e a produção de calor em bovinos.

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CAPÍTULO 2

Energy and protein requirements for Angus and Nellore young bulls

ABSTRACT: Thirty-two animals with initial body weight (BW) of 380±5.2 kg were used to determine energy and protein requirements of Nellore and Angus young bulls using the comparative slaughter technique. Four animals per breed were slaughtered at beginning of the experiment. The remainder were housed in individual stalls, where eight animals per breed were fed ad libitum a silage/concentrate (SC) diet (300 g/kg of silage and 700 g/kg of a concentrate based on corn and soybean meal, dry matter basis). Another 4 animals per breed were fed the SC diet at 55% of their dry matter intake adjusted for the metabolic BW of animals that received the SC diet ad libitum. Intake was measured daily and a metabolism trial was conducted with total collection of feces and urine. The data were used then to estimate the metabolizable energy intake. After 84 d of growth the cattle were slaughtered. The data were analyzed using the GLM and NLIN procedures of SAS adopting significance level of 0.05. The metabolizable energy requirements for maintenance differed between Angus and Nellore: 157 versus 123 kcal/kg $EBW^{0,75}\cdot d^{-1}$ when calculated by logarithm model and 158 versus 129 kcal/kg $EBW^{0,75}\cdot d^{-1}$ when calculated by nonlinear model. There was no difference between breeds in the nutritional requirements for growth. Our results support that Zebu bulls have lower net energy requirements for maintenance than *Bos taurus taurus* bulls.

Key words: *Bos taurus indicus*; *Bos taurus taurus*; energy requirements; non-castrate; protein requirements.

1 INTRODUCTION

Bos taurus indicus cattle and their crossbreds are commonly used in tropical livestock systems around the world. This subspecies share a common ancestor with *Bos taurus taurus* (Lotfus et al., 1994). However, both subspecies have undergone separate evolution for hundred thousand of years and during this period *B. taurus indicus* cattle have been exposed to harsh environments, resulting in acquired adaptations to survive. For example, *B. taurus indicus* cattle are adapted to hot and humid weather and to poor quality forages (Turner, 1980).

Many factors can affect the energy requirements of beef cattle, for example, genotype. According to NRC (2000) the net energy requirements for maintenance (NE_m) of beef cattle have been estimated as 77 kcal/kg empty body weight $(EBW)^{0.75}\cdot d^{-1}$, based on the findings of Lofgreen and Garret (1968) who used data from Angus steers and heifers. The same committee considers that Zebu cattle have NE_m 10% lower than *B. taurus taurus* based on several studies comparing *B. taurus indicus* with British breeds. Other committee, the CSIRO (2007), adopted an equation to calculate NE_m which assumes variables requirements accord to age and body weight, and for a *B. taurus taurus* steer or heifer with 400 kg of body weight and two years old, the NE_m would be 97 kcal/kg $EBW^{0.75}\cdot d^{-1}$, admitting which Zebu breeds have requirements 17% lower than this value. Both committees consider that *B. taurus taurus* x *B. taurus indicus* crossbred have NE_m intermediate between the two purebred genotypes. However, other authors found no difference in energy requirements for maintenance between Nellore purebreds and crossbred (Marcondes et al. 2013).

Besides genotype, sexual condition can also affect the energy requirements. The application of hormone implants is forbidden in several countries, then the use of non-castrate males would be a strategy to take advantage of anabolic effects of endogenous sexual hormones, since young bulls present higher growth rates, heavier carcass and higher proportion of muscles and edible cuts when compared to the not implanted steers (Prado et al., 2015; Silva et al., 2008). Beside this, consumers have becoming more concerned about animal welfare, with a lobbying by some sectors of society to reduce the practice of castration. Both NRC (2000) and CSIRO (2007) admit that non-castrate males have NE_m 15% higher than steers and heifers. Factors responsible for that difference include the greater protein concentration in the intact male body and the differences in stage of maturity when the animals are compared at the same body weight (NRC, 2007).

The nutritional requirements for growth are estimated by the retained energy in the animal body (NRC, 1984). Then, it would be expected that factors that affect body composition also would affect the net energy requirements for growth (NE_g). During the growth, with the animal weight nearing of mature weight, the proportion of fat in the weight gain increases as the muscle decreases, with early maturing breeds reaching the mature weight before late maturing breeds. According to Chizzotti et al. (2008), there was a tendency (P = 0.06) of difference in the NE_g between Nellore purebred and crossbred with *B. taurus taurus* breeds, as a result of differences in retained energy between animals of two genotypes.

Although the knowledge of nutritional requirements is important to provide balanced diets that precisely meet the needs of the animals, few studies have compared the energy and protein requirements of *B. taurus indicus* and *B. taurus taurus* purebred bulls. Beside this, on the last decades the beef cattle past by genetic gains, with improvement on the feed efficiency and daily weight gain, and it could have changed the nutritional requirements. We hypothesized that nutritional requirements differ between *B. taurus indicus* and *B. taurus taurus* and that the recommendations by the committees would be different for modern bulls. Therefore, the aim of this work was estimate the nutritional requirements for finishing Angus and Nellore bulls.

2 MATERIAL AND METHODS

Humane animal care and handling procedures were approved by the Committee on Ethics in Animal Utilization of the Universidade Federal de Lavras, under protocol #048/2012.

2.1 Local, animal and management description

The study was conducted at the Universidade Federal de Lavras (Lavras, Minas Gerais, Brazil), located at 21°14' south latitude, 45° 00' west longitude, and at an altitude of 918 m. During the experimental period, the average temperature was 23°C, the maximum temperature was 36°C, and the minimum temperature was 20°C. The average relative humidity was 75%.

Thirty-two bulls were used (16 Nellore and 16 Angus) with an initial body weight (BW) of 380±5.2 kg. The animals were fed the same silage/concentrate (SC) diet (300 g/kg silage and 700 g/kg concentrate, dry matter basis; Table1) on an *ad libitum* basis for 28 d, before beginning of the experiment. Then, four animals of each breed were slaughtered (baseline animals). Simple regressions were developed for each breed from baseline animals to estimate the initial empty body weight (EBW) and chemical composition of other bulls. The remaining animals were housed in individual covered pens. Eight animals of each breed were fed the SC diet on an *ad libitum* basis. Another four animals of each breed were fed the SC diet at 55% of feed restriction (FR), based on dry matter intake (DMI) adjusted for the metabolic BW of animals that received the SC diet ad libitum. The SC diet was formulated according to NRC (2000) for an average daily gain (ADG) of 1.4 kg/d. The cattle were fed twice daily, at 0730 and 1530 h. Feed and orts were weighed and sampled daily to quantify the average daily feed intake (ADFI). Ingredients and orts samples were oven-dried at 55°C for 72 h. Animals fed ad libitum were offered enough feed to ensure about 5% of orts daily. To determine the ADG the bulls were weighed each 28 d.

A digestion trial was conducted with all animals. Feed intake, feed refusals, feces, and urine were recorded daily for 3 d. The feces were collected directly from the floor, immediately after the animal had defecated, and urine was collected using a rubber funnel tied to the animal's body and connected to a container filled with 200 ml of 20% H_2SO_4 by a drainage hose. Daily, a 10% sample of orts, feces and urine was collected. The urine samples were stored at -20°C and the feces samples were immediately dried at 55°C for 72h.

2.2 Slaughter procedures

After 84 d, the bulls were feed-fasted for 12 h and weighed to obtain the shrunk body weight (SBW). Cattle were desensitized with a nonpenetrating stunner and harvested by exsanguination using conventional humane procedures, followed by evisceration and hide removal. Hide and blood were weighed and sampled. Head and feet were weighed, ground and sampled. The gastrointestinal tract (GIT) of each animal was emptied, washed and weighed and then ground together with internal organs, reproductive tract, tongue and tail. These ground viscera, together with the hide, head, feet and blood formed a pooled sample, with each component sampled in proportion to its contribution to empty BW (EBW). The carcass was split into two longitudinal halves and weighed before and after a 24 h chill. The left half of the carcass was separated into bone and soft tissues, which were weighed, sampled in proportion and ground, forming a left half carcass sample. The EBW was determined by the sum of the weight of carcass, blood, internal organs, reproductive tract, empty GIT, tongue, head, feet and tail. The collected samples were frozen and freeze-dried. Analyses of dry matter (DM), ash, crude protein (CP), ether extract (EE) and gross energy (GE) in these samples were performed as described below.

2.3 Chemical analyses

The AOAC (1990) methods were used to quantify DM (method 930.15), ash (method 942.05), EE (method 920.39) and nitrogen content (method 984.13) of feed, orts, feces and body samples. The protein content was estimated as 6.25 x nitrogen content. The neutral detergent fiber (NDF) was expressed as exclusive of residual ash according to Mertens (2002) with use of α-amylase and sodium sulphite. Gross energy of body, diet ingredients, orts and feces was estimated assuming the heat of combustion of carbohydrate, protein and fat to be 4.186, 5.6405 and 9.3929 Mcal/kg, respectively (ARC, 1980).

2.4 Data Calculation

The quantity of protein, fat or ash present in the empty body (kg) as a function of the EBW (kg) was predicted via allometric equation (Eq. 1).

$$y = \alpha \times \text{EBW}^{ß} + \varepsilon \qquad \text{Eq. [1]}$$

Where y is the total amount of compound of the EBW (kg); EBW is the empty body weight; α and ß are regression parameters; and ε is the residual.

Metabolizable energy intake (MEI) was determined by subtracting the energy lost in feces, urine and the emission of methane of the energy ingested by the animal. The energy lost by methane emission was estimated through equation number 19 proposed by Ramin and Huhtanen, 2013, considering that each liter of methane is 0.650 g and that methane combustion produces 0.0133 Mcal/g (Holter and Young, 1992). The GE of urine was estimated assuming 33.85 calories per mg of nitrogen (Gionbelli, 2013). The centered DMI (cDMI) was calculate according to the author, subtracting the mean DMI from each individual DMI.

Heat production (HP, kcal/kg $EBW^{0.75} \cdot d^{-1}$) was calculated as the difference between MEI (kcal/kg $EBW^{0.75} \cdot d^{-1}$) and retained energy (RE, kcal/kg $EBW^{0.75} \cdot d^{-1}$). The NE_m requirements were estimate by Eq. 2, considering the intercept α (Ferrell and Jenkins, 1998), and as the antilog of the intercept of the linear regression between the log HP on MEI (Lofgreen and Garret, 1968).

$$HP = \alpha \times e^{(ß \times MEI)} + \varepsilon \qquad \text{Eq. [2]}$$

Where: HP is the heat production, kcal/kg $EBW^{0.75} \cdot d^{-1}$; MEI is the ME intake, kcal/kg $EBW^{0.75} \cdot d^{-1}$; α and ß are the regression parameters; ε is the residual.

The metabolizable energy requirements for maintenance (ME_m) requirements were calculated by iteration, assuming that ME_m is the value at which HP is equal to MEI. The net efficiency of ME utilization for maintenance (k_m) was calculated as the NE_m divided by the ME_m. The NE_g requirements were considered to be the energy content in the empty body gain (EBG) and was calculated as shown in Eq. 3. Only the animals fed ad libitum were used to calculate the growth requirements.

$$RE = \alpha \times EBW^{0.75} \times EBG^{ß} + \varepsilon \qquad \text{Eq. [3]}$$

Where RE is the retained energy Mcal/d; EBW is the empty body weight, kg; EBG is the empty body gain, kg/d; α and ß are the regression parameters; ε is the residual.

The slope of the regression of RE (kcal/kg $EBW^{0.75} \bullet d^{-1}$) on MEI above maintenance (kcal/kg $EBW^{0.75} \bullet d^{-1}$) was assumed to be the efficiency of energy utilization for growth (k_g). The derivative of allometric equation (Eq. 1) was used to calculate the net protein requirements for growth (NP_g, Eq. 4)

$$NP_g = \alpha \times ß \times EBW^{(ß-1)} \quad \text{Eq. [4]}$$

Where NP_g is the protein concentration per unit of EBW gain (g/kg); EBW is the empty body weight; α and ß are the parameters determined from Eq. 1.

2.5 Statistical analysis

Statistical analyses was performed using SAS 9.2 (SAS Inst. Inc., Cary, NC). Linear regression analysis was performed with the GLM procedure and intercepts and slopes were compared using the *solution* statement and the sum of squares type 3. To predict EBW and EBG, models without intercept were run using *noint* statement. The NLIN procedure was used to fit nonlinear models and a likelihood ratio test (Eq. 5) was used to test if estimation of parameters specific to each breed improved fit of the data relative to estimation of parameters from the overall model. A *P*-value for the F distribution was used to evaluate if the the relationship between traits differs between breeds.

$$F = [(RSS_O - RSS_A - RSS_N)/(Rdf_O - Rdf_A - Rdf_N)]/[(RSS_A + RSS_N)/(Rdf_A + Rdf_N)] \quad \text{Eq. [5]}$$

Where: RSS is the residual sums of squares; Rdf is the residual degrees of freedom; subscript O, A and N indicate, respectively, overall, Angus and Nellore models.

When two models were used to estimate the same variable, the choice of the best model was based on Akaike's information criterion (AIC), estimated as Eq. 6 (Kaps and Lamberson, 2004), considering the best model that with the smallest AIC.

$$AIC = n \times \log(SS_{res}/n) + 2 \times p \quad \text{Eq. [6]}$$

Where: n is the number of observations; SS_{RES} is residual sum of square; and p is the number of parameters of the model.

Performance, intake, and body composition data were analyzed as a completely randomized design, in a factorial scheme (2 intake levels x 2 breeds), using the GLM procedure and the comparisons of means were performed using least squares means at $P = 0.05$.

3 RESULTS

Table 2 presents the data describing the baseline animals. There was no effect of breed on initial body composition ($P \geq 0.072$) of Angus and Nellore bulls. Table 3 describe the equations to predict EBW and EBG. There is difference between breeds ($P < 0.001$) in both EBW and EBG equations.

The initial BW was not different between breeds or diets (Table 4). However, Angus bulls fed *ad libitum* performed better, with ADG 78% (P<0.001) and final BW 17% greater ($P = 0.002$) than Nellore bulls. Only the final body fat was different between the breeds, with Nellore bulls fed *ad libitum* presenting greater proportion of this compound in the EBW than Angus cattle (Table 4). Additionally there was no difference between breeds in the allometric equations (Table 5, Fig. 1), except for fat ($P = 0.038$). The protein deposition was isogonic (ß not different from 1; confidence limits between 0.988 and 1.269). The ß parameters of allometric equation of the quantity of fat present in the empty body indicate that Angus cattle had latter fat deposition than Nellore.

The NE_m, ME_m, and k_m estimated by logarithm (Lofgreen and Garret, 1968) and exponential (Ferrell and Jenkins, 1998) models were similar, but the logarithm model presented smaller AIC (Fig. 2; Tables 6 and 7). The NE_m and ME_m requirements for Angus were on average 27% greater than Nellore, however, both breeds had similar k_m. Table 8 depicts the equation used to estimate the NE_g requirements. There were no differences between breeds, which varied from 4.7 to 6.2 Mcal/kg BW gain·d^{-1} for animals between 350 and 500 kg BW. The regression of retained energy on metabolizable intake (P < 0.001; RMSE = 8.81) used to describe energy utilization of Angus and Nellore bulls indicated the same slope for both breeds (*P* = 0.615), meaning a common kg of 0.21 for Angus and Nellore cattle (Table 9).

Appling the first derivative of the Eq. 1 and using the parameters α and ß of overall allometric equation of the quantity of protein present in the empty body as a function of the EBW (Table 5; Eq. 7), the estimated the NP_g requirements indicated no effect of breed and a slightly increase for animals between 350 and 500 kg BW, ranging from 210 to 220 g/kg EBG·d^{-1}.

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$$NPg = (0.1 \times EBW^{0.129}) \quad \text{Eq. [7]}$$

Where NP_g is the protein content (kg) per unit of EBW (kg).

4 DISCUSSION

The NE_m requirement used by NRC (2000) are based on the findings of Lofgreen and Garret (1968) who used data from steers and heifers of British ancestry and, according to that committee, the maintenance requirements for bulls are between 9 and 20% greater than for steers and heifers, adopting an average value of 15%. The same committee present a divergence between the units used to calculate the NE_m. In the page number 6 the NE_m is expressed per kg of $EBW^{0.75}$, while in the table present in the page 106 it is expressed in kg of $BW^{0.75}$. Considering the value present in that table, the NE_m of Angus bulls are similar to proposed by NRC (2000) for growing bull, of 88.6 kcal/$BW^{0.75}$·d^{-1}. On the other hand, considering the recommendation of CSIRO (2007) the NE_m requirements for Angus bulls would be 100 kcal/kg $BW^{0.75}$·d^{-1} (considering a *B.*

taurus taurus bull, with the average BW 463 kg and 2.5 years old) that is on average 15% greater than that found in this study.

Nellore bulls presented NE_m requirements similar than the value proposed by Marcondes et al. (2013), which was 71 kcal/kg $BW^{0.75}\cdot d^{-1}$. This estimate was from a data base of 752 animals (including Nellore purebred and crossbred bulls, heifers and steers). The NRC (2000) and CSIRO (2007) concluded that *B. taurus indicus* cattle have NE_m requirements, respectively, 10 and 17% lower than *B. taurus taurus*. However in this experiment, NE_m requirements were on average 27% lower than those for Angus. Oxygen consumption, uptake and metabolism of nutrients, intestines and liver are responsible for about half of the animal's maintenance requirements (CSIRO, 2007). Variation in activity of these tissues could result from the animal's genotype and feed intake. Zebu cattle have lower liver and GIT weight than *B. taurus taurus* (Menezes et al., 2007; Peron et al., 1993) which could result in lower energy requirements. In this experiment, the proportions (g/kg EBW) of liver and GIT from *ad libitum* fed Nellore were 19% lower ($P < 0.001$) than the *ad libitum* fed Angus bulls (data not presented).

Additionally, differences in protein turnover rates between the two genotypes can contribute to differences in energy expenditures. The process of protein synthesis and degradation occur continuously and lower turnover rates are associated with reduced energy expenditure (Oddy et al., 1997). Our Angus bulls presented lower calpastatin activity than Nellore (Duarte et al., 2013), which could result in greater muscular protein degradation by calpains and more energy expenditure in protein turnover in *B. taurus taurus*.

Heat stress also could be associated to the higher NE_m requirements observed in Angus. *B. taurus indicus* evolved under tropical conditions which has resulting in greater tolerance to heat than *B. taurus taurus* cattle. Valente et al. (2013) reported that the respiration rate of Angus animals was on average

146% greater than Nellore (95.7 vs. 38.9 breaths/min, at average ambient temperature of 28.5°C), indicating a greater energy expenditure to dissipate heat that contributes to the higher NEm in Angus under tropical environment.

As our results, Chizzotti et al. (2008) also reported no differences on k_m between genotypes. Using the equations proposed by Marcondes et al. (2013) to determine k_m of purebred and crossbred Nellore which consider the EBG (kg/d) and k_g, the k_m would be 0.64 for Nellore and 0.66 for Angus cattle, which are close to our findings.

The allometric coefficients for the body protein indicates that protein deposition was proportional to the observed BW increase. The higher fat content in empty body gain for Nellore indicate that the Angus animals used in this study may have a greater maturity weight than Nellore. Supporting this, the baseline Nellore animals had lower protein (P = 0.072) and greater fat (P = 0.104) content in EBW than Angus, despite a similar initial body weight. Early maturing cattle have lower mature size and begin to fatten at lighter weights than late maturing breeds (Berg and Butterfield, 1976). Purebred Nellore cattle have lighter mature weights than purebred Angus and crossbreds *B. taurus taurus* x *B. taurus indicus* (Forni et al., 2009; Kaps et al., 1999; Marcondes et al., 2013), therefore the difference in fat content in the gain might be related to differences in maturity level at slaughter between Angus and Nellore in this study.

The NE_g requirements found in this study were similar to the values proposed for bulls by NRC (2000) and Valadares Filho et al. (2010). However, the NP_g requirement was greater. Our results suggest that in the BW range used in our study, the bulls were at the linear phase of growth, resulting in a small variation in NP_g requirement. Similar to our findings, Fonseca (2013) also noted NP_g requirements around 196 g/kg $EBG{\cdot}d^{-1}$ for F1 Nellore x Angus bulls between 300 and 500 kg.

The k_g found in this study was lower than those reported by of other authors (Tedeschi et al., 2002; Chizzotti et al., 2007; Marcondes, 2010; Fonseca, 2013). A possible explanation for the low k_g could be the low fat proportion of the BW of the animals used in this study, as a determinant factor of k_g is composition of the retained tissue, because energetically fat accretion is more efficient than protein (Chizzotti et al., 2008) and kg decreases as the percentage of energy retained as protein increase (Valadares Filho, et al., 2010).

5 CONCLUSION

This study demonstrated that energy requirements for maintenance are different between Nellore and Angus bulls. The Angus bulls had greater maintenance energy requirements than previously reported. However, there was no difference in the growth requirements probably because both breeds were at similar proportion of maturity weight. More studies should be carried out to determine the nutrient requirements of modern large frame Angus cattle under tropical conditions.

Table 1: Ingredient and chemical composition of feeds in g/kg DM.

Item[1]	**g/kg DM**
Ingredients	
Corn Silage	300
Cracked corn grain	580
Soybean meal	100
Commercial premix[3]	20
Chemical composition	
DM	589
CP	117
EE	23
NDF	267
NFC	541

[1]DM = dry matter; CP = crude protein; EE = ether extract; NDF = neutral detergent fiber; NFC = non-fibrous carbohydrate.
[2]Respectively A, B and C fractions of protein, g/kg CP.
[3]calcium: 170 g/kg; phosphorus: 31 g/kg; sodium 155 g/kg; zinc: 2 mg/kg; manganese: 515 mg/kg; copper: 15 mg/kg; iodine: 29 mg/kg; selenium: 2.4 mg/kg.

Table 2: Body composition of baseline animals

Item[1]	**Angus**	**Nellore**	**SEM**	***P*-value**
BW, kg	387	363	19.6	0.410
EBW, kg	326	317	16.9	0.702
Water, g/kg EBW	692	680	5.6	0.192
Ash, g/kg EBW	36.9	45.0	3.8	0.179
Fat, g/kg EBW	78.1	96.0	6.6	0.104
Protein, g/kg EBW	193	179	4.7	0.072
Energy, Mcal/kg EBW	1.8	1.9	0.05	0.273

[1]BW = body weight; EBW = empty body weight.

Table 3: Slope of the equation to estimate empty body weight and empty body gain of Angus and Nellore bulls.

Item[1]	Slope	*P*-value
Empty body weight, kg		
Angus	0.889(±0.0068) x BW	<0.001
Nellore	0.901(±0.0081) x BW	
Empty body gain, kg/d		
Angus	0.898(±0.0040) x ADG	<0.001
Nellore	0.911(±0.0070) x ADG	

[1]BW = body weight, kg; ADG = average daily gain, kg/d.

Table 4: Effect of breed and diet[1] on performance, intake, body composition, and energy balance.

Item[2]	**Angus**		**Nellore**			***P*-value**		
	SC	**FR**	**SC**	**FR**	**SEM**	**Breed**	**Diet**	**B*D**
iBW	386	385	374	383	13.2	0.589	0.775	0.721
fBW, kg	540	454	461	415	16.1	<0.001	<0.001	0.230
EBW, kg	486	397	419	360	14.9	<0.001	0.002	0.206
ADG, kg/d	1.73	0.86	0.97	0.41	0.149	<0.001	<0.001	0.319
EBG, kg/d	1.55	0.75	0.88	0.36	0.134	<0.001	<0.001	0.319
Water, g/kg EBW	620	669	630	640	11.6	0.430	0.020	0.114
Ash, g/kg EBW	37	32	25	34	5.7	0.530	0.864	0.341
Fat, g/kg EBW	143	110	149	132	6.2	0.041	<0.001	0.233
Protein, g/kg EBW	199	188	193	194	5.2	0.917	0.332	0.269
CP intake, g /kg $EBW^{0.75} \cdot d^{-1}$	17.6[a]	9.0[c]	12.8[b]	7.5[c]	0.67	<0.001	<0.001	0.025
Retained protein, g/ kg $EBW^{0.75} \cdot d^{-1}$	4.3	1.8	3.0	2.0	0.44	0.211	<0.001	0.123
GEI, Mcal/kg $EBW^{0.75} \cdot d^{-1}$	0.64[a]	0.33[a]	0.48[a]	0.28[b]	0.022	<0.001	<0.001	0.025
DEI, Mcal/kg $EBW^{0.75} \cdot d^{-1}$	0.46	0.26	0.35	0.22	0.019	<0.001	<0.001	0.077
MEI, Mcal/kg $EBW^{0.75} \cdot d^{-1}$	0.41	0.23	0.30	0.17	0.018	<0.001	<0.001	0.129
RE, Mcal/kg $EBW^{0.75} \cdot d^{-1}$	0.08	0.04	0.06	0.03	0.005	0.027	<0.001	0.058
HP, Mcal/kg $EBW^{0.75} \cdot d^{-1}$	0.34	0.19	0.25	0.14	0.016	<0.001	<0.001	0.250
MEI:DEI	0.89	0.87	0.87	0.83	0.007	<0.001	<0.001	0.408

[a-c]Means without a common superscript letter differ ($P < 0.05$).

[1]SC = silage/concentrate diet; FR = feed restriction.

[2]iBW = initial body weight; fBW = final body weight; EBW = empty body weight; ADG = average daily gain; EBG = empty body gain; CP = crude protein; GEI =gross energy intake; DEI = digestible energy intake; MEI = metabolizable energy intake; RE = retained energy; HP = heat production; MEI:DEI = relationship between metabolizable and digestible energy intake.

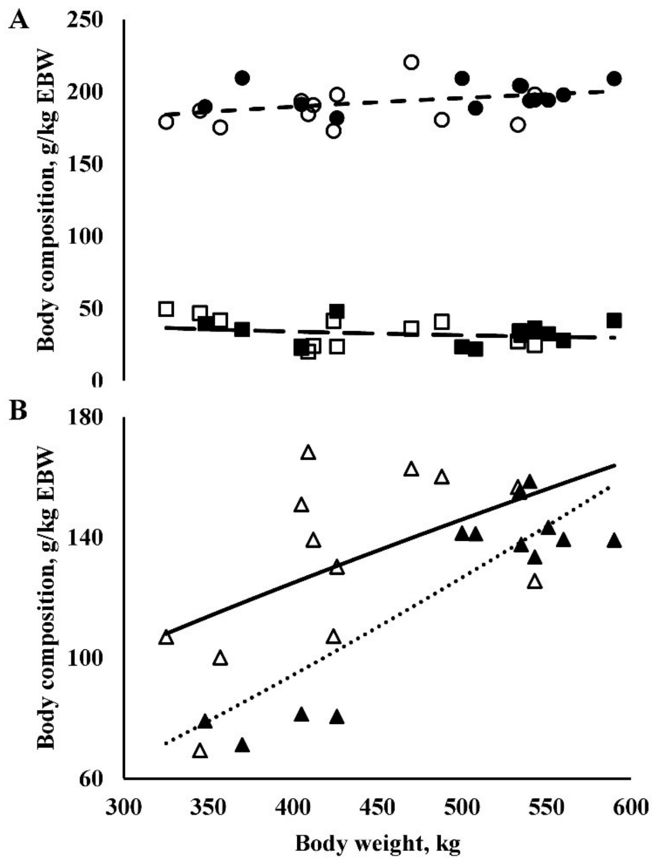

Figure 1: Body composition of Angus and Nellore bulls. The lines represent the allometric equations of the quantity of compound present in the empty body as a function of the EBW. A) Dashed line represents overall protein equation and long dashed line represents overall ash equation; B) solid line represents Angus fat equation; dotted line represents Nellore fat equation; Circles are for protein, triangles are for fat and squares are for ash. Filled symbols are for Angus and nonfilled symbols are for Nellore.

Table 5: Allometric equations to estimate body composition

Item	Parameter		RMSE	Residual		F	*P*-value
	α	ß		Sum of Square	df		
Water							
Angus	3204±1156	0.735±0.059	10.3	1.10E9	11	1.1	0.339
Nellore	1473 ±678	0.861±0.077	10.9	1.17E9	10		
Overall	2140 ±579	0.800±0.045	10.5	2.53E9	23		
Crude protein							
Angus	121±56	1.080±0.075	3.7	1.47E8	11	0.9	0.414
Nellore	100±81	1.106±0.136	5.5	3.08E8	10		
Overall	89±37	1.129±0.068	4.6	4.96E8	23		
Fat							
Angus	0.077±0.110	2.213 ±0.232	5.6	3.50E8	11	3.9	0.038
Nellore	2.915±5.88	1.641±0.335	9.5	9.04E8	10		
Overall	1.433±1.7767	1.747±0.203	8.6	1.71E9	23		
Ash							
Angus	40±101	0.964±0.415	3.4	1.17E8	10	1.1	0.368
Nellore	5906 ±16468	0.127 ±0.469	3.4	1.18E8	10		
Overall	215±375	0.686±0.288	3.4	2.59E8	22		
Energy							
Angus	0.042±0.0280	1.659±0.110	230	33280	11	2.3	0.121
Nellore	0.206±0.2762	1.406±0.198	411	96859	10		
Overall	0.141±0.0914	1.463±0.106	348	159198	23		

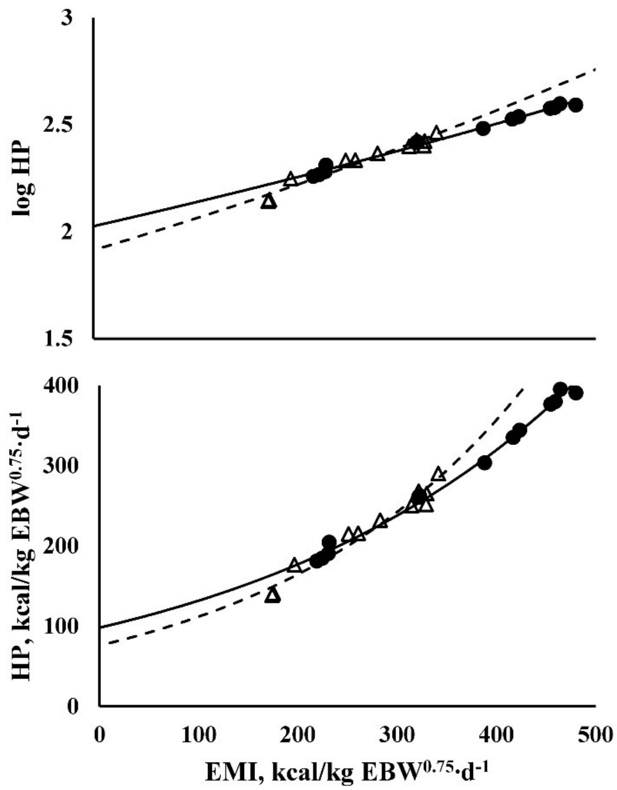

Figure 2: (a) Relationship between metabolizable energy intake (MEI) and logarithm of heat production (HP; Lofgreen and Garret, 1968). Angus equation is log HP = 1.99 + 0.0013 x MEI and Nelore equation is log HP = 1.88 + 0.0017 x MEI (*P* < 0.001; RMSE = 0.019). (b) Relationship between MEI and HP (Ferrel and Jenkins, 1998). Angus equation is HP = 99.8 x $\exp^{(0.0029 \text{ x MEI})}$ (*P* < 0.001; RMSE =7.4) and Nellore equation is HP = 79.9 x $\exp^{(0.0037 \text{ x MEI})}$ (P < 0.001; RMSE = 11.3). Solid lines and circles are data from Angus and dashed line and triangles are data from Nellore.

Table 6: Parameters of equations used to estimate the net energy requirements for maintenance.

Lofgreen and Garret (1968)[1]	α	ß	*P*-value				AIC
			α		ß		
Angus	1.992±0.059	0.0013±0.0002	0.0029		0.0015		-84.5
Nellore	1.881±0.026	0.0017±0.00009					
Overall	1.963±0.017	0.0014±.00005					
Ferrell and Jenkins (1998)[2]	**α**	**ß**	**Residual**				**AIC**
			Sum of Square	df	F[3]	*P*-value	
Angus	99.8±3.41	0.0029±0.00008	600.1	11	5.4	0.014	54.7
Nellore	79.9±6.89	0.0037±0.0004	1139.3	9			
Overall	97.6±3.35	0.0030±0.00009	2673.1	22			

[1]$\log HP = \alpha + \beta \times MEI$
[2]$HP = \alpha \times e^{(\beta \times MEI)}$
[3]test the hypothesis that breed models are equivalent
HP = heat production, kcal/kg $EBW^{0.75} \cdot d^{-1}$; MEI = metabolizable energy intake, kcal/kg $EBW^{0.75} \cdot d^{-1}$.

Table 7: Net and metabolizable energy requirements for maintenance for Angus and Nellore bulls.

Item[1]	Lofgreen and Garret (1968)[2]		Ferrell and Jenkins (1998)[3]	
	Angus	Nellore	Angus	Nellore
NE_m, kcal/$EBW^{0.75} \cdot d^{-1}$	98.2	76.0	99.8	79.9
NE_m, kcal/$BW^{0.75} \cdot d^{-1}$	87.3	68.5	89.9	72.0
ME_m, kcal/$EBW^{0.75} \cdot d^{-1}$	157.1	123.1	157.6	128.6
ME_m, kcal/$BW^{0.75} \cdot d^{-1}$	139.7	110.9	140.1	115.9
k_m	0.64	0.65	0.63	0.62

[1]NE_m = net energy requirements for maintenance; ME_m = metabolizable energy requirements for maintenance; k_m = efficiency of use of ME_m for NE_m.
[2]$\log HP = \alpha + \beta \times MEI$
[3]$HP = \alpha \times e^{(\beta \times MEI)}$
HP = heat production, kcal/kg $EBW^{0.75} \cdot d^{-1}$; MEI = metabolizable energy intake, kcal/kg $EBW^{0.75} \cdot d^{-1}$.

Table 8: Parameters of equation[1] $NE_g = \alpha \times EBW^{0.75} \times EBG^{\beta}$

Item	**Parameter**		**RMSE**	**Residual**		**F**	***P*-value**
	α	**ß**		**Sum of Square**	**df**		
Angus	0.0615±0.0051	0.4936±0.1687	0.68	3.2	7	1.8	0.199
Nellore	0.0585±0.0039	0.2365±0.1259	0.89	4.8	6		
Overall	0.0662±0.0027	0.4067±0.0915	0.82	10.2	15		

[1]EBW = empty body weight, kg; EBG = daily empty body gain, kg/d.

Table 9: Regression of retained energy, kcal/EBW$^{0.75}\cdot$d^{-1}, on metabolizable intake, kcal/EBW$^{0.75}\cdot$d^{-1}, to describe energy utilization of Angus and Nellore bulls.

Item	Intercept	Slope	k_g	*P*-value	
				Intercept	Slope
Angus	25.7±15.8	0.190±0.094	0.19	0.3009	0.6145
Nellore	16.3±6.94	0.216±0.043	0.22		
Overall	20.5±4.05	0.206±0.020	0.21		

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CAPITULO 3

Technical note: Relationship between infrared thermography and heat production in young bulls

ABSTRACT. The traditional techniques to measure heat production (HP) are calorimetry (direct and indirect) and comparative slaughter. Both methods are expensive and require extensive amounts of time and infrastructure. Infrared thermography (IRT) could be a faster and less expensive alternative to estimate cattle HP. The objective of this study was to evaluate the use of IRT technique as an indicator of HP in cattle. A total of 24 bulls (12 Nellore and 12 Black Angus) with initial BW of 380 ± 7 kg were used. Initially, four animals of each breed were harvested (baseline animals) and simple regressions were developed for each breed from these baseline animals to estimate the initial chemical composition of the remaining bulls. Eight animals of each breed were fed for *ad libitum* intake a silage/concentrate diet in individual stalls. On the 25^{th}, 50^{th} and 75^{th} experimental day infrared thermal images (Fluke Ti 55ft, Fluke Corporation) were taken of each animal's face to access skin and ocular surface temperatures. A metabolism trial was conducted to estimate the ME intake (MEI). After 84 experimental days, the cattle were harvested and retained energy (RE) and HP were calculated. The data were analyzed using the MIXED and REG procedures of SAS adopting significance level of 0.05. Angus cattle had a greater daily MEI, HP and skin and eye temperatures than Nellore. We found significant correlations ($P \leq 0.005$) between daily HP and maximum (r = 0.65) and average skin temperatures (r = 0.65) and maximum (r = 0.65) and average ocular surface (r = 0.69) temperatures recorded on d 50. Infrared thermography has potential to be used to evaluate HP in cattle.

Key words: Angus, cattle, feed efficiency, non-castrate, Nellore, body temperature.

1 INTRODUCTION

The efficiency of feed utilization in animal production has obvious economic and environmental impacts. The proportion of feed energy converted in animal products is inversely related to the amount of energy that is not retained and lost by the animal. The proportion of the ME intake (MEI) lost by heat production (HP) is at the best around 60% (Lawrence and Fowler, 1997). Although the HP of an animal can be measured by calorimetry or comparative slaughter techniques, both methods are expensive and require considerable infrastructure. One potential alternative is infrared thermography (IRT). The IRT is a non-contact and non-invasive temperature measurement and has been evaluated to estimate cattle feed efficiency, since less efficient animals have greater HP and would present greater body surface temperature than more efficient animals (Montanholi et al., 2009a). Previous research comparing high and low residual feed intake cattle demonstrated that IRT images are reflective of feed efficiency (Montanholi et al., 2009b; DiGiacomo et al., 2014). Montanholi et al. (2008) found a strong relationship between HP measured by indirect calorimetry and surface skin temperature recorded by IRT. However, IRT had not been evaluated with comparative slaughter studies, where HP is estimated as the difference between the MEI and retained energy (RE; Lofgreen and Garret, 1968), and we hypothesized that both daily HP and temperatures recorded by IRT could be correlated. Therefore, the objective of this study was to evaluate the relationship between IRT and RE and HP in Angus and Nellore young bulls.

2 MATERIAL AND METHODS

All animal procedures were approved by the University's Bioethics Committee, protocol number 048/2012 and followed established standards for humane care and use. The study was conducted at the Universidade Federal de Lavras (Lavras, Minas Gerais, Brazil), located at latitude 21°14' south and longitude 45°00' west, and at an altitude of 918 m. During the experimental period, the average temperature was 23°C, with a high of 36°C and a low of 20°C. The average relative humidity was 75%.

Data for this study were obtained from 24 bulls (12 Angus and 12 Nellore), that came from a growing phase in a pasture system, with an initial BW of 380 ± 7 kg. Initially, four animals of each breed were slaughtered (baseline animals) and simple regressions were developed for each breed to estimate the initial chemical composition of the other bulls. The remaining cattle were housed in individual covered pens where eight animals of each breed were fed for ad libitum intake twice a day (at 0730 and 1530 h) a silage/concentrate diet (300 g/kg silage, 580 g/kg cracked corn grain, 100 g/kg soybean meal, and 20 g/kg commercial premix, on DM basis; 589 g/kg DM, 117 g/kg CP, 23 g/kg ether extract, 267 g/kg NDF and 541 g/kg non-fibrous carbohydrate, on DM basis) formulated according to NRC (2000) for an ADG of 1.4 kg/d. Daily feed and orts were weighed, sampled and dried at 55°C for 72 h. A 3 d digestion trial with total fecal and urine collection was conducted with all animals, between d 60 and d 63. Before the collections, the urine container was filled with 200 ml of 20% H_2SO_4 to avoid nitrogen losses. Feces and urine were weighed daily, and a 10% sample was collected. The urine samples were stored at -20°C and the feces samples were immediately dried at 55°C for 72 h.

Thermal images of the head were taken with an infrared camera (Fluke Ti 55ft, Fluke Corporation) on d 25, d 50 and d 75 of the experimental period, after the morning meal, between 0800 and 1000 h. The equipment has ±2% of precision. A half hour before and during the imaging procedures, the bulls were restrained in the shade provided by the covered pens. The average ambient temperatures recorded during imaging time at d 25, d 50 and d 75 were, respectively, 24.5, 24.5 and 21 °C. The emissivity value used was 0.98 and images were recorded from approximately 1.5 m of the animal's head. Face images were chosen because the face has cleaner surface than other body parts. The pictures were analyzed using the software SmartView 3.0. To delimit a constant area of evaluation, a circle, corresponding about 0.1% of the image area, was made around the ocular surface and this same circle was dragged to the region of the skin located immediately below the eye (Fig. 1). Skin temperature reflects heat dissipation (Scharf et al., 2014) and ocular surface is representative of the core body temperature (Dunbar et al., 2009). The maximum and average temperatures within these areas were defined as the infrared traits.

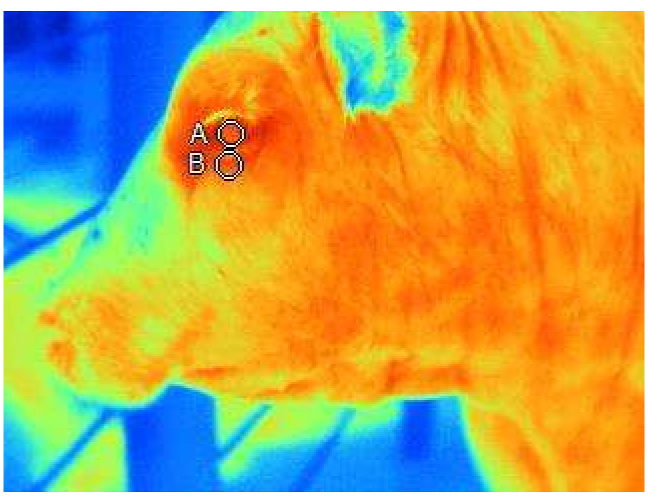

Figure 1: Illustrative infrared images of the head. The temperatures of ocular surface (A) and skin (B) were analyzed from surrounded areas.

After 84 experimental days, the bulls were stunned with a non-penetrating stunner and harvested by exsanguination using conventional humane procedures. Non-carcass compounds (internal organs, reproductive tract, hide, empty gastrointestinal tract, blood, tongue, head, feet and tail) were weighed, ground and sampled. The carcasses was split into two longitudinal halves and weighed before and after a 24 h chill. The left half of the carcass was weighed, ground and sampled, following the procedures proposed by Chizzotti et al. (2007). The collected samples were frozen, freeze-dried and ground.

The AOAC (1990) methods were used to determine DM (method 930.15), ash (method 942.05), ether extract (method 920.39) and nitrogen content (method 984.13) of feed, orts, feces and body samples. The protein content was estimated applying a conversion factor of 6.25 on the nitrogen content. The NDF was expressed exclusive of residual ash according to Mertens (2002) with use of α-amylase and sodium sulphite. Gross energy of diet ingredients, orts and feces were estimated assuming the heat of combustion of carbohydrate, protein and fat to be 4.186, 5.6405 and 9.3929 Mcal/kg, respectively (ARC, 1980). Gross energy of empty body (carcass and non-carcass compounds) also was estimated assuming the heat of combustion of protein and fat (Chizzotti et al., 2007). Metabolizable energy intake was determined by subtracting the energy lost in feces, urine and as methane of the energy ingested by the animal. The energy lost by methane emission was estimated through Eq. 1 (Ramin and Huhtanen, 2013), considering that each liter of methane has 0.650 g and that methane combustion produces 0.0133 Mcal/g (Holter and Young, 1992) and urine energy was estimated from urine N content (Gionbelli, 2013), assuming 33.85 calories per mg of nitrogen. The retained energy (RE) was estimated by the comparative slaughter technique, calculated as the difference between the final energy content in the animal's body, determinate by the body composition at the end of experiment, and the initial energy content, estimated by the body composition from the baseline animals (Lofgreen and Garret, 1968). The HP was calculated as the difference between MEI and RE.

$$\text{Methane (L/d)} = -64 + 26 \times \text{DMI} - 0.61 \times (\text{cDMI})^2 + 0.25 \times [\text{OMD} + 1.83 \times (\text{DMIBW} - 10)] - 66.4 \times \text{EEI} - 45 \times (\text{NFC/CHO}) \quad \text{Eq. [1]}$$

Where DMI, kg/d; cDMI is centered DMI, kg/d; OMD is OM digestibility, g/kg DM; DMIBW is the relationship between DMI and BW, g/kg; EEI is ether extract intake, kg/d; NFC is non-fiber carbohydrate, g/kg DM; and CHO is total carbohydrate, g/kg DM.

Statistical analyses were performed using SAS 9.2 (SAS Inst. Inc., Cary, NC). Data from performance, intake and energy losses were analyzed as completely randomized design and the infrared traits and average daily DMI by period (from d 1 to d 24, DMI-25; from d 25 to d 49, DMI-50; and from d 50 to d 74, DMI-75) as repeated measures, using the MIXED procedure, considering breed (Angus or Nellore) as fixed and animal and day sampling (for repeated measures) as random effect. The comparisons of means were performed using least squares means at $P = 0.05$. Linear regression analysis between DMI, MEI, HP, and RE and IRT traits was performed with the GLM procedure, and the slope was compared to detect breed effects ($P < 0.05$). Pearson correlation coefficients between infrared variables and efficiency traits were calculated using the CORR procedure.

Table 1: Effect of breed on performance, intake and energy losses.

Item	Angus	Nellore	SEM	*P* - value
Initial BW, kg	386	374	11.8	0.474
Final BW, kg	550	461	14.8	0.002
DMI, kg/d	13.7	9.7	0.52	< 0.001
GE intake, Mcal/d	57.9	41.0	2.3	< 0.001
ME intake, Mcal/d	37.2	25.8	1.62	< 0.001
RE, Mcal/d	6.8	4.7	0.38	0.001
Energy losses				
HP[1], Mcal/d	30.4	21.1	1.36	< 0.001
Feces, Mcal/d	15.1	12.2	1.1	0.094
Urine, Mcal/d	0.74	0.81	0.09	0.619
Methane[1], Mcal/d	3.6	2.9	0.1	< 0.001

HP = heat production; RE = retained energy.
[1]The equations are showed in the text body.

3 RESULTS AND DISCUSSION

Angus cattle presented MEI, GE intake, and HP around 30% greater than Nellore bulls ($P < 0.001$; Table 1). The relationship between MEI and HP is exponential because an increment of intake leads to a rise of organ metabolic activity, caused by digestion, absorption and metabolism of nutrients (Chizzotti et al., 2008). Consequently, a rise in heat losses could reflect in an increase on the body temperature. In fact, Angus bulls also had greater body temperatures measured by IRT (Table 2). The animals presented greater body temperature recorded on d 50 ($P < 0.05$), with no difference found between d 25 and d 75.

Table 2: Effect of breed and experimental days on dry matter intake and infrared traits.

	Angus			Nellore				*P* - Value		
Item	d 25	d 50	d 75	d 25	d 50	d 75	SEM	Breed	Day	Breed*Day
DMI[1], kg/d	12.3[Ab]	14.6[Aa]	13.7[Aab]	10.1[A]	10.2[B]	11.0[B]	0.58	< 0.001	0.025	0.012
Maximum ocular surface, °C	35.3[b]	37.2[a]	35.0[b]	35.2[b]	36.6[a]	34.6[b]	0.21	0.036	< 0.001	0.532
Average ocular surface, °C	33.5[b]	35.5[a]	33.2[b]	33.6[b]	34.8[a]	32.7[b]	0.23	0.097	< 0.001	0.150
Maximum skin, °C	34.9[Ab]	36.8[a]	34.8[b]	33.7[Bb]	35.9[a]	34.1[b]	0.25	< 0.001	< 0.001	0.593
Average skin, °C	33.7[b]	35.6[a]	32.7[b]	32.5[b]	34.6[a]	32.8[b]	0.30	0.012	< 0.001	0.438

[A-B]Distinct capital letters in the same row, within days, differ at P < 0.05 by least squares means for breed effect.

[a-b]Distincts lowercase letter in the same row, within breed, differ at P < 0.05 by least squares means.

[1]DMI by period, d 25 = from d 1 to d 24; d 50 = from d 25 to d 49; d 75 = from d 50 to d 74

There was no breed effect on slope ($P \geq 0.05$) of the regressions between DMI, MEI, HP, and RE and infrared traits. The overall correlations are reported in Table 3. The maximum and average ocular surface and skin temperatures measured on d 50 were correlated ($P \leq 0.005$) with DMI, MEI, HP and RE (Figure 2). There was no correlation of temperatures recorded on d 75 ($P \geq 0.170$) with the efficiency traits, while only maximum skin temperatures collected on d 25 were correlated with DMI ($P = 0.038$; r = 0.51), MEI ($P = 0.035$; r = 0.51), HP ($P = 0.046$; r = 0.49) and RE ($P = 0.031$; r = 0.52). When DMI was divided by period, only DMI-50 was correlated with IRT traits recorded on d 50 ($P \leq 0.028$; Table 3), with no correlation found between temperatures on d 25 and d 75 and theirs respective DMI accumulated by periods ($P \geq 0.081$). In the comparative slaughter technique, HP is representative of the energy lost during the experimental period, but might be dynamic during the trial. Therefore, the temperatures recorded at middle of study may have represented better the daily heat losses for this trial.

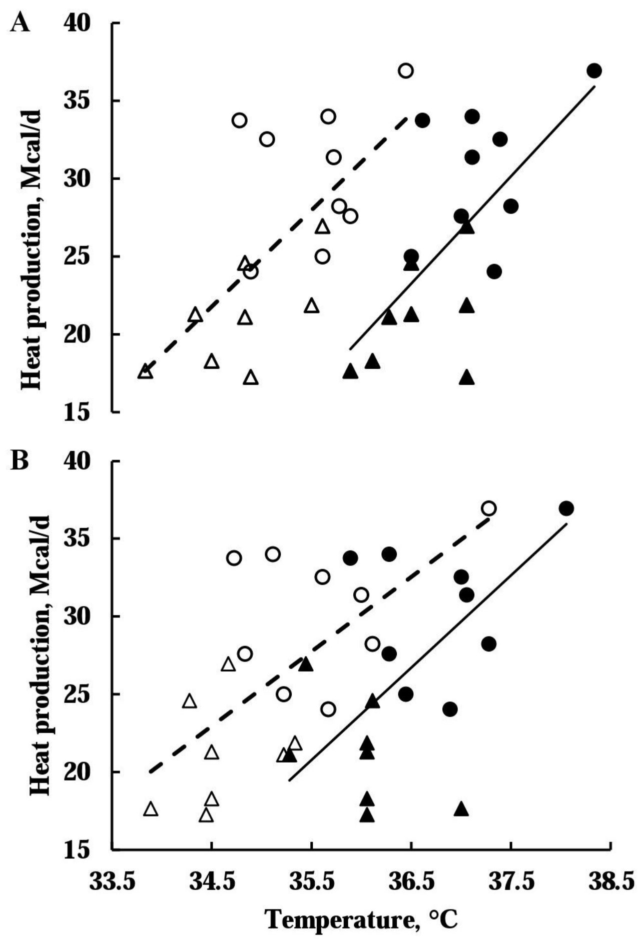

Figure 2: Skin temperatures on the d 50. Solid lines and filled symbols represent the maximum temperatures; dashed lines and nonfilled symbols represent average temperatures. Circles are for Angus and triangles are for Nellore data. Equations are HP = –225 (± 75) + 6.81 (± 2.04) × MaxOcular (P = 0.004, RMSE = 4.8, R^2 = 0.43); HP = –193 (± 61) + 6.2 (± 1.73) × AvgOcular (P = 0.003, RMSE = 4.6, R^2 = 0.46); HP = –

187 (± 62) + 5.86 (± 1.69) × MaxSkin (*P* = 0.004, RMSE = 4.7, R^2 = 0.44); and HP = –141 (± 51) + 4.77 (± 1.45) × AvgSkin (*P* = 0.005, RMSE = 4.8, R^2 = 0.42), in which MaxOcular = maximum ocular surface temperature, AvgOcular = average ocular surface temperature, MaxSkin = maximum skin temperatures, AvgSkin = average skin temperature, and RMSE = root mean square error.

Table 3: Person correlation coefficients between infrared traits recorded at 50th and DMI, ME intake and heat production.

Temperatures	DMI (*P* - value)	DMI-50[1] (*P* - value)	MEI[1] (*P* - value)	HP[1] (*P* - value)	RE[1] (*P* - value)
Maximum ocular surface	0.73 (0.001)	0.68 (0.005)	0.67 (0.003)	0.65 (0.004)	0.65 (0.005)
Average ocular surface	0.70 (0.002)	0.57 (0.0026)	0.70 (0.002)	0.69 (0.003)	0.67 (0.003)
Maximum skin	0.78 (< 0.001)	0.66 (0.007)	0.71 (0.002)	0.65 (0.005)	0.77 (< 0.001)
Average skin	0.75 (0.001)	0.56 (0.028)	0.68 (0.003)	0.65 (0.005)	0.72 (0.001)

[1]DMI-50 = daily DMI from d 25 to d 49; MEI = ME intake; HP = heat production; RE = retained energy.

It should be emphasized that the high cost and labor required for a comparative slaughter experiment make it difficult to collect a bigger sample size, which could improve the accuracy of the results. Even then, this study indicates that both areas, ocular surface or skin, are suitable to predict HP and the evaluation of the average or the maximum temperature in the selected area can be used to evaluate the HP in cattle but the average ocular surface temperature was slightly superior, and beside this, it is easier to demarcate a standard anatomical area to be analyzed, which could minimize the sampling error between animals.

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