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Tese

Diferenças entre raças e heterose no crescimento, eficiência alimentar e carcaça de bovinos de corte puros e cruzados no sul do Brasil

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Tese apresentada ao Programa de Pós-Graduação em Zootecnia da Universidade Federal de Pelotas, como requisito parcial à obtenção do título de Doutor em Ciências (área do conhecimento: Melhoramento animal).

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RESUMO

LEAL, Willian Silveira. **Diferenças entre raças e heterose no crescimento, eficiência alimentar e carcaça de bovinos de corte puros e cruzados no sul do Brasil**. 2019. Tese (Doutorado) – Programa de Pós-Graduação em Zootecnia. Universidade Federal de Pelotas, Pelotas.

ABSTRACT: O objetivo deste estudo foi avaliar o desempenho de bovinos de corte puros e cruzados criados no sul do Rio Grande do Sul. Diferentes grupos genéticos foram utilizados: touros Caracu (C), Hereford (H) e Nelore (N) acasalados com fêmeas Angus (A), e touros A acasalados com fêmeas H e N para produzir uma primeira geração de animais cruzados que foram contemporâneos com animais puros A, H e N. Novilhas dessa primeira geração foram acasaladas com touros Brangus (BN) e Braford (BR) para produzir a segunda geração, os quais foram avaliados até a desmama. Os dados foram analisados para estimar as médias dos grupos, efeito individual e materno das raças, e efeito de heterose para peso ao nascer, peso a desmama, ganho de peso pré-desmama, peso ao sobreano, ganho de peso pós-desmama, peso ao abate (em torno dos 24 meses), idade ao abate, ganho de peso durante a terminação, consumo alimentar e características de eficiência alimentar em confinamento, bem como características de carcaça de animais terminados em confinamento e em pastagem. De maneira geral, bezerros cruzados apresentaram melhor desempenho do que os puros. Fêmeas AN e CA desmamaram bezerros mais pesados. Novilhos AN, NA e CA foram mais pesados ao sobreano enquanto que novilhos NA, CA, AN foram mais pesados ao abate. Os efeitos das raças taurinas foram maiores que o efeito da raça N para características de desempenho pós desmama. Em relação a avaliação das características de eficiência alimentar medidas em confinamento, a raça H mostrou menor ingestão de matéria seca (IMS). Hereford e A tiveram menor taxa de conversão alimentar. Todos os grupos genéticos apresentaram consumo alimentar residual (CAR) negativo, sendo o grupo H menor que os demais. Os efeitos individuais das raças H e C foram negativos para IMS, e a raça H apresentou efeito individual negativo para CAR. Para as características de carcaça, novilhos NA obtiveram maior peso de carcaça em pastagem e rendimento de carcaça em confinamento. O cruzamento AN mostrou melhores pesos de traseiro, costela e dianteiro em pastagem. Efeito individual da raça C foi negativo para cobertura de gordura. Os efeitos positivos da heterose entre taurinos e zebuínos deve ser explorado para melhorar a eficiência dos sistemas de produção de bovinos de corte no sul do estado. A utilização do germoplasma C mostrou-se proveitoso para incrementar características pré-desmama.

Palavras chave: cruzamento, carcaça, heterose, eficiência alimentar.

ABSTRACT

LEAL, Willian Silveira. **Differences between breeds and heterosis on growth, feed efficiency and carcass of purebred and crossbred beef cattle raised on southern Brazil**. Thesis (Doctor) – Animal Science Post Graduation. Federal University of Pelotas, Pelotas.

The aim of this study was evaluating the performance of pure and crossbreed beef cattle raised in Rio Grande do Sul state. Different genetic groups were tested: Caracu (C), Hereford (H), and Nelore (N) sires were mated with Angus (A) dams, and A sires were mated with H and N dams to produce a first generation of crossbred progeny that were contemporary with purebred A, H, and N calves. Heifers from this first generation (G1) were mated with Brangus (BN) and Braford (BO) sires to produce a second generation (G2) of progeny, that were evaluated until weaning. Data were analyzed to estimate breed group means, individual and maternal breed additive effects, and heterosis effects on birth weight, weaning weight, pre-weaning average daily gain, yearling weight, post-weaning average daily gain, final weight (around 24 months), average daily gain in the fattening phase and age at slaughter, feed efficiency traits, carcass traits in animals fattened on feedlot or pasture as well. . In general, crossbred calves outperformed purebred calves. Angus-N and CA crossbred cows weaned heavier calves. Individual taurine-indicine heterosis (Z) significantly increased weaning weight. The AN, NA and CA steers were heaviest at yearling, while NA, CA, AN, and HA had the greatest final weights. In relation to feed efficiency traits measured in feedlot H breed showed lower dry matter intake (DMI). Hereford and A had lower feed conversion ratio. All genetic groups showed negative residual feed intake (RFI) being H lower than other. Hereford and C individual breed effect were negative to DMI and H showed negative breed effect to RFI. To carcass traits NA steers had higher carcass weight in pasture and dressing percentage in feedlot. The AN crossing showed better weights of primary carcass cuts. Caracu individual breed effect was negative to back fatness. Positive effects of heterosis between taurine and indicine should be explored to increase beef cattle production efficiency. Caracu germplasm proved to be beneficial for increasing pre-weaning traits.

Key-words: crossbreeding, carcass, heterosis, feed efficiency.

Sumário

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Introdução

O agronegócio brasileiro representa 21,6% do PIB do Brasil, sendo que o ramo pecuário participa com 6,6% do PIB (CEPEA/ESALQ – USP, 2018). Essa referência confirma a importância do agronegócio para o país. No Rio Grande do Sul, o rebanho bovino diminui em torno de 6,4% dos anos de 2010 para 2016, com atualmente 13.590.282 cabeças (EMATER-RS, 2018), e as áreas de soja, principal cultura agrícola do estado, aumentaram ao redor de 37,8% no ano de 2017 em relação a 2010.

O exposto acima nos mostra que mesmo com um crescimento importante das áreas agrícolas, o rebanho teve leve redução, nos levando a acreditar que a pecuária tem conseguido manter seus números em áreas reduzidas ou menos produtivas, ou seja, houve uso de algum tipo de tecnologia que fez com que a produção se mantive em níveis estáveis.

Atualmente existem diversas tecnologias disponíveis para auxiliar no incremento da produtividade da pecuária de corte. O melhoramento genético é uma dessas ferramentas, e dentro do melhoramento podemos citar o cruzamento entre raças, que é de baixo custo e de rápida resposta.

O cruzamento tem por objetivo explorar a heterose, ou vigor híbrido, que seria a superioridade média dos filhos cruzados em relação a média dos pais puros e a complementariedade entre raças, ou seja, características de interesse econômico presentes em uma raça e ausente, ou de baixa expressão, em outra (PEREIRA, 2008). Em um sistema de cruzamento podemos explorar a heterose individual, a materna e a paterna (menos usual). Em bovinos de corte a heterose individual pode aumentar a taxa de concepção em 6%, o peso ao nascer em 3% e peso a desmama em 5%. Já a heterose materna, pode aumentar o peso ao nascimento em 1,5%, o peso a desmama em 8% e o peso ao sobreano em 2% (BOURDON & BOURBON, 2000). Portanto, o cruzamento é uma ferramenta disponível ao produtor, porém, a correta utilização e cruzamento das raças é de extrema importância para explorar ao máximo a heterose e complementariedade entre as raças de maneira correta e sustentável ambiental e economicamente.

Hipóteses

- Animais da primeira geração do cruzamento entre taurinos e zebuínos apresentam melhor performance em relação aos puros;
- A utilização de fêmeas cruzadas aumenta o peso ao nascer e a desmama das progênies;
- As heteroses individual e materna são positivas e significativa para as características de interesse econômico;
- A raça Caracu pode ser usada no cruzamento com raças britânicas no sul do Brasil como uma alternativa às raças zebuínas;
- Animais de raças taurinas apresentam melhor desempenho em condições favoráveis de terminação.

Objetivos

O objetivo geral do trabalho foi avaliar o desempenho de bovinos de corte puros e cruzados, do nascimento até a terminação, considerando dois sistemas de terminação, em pastagem cultivada e confinamento, de acordo com os seguintes objetivos específicos:

1) Avaliar o desempenho de fêmeas e machos, puros e cruzados, na fase pré-desmama;
2) Avaliar o desempenho pós-desmama, rendimento e qualidade da carcaça dos diferentes genótipos em confinamento e em pastagem; e,
3) Desenvolver um modelo bioeconômico para auxiliar na tomada de decisão em relação a escolha das raças e do esquema de cruzamento.

Revisão de literatura

Utilização do cruzamento na pecuária

Aumentar a produtividade da pecuária de corte através do melhoramento genético se dá basicamente através de duas maneiras: 1 – seleção dentro de raças para características específicas; 2 – seleção entre e combinação de raças para produzir indivíduos que desempenhem melhor de acordo com o ambiente ao qual estão expostos (LONG, 1980).

O cruzamento nos permite explorar os efeitos genéticos não aditivos (dominância, sobredominância e epistasia), a heterose, ou vigor híbrido, e a complementariedade entre raças (PEREIRA, 2008).

A teoria da dominância refere-se a interação entre alelos do mesmo locos e seu efeito ocorre no genótipo heterozigoto, e o grau de dominância entre os alelos é que determina o valor da característica expressa pelo heterozigoto. Já a sobredominância ocorre quando o valor fenotípico do heterozigoto é superior a um dos homozigotos. Existem evidências que características relacionadas ao potencial de adaptação ao ambiente são controladas por genes sobredominantes, ou seja, os heterozigotos seriam mais vigorosos (RAMALHO et al., 2012). E por fim, a epistasia é a interação entre alelos de diferentes locos, com um loco alterando a expressão de outro (RAMALHO et al., 2012).

Essa complementariedade entre raças, nada mais é que a escolha de características que uma determinada raça possui e que é ausente ou de baixa expressão em outra, como por exemplo, a rusticidade e a tolerância ao carrapato do Nelore, complementa o Angus em um cruzamento, e em contrapartida, a raça Angus é precoce e produz carcaça e carne de qualidade superior, logo os produtos desse cruzamento serão rústicos e com habilidade de produção de carcaça.

O termo heterose foi proposto por Shull em 1914, e serve para descrever a superioridade média dos filhos em relação a média dos pais de linhagens ou raças puras. A literatura mostra resultados da utilização do cruzamento e exploração da heterose em diversas espécies, como por exemplo, em aves (FIGUEIREDO et al., 1998; BESBES, 2009), suínos (YEN et al., 1991; VISSCHER et al., 2000), em bovinos de corte (CUNDIFF, 1970; TEIXEIRA & ALBUQUERQUE, 2005), e em bovinos de leite (MADALENA et al., 1990; MULLEN & WASHBURN, 2016). Os tópicos a seguir irão dissertar sobre os efeitos da heterose em diferentes características de interesse produtivo.

Desempenho de bovinos de corte cruzados

De acordo com Koger (1980), o principal objetivo de um sistema de cruzamento envolvendo bovinos de corte, é maximizar a soma dos valores aditivos e os níveis de heterose para cada característica de interesse. Nesse sentido, Long (1980) em extensa revisão sobre cruzamentos em para produção de bovinos de corte, fazendo uso de dados de diversos trabalhos que estudaram várias raças, verificou que em média a heterose para peso ao nascer é de 1 a 11% para cruzamentos envolvendo taurinos britânicos (Angus, Hereford e Shorthorn) e continentais (Charolês) e suas cruzas com zebuínos (Brahman). Para peso a desmama, a heterose varia de 3 a 16% - na média 5% - para os mesmos sistemas de cruzamento citados anteriormente. A heterose para ganho de peso pós-desmama foi de 2 até 11% - na média 6% - e para peso ao sobreano de 2 a 7%.

Com o objetivo de estimar os efeitos aditivos e heteróticos, diretos e marternos, nas raças Charolesa e Nelore, para o peso ao nascer e à desmama e o ganho médio diário pré-desmama, Trematore et al. (1998), verificaram efeito aditivo direto da raça Charolesa para peso ao nascer de 2,07 kg como desvio ao Nelore, e de 9,99 kg para peso a desmama. Para as mesmas características, os autores verficaram efeito heterótico individual de 1,66 e 14,77 kg, para peso ao nascer e peso a desmama, respectivamente. Já para heterose materna, o efeito foi de 0,62 e 44,16, para peso ao nascer e à desmama, nessa mesma ordem, em relação ao Nelore. Esses resultados mostram os efeitos positivos do cruzamento e do uso de matrizes cruzadas, já que os filhos cruzados foram 8,69% mais pesados a desmama, e alcançaram ganho médio diário 8,18% superior em comparação à média dos puros.

Dillard et al. (1980) estudando o desempenho e os efeitos aditivos e heteróticos e um rebanho das raças puras Angus (A), Hereford (H), e suas cruzas entre si e com Charolês (C), constataram heterose para peso a desmama de 4,4% nos cruzamentos A x H e H x A, em relação a médias dos puros, e 6,2% para ganho diário nos cruzamentos C x H e H x C, em relação ao puros. No mesmo estudo, os autores verificaram efeito genético aditivo da raça C para peso a desmama de 20,1 kg, como desvio ao H, e efeito heterótico do cruzamento H x C de 9,5 kg para a mesma característica.

Peacock et al. (1981), em trabalho similar ao citados anteriormente, porém, trabalhando com as raças Angus (A), Charolês (C) e Brahman (B) e suas cruzas, verificaram efeito aditivo da raça B para peso a desmama, ajustado para 205 dias, de -18 kg, e de -3,6 kg para a raça A. A heterose materna proporcionou um efeito positivo de 24,3 kg quando os produtos eram filhos de vacas A x B. No mesmo estudo foi verificado que a taxa de desmama nos rebanhos puros foi de 74,7 %, enquanto que nos rebanhos em sistema de cruzamento rotacionado em três raças, a taxa teve média de 84,7%.

Usando dados de trabalhos publicados entre 1976 e 1996, Williams et al. (2010) inferiram os efeitos aditivo e materno, e a heterose direta e materna de raças taurinas britânicas e continentais, um zebuíno (Brahman), e taurinas britânicas e continentais especializadas na produção de leite, e os cruzamentos entre si. O estudo, que usou a raça Angus como base, verificou efeito direto da raça Simmental de 15,81 kg para ganho de peso pós desmama (em relação ao Angus) e de -17,85 kg para o Brahman, e heterose direta de 14,68 kg para ganho pós desmama nos cruzamentos entre taurinos britânicos e zebuínos.

Vaz et al. (2001) estudaram o desempenho de novilhos Nelore, Charolês e suas cruzas, terminados em confinamento e pastagem de inverno, e verificaram heterose de 10,7% para peso ao abate, tendo sido a média dos cruzados de 465 kg e a dos puros 420 kg.

Avaliando o desempenho em confinamento de novilhos Hereford e suas diferentes composições com Nelore, Restle et al. (2000) constataram maior peso ao abate em novilhos ½ sangue H x N (426 kg) e menor em novilhos ¼ Hereford ¾ Nelore (382 kg).

Efeitos do cruzamento sobre características da carcaça

O mercado de comercialização de bovinos para abate está migrando de um sistema onde o pagamento é feito pelos kg de peso vivo do animal, para um sistema que paga pelo kg de carcaça. Além disso, os modelos de bonificação paga ao produtor por animais de melhor qualidade, levam em conta, de maneira geral, o peso de carcaça, a idade e a cobertura de gordura do animal. Logo, a escolha de raças e suas combinações que proporcionem carcaças pesadas e com boa cobertura de gordura em uma idade jovem (18 – 24 meses) é de grande importância dentro dos sistemas de produção.

Segundo Cundiff (1970) os efeitos da heterose tendem a ser maiores para características da carcaça relacionadas ao crescimento e menores para as demais. A revisão de Long (1980) corrobora com essa afirmação, já que o autor encontrou efeito da heterose para área de olho de lombo (relacionada com o crescimento) da ordem de -1 a 7%, e -3 a 3% para qualidade de carcaça (USDA quality grade), sendo esta última sem relação com o crescimento.

Williams et al. (2010) mostraram em sua revisão que os animais de origem britânica continental das raças Charolês e Simmental obtiveram 53,40 e 35,49 kg, respectivamente, de efeito direto da raça em desvio ao Angus. Ainda na mesma revisão de literatura, a raça Limousin demonstrou efeito direto de 17,43 cm^2 para área de olho de lombo, em desvio ao Angus. Em relação a cobertura de gordura, o trabalho mostra que todas as principais raças (Hereford, Shorthorn, Charolês, Limousin, Simmental, Brahman) tiveram efeito direto negativo para cobertura de gordura em desvio ao Angus, ou seja, a maior participação de genes dessas raças em cruzamentos, tende a diminui a cobertura de gordura. Porém, a heterose foi positiva entre cruzas britânicas x zebuínos, britânicas x britânicas e continentais x zebuínos. Essa mesma heterose em cruzas britânicas x zebuínos foi de 42,04 kg a mais em relação ao peso de carcaça do Angus puro.

Em um estudo envolvendo as raças Red Poll, Brown Swiss, Hereford, Angus e suas cruzas, Gregory et al. (1978), encontraram efeito direto da raça Angus de 6,4 kg e de 16,8 kg da raça Brown Swiss, para peso ao abate e peso de carcaça, nessa mesma ordem, em relação à média geral das raças puras (458,7 kg e 271,4 kg). Já a heterose individual para peso de carcaça foi 13,2 kg nos cruzamentos envolvendo Brown Swiss em relação a médias das raças puras.

DeRouen et al. (1992) trabalhando com dados de cruzamentos entre as raças Angus (A), Hereford (H), Charolês (C) e Brahman (B), coletados entre 1970 e 1987 em Louisiana, EUA, encontraram efeitos da raça B de -20,4 kg para peso de carcaça quente em relação a média geral (272,9 kg), e efeito de heterose de 59,6 kg no grupo genético AB em relação a média geral. Já para o mesmo grupo genético, o efeito da heterose materna foi de -5,9 kg de carcaça. E em relação a cobertura de gordura, as raças A e H apresentaram efeito direto de 0,3 cm em desvio a média geral (0,81 cm), e valores de heterose individual de 0,24 cm no grupo AB e heterose materna de 0,09 cm no grupo AH.

Trabalhando com as raças puras Charolesa (C), Limousin (L), Hereford (H), Braunvieh (B), Angus (A), Gelbvieh (G), Simmental (S), Pinzgauer (P) e Red Poll, e a formação dos compostos MARC I ((C x LH) x (B x LA)), MARC II (GH x AS ou AS x GH) e MARC III (PA x RH ou RH x PA), em Nebraska, EUA, Gregory et al. (1994) verificaram que o composto MARC II apresentou heterose de 30,7 kg para peso ao abate em relação a média dos puros, e 0,028 kg de heterose para ganho diário em confinamento. O mesmo composto demonstrou heterose de 19,2 kg de carcaça em relação aos puros envolvidos na formação.

Peroto et al. (2000) trabalharam com novilhos inteiros, terminados em confinamento, Caracu, Charolês e duas gerações avançadas de cruzamentos recíprocos em um sistema alternado de cruzamentos entre essas duas raças. Os autores verificaram que a heterose retida, ou seja, a média dos animais ¾ e 5/8 menos a média dos puros, foi de 26,6 kg para peso de carcaça quente e de 0,74% para rendimento de carcaça.

A literatura nos diz que a heterose é inversamente proporcional a herdabilidade (CARPENTER, 1973; PRESTON e WILLIS, 1974). Logo, características de alta herdabilidade, como as características quantitativas de carcaça, não poderiam ter grandes respostas a heterose. Contudo, LONG (1980) cita evidências de que a resposta heterótica para algumas medidas de gordura da carcaça permanece mesmo após o ajuste para diferenças de peso.

Características de eficiência alimentar e suas respostas ao cruzamento

Sabendo que a alimentação é o item de maior impacto dentro de um centro de custos (PACHECO et al. 2006), podendo alcançar até 70% do custo de produção de um sistema de terminação (RESTLE & VAZ, 1999), a busca por eficiência alimentar dentro dos sistemas de produção é cada vez mais necessária, em função da sustentabilidade e viabilidade da pecuária de corte.

Moore et al. (1975), em trabalho clássico com diversas raças de bovinos de corte, concluíram que a raça Hereford é que melhor responde ao incremento da qualidade da dieta, devido a eficiência na retenção de nitrogênio e por apresentar maiores taxas de digestibilidade da energia, porém isso não se confirma quando o nível alimentar é baixo. Entretanto, em climas tropicais, os zebuínos (Nelore, Guzerá, Gir, Brahman) e os taurinos adaptados (Caracu) desempenham melhor em função da rusticidade e do melhor aproveitamento de dietas ricas em fibras de baixa qualidade (ALONSO et al., 2013)

Existem diversas características de eficiência que podem ser levadas em conta no momento da seleção dos bovinos ou da escolha do melhor sistema de cruzamento. Entre elas podemos citar a conversão alimentar, que seria a quantia de alimento consumido para o ganho de peso vivo e a eficiência de ganho, que seria o oposto da conversão, porém, a conversão alimentar é fortemente correlacionada geneticamente ($r_g > 0,50$) com características de crescimento e sua seleção poderia aumentar o mérito genético para crescimento e peso madura das fêmeas do rebanho de cria (HERD & BISHOP, 2000), o que, em nossos sistemas baseados a pasto, não seria interessante, já que quanto maior o tamanho adulto, maiores são as exigências para manutenção.

Existem também algumas medidas não tradicionais, mas que também são utilizadas em experimentos de avaliação de eficiência alimentar. Podemos citar, então, a Kleiber Ratio (KR), que nada mais é que o ganho de peso por unidade de medida metabólica, e usada em situações onde a avaliação do consumo não é possível devido a sua alta correlação com a conversão alimentar (ESKANDARINASAB et al., 2010). Também há Taxa Relativa de Crescimento (TRC) que é o crescimento do animal expresso em porcentagem da mudança de peso vivo por dia, e que devido a sua baixa correlação genética com o peso corporal (FITZHUGH, JR. & TAYLOR, 1971) pode ser usada para selecionar animais mais eficientes – de crescimento mais precoce – sem selecionar indiretamente para aumento de peso corporal.

Outra medida seria o consumo alimentar residual (CAR), que também é uma característica de eficiência alimentar que vem sendo bastante utilizada, pois é geneticamente independente do peso a idade adulta (ARCHER et al., 1999). O CAR é a diferença entre o consumo observado e o consumo esperado com base na regressão da ingestão da matéria seca diária em função do ganho médio diário e do peso metabólico. Uma seleção através do CAR pode diminuir os custos com alimentação em até 10% (HERD et al., 2003), a produção de dejetos em 8-16% e a emissão de metano em 24-28% (NKRUMAH et al., 2006).

De acordo com Cundiff (1970) o efeito da heterose para características de eficiência alimentar é muito pequeno. Em trabalho de revisão, Long (1980) relata que animais cruzados geralmente requerem menos alimento por unidade de ganho do que os puros, muito provavelmente devido a uma taxa de ganho relativo ao peso metabólico maior.

Em um estudo sobre o desempenho em confinamento de vacas de descarte das raças Nelore, Charolês e ½ sangue oriundo do cruzamento dessas raças, Restle et al. (2001) verificaram heterose de 3,57% para consumo de matéria seca por 100 kg de peso vivo e de 5,84% para conversão alimentar, em relação a média das raças parentais puras (2,88% e 8,73, respectivamente), tendo nesse caso, os animais cruzados apresentado pior conversão alimentar, já que quanto menor for a conversão alimentar, mais eficiente o animal é. Segundo os autores, esse efeito é resultado da maior ingestão de matéria seca das vacas cruzadas. Por outro lado, Restle et al. (2000) trabalhando com animais inteiros e castrados terminados em confinamento, concluíram que a heterose para conversão alimentar foi de -3,46 na média dos cruzados Charolês x Nelore – e cruzamento recíproco – em comparação à média dos puros, sendo, portanto, nessa situação, o grupo cruzado mais eficiente do ponto de vista alimentar.

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Capítulo 1 – Artigo 1

Direct and maternal breed additive and heterosis effects on growth traits of beef cattle raised in southern Brazil

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Direct and maternal breed additive and heterosis effects on growth traits of beef cattle raised in southern Brazil

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ABSTRACT: The objective of this study was to compare growth from birth to slaughter of different breed groups that were raised in Rio Grande do Sul, Brazil and estimate the consequent breed additive and heterosis effects. Caracu (C), Hereford (H), and Nelore (N) sires were mated with Angus (A) dams, and A sires were mated with H and N dams to produce a first generation of crossbred progeny that were contemporary with purebred A, H, and N calves. Heifers from this first generation (G_1) were mated with Brangus (BN) and Braford (BO) sires to produce a second generation (G_2) of progeny. Data were analyzed to estimate breed group means, individual and maternal breed additive effects, and heterosis effects on birth weight, weaning weight, pre-weaning average daily gain, yearling weight, post-weaning average daily gain, fattening phase initial weight (around 19 months), final weight (around 24 months), average daily gain in the fattening phase and age at slaughter. In general, crossbred calves outperformed purebred calves. Angus-N and CA crossbred cows weaned heavier calves. Individual taurine-indicine heterosis (Z) significantly increased weaning weight. The AN, NA and CA steers were heaviest at yearling, while NA, CA, AN, and HA had the greatest final weights. However, AH steers were 1 month older at slaughter than NA contemporaries. Taurine breed effects on post-weaning traits and final weight were greater than for N. Maternal breed effects on birth weight and ADG in the fattening phase were greater for A and H than for N. In conclusion, heterosis effects were sufficiently large for use of N to be recommended as a component of such systems, despite their relatively low breed additive effects compared to taurine breeds. Moreover, germplasm from the tropically adapted *Bos taurus* C may be particularly useful when increased milk production is desired. With the breed and heterosis effects derived in the present study, it is possible to predict the performance and infer which breed and breed crosses will perform better in crossbreeding systems designed for the subtropical conditions of Southern Brazil and similar regions.

Key words: crossbreeding, indicine, performance, steers, taurine

INTRODUCTION

Use and benefits of crossbreeding have been widely reported (e.g., Gregory et al., 1966; Cundiff, 1970; Williams et al., 2010). Crossbred animals grow more rapidly and are better adapted, particularly when the parental breeds are genetically distant (e.g., *Bos Taurus* and *Bos indicus* crosses). This better performance occurs due the combination of breed complementarity of breed additive effects and heterosis (Gregory et al., 1966; Cundiff, 1970). In addition to the genetic effects on individual performance, heterosis also enables crossbred dams to increase milk production and thus provide a maternal environment that supports greater pre-weaning growth.

Dickerson (1969; 1973) presented mathematical models to partition breed groups into their genetic components allowing estimation of direct and maternal breed additive effects, and individual and maternal heterosis. Henderson (1977) proposed estimating these effects using multiple regression methods and using them in prediction of untested crosses. Robison et al. (1981) and MacNeil et al. (1982) provide early examples of the use of these approaches. However, the use of this approach to design optimal breed combinations and crossbreeding systems entails the availability of reliable parameter estimates under the local conditions and systems where the crossbred animals will be raised. Therefore, the aim of this study was to partition variation among breed groups into breed additive and heterosis effects on growth traits that were recorded from birth to slaughter of beef cattle that had been raised in southern subtropical part of Brazil.

MATERIAL AND METHODS

All experimental procedures that involved animals were approved by the Committee for Ethics in Animal Experimentation from the Federal University of Pelotas (Pelotas, Brazil; Process CEEA No. 8250-2015).

This study was conducted from 2006 to 2016 at Embrapa Pecuária Sul Research Center of the Brazilian Agricultural Research Corporation (Embrapa), located in the city of Bagé, Rio Grande do Sul State, Brazil. The regional climate is subtropical, according to Koppen classification, with precipitation evenly distributed throughout the year (1350 mm average). Numerous environmental stressors including: cold during winter (min. 9.4 – max. 16 ºC on average), heat during summer (min. 19.5 – max. 27.8 ºC on average), infestation of *Erasgostis plana* weed in pastures, and external parasites, particularly *Rhipicephalus microplus* ticks.

Data

Caracu (C – taurine), Hereford (H – taurine), and Nelore (N – indicine) sires were mated with Angus (A – taurine) dams, and A sires were mated with H and N dams to produce a first generation of crossbred progeny that were contemporary with purebred A, H, and N calves. Heifers from this first generation (G_1) were mated to advanced generation Brangus (BN – composite 3/8 N 5/8 A) and Braford (BO – composite 3/8 N 5/8 H) sires to produce a second generation (G_2) of progeny. Sires were chosen to represent commercial seedstock from locally available semen and herd clean up bulls. There were 14 A, 8 H, 8 C, 2 BN, 1 BO and 9 N sires and 147 A, 73 H and 58 N cows that were kept in the herd as long as they were calving, allowing for a single failure during their productive live. All animals of the different breed compositions were managed as a single herd. Males were castrated at weaning and heifers were exposed to bulls at two years of age.

Body weights were recorded at birth (BW – occurred between September and December), weaning at approximately 7 months of age (WW), long-yearling at approximately 18 months of age (W18), at the beginning of a fattening phase (around 19 months) and at slaughter (around 24 months). Average daily gain (ADG) was calculated from birth to weaning, from weaning to yearling, and during fattening phase. Males and females were managed together until weaning, them males were backgrounded in native pasture. In 2008 and 2009, castrated males were fattened on cool-season pasture. In 2010 and 2011 the steers were fattened in cool-season pasture or in a feedlot. A minimum of 3 mm of rib-eye fat thickness – measured by ultrasound – was used as a criterion to determine harvest point. All genetic groups were represented in both feeding systems. Replacement females were raised exclusively on native pastures. Performance of G_2 calves was recorded only until they were weaned.

Statistical analyses

Data were analyzed in R Package (R Core Team, 2017) using the following model:

$$Y_{ijklm} = \mu + BG_i + G_j + CA_k + CA_k^2 + DA_l + DA_l^2 + e_{ijklm}.$$

In this model: Y_{ijk} = an observation from the k^{th} calf of the i^{th} breed group (BG_i), that was reared in the j^{th} contemporary group (G_j), with its k^{th} age and l^{th} age of its dam equal to CA_k and DA_l, respectively, and e_{ijklm} was a random deviation (0, σ_e^2) of the observation from its expectation given the model. Here, G was defined by the season (before or after Julian day 292) and year of birth of the calf and its sex. The DA effects were only included in the analyses of pre-weaning traits.

Constraining individual and maternal breed additive effects of Nelore to zero is necessary in order to obtain a unique solution, the BG effects can be replaced by a series of linear breed effects as shown here:

$$BG = b_1 g_A^i + b_2 g_C^i + b_3 g_H^i + b_4 h_t^i + b_5 h_z^i + b_6 g_A^m + b_7 g_C^m + b_8 g_H^m + b_9 h_t^m + b_{10} h_z^m$$

In the foregoing equation: b_i = breed additive effects of Angus, Caracu, and Hereford, respectively for i = 1, 2 and 3; estimates of individual heterosis as expressed by taurine crosses and crosses of taurine and indicine breeds, respectively for i = 4 and 5; maternal breed additive effects of Angus, Caracu, and Hereford, respectively for i = 6, 7 and 8, and maternal heterosis effects as expressed by taurine crosses and crosses of taurine and indicine breeds, respectively for i = 9 and 10. The g^i represent the breed proportions for A = Angus (g_A^i), C = Caracu (g_C^i), and H = Hereford (g_H^i) that define the breed composition of calves; and likewise, the g^m represent the breed proportions of the dams (A, C and H) of calves. Following Gregory and Cundiff (1980), individual and maternal heterosis effects were assumed proportional to expected heterozygosity of the individual and its dam (h^i and h^m, respectively). The heterosis effects were further partitioned into whether the heterozygosity resulted from the combination of alleles from two taurine breeds (subscript t) or from a taurine breed and an indicine breed (subscript z). Genetic expectations of each BG are shown in Table 1. Predicted means for breed groups and crossbreeding systems were estimated with the R contrast function (Max et al., 2013).

For post-weaning traits, the model did not include maternal heterosis because the performance of G_2 calves was not recorded after weaning. The interaction of sex and genetic group was also evaluated in preliminary analyses but was discarded because it was not significant ($P > 0.05$).

RESULTS

Breed additive and heterosis effects

For the three pre-weaning traits, effects of individual and maternal heterosis were consistently greater in indicine x taurine crosses than in crosses among taurine breeds (Table 2). The maternal breed additive effects indicated that N dams suppressed birth weight in comparison with the taurine breeds, which were similar. The C maternal breed additive effect indicates that C dams may provide an environment for greater weaning weight than the other breeds. During the post-weaning period (Table 3), the individual breed additive effects indicate greater growth potential for A, C, and H than for N, with the former breeds being similar to each other. Both taurine-taurine and taurine-indicine individual heterosis effects also increased growth, with the latter effects again being substantially greater than the former. The maternal breed additive effect of H on W18 was negative ($P < 0.01$).

Individual and maternal breed additive effects of A and H on ADG during the fattening period were positive, as were the individual breed additive effects of all three taurine breeds on initial and final weight (Table 3). As in the post-weaning period, both taurine-taurine and taurine-indicine individual heterosis effects also increased growth during the finishing period. Taurine breed effects were positive and significant for ADG in fattening phase. Individual breed effect A increased age at slaughter as deviation from N, with taurine x indicine heterosis decreasing age at slaughter. There were unexpected maternal breed additive effects of A on final weight and A and H on ADG during the finishing period.

Genetic group performance differences

Birth weight ranged from 28.89 to 36.63 kg (Table 4). The NA animals had 16.9% greater birth weight when compared to their parental breeds. In G_2 the use of terminal sires on HA and CA dams increased birth weight. The use of Angus as dam breed in the crossbreeding with Nelore also resulted in increased birth weight. Pre-weaning ADG (range 0.558 – 0.817 kg/day) was greater for calves born to NA, AN and CA dams that were mated with BN and BO sires. Purebred (A, H, C and N), and G_1 and G_2 taurine-taurine crossbred calves grew more slowly in pre-weaning phase. Thus, calves born to NA and AN dams mated with BN and BO sires had the greatest weaning weights. Calves from CA dams were somewhat lighter at weaning than those from NA and AN dams. Purebred, G_1 Taurine crossbred, and purebred dams mated with BN and BO, weaned the lightest calves.

During the post-weaning phase, purebred calves grew less rapidly compared to the crossbred animals (Table 5) and were the purebreds H had the greatest and N the least ADG. At 18 months of age, AN and NA were heaviest, followed by CA and HA.

As would be expected from the 18-month weights, initial weights going into the finishing phase were greater for NA and AN compared to the other groups (Table 5) and 22% superior to the A and N means. The CA steers showed superior initial weights compared to the purebreds (A, H and N). Between A and H crossbred HA had the greater performance. During the fattening phase, AH and HA steers had the greatest ADG, followed by H steers. Between taurine-indicine crossbred, NA grew most rapidly. Age at slaughter ranged from 23.99 to 25.39 months, with NA and AN steers being harvested youngest. The purebreds and taurine crossbreds were older at harvest than taurine-indicine and C x taurine crossbreds. Despite this difference in age, crossbred steers were generally heavier at slaughter than the purebreds, with Nelore steers having the least final weight.

DISCUSSION

Differences in breed additive and heterosis effects help to explain the differences in the animal performance. The positive and significant effect of maternal breed effect and individual and maternal heterosis explain the greater birth weights from purebreds and crossbreds in relation to N. The lighter birth weights from calves out of N dams are consistent with previous observations that indicine dams suppress birth weight (Roberson et al, 1986; Alencar et al, 1998; Prayaga, 2003). This reduced birth weight may be favorable because neonatal care is not always feasible in extensive production systems, birth weight is positively correlated with dystocia, and dystocia can result in death of the calf and more rarely its dam (Bellows et al., 1971; Laster et al., 1973).

Weaning weight has a high phenotypic correlation of 0.91 with milk yield (Gregory et al., 1992). Rodrigues *et al.* (2014), using some of the same genetic groups as were evaluated in the present study, found that NA and CA dams produced more milk over a 210-d lactation than AN and HA dams. Reduced pre-weaning ADG and consequently lighter weaning weight of calves born to H dams may be due the lower milk production from H dams (Gregory et al., 1992; Kress and MacNeil, 1999). Teixeira e Albuquerque (2005) report similar situation with individual (-0.025 kg/day) and maternal (-0.198 kg/day) additive effect to Hereford as deviation from Nelore.

Caracu is a taurine adapted to tropical and subtropical environment and performs well in grass feed systems. The breed was originated from the first bovines brought to Brazil by the Portuguese people and underwent by an intense natural selection process (Mercadante, 2005). The maternal breed additive effect of C was reflected in performance of calves from CA dams in the G_2 and is consistent with CA cows producing more milk than other taurine crosses with A (Rodrigues et al., 2014). Cow-calf farmers can capture additional revenue from their weaned calves by exploiting maternal heterosis. Here the magnitude of maternal heterosis expressed by taurine-indicine cross dams was greater than taurine-taurine maternal heterosis, perhaps due to the greater genetic distance between taurine and indicine breeds (Decker et al., 2014).

Calves from taurine-taurine and taurine-indicine crossed dams in the present study confirmed the knowledge that use of crossbred dams to improves performance for pre-weaning traits (Gregory et al., 1966). Kippert et al. (2008) reported a positive and significant maternal heterosis effect (16.40 kg, $P < 0,001$) for weaning weight in Angus x Nelore crosses. Williams et al. (2010) found higher values for individual heterosis when cross British x Zebu (23.02 + 0.54 kg) and Continental x Zebu (25.93 + 1.20 kg) for weaning weight as deviation from Angus.

The positive and significant breed additive effects, relative to N, on ADG during the post-weaning phase and on W18 (Table 3) were expected due to that phase being in part coincident with winter; a season in which purebred N are not well adapted. Arthur et al. (1994) also found the Brahman breed additive effect for post-weaning ADG to be less than that for Hereford (- 30 $\pm$ 17 g/day). Breed effects of A, H and C contributed to increased initial weight relative to N (Table 3). Thus, steers with a greater proportion of A, H and C germplasm had greater initial weights than those that were predominately N. Both taurine-taurine and taurine-indicine individual heterosis effects were also positive for initial weight. The magnitude of the taurine-indicine heterosis effect was sufficiently great to offset the reduced N breed additive effect (Table 3) and resulted in the AN and NA crosses having the greatest initial weights (Table 5).

Maternal breed additive effects were occasionally significant for post-weaning traits (Table 3). Meyer (1992) showed significant maternal effect to yearling weight and final weight to Hereford and Zebu crosses. The author commented that with a direct heritability for Hereford of 22%, the maternal environmental effect was approximately 40% as important as the animal's genotype in determining final weight. Prayaga (2003) also found significant maternal effects on final weight that were attributable to Zebu. Thus, it appears that maternal breed additive effects should not be ignored in interpreting results from crossbreeding studies that are conducted in the environment of southern Brazil, nor in making recommendations to farmers about crossbreeding systems.

Yearling weight (Table 5) serves as an important indicator to identify heavier animals at the beginning of the fattening phase and is considered as a selection criterion in breeding programs (Marcondes et al., 2000). In part, the reduced weight of purebred N may be due to their not being adapted to the winter of southern Brazil which coincides with the post-weaning period.

Environmental adaptation also may contribute to the improved performance of purebred taurine breeds (A and H) in relation to the indicine N. Nonetheless, heterosis enabled crossbred animals to outperform straightbred contemporaries raised in the same environment. Both in the present study and in Prayaga (2003) the benefit of interspecies crossbreeding between adapted taurine and indicine breed was illustrated.

Heavier weight at the beginning of the fattening phase is important because it is associated with greater gains, decreased time required to finish the steers for slaughter, and decreased costs in this phase (Pacheco et al., 2006). Purebreds had the lightest weights going into the fattening phase as a result of their poor performance in previous phases. Similarly, Gregory et al. (1991) verified lower initial weights for Angus (233 kg) and Hereford (217 kg) when compared to three crossbred composites of different European breeds (MARC I, II and III).

Final weight represents the accumulation of performance from the previous phases. Crosses among genetically distant breeds (NA, CA) were heaviest at harvest due to maximum heterosis. These results corroborate with Maggioni et al. (2010) that reported that F1 Nelore x European steers had greater final weight when compared to Nelore pure breed, 531.6 and 446.4 kg, respectively.

The British breed groups had greater gains in this phase, compared with N likely due to their longer history of selection under intensive production systems (Restle and Vaz, 1999). According to the authors mentioned above the greater selection pressure in the European breeds compared to indicine cattle, allows animals with higher percentage of taurine composition to express a faster growth rate in good feed conditions. However, again, crossbred steers showed better performance in the final phase. Thus, crossbreeding using C, H and A germplasm may be a good option to exploit heterosis and their increased rate of growth in the fattening phase. It is important to notice the effect of the heterosis on decrease the age at slaughter but keeping high final weight when compared with purebreds.

CONCLUSION

Crossbreeding using both taurine and indicine breeds is recommended to increase beef cattle performance from birth to slaughter in southern Brazil where a level of tropical adaptation is beneficial. Heterosis effects were sufficiently great for use of N to be recommended as a component of such systems, despite their relatively low breed additive effects. Breed additive effects of A and H suggest they also have important roles. Germplasm from the tropically adapted *Bos tiliz* C may be particularly useful to explore the positive maternal effect. With the breed and heterosis effects derived in the present study, it is possible to predict the performance and infer which breed and breed crosses will perform better in crossbreeding systems designed for the subtropical conditions of Southern Brazil and similar regions.

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Table1. Fractional coefficients of breed effects for genetics groups in the study: g^i = individual additive effect, g^i = maternal additive effect, h^i= individual heterosis, h^m = maternal heterosis; with subscripts A = Angus, H = Hereford, C = Caracu, N = Nelore, BO = Braford, BN= Brangus, t = taurine breed crosses, and z = taurine-indicine crosses

Genetics group[1]	Breed and heterosis effects											
	g_A^i	g_H^i	g_C^i	g_N^i	h_t^i	h_z^i	g_A^m	g_H^m	g_C^m	g_N^m	h_t^m	h_z^m
Purebred												
A	1	0	0	0	0	0	1	0	0	0	0	0
H	0	1	0	0	0	0	0	1	0	0	0	0
N+	0	0	0	1	0	0	0	0	0	1	0	0
G_1												
CA	0.5	0	0.5	0	1	0	1	0	0	0	0	0

HA	0.5	0.5	0	0	1	0	1	0	0	0	0	0
NA	0.5	0	0	0.5	0	1	1	0	0	0	0	0
AH	0.5	0.5	0	0	1	0	0	1	0	0	0	0
AN	0.5	0	0	0.5	0	1	0	0	0	1	0	0
G_2*												
(BN)A	0.8125	0	0	0.1875	0	0.375	1	0	0	0	0	0
(BO)A	0.5	0.3125	0	0.1875	0.625	0.375	1	0	0	0	0	0
(BN)CA	0.5625	0	0.25	0.1875	0	0.375	0.5	0	0.5	0	1	0
(BO)CA	0.25	0.3125	0.25	0.1875	0.3125	0.375	0.5	0	0.5	0	1	0
(BN)HA	0.5625	0.25	0	0.1875	0.3125	0.375	0.5	0.5	0	0	1	0

(BO)HA	0.25	0.5625	0	0.1875	0.3125	0.375	0.5	0.5	0	0	1	0
(BN)NA	0.5625	0	0	0.4375	0	0.5	0.5	0	0	0.5	0	1
(BO)NA	0.25	0.3125	0	0.4375	0.3125	0.5	0.5	0	0	0.5	0	1
(BN)AH	0.5625	0.25	0	0.1875	0.3125	0.375	0.5	0.5	0	0	1	0
(BO)AH	0.25	0.5625	0	0.1875	0.3125	0.375	0.5	0.5	0	0	1	0
(BN)H	0.3125	0.5	0	0.1875	0.625	0.375	0	1	0	0	0	0
(BO)H	0	0.8125	0	0.1875	0	0.375	0	1	0	0	0	0
(BN)AN	0.5625	0	0	0.4375	0	0.5	0.5	0	0	0.5	0	1
(BO)AN	0.25	0.3125	0	0.4375	0.3125	0.5	0.5	0	0	0.5	0	1
(BN)N	0.3125	0	0	0.6875	0	0.625	0	0	0	1	0	0

(BO)N	0	0.3125	0	0	0	0.625	0	0	0	1	0	0

[1] Breed of sire is identified by the first symbol in crossbred groups.

[+] Nelore breed effects were set equal to zero in the model in order to obtain a unique solution.

* Second generation

Table 2. Estimates of individual and maternal breed effects and heterosis effects on pre-weaning growth traits

Effects[1]	Pre-weaning		
	Birth weight kg	Weaning weight kg	ADG kg/day
g^{i}_{A}	-0.06 ± 1.48	3.78 ± 7.17	0.038 ± 0.033
g^{i}_{H}	0.71 ± 1.69	2.06 ± 8.16	0.031 ± 0.037
g^{i}_{C}	-2.87 ± 2.07	11.45 ± 9.68	0.106 ± 0.045*
g^{m}_{A}	4.92 ± 0.99***	0.45 ± 4.91	-0.031 ± 0.023
g^{m}_{H}	5.25 ± 1.19***	-8.44 ± 5.90	-0.089 ± 0.027**
g^{m}_{C}	5.79 ± 1.61***	17.16 ± 7.82*	0.041 ± 0.036
h^{i}_{t}	0.81 ± 0.61	4.31 ± 2.91	0.018 ± 0.013
h^{i}_{z}	2.86 ± 0.73***	21.75 ± 3.49***	0.111 ± 0.016***
h^{m}_{t}	0.61 ± 0.53	10.48 ± 2.65***	0.056 ± 0.012***
h^{m}_{z}	1.19 ± 0.54*	27.05 ± 2.70***	0.135 ± 0.012***

*P < 0.05; **P < 0.01; ***P < 0.001

[1]g^{i} = individual breed effect, g^{i} = maternal breed effect, h^{i}= individual heterosis, h^{m} = maternal heterosis; with subscripts A = Angus, C = Caracu, H = Hereford, t = taurine breed crosses, and z = taurine-indicine crosses.

Table 3. Individual and maternal breed effects, individual and maternal heterosis for weight at yearling (W18), post-weaning ADG and fattening phase growth traits

Effects[3]	Post-weanning[1]		Fattening phase[2]			
	W18 Kg	ADG kg	Initial weight[4] kg	Final weight[5] kg	ADG kg	Age at slaughter months
g_A^i	24.35 $\pm$ 9.79*	0.09 $\pm$ 0.02***	0.14 $\pm$ 13.44	34.42 $\pm$ 14.60*	0.15 $\pm$ 0.05**	0.74 $\pm$ 0.28**
g_H^i	36.99 $\pm$ 12.25**	0.12 $\pm$ 0.02***	26.25 $\pm$ 15.10	50.77 $\pm$ 16.33**	0.16 $\pm$ 0.06**	0.17 $\pm$ 0.32
g_C^i	56.56 $\pm$ 13.84***	0.16 $\pm$ 0.03***	45.67 $\pm$ 17.44**	63.43 $\pm$ 19.06**	-0.01 $\pm$ 0.07	-0.42 $\pm$ 0.38
g_A^m	-5.48 $\pm$ 6.91	-0.04 $\pm$ 0.01*	18.33 $\pm$ 9.38	26.72 $\pm$ 9.98**	0.09 $\pm$ 0.04**	-0.35 $\pm$ 0.20
g_H^m	-17.08 $\pm$ 9.48	-0.03 $\pm$ 0.02	-1.40 $\pm$ 12.11	19.74 $\pm$ 12.91	0.14 $\pm$ 0.05**	0.06 $\pm$ 0.26
h_t^i	17.40 $\pm$ 4.56***	0.03 $\pm$ 0.01***	25.33 $\pm$ 6.31***	22.67 $\pm$ 7.04**	0.07 $\pm$ 0.03**	-0.07 $\pm$ 0.14

h^i_z	63.19 ± 4.86***	0.12 ± 0.01***	76.66 ± 6.27***	67.26 ± 7.50***	0.07 ± 0.03**	-0.90 ± 0.16***

*P < 0.05; **P < 0.01; ***P < 0.001

[1] Steers and heifers

[2] Just steers

[3] g^i = individual breed effect, g^i = maternal breed effect, h^i= individual heterosis, h^m = maternal heterosis; with subscripts A = Angus, H = Hereford, C = Caracu, t = taurine breed crosses, and z = taurine-indicine crosses.

[4] Age around 19 months; [5] Age around 24 months

Table 4. Estimated means and standard errors for pre-weaning traits of the genetic groups that were evaluated. Ranking of groups is given in parentheses

Genetic group [1]	n	Birth weight kg	n	Weaning weight kg	ADG kg
Purebred					
A	67	33.7 ± 0.5 (19)	65	154.9 ± 2.6 (20)	0.62 ± 0.02 (19)
H	43	34.8 ± 0.7 (13)	43	144.2 ± 3.6 (24)	0.56 ± 0.02 (24)
N	35	28.9 ± 0.8 (24)	31	150.6 ± 4.5 (22)	0.61 ± 0.02 (20)
G_1					
CA	75	33.1 ± 0.6 (20)	74	163 ± 2.9 (16)	0.68 ± 0.02 (15)
HA	56	34.9 ± 0.6 (12)	55	158.3 ± 2.9 (18)	0.62 ± 0.02 (18)
NA	46	36.6 ± 0.6 (1)	43	174.7 ± 3.4 (7)	0.71 ± 0.02 (8)
AH	42	35.3 ± 0.6 (11)	40	149.4 ± 3.2 (23)	0.58 ± 0.02 (23)
AN	39	31.7 ± 0.7 (21)	37	174.3 ± 3.7 (8)	0.74 ± 0.02 (7)
G_2					
(BN)A	58	34.8 ± 0.4 (14)	55	162.3 ± 2 (17)	0.66 ± 0.02 (17)

(BO)A	33	35.6 ± 0.4 (9)	26	164.5 ± 2.2 (15)	0.68 ± 0.02 (16)
(BN)H	42	36 ± 0.5 (6)	38	155.2 ± 2.8 (19)	0.61 ± 0.02 (21)
(BO)H	10	35.8 ± 0.6 (8)	9	152 ± 3.1 (21)	0.59 ± 0.02 (22)
(BN)N	23	30.6 ± 0.5 (23)	22	165.4 ± 3 (13)	0.70 ± 0.02 (9)
(BO)N	7	30.9 ± 0.6 (22)	7	164.9 ± 3.2 (14)	0.69 ± 0.02 (10)
(BN)CA	108	35.4 ± 0.4 (10)	97	184.4 ± 2.6 (6)	0.77 ± 0.02 (6)
(BO)CA	45	35.9 ± 0.5 (7)	34	185.2 ± 2.9(5)	0.78 ± 0.01 (5)
(BN)HA	86	36.1 ± 0.4 (4)	73	169.3 ± 2.6 (9)	0.69 ± 0.02 (11)
(BO)HA	36	36.3 ± 0.5 (2)	28	168.7 ± 2.7 (11)	0.69 ± 0.02 (13)
(BN)NA	97	33.9 ± 0.4 (17)	89	190.9 ± 2.4 (3)	0.81 ± 0.02 (3)
(BO)NA	33	34.4 ± 0.4 (15)	27	191.7 ± 2.6 (1)	0.82 ± 0.02 (1)
(BN)AH	43	36.1 ± 0.4 (5)	39	169.3 ± 2.6 (10)	0.69 ± 0.02 (12)
(BO)AH	13	36.3 ± 0.5 (3)	11	168.7 ± 2.7 (12)	0.69 ± 0.02 (14)
(BN)AN	54	33.9 ± 0.4 (18)	50	190.9 ± 2.5 (4)	0.81 ± 0.02 (4)
(BO)AN	19	34.4 ± 0.4 (16)	15	191.7 ± 2.6 (2)	0.82 ± 0.02 (2)

[1] A=Angus; C= Caracu, H=Hereford, N=Nelore, BO=Braford, BN=Brangus; Breed of sire is identified by the first symbol in crossbred groups.

Table 5. Estimated means and standard error for yearling and fattening phase traits. Ranking of genetic groups is given in parentheses

		Yearling[1]			Fattening phase[2]			
Genetic group[3]	n	W18 kg	ADG kg	n	Initial weight[4] kg	Final weight[5] kg	ADG kg	Age months
A	63	296.5 ± 3.8(7)	0.39 ± 0.01 (7)	30	304.7 ± 7.4 (7)	458.2 ± 6.4 (7)	1.02 ± 0.02 (4)	25.26 ± 0.13 (6)
H	40	297.5 ± 5.3 (6)	0.42 ± 0.01 (6)	40	311.1 ± 8.1 (6)	467.6 ± 7.2 (6)	1.08 ± 0.02 (3)	25.39 ± 0.14 (8)
N	30	277.6 ± 6.1 (8)	0.33 ± 0.01 (8)	28	286.2 ± 8.6 (8)	397.1 ± 8.5 (8)	0.78 ± 0.03 (8)	24.86 ± 0.17 (4)
CA	69	329.9 ± 3.4 (3)	0.45 ± 0.01 (3)	20	352.8 ± 6.9 (3)	495.4 ± 5.7 (2)	1.01 ± 0.02 (6)	24.60 ± 0.11 (3)
HA	54	320.2 ± 4.1 (4)	0.43 ± 0.01 (5)	22	343.1 ± 7.3 (4)	489.1 ± 6.5 (3)	1.10 ± 0.02 (2)	24.90 ± 0.15 (5)
NA	41	347.5 ± 4.9 (2)	0.47 ± 0.01 (2)	25	381.3 ± 8.9 (1)	508.3 ± 8.1 (1)	1.01 ± 0.03 (5)	23.99 ± 0.16 (1)

AH	38	308.6 ± 5.2 (5)	0.44 ± 0.01 (4)	21	323.3 ± 8.6 (5)	482.1 ± 7.5 (4)	1.14 ± 0.03 (1)	25.31 ± 0.15 (7)
AN	35	352.9 ± 5.1 (1)	0.50 ± 0.01 (1)	19	362.9 ± 6.9 (2)	481.5 ± 7.2 (5)	0.92 ± 0.02 (7)	24.33 ± 0.13 (2)

[1] Male and female

[2] Just male

[3] A=Angus; C= Caracu, H=Hereford, N=Nelore, Sire breed is represented by the first letter in G_1 crosses.

[4] Age around 19 months

[5] Age around 24 months

Capítulo 2

Feed efficiency in beef cattle crossbred steers

Feed efficiency in beef cattle crossbred steers

Abstract

The aim of this study was to evaluate the feed efficiency and residual feed intake of steers of different genetic groups, involving taurine, adapted taurine and zebuine breeds evaluated in feedlot and pasture and estimate the consequent breed additive and heterosis effects. Caracu (C), Hereford (H), and Nelore (N) sires were mated with Angus (A) dams, and A sires were mated with H and N dams to produce a first generation of crossbred progeny that were contemporary with purebred A, H, and N calves. The evaluation of dry matter intake (DMI) on feedlot was made through the difference between the feed offered and the leftovers. On pasture the evaluation was made using alcanes technique. Performance traits evaluated were initial weight (IW), final weight (FW) and average daily gain (ADG). Feed efficiency traits evaluated were DMI, feed conversion rate (FCR), feed efficiency (FE), daily intake in relation to body weight (DI%), residual feed intake (RFI), residual average daily gain (RADG), Kleiber ratio (KR) and relative growth rate (RGR). The variation coefficient of DMI in pasture was high, so the data was discarded and just the performance data was analyzed. Angus, H and its crosses had better performance in both systems compared with N and its crosses with A. Hereford showed lower DMI and DI%. Hereford, A and its crosses had lower FCR. All genetic group showed negative RFI being H intake lower than others. Angus demonstrated higher ADG than expected according to RADG. There was H and C negative individual breed effect to DMI and DI% and negative H individual breed effect to RFI.

There was positive A individual breed effect to RADG, KR and RGR. Even there was not taurine heterosis effects, H, A and its crosses were more efficient when we analyze the feed efficiency traits.

Keywords: alkane, feedlot, feed conversion, residual feed intake

Introduction

In beef cattle, food represents the highest cost component in animal production, with concentrate being the most expensive item (PACHECO et al., 2006). In feedlot the feed represents 70% of the total cost of production, and of these 70% approximately 2/3 are represented by the concentrated fraction (RESTLE & VAZ, 1999). Therefore, looking for more efficient animals that produce satisfactorily without excess consumption, can guarantee greater profitability to the system.

Feed efficiency is defined as the maximization between production and consumption, being more efficient those individuals who have better production with the same food supply or production similar to the other animals in its group, but with a lower feed intake (ALMEIDA et al. 2004).

An alternative measure of efficiency is the residual feed intake (RFI), which consists of the difference between the observed amount of food eaten minus the estimated consumption as a function of body size and growth rate (KOCH et al., 1963; ARTHUR & HERD, 2008). In this case, negative RFI animals are more efficient because they consumed less than expected due to their weight gain and body size.

Differences between breeds and heterosis are genetic tools that can be exploited through crossbreeding systems to match the genetic potential of animals to the environment and production system and to the market (GREGORY et al., 1999). Due to the use of crosses and feeding systems such as feedlot and pasture supplementation, there is a need for more detailed evaluations of the most important genotypes in relation to the bioeconomic efficiency in the use of food (EUCLIDES FILHO et al., 2003).

The aim of this study was to evaluate the feed efficiency and residual feed intake of steers of different genetic groups, involving taurine, adapted taurine and zebuine breeds evaluated in feedlot and pasture and estimate the consequent breed additive and heterosis effects.

Material and Methods

All experimental procedures that involved animals were approved by the Committee for Ethics in Animal Experimentation from the Federal University of Pelotas (Pelotas, Brazil; Process CEEA No. 8250-2015).

Phenotypic data

Phenotypic data from 118 pure and crossed steers fattened on feedlot (n = 61) or pasture (n = 57) in 2010 and 2011 were collected in the present study. The study occurred at the unity of Embrapa Pecuária Sul Research Center of the Brazilian Agricultural Research Corporation.

Data came from a crossbreed scheme as follow: Caracu (C), Hereford (H), and Nelore (N) sires mated with Angus (A) dams; A sires mated with H and N dams. The progeny – females and males calves - was weaned with about 7 months them males were castred and backgrounded in native pasture until yearling. Animals received sanitary treatment according to technical recommendation and mineral supplementation as well. When steers achieved around 22 months were allocated on feedlot or pasture.

Feedlot feed intake evaluation

The animals evaluated on feedlot were kept for two weeks in collective facilities and after allocated in individual pens with approximately $31m^2$. Steers were submitted to adaptation to the new diet, it being on the first 10 days fed with diet in a ratio of 80:20 (forage:concentrated). After 11^{st} to 20^{th} day the steers were fed with a diet in a ratio of 70:30 and after the 21^{st} day the steers received a diet in a ratio of 60:40 maintained until the end of the period (95 days on 2010 and 83 on 2011). The forage was constituted of 50% of corn silage and 50% of sorgum silage and the concentrated used was a commercial product (Table 1).

The steers were fed twice a day, morning and evening, 40% of the diet on the morning (from 0800 o'clock) and 60% on the evening (from 1530 o'clock). On the beginning of the study it was offered 2.5% of the live weight of dry matter to the animals and after the amount was adjusted in every two days for what the leftovers were around 5% of the feed offered.

Feed intake evaluation had start after the adaptation period and was made through the difference between the feed offered and the leftovers. The feed offered and the leftovers were daily weighted. Every 28 days the steers were weighted to measure weight. Four measures were made on feedlot evaluation.

Pasture intake evaluation

To measure dry matter intake (DMI), for 12 uninterrupted days, the steers were dosed twice daily at 0800 and 1600 hours with a cellulose pellet containing 267.07± 2.65 mg SD of C32-alkane (97%, Sigma-Aldrich Corp., St. Louis, MO, USA). From days 7 to 12, fecal samples were collected twice daily, per rectum, before n-alkane pellet administration. In 2010, DMI was measured in 33 steers and in 2011, 24 steers were evaluated.

Forage samples were collected to quantify the n-alkane profile and nutritive value. To obtain a sample of forage apparently consumed by the animals, we used the hand-plucking technique (De Vries, 1995).

The n-alkanes contents of individual samples of forage and feces were analyzed in duplicate according to the method of Dove and Mayes (2006). Identification and quantification of the n-alkanes were carried out by gas chromatography, using a SHIMADZU GC-2010 (Shimadzu, Tokyo, Japan).

The dry matter intake was estimated from the concentrations of n-alkanes naturally present in the forage (C33) and its homologous pair dosed orally (C32) using the equation (De-Stefani Aguiar et al., 2013):

DMI = ((Faecal C33/(Feacal C32 – Forage C32) x Dose value)/ Forage C33)/1000

where DMI represents daily dry matter intake (kg); Faecal C33 and Forage C33 represent the concentration (mg.kg DM-1) of internal alkane (C33) in feces and forage, respectively; Feacal C32 and Forage C32 represent the concentration (mg.kg DM-1) of external alkane (C32) in feces and forage, respectively, and dose value represents the oral dose (mg) of alkane C32.

The methodology was not useful to predict DMI on the present study. The highest coefficient of variation of DMI (17.2%) and the lower coefficient of determination (R^2=0.10) based on a regression of DMI on average metabolic weigh (AMW) and ADG could have impact on the analysis. We did not find any statistical difference on the intake measures observed on pasture.

Feed efficiency traits

Feed efficiency traits evaluated (Table 2) were calculated through R software, using linear models to predict residual feed intake and residual average daily gain.

Statistical analysis

Data were analyzed using linear model in R Package (R Core Team, 2017) using the following model:

$$Y_{ijklm} = \mu + Y_i + SA_j + AW_k + GG_l + e_{ijklm}.$$

In this model: Y_{ijklm} = an observation of k^{th} steers on the i^{th} year (Y) of test, in the j^{th} age (SA) and k^{th} average weight (AW) of the l^{th} genetic group (GG), respectively, and e_{ijklm} was a random deviation (0, σ_e^2) of the observation from its expectation given the model. Interaction test was made in that traits that were not influenced by the feed efficiency evaluation methodology.

Individual and maternal breed effects and individual heterosis effect on feedlot were analyzed using the same linear model but doing the partition of the genetic group effects. Constraining individual and maternal breed additive effects of Nelore to zero is necessary in order to obtain a unique solution, the GG effects can be replaced by a series of linear breed effects as shown here:

$$GG = b_1 g_A^i + b_2 g_C^i + b_3 g_H^i + b_4 h_t^i + b_5 h_z^i + b_6 g_A^m + b_7 g_C^m + b_8 g_H^m$$

In the foregoing equation: b_i = breed additive effects of Angus, Caracu, and Hereford, respectively for *i* = 1, 2 and 3; estimates of individual heterosis as expressed by taurine crosses and crosses of taurine and indicine breeds, respectively for *i* = 4 and 5; maternal breed additive effects of Angus, Caracu, and Hereford, respectively for *i* = 6, 7 and 8. The g^i represent the breed proportions for A = Angus (g_A^i), C = Caracu (g_C^i), and H = Hereford (g_H^i) that define the breed composition of steers; and likewise, the g^m represent the breed proportions of the dams (A, C and H) of steers. Following Gregory and Cundiff (1980), individual heterosis effects was assumed proportional to expected heterozygosity of the individual (h^i). The heterosis effects were further partitioned into whether the heterozygosity resulted from the combination of alleles from two taurine breeds (subscript t) or from a taurine breed and an indicine breed (subscript z). Genetic expectations of each GG are shown in Table 3.

Results

Genetic groups AN and N showed higher estimated IW (Table 4) in both systems, however the lower estimated ADG reflected in the FW. Although there was no clear tendency of taurine or indicine crossbreeding over purebreds, when the breed effects were derived, there was a significant effect of hti and hzi for IW, FW and ADG (Table 5).

Purebred steers A and crossed AH although showed higher DMI and DI% (Table 6) than purebred H, where similar in FCR and FE due to the higher ADG. There was a negative and significative effect of individual breed effect of H and C for DMI and DI% (Table 7). The use of C germplasm looks to be a good alternative in crosses with the taurine A.

Hereford steers were more efficient according the RFI, showing lower feed intake that was expected for maintenance and growth, being statically different from AN and N (Table 8). In relation to RADG, again, AN and N steers were lower than the other groups ($P < 0.05$), so AN and N showed lower gain than the expect according the feed intake and metabolic weight. The same genetic group were lower to KR and RGR. Between purebreds, A and H were superior to N to KR and RGR. Between purebreds and crossbreds no clear differences were observed to KR as well there was not effect of taurine heterosis and zebuine heterosis.

Looking to the breed effects (Table 9), the individual breed effect H was negative and significant for RFI and the breed effect A was positive and significant for RADG. Angus steers showed the highest values for KR and RGR due to the FW and ADG confirmed by the positive individual breed effect.

Discussion

Results of performance during test (Table 4) point to a lower growth rate of zebuine animals on feedlot. Restle et al. (1995) comparing the performance of crossbreeding animals Charolais x Nelore on feedlot verified higher growth rate on animals with higher percentage of taurine breed. These differences could be related to greater selection pressure in the European breeds compared to indicine cattle (RESTLE & VAZ, 1999), directed mainly to characteristics of efficiency in intensive feeding systems, as occurred in the present study.

Climatic factors may also have influenced ADG on N steers. The feedlot was made during winter when the temperature is low in southern Brazil (min. 9.4 – max. 16 ºC on average). Nelore and others zebuine cattle generally has better adaptability to heat depending on this region of origin and characteristics of leather and fur (Turner, 1980) and taurine cattle is better adapted to cold (Restle et al., 2001). In cold temperatures, Nelore cattle to maintein the body temperature through thermoregulatory processes probably needed to divert energy that could be used to production, thus increasing the basal energy cost. Restle et al. (1987) working with Charolais, Abeerden Angus and Nelore in growing stage raised on cold pasture on southern Brazil verified better performance of taurine steers.

Looking for feed efficiency traits, we can see that H was more efficient because the steers needed less feed to a superior ADG comparing with NA, AN and N. Moore et al. (1975) studying feed efficiency in Angus, Barzona, Brahman, Hereford, Santa Gertrudis and Shorthorn, concluded that Hereford was the breed with the best response to high grain diets, showing higher energy digestibility coefficient and better nitrogen retention comparing with Brahman. Krehbiel et al. (2000) also found lower DMI in taurine steers (MARC III = ¼ Angus, Hereford, Pinzgauer, and Red Poll) in comparison with indicine steers (Brahman, Boran).

Some considerations need to be made about FCR. Fed conversion ratio is strongly correlated (r_g > .50) with growth traits (ARTHUR et al., 2001, SCHENKEL et al., 2004) and the selection for reduce FCR would increase genetic merit for growth and mature size of breeding females (HERD & BISHOP, 2000). Also, FCR is a measure that does not attempt to partition feed intake between maintenance and growth requirements. In southern Brazil, the female breeding herd is raised mostly on native pasture, so increase the mature weight is not interesting because more requirements are necessary to maintenance, growth and production. Crowley et al. (2010) working with the data of bulls, found FCR for A of 7.4 and 6.82 for H, similar with the result of the present study.

Residual feed intake is an alternative measure because it is phenotypically independent of the production traits used to calculate expected feed intake (ATHUR & HERD, 2008) and it is also genetically independent of mature weight (HERD & BISHOP, 2000; Archer et al., 2002). In the present study H was the breed more efficient according to RFI followed by its crosses with A. The physiological basis for the variation in the RFI have been studied. According to Richardison and Herd (2004) the heat production from metabolic process, body composition and activity explained 73% of the variation in RFI.

The protein turnover, tissue metabolism and stress correspond to 37% of the proportion. Hereford is known as a docile and less reactive breed (WAGNON et al., 1966; HOPPE et al., 2010) maybe this can help to explain the feed efficiency of H on feedlot.

Studies have demonstred that FCR and RFI traits beyond being positively correlated (R= 0.62 to 0.85) its have moderated heritability, similar to growing traits, indicating the possibility to use as a selection criteria both traits (ARCHER et al., 2002; HERD & BISHOP, 2000; ROBINSON & ODDY, 2004; SHENKEL et al., 2004; HOQUE et al., 2006ab; NKRUMAH et al.,2007).

Highest values of KR indicate increases in weight gain with the same metabolic weight, that means that higher growth is obtained without increase the cost of energy for maintenance, that is higher dilution of energy requirements for maintenance (TEDESCHI et al.. 2006). Mello et al. (2010) in an experiment with ½ Red Angus x ½ Nelore and ½ Blonde D'Aquitaine x ½ Nelore slaughtered in different weights found that in a similar weight of the present study (480 kg) the Red Angus crossed steers had a lower KR (14.4) comparing with Blonde D'Aquitaine crossed steers (18.8).

Relative growth rate (RGR) is the rate of growth of an animal relative to its weight at the end of the measuring period (BROWN et al., 1988). Due to the low genetic correlations between body weight and RGR (FITZHUGH, JR. & TAYLOR, 1971), RGR could be used to select for more efficient animals without increase the body mature size. It is important to note that is necessary an analysis of all the feed efficiency traits together. Angus, H and its crosses looks be the best groups when we analyze the Tables 5 and 6, and it is confirmed in part to the individual breed effects but there was not effect of taurine heterosis for these traits.

Frisch and Vercoe (1977) comment that in high quality diet *Bos taurus* cattle consume more feed relative to their maintenance requirements but gaining faster and more efficiently than *Bos indicus*, what is confirmed in some traits of the present study like FCR, FE and RFI.

The best performance of H can be affirmed by the negative individual breed effect to DMI (Table 7). Caracu showed lower DMI and negative individual breed effect too. Perotto et al. (2000) found an additive genetic effect of 0.026 of Caracu in relation to Charolais. Mason (1971) concluded that animals with the same age will be more efficient that ones with a fast growth and with less fat on the carcass at the end of feedlot. As a taurine, is expected that C show a better performance on feedlot in relation to N.

Even though there is no maternal effect to feed efficiency traits, N dams produced less efficient steers. It is important to note, however, that maternal effects were no longer expected for these traits, since these measures were made in the fattening phase, a phase in which the well-evidenced effects of maternal ability, mainly due to the milk production and uterine environment, no longer has so much influence.

Conclusions

Angus, Hereford and its crosses had better performance in feedlot and pasture. The same genetic groups showed lower FCR. Purebreds and crossbreds showed negative RFI, being H more efficient. Angus has a better gain with the same metabolic weight in relation to the other groups. There was individual breed effect of H and C to DMI and DI%. Hereford individual breed effect was negative to RFI. Angus individual breed effect to RADG, KR and RGR was positive. Is possible to conclude that H consume less feed in feedlot than expected and A gain more weight than expected. Making a joint analysis of performance and feed efficiency traits, it is possible to conclude that H, A and its crosses were more efficient.

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Table 1 – Dry matter (DM), pH, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin (LIG) and ethereal extract of the diet offered on feedlot and pasture.

Diet	%DM	pH	%CP	%NDF	%ADF	% LIG	%EE
Feed offered[1]	34,44	7,49	9,62	67,75	40,98	5,29	2,37
Sorghum silage	36,70	4,86	5,18	-	-	-	-
Corn silage	21,09	4,65	6,07	-	-	-	-
Comercial feed	83,00*	-	12,90**	-	20,00*	-	2,50**
Pasture	87.24	-	13.74	63.77	37.26	4.1	-

* maximum, ** minimum, [1]Feed offered daily composed by corn silage and sorgum silage (50:50) + comercial feed.

Table 2 – Summary of measures

Trait	Definition	Formula
Dry matter intake (DMI)	Daily dry matter intake	Observed feed intake x dry matter content of the feed
Average daily gain (ADG)	Weight gain per day	Regression coefficient from the regression of weight on time
Daily intake (DI%)	Daily intake relative to body weight	(Dry matter intake ÷ mid-test weight) x 100
Feed conversion ratio (FCR)	Ratio of dry matter intake to gain	DMI ÷ ADG
Feed efficiency (FE)	Ratio of gain to dry matter intake	ADG ÷ DMI
Kleiber ratio (KR)	Weight gain per unit of metabolic weight	ADG ÷ average metabolic weight
Relative growth rate (RGR)	Growth relative to instantaneous size. Expressed as percentage of change in live weight per day	100 x (log final weight – log initial weight) ÷ days on test
Residual feed intake (RFI)	Expected feed intake requirement for maintenance and growth	Observed feed intake – expected feed intake, where expected feed intake was obtained by the regression of DMI on AMW and ADG
Residual average	Difference between actual	Observed ADG – expected

daily gain (RADG)	gain and expected gain based on dry matter intake	ADG, where expect ADG was obtained by the regression of ADG on DMI and AMW

Table 3 - Fractional coefficients of breed effects for genetics groups in the study: g^i = individual additive effect, g^i = maternal additive effect, h^i= individual heterosis; with subscripts A = Angus, H = Hereford, C = Caracu, N = Nelore, BO = Braford, BN= Brangus, t = taurine breed crosses, and z = taurine-indicine crosses

Genetic Group[1]	Breed and heterosis effects									
	g_A^i	g_H^i	g_C^i	g_N^i	h_t^i	h_z^i	g_A^m	g_H^m	g_C^m	g_N^m
A	1	0	0	0	0	0	1	0	0	0
H	0	1	0	0	0	0	0	1	0	0
N+	0	0	0	1	0	0	0	0	0	1
CA	0.5	0	0.5	0	1	0	1	0	0	0
HA	0.5	0.5	0	0	1	0	1	0	0	0
NA	0.5	0	0	0.5	0	1	1	0	0	0
AH	0.5	0.5	0	0	1	0	0	1	0	0
AN	0.5	0	0	0.5	0	1	0	0	0	1

+ Nelore breed effects were set equal to zero in the model in order to obtain a unique solution.

[1]In genetic groups the first capital letter identifies the sire breed.

Table 4 – Least square means and standard error for initial weight (IW), final weight (FW) and average daily gain (ADG) of steers evaluated in feedlot and pasture.

	IW (kg)				FW (kg)				ADG (kg/d)			
Genetic Group[1]	Feedlot		Pasture		Feedlot		Pasture		Feedlot		Pasture	
A	345.02	±2.37^{b}	341.15	±2.50^{bc}	461.48	±2.37^{a}	465.36	2.50^{ab}	1.45	±0.06^{a}	1.39	±0.06^{a}
CA	357.15	±2.22^{abA}	345.17	±2.15^{bcB}	449.36	±2.22^{bcA}	461.34	2.15^{aB}	1.16	±0.05^{bc}	1.30	±0.05^{a}
HA	349.48	±2.34^{b}	343.62	±2.38^{bc}	457.02	±2.34^{ab}	462.88	2.38^{a}	1.34	±0.06^{ab}	1.34	±0.06^{a}
NA	358.04	±3.36^{ab}	352.00	±3.72^{ab}	448.47	±3.36^{abc}	454.51	3.72^{bc}	1.16	±0.08^{abc}	1.13	±0.09^{ab}
AH	346.44	±2.59^{b}	339.84	±2.50^{b}	460.06	±2.59^{ab}	466.66	2.50^{ab}	1.43	±0.06^{ab}	1.41	±0.06^{a}
H	354.00	±2.20^{abA}	336.36	±2.28^{cB}	452.50	±2.20^{abcA}	470.14	2.28^{aB}	1.23	±0.05^{abc}	1.48	±0.05^{a}
AN	361.86	±2.52^{a}	359.51	±3.21^{a}	444.65	±2.52^{c}	446.99	3.21^{c}	1.04	±0.06^{c}	0.97	±0.08^{b}
N	364.64	±3.07^{a}	358.74	±3.37^{a}	441.86	±3.07^{c}	447.77	3.37^{c}	0.98	±0.07^{c}	0.99	±0.08^{b}

Least square means on the same column followed by different letters are statistically different (P<0.05)

Table 5 – Individual breed effects, heterosis and maternal breed effects for performance during test.

Effects	IW (kg)		FW (kg)		ADG (kg/d)	
g_A^i	-10.07	$\pm$22.18	18.43	$\pm$26.46	0.32	$\pm$0.10**
g_H^i	15.24	$\pm$25.26	34.19	$\pm$30.14	0.14	$\pm$0.12
g_C^i	46.89	$\pm$29.60	52.35	$\pm$35.32	-0.07	$\pm$0.14
h_t^i	22.78	$\pm$8.57**	26.05	$\pm$10.22*	0.00	$\pm$0.04
h_z^i	71.79	$\pm$10.84***	73.74	$\pm$12.94**	-0.13	$\pm$0.06*
g_A^m	-2.51	$\pm$16.35	8.39	$\pm$19.51	0.13	$\pm$0.08
g_H^m	-20.95	$\pm$21.06	-5.72	$\pm$25.13	0.21	$\pm$0.10*

Table 6 - Least square means and standard error for dry matter (DMI), feed conversion rate (FCR), feed efficiency (FE) and daily intake (DI%) evaluated in feedlot

	DMI (KG)		FCR (DMI/ADG)		FE (ADG/DMI)		DI%	
A	9.45	±0.21^{a}	6.63	±0.43^{b}	0.15	±0.01^{a}	2.36	±0.05^{a}
CA	8.72	±0.21^{ab}	7.81	±0.43^{ab}	0.13	±0.01^{ab}	2.18	±0.05^{ab}
HA	8.92	±0.22^{ab}	7.01	±0.45^{b}	0.15	±0.01^{ab}	2.23	±0.05^{ab}
NA	9.13	±0.32^{ab}	8.20	±0.66^{ab}	0.13	±0.01^{abc}	2.27	±0.08^{ab}
AH	9.26	±0.23^{a}	6.38	±0.48^{b}	0.15	±0.01^{a}	2.31	±0.06^{a}
H	8.03	±0.19^{b}	6.53	±0.40^{b}	0.15	±0.01^{a}	2.01	±0.05^{b}
AN	8.90	±0.25^{ab}	9.12	±0.52^{a}	0.11	±0.01^{bc}	2.22	±0.06^{ab}
N	8.90	±0.29^{ab}	9.49	±0.59^{a}	0.11	±0.01^{c}	2.27	±0.07^{a}

Least square means on the same column followed by different letters are statistically different ($P<0.05$)

Table 7 – Individual breed effects, heterosis and maternal breed effects for dry matter (DMI), feed conversion rate (FCR), feed efficiency (FE) and daily intake (DI%)

Effects	DMI (kg)		FCR (DMI/ADG)		FE (ADG/DMI)		DI%	
g_A^i	0.33	±0.53	-1.94	±1.09	0.04	±0.02	0.04	±0.13
g_H^i	-1.43	±0.61*	-1.40	±1.26	0.03	±0.02	-0.39	±0.15*
g_C^i	-1.84	±0.74*	0.20	±1.52	0.00	±0.03	-0.50	±0.18**
h_t^i	0.35	±0.21	0.11	±0.44	0.00	±0.01	0.08	±0.05
h_z^i	-0.16	±0.29	0.60	±0.59	-0.01	±0.01	-0.07	±0.07
g_A^m	0.22	±0.40	-0.93	±0.82	0.01	±0.01	0.05	±0.10
g_H^m	0.56	±0.53	-1.56	±1.08	0.02	±0.02	0.13	±0.13

*P<0.05; **P<0.01; ***P<0.001

Table 8 - Least square means and standard error for residual feed intake (RFI), residual average daily gain (RADG), Kleiber ratio (KR) and relative growth rate (RGR)

Genetic group	RFI	RADG	KR	RGR
A	-0.95 ±0.23^{ab}	0.18 ±0.06^{a}	16.15 ±0.72^{a}	0.37 ±0.02^{a}
CA	-1.02 ±0.23^{ab}	-0.09 ±0.06^{a}	12.86 ±0.72^{ab}	0.29 ±0.02^{abc}
HA	-1.23 ±0.24^{ab}	0.08 ±0.06^{a}	14.69 ±0.74^{ab}	0.33 ±0.02^{ab}
NA	-0.65 ±0.35^{ab}	-0.09 ±0.09^{a}	12.99 ±1.10^{a}	0.29 ±0.03^{abc}
AH	-1.13 ±0.25^{ab}	0.18 ±0.07^{a}	15.92 ±0.79^{a}	0.36 ±0.02^{a}
H	-1.88 ±0.21^{b}	0.00 ±0.06^{ab}	13.66 ±0.66^{a}	0.31 ±0.02^{abc}
AN	-0.54 ±0.28^{a}	-0.23 ±0.07^{b}	11.32 ±0.86^{bc}	0.25 ±0.02^{bc}
N	-0.42 ±0.31^{a}	-0.27 ±0.08^{b}	10.48 ±0.97^{c}	0.23 ±0.02^{c}

Least square means on the same column followed by different letters are statistically different ($P<0.05$)

Table 9 – Individual breed effects, heterosis and maternal breed effects for residual feed intake (RFI), residual average daily gain (RADG), kleiber ratio (KR) and relative growth rate (RGR)

Effects	RFI		RADG		KR		RGR	
g_A^i	-0.42	0.58	0.31	0.15*	4.00	1.80*	0.09	0.04*
g_H^i	-1.45	0.67*	0.04	0.18	0.29	2.09	0.01	0.05
g_C^i	-1.05	0.81	-0.30	0.22	-3.38	2.52	-0.07	0.06
h_t^i	0.24	0.23	0.04	0.06	0.40	0.72	0.01	0.02
h_z^i	0.09	0.31	-0.11	0.08	-1.16	0.97	-0.03	0.02
g_A^m	-0.11	0.44	0.14	0.12	1.67	1.35	0.04	0.03
g_H^m	-0.01	0.58	0.24	0.15	2.89	1.80	0.07	0.04

*P<0.05; **P<0.01; ***P<0.001

Capítulo 3

Direct and maternal breed additive and heterosis effects on carcass traits of beef cattle raised in southern Brazil

Direct and maternal breed additive and heterosis effects on carcass traits of beef cattle raised in southern Brazil

Abstract

The objective of this study was to evaluate the carcass traits of different genetic groups fattened on feedlot or cool season pasture as well as the heterosis, direct and maternal breed effect on these traits. Phenotypic data from 119 crossed steers fattened on feedlot (n = 61) or pasture (n = 58) in 2010 and 2011 were collected in the present study. Data came from a crossbreed scheme as follow: Caracu (C), Hereford (H), and Nelore (N) sires mated with Angus (A) dams; A sires mated with H and N dams. There were no breed differences for performance on feedlot. On pasture NA had higher initial and slaughter weight. Hereford x Angus had higher average daily gain on feedlot and pasture. On pasture NA had higher carcass weight and dressing percentage on feedlot. Nelore x Angus showed better weights of forequarter, ribcut and hindquarter on pasture. Taurine x indicine heterosis, A and H maternal effect were significant to increase performance on fattening phase and increase weight and dressing of primary cuts. Caracu breed effect was negative to back fatness. The positive effects of taurine x indicine heterosis can be exploited on beef cattle production systems of southern Brazil.

Keywords: breed effects, crossbreeding, feedlot, pasture

Introduction

Carcass traits including yield, weight, composition and quality are important in the evaluation of breeds and breed combinations to improve beef production (DEROUEN et al. 1992). The crossbreeding in beef cattle is an important tool to improve the herd productivity, combining and complementing the characteristics of economic importance that are expressed with different intensity by the purebred animals, as well as taking advantage of the resulting heterosis (RESTLE et al. 2000).

On the southern Brazil it is more common the use of cold season pasture to do the fattening on beef cattle (VAZ et al. 2008), but with the soybean cultivated area increment, the area to beef production was reduced with the herd size maintained (NESPRO & EMBRAPA, 2018). Therefore, the intensification of the production system is needed and the use of feedlot to fattening is an option and use of the tool is important, since with the increase of agricultural areas there is also a greater supply of protein and energy sources as well as co-products from the cereal processing industry.

The objective of this study was to evaluate the carcass traits of different genetic groups fattened on feedlot or cool season pasture as well as the heterosis, direct and maternal breed effect on these traits.

Material and Methods

All experimental procedures that involved animals were approved by the Committee for Ethics in Animal Experimentation from the Federal University of Pelotas (Pelotas, Brazil; Process CEEA No. 8250-2015).

Phenotypic data

Phenotypic data from 119 crossed steers fattened on feedlot (n = 61) or pasture (n = 58) in 2010 and 2011 were collected in the present study. The study occurred at the unity of Embrapa Pecuária Sul Research Center of the Brazilian Agricultural Research Corporation.

Data came from a crossbreed scheme as follow: Caracu (C), Hereford (H), and Nelore (N) sires mated with Angus (A) dams; A sires mated with H and N dams. The progeny was weaned with about 7 months them males were castred and backgrounded in native pasture until yearling. Animals received sanitary treatment according to technical recommendation and mineral supplementation as well. When steers achieved around 19 months were allocated on feedlot or pasture.

The animals evaluated on feedlot were kept for two weeks in collective facilities and after allocated in individual pens with approximately $31m^2$. Steers were submitted to adaptation to the new diet, it being on the first 10 days fed with diet in a ratio of 80:20 (forage:concentrated). After 11^{st} to 20^{th} day the steers were fed with a diet in a ratio of 70:30 and after the 21^{st} day the steers received a diet in a ratio of 60:40 maintained until the end of the period (95 days on 2010 and 83 on 2011). The forage was constituted of 50% of corn silage and 50% of sorgum silage and the concentrated used was a commercial product[2] (Table 1). Diet was set according to NRC (2006).

The steers were fed twice a day, morning and evening, 40% of the diet on the morning (from 0800 o'clock) and 60% on the evening (from 1530 o'clock). On the beginning of the study it was offered 2.5% of the live weight of dry matter to the animals and after the amount was adjusted in every two days for what the leftovers were around 5% of the feed offered.

Animals fattened on pasture were kept for around 120 days on pasture of ryegrass (*Lolium* multiflorum) and oats (*Avena sativa*). A minimum of 3 mm of rib-eye fat thickness – measured by ultrasound – was used as a criterion to determine harvest point, and ultrasound was used to estimate rib eye area (REA) and back fatness (BF). All genetic groups were represented in both feeding systems.

Animals were slaughtered in the slaughterhouse business, which includes the Federal Inspection Service. Slaughter followed the establishment flow and the line industrialization was made weighing the carcass is still hot. After slaughter, carcasses were identified, cleaned and cooled to -2° C for a period of 24 hours. After this, the carcasses were reweighted, and the commercial cuts were weighed to calculate their percentage related to the weight of cold carcass. The primary cuts were obtained by the division of the forequarter, separating completely from the hindquarter between the fifth and sixth ribs. The forequarter is formed by chuck and shoulder. The hindquarter was divided in ribcut and pistol hindquarter, the last including the round, rump and loin. The ribcut was obtained by dividing the hindquarter to approximately 30 cm from the back line. Such as the study was conducted from the industrialization perspective of viability of carcasses, cuts were made following the slaughterhouse standard procedure.

Statistical analysis

Data were analyzed using linear model in R Package (R Core Team, 2017) using the following model:

$$Y_{ijklm} = \mu + Y_i + FS_j + MD_k + GG_l + e_{ijklm}.$$

In this model: Y_{ijklm} = an observation of kth steers on the ith year (Y) of test, in the jth fattening system (FS) and kth measure date into the year (MD) of the lth genetic group (GG), respectively, and e_{ijklm} was a random deviation (0, σ_e^2) of the observation from its expectation given the model. Interaction test between genetic group and fattening system was tested but was not significant for any trait.

Individual and maternal breed effects and individual heterosis effect on feedlot were analyzed using the same linear model but doing the partition of the genetic group effects. Constraining individual and maternal breed additive effects of Nelore to zero is necessary in order to obtain a unique solution, the GG effects can be replaced by a series of linear breed effects as shown here:

$$GG - b_1 g_A^i + b_2 g_C^i + b_3 g_H^i + b_4 h_t^i + b_5 h_z^i + b_6 g_A^m + b_7 g_C^m + b_8 g_H^m$$

In the foregoing equation: b_i = breed additive effects of Angus, Caracu, and Hereford, respectively for *i* = 1, 2 and 3; estimates of individual heterosis as expressed by taurine crosses and crosses of taurine and indicine breeds, respectively for *i* = 4 and 5; maternal breed additive effects of Angus, Caracu, and Hereford, respectively for *i* = 6, 7 and 8. The g^i represent the breed proportions for A = Angus (g_A^i), C = Caracu (g_C^i), and H = Hereford (g_H^i) that define the breed composition of steers; and likewise, the g^m represent the breed proportions of the dams (A, C and H) of steers. Following Gregory and Cundiff (1980), individual heterosis effects was assumed proportional to expected heterozygosity of the individual (h^i). The heterosis effects were further partitioned into whether the heterozygosity resulted from the combination of alleles from two taurine breeds (subscript t) or from a taurine breed and an indicine breed (subscript z). Genetic expectations of each GG are shown in Table 2.

Results and Discussion

Carcass traits

Initial weight of NA was different from H and N on pasture but the same genetic group was only different from N for SW. The superior initial weight (Table 3) is reflex of the better development of the crossbred before this phase (Leal et al., 2018) where the NA and AN animals had higher weight at yearling – circa 18 months – and the superior initial weight has impact on the final weight. Choosing animals with higher initial weight we can decrease the time on the fattening phase, decreasing the costs also.

Breed differences on slaughter weight were significant just on pasture, being NA different from N and 25.91% superior. Restle et al. (1999) working with H and N crosses finished on feedlot, showed that the highest slaughter weight was achieved in the F1 (443 kg) being different from ¼ H ¾ N (382 kg).

Angus x Hereford had the higher ADG, being different from CA, NA, AN and N on feedlot and different from AN and N on pasture. This can be explained by the selection made on taurine breeds to express gain capacity on better feed conditions (RESTLE & VAZ, 1999) and by the individual breed effect A and H (Table 4).

On pasture, NA had the higher carcass weight (Table 5) being followed by AN but different from H and N. Carcass weight was higher on crosses with A dams, effect of maternal A and taurine x indicine heterosis (Table 4). DeRouen et al. (1992) studying the additive and nonadditive (heterotic) direct and maternal genetic effects of A, H, Brahman (B) and Charolais (C) on carcass traits, found A maternal additive effect of 6.8 kg as deviation from overall mean, and positive direct heterotic of 59.6 kg in AB crosses as deviation from overall mean.

The dressing percentage was higher in NA on feedlot and in AN on pasture, having HA the lower DP on feedlot and CA on pasture (Table 5). According to Galvão (1991) indicine crossbred animals show higher DP than taurine animals due to the lower relative weight of leather, paws, head and digestive tract. Studying the crosses between Charolais and Nelore, Restle et al. (1995a) found higher DP of 54.68% in ½ Charolais ½ Nelore and 52,42% in purebred Charolais. Restle et al. (1995b) also found higher DP in H x N crossbred when compared with H purebred. Di Marco (1993) say that quantitative carcass traits are affected, mainly, by the final weight because this can indicate the best development of the skeleton, muscle and fat that composes the carcass. There was no statistical difference between genetic groups to REA and BF (Table 6).

There was breed differences in carcass primary cuts weight just in pasture (Table 7), maybe because on feedlot the diet is more balanced. Bianchini et al. (2007) did not find breed differences between Nelore, Simental and ½ Nelore + ½ Simental finished on feedlot. The authors say that the differences between breeds can be minimized by systems that allow a more homogeneous production. According to Wheeler et al. (1995) this can be explained by the fact that young animals – in growing phase – show lower gain composition differences and carcass, consequently.

On the primary cuts, forequarter weight was higher on NA on pasture, being different from H and N (Table 7). The same genetic group showed the higher ribcut weight (RW) and pistol hindquarter weight (PHW) on pasture, being followed by NA and CA and different from H and N. There was no statistical difference from forequarter dressing (FD) in both fattening systems (Table 8). Nelore x Angus showed better ribcut dressing (RD) on feedlot compared with N. Hindquarter is where are the principal and most valuable cuts of the carcass. In this study N had the higher pistol hindquarter dressing (PHD) on pasture being different from A and its crosses when the dam is A. Silva et al. (2015) did not find statistical difference to HD between young bulls A and N. Higher HD on N can be explained by lowest RD on N. The size of gastrointestinal tract has relation with the weight and dressing of the ribcut and N has smaller gastrointestinal tract than European breeds (DA COSTA et al., 2007).

Direct and maternal breed additive and heterosis effects

The effect of taurine-indicine heterosis and the A maternal effect was positive and significant to IW as deviation from N (Table 4). Beside these effects, taurine heterosis and H maternal effect also was positive to SW. Gregory et al. (1978) found negative H and A maternal effect to slaughter weight, -12.1 and -24.8, respectively.

Looking to ADG, A and H individual effect indicates positive effect showing that A and H can provide better weight gain on fattening phase. In a revision of several studies, Cundiff (1970) describe ADG heterosis of 7% to HA crosses in relation to the mean of purebred and 9% to slaughter weight on heifers.

The positive and significant effect of taurine-indicine heterosis and the A maternal effect to CW can be exploited to improve carcass weight. On the same way taurine-indicine heterosis was positive to improve DP. Studying the breed effect and the retained heterosis, Rio-Utrera et al. (2006) also not found significant effect of taurine heterosis for dressing percentage in MARC I, II and III (composite of Meat Animal Research Center).

Maternal effects are usually not detected in post weaning traits. Prayaga (2003) evaluating tropically adapted British, Sanga-derived, Zebu cross, Zebu and Continental beef cattle breed, also found signifcant maternal effects on final weight that were attributable to Zebu. Therefore, maternal breed additive effects to performance and carcass traits should not be ignored in interpreting results from crossbreeding studies in similar conditions to this study.

In relation to primary cuts all of them had positive effect of taurine-indicine heterosis (Table 9), which proves the importance of exploring crossbreeding. We found A and H positive maternal effect to FW and A positive maternal effect to PHW. Taurine-taurine heterosis had negative effect for FD, in relation to N, decreasing the dressing of this cut in AH and HA. Individual breed effect A and H was responsible to increase RD, unlike the A individual breed and taurine-indicine heterosis effects that was negative and decreased PHD.

DeRouen et al. (1992) found significant heterotic effect to retail yield just on the Brahman (B) crosses, being AB and HB 5.8 kg superior to the overall mean.

Breed differences in RD (Table 8) were consequence of A, H and C individual effect and of heterosis (Table 10). Restle et al. (1995c) observed positive and significative heteroses (7.78%) for RD in Charolais x Nelores steers, justifying this difference between crossbred and purebred as an effect of higher back fatness deposition. In the present study this statement does not applied because CA – even not being significant – had the lowest BF deposition, reinforcing the effect of C positive breed effect.

Taurine x indicine heterosis to REA was positive and significant as deviation from N (Table 10). Back fatness had negative effect of Caracu breed and positive effect of taurine x taurine heterosis. Williams et al. (2010) estimating breed and heterosis effects for carcass traits using published crossbreeding studies found positive heterosis of 6.57 cm^2 to REA and 0.20 cm to fat thickness in British x Zebu biological type combination.

Conclusions

The crossbreeding between taurine and indicine cattle is recommended to improve performance on feedlot and pasture in fattening phase. The Angus x Nelore crosses showed the highest slaughter weight, carcass weight and dressing percentage and increased the weight of primary cuts. Caracu breed effect can decrease back fatness. The positive effects of taurine x indicine heterosis can be exploited on beef cattle production systems of southern Brazil.

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Table 1 – Dry matter (DM), pH, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin (LIG) and ethereal extract of the diet offered on feedlot and pasture.

Diet	%DM	pH	%CP	%NDF	%ADF	% LIG	%EE
Feed offered[1]	34,44	7,49	9,62	67,75	40,98	5,29	2,37
Sorghum silage	36,70	4,86	5,18	-	-	-	-
Corn silage	21,09	4,65	6,07	-	-	-	-
Comercial feed	83,00*	-	12,90**	-	20,00*	-	2,50**
Pasture	87.24	-	13.74	63.77	37.26	4.1	-

* maximum, ** minimum, [1]Feed offered daily composed by corn silage and sorgum silage (50:50) + comercial feed.

Table 2 - Fractional coefficients of breed effects for genetics groups in the study: g^i = individual additive effect, g^m = maternal additive effect, h^i= individual heterosis; with subscripts A = Angus, H = Hereford, C = Caracu, N = Nelore, t = taurine breed crosses, and z = taurine-indicine crosses

Genetic Group	Breed and heterosis effects									
	g_A^i	g_H^i	g_C^i	g_N^i	h_t^i	h_z^i	g_A^m	g_H^m	g_C^m	g_N^m
A	1	0	0	0	0	0	1	0	0	0
H	0	1	0	0	0	0	0	1	0	0
N+	0	0	0	1	0	0	0	0	0	1
CA	0.5	0	0.5	0	1	0	1	0	0	0
HA	0.5	0.5	0	0	1	0	1	0	0	0
NA	0.5	0	0	0.5	0	1	1	0	0	0
AH	0.5	0.5	0	0	1	0	0	1	0	0
AN	0.5	0	0	0.5	0	1	0	0	0	1

+ Nelore breed effects were set equal to zero in the model in order to obtain a unique solution.

Table 3 – Least square means and standard error for initial weight (IW), slaughter weight (SW) and average daily gain (ADG) on feedlot and pasture.

Genetic	IW, kg		SW, kg		ADG, kg	
Group[1]	Feedlot[2]	Pasture[3]	Feedlot	Pasture	Feedlot	Pasture
A	288.45 ±12.98	288.56 ±14.72[ab]	445.8 ±14.57	451.68 ±16.52[ab]	1.21 ±0.05[ab]	1.23 ±0.06[ab]
CA	336.22 ±12.98	326.09 ±12.30[ab]	477.42 ±14.57	483.05 ±13.81[a]	1.08 ±0.05[bc]	1.2 ±0.05[ab]
HA	311.00 ±13.76	311.39 ±13.79[ab]	469.00 ±15.45	465.43 ±15.48[ab]	1.25 ±0.05[ab]	1.19 ±0.05[ab]
NA	359.29 ±22.77	372.57 ±17.54[a]	493.44 ±25.57	517.86 ±19.70[a]	1.06 ±0.09[bc]	1.13 ±0.07[ab]
AH	300.88 ±13.76	297.24 ±13.79[ab]	476.25 ±15.45	464.69 ±15.48[ab]	1.34 ±0.05[a]	1.29 ±0.05[a]
H	287.27 ±11.74	275.39 ±12.33[b]	444.80 ±13.18	436.35 ±13.84[ab]	1.18 ±0.04[ab]	1.22 ±0.05[ab]
AN	338.42 ±14.72	345.81 ±17.42[ab]	473.82 ±16.52	468.25 ±19.55[ab]	1.07 ±0.06[bc]	0.95 ±0.07[b]
N	294.59 ±17.42	267.17 ±17.54[b]	413.35 ±19.55	383.66 ±19.70[b]	0.88 ±0.07[c]	0.88 ±0.07[b]

[1] on the genetic group the first capital letter identifies the sire breed; [2]n = 9 A, 9 CA, 8 HA, 4 NA, 8 AH, 11 H, 7 AN, 5 N; [3]n = 7 A, 10 CA, 8 HA, 5 NA, 8 AH, 10 H, 5 AN, 5 N. Least square means on the same column followed by different letters are statistically different (P<0.05)

Table 4 - Individual and maternal breed effects and individual heterosis for initial weight (IW), slaughter weight (SW), average daily gain (ADG), carcass weight (CW) and dressing percentage (DP)

Effects	IW, kg		SW, kg		ADG, kg		CW, kg		DP, %	
g_A^i	-43.96	±26.36	0.01	±26.67	0.37	±0.11***	8.52	±13.46	-1.37	±0.91
g_H^i	-40.79	±29.98	-11.82	±30.32	0.27	±0.12*	3.12	±15.32	-1.42	±1.04
g_C^i	6.23	±35.91	18.27	±36.32	0.08	±0.15	27.93	±17.80	-1.02	±1.22
h_t^i	18.77	±10.47	23.68	±10.59*	0.07	±0.04	6.83	±5.33	0.02	±0.37
h_z^i	73.79	±13.14**	68.62	±13.30***	-0.01	±0.05	43.57	±7.00***	2.32	±0.47***
g_A^m	42.87	±19.76*	45.57	±19.99*	0.01	±0.08	22.28	±9.74*	0.34	±0.67
g_H^m	35.99	±24.97	51.38	±25.25*	0.07	±0.10	24.36	±12.53	0.39	±0.87

*P<0.05; **P<0.01; ***P<0.001

Table 5 – Least square means and standard error for carcass weight and dressing percentage

Genetic group	Carcass weight, kg		Dressing percentage, %	
	Feedlot	Pasture	Feedlot	Pasture
A	222.75 ±7.99	229.22 ±9.08^{ab}	50.43 ±0.51^{ab}	51.02 ±0.57^{c}
CA	244.93 ±8.02	239.32 ±7.82^{ab}	51.31 ±0.51^{ab}	50.65 ±0.49^{c}
HA	225.12 ±8.82	230.95 ±8.69^{ab}	49.79 ±0.56^{b}	51.60 ±0.55^{bc}
NA	255.42 ±13.88	269.43 ±11.19^{a}	52.78 ±0.88^{a}	54.43 ±0.71^{ab}
AH	236.78 ±8.52	226.87 ±8.82^{ab}	50.68 ±0.54^{ab}	51.00 ±0.56^{c}
H	225.57 ±7.65	220.44 ±7.78^{b}	50.18 ±0.48^{ab}	51.40 ±0.49^{c}
AN	239.69 ±9.24	243.06 ±10.78^{ab}	52.42 ±0.58^{ab}	54.52 ±0.68^{a}
N	222.50 ±10.93	197.09 ±10.74^{b}	51.73 ±0.69^{ab}	51.81 ±0.68^{abc}

Least square means on the same column followed by different letters are statistically different (P<0.05)

Table 6 – Least square means and standard error for rib eye area (REA) and back fatness (BF)

Genetic group	REA, cm^2				Back fatness, mm			
	Feedlot		Pasture		Feedlot		Pasture	
A	61.83	±3.33	69.88	±3.88	4.28	±0.57	3.15	±0.62
CA	73.37	±3.34	72.98	±3.27	2.52	±0.58	3.41	±0.54
HA	67.12	±3.67	69.79	±3.46	4.29	±0.63	5.33	±0.6
NA	70.62	±6.52	77.96	±4.44	3.85	±1.13	4.69	±0.77
AH	70.65	±3.39	68.38	±3.51	3.56	±0.59	3.59	±0.65
H	70.67	±3.06	68.52	±3.10	3.68	±0.53	2.84	±0.54
AN	68.09	±4.17	81.65	±4.28	4.12	±0.72	4.44	±0.74
N	63.96	±4.34	62.14	±4.26	3.72	±0.75	3.08	±0.74

Least square means on the same column followed by different letters are statistically different ($P<0.05$)

Table 7 – Least square means and standard error for forequarter weight (FW), ribcut weight (RW) and pistol hindquarter weight (HW)

Genetic group	FW, kg		RW, kg		PHW, kg	
	Feedlot	Pasture	Feedlot	Pasture	Feedlot	Pasture
A	42.89 ±1.68	43.32 ±1.68^{ab}	17.71 ±0.75	17.65 ±0.75^{ab}	51.48 ±1.98	53.81 ±1.97^{ab}
CA	46.45 ±1.69	45.11 ±1.41^{ab}	19.40 ±0.75	18.05 ±0.63^{ab}	56.99 ±1.99	56.61 ±1.65^{ab}
HA	42.29 ±2.25	43.40 ±1.60^{ab}	17.19 ±1.05	17.78 ±0.71^{ab}	53.89 ±2.64	54.63 ±1.88^{ab}
NA	49.11 ±4.47	51.40 ±2.09^{a}	20.13 ±1.99	20.14 ±0.93^{a}	58.37 ±5.25	63.46 ±2.46^{a}
AH	44.85 ±1.56	42.42 ±1.62^{ab}	18.69 ±0.69	17.12 ±0.72^{abc}	55.02 ±1.83	53.87 ±1.90^{ab}
H	41.74 ±1.44	42.55 ±1.40^{b}	17.17 ±0.62	15.33 ±0.62^{bc}	53.17 ±1.62	52.61 ±1.65^{b}
AN	44.55 ±2.26	46.06 ±2.03^{ab}	18.29 ±1.01	18.47 ±0.90^{ab}	54.72 ±2.65	57.69 ±2.38^{ab}
N	42.74 ±2.28	37.51 ±2.01^{b}	15.27 ±1.02	13.15 +0.90^{c}	53.38 ±2.68	48.75 ±2.37^{b}

Least square means on the same column followed by different letters are statistically different ($P<0.05$)

Table 8 – Least square means and standard error for forequarter dressing (FD), ribcut dressing (RD) and pistol hindquarter dressing (HD)

Genetic group	FD, %		RD, %		PHD, %	
	Feedlot	Pasture	Feedlot	Pasture	Feedlot	Pasture
A	38.03 $\pm$0.35	37.55 $\pm$0.35	15.70 $\pm$0.29[a]	15.31 $\pm$0.29	45.81 $\pm$0.35	46.75 $\pm$0.35[b]
CA	37.62 $\pm$0.35	37.57 $\pm$0.29	15.77 $\pm$0.29[a]	15.01 $\pm$0.24	46.28 $\pm$0.35	47.12 $\pm$0.29[b]
HA	37.31 $\pm$0.47	37.47 $\pm$0.33	15.07 $\pm$0.39[ab]	15.31 $\pm$0.27	47.38 $\pm$0.47	47.13 $\pm$0.33[b]
NA	37.9 $\pm$0.93	37.98 $\pm$0.43	15.63 $\pm$0.77[ab]	14.91 $\pm$0.36	45.34 $\pm$0.93	46.98 $\pm$0.44[b]
AH	37.71 $\pm$0.32	37.28 $\pm$0.34	15.69 $\pm$0.27[a]	14.98 $\pm$0.28	46.29 $\pm$0.32	47.31 $\pm$0.34[ab]
H	37.82 $\pm$0.29	38.39 $\pm$0.29	15.16 $\pm$0.24[ab]	13.86 $\pm$0.24	46.98 $\pm$0.29	47.50 $\pm$0.29[ab]
AN	37.77 $\pm$0.47	37.78 $\pm$0.42	15.48 $\pm$0.39[ab]	15.11 $\pm$0.35	46.41 $\pm$0.47	47.28 $\pm$0.42[ab]
N	38.04 $\pm$0.47	37.68 $\pm$0.42	13.56 $\pm$0.39[b]	13.32 $\pm$0.34	47.76 $\pm$0.47	49.14 $\pm$0.42[a]

Least square means on the same column followed by different letters are statistically different ($P<0.05$)

Table 9 - Individual and maternal breed effects and individual heterosis for weight of forequarter, ribcut and pistol hindquarter

Effects	FW, kg		RW, kg		PHW, kg	
g_A^i	0.11	$\pm$2.88	1.94	$\pm$1.36	-3.69	$\pm$3.54
g_H^i	-1.33	$\pm$3.26	0.37	$\pm$1.54	-3.51	$\pm$4.00
g_C^i	3.47	$\pm$3.75	2.25	$\pm$1.79	1.33	$\pm$4.65
h_t^i	0.91	$\pm$1.10	0.85	$\pm$0.53	1.56	$\pm$1.38
h_z^i	8.00	$\pm$1.47***	3.72	$\pm$0.70***	7.97	$\pm$1.81***
g_A^m	5.42	$\pm$2.21*	1.98	$\pm$1.07	6.16	$\pm$2.76*
g_H^m	5.85	$\pm$2.75*	2.14	$\pm$1.33	6.24	$\pm$3.44

*P<0.05; **P<0.01; ***P<0.001

Table 10 - Individual and maternal breed effects and individual heterosis for dressing of forequarter (FD), ribcut (RD) and pistol hindquarter (PHD), rib eye area (REA) and back fatness (BF)

Effects	FD, %	RD, %	PHD, %	REA, cm^2	BF, mm
g_A^i	-0.40 ±0.63	2.30 ±0.54***	-1.88 ±0.63**	3.64 ±5.97	0.47 ±1.06
g_H^i	-0.17 ±0.71	1.32 ±0.61*	-0.65 ±0.71	7.16 ±6.74	0.97 ±1.20
g_C^i	0.17 ±0.82	1.38 ±0.71*	-1.38 ±0.83	15.74 ±7.95	-2.86 ±1.41*
h_t^i	-0.49 ±0.24*	0.33 ±0.21	0.17 ±0.24	1.58 ±2.37	0.93 ±0.42*
h_z^i	-0.03 ±0.32	0.88 ±0.27**	-0.77 ±0.32*	11.90 ±3.09***	0.98 ±0.55
g_A^m	0.19 ±0.49	-0.08 ±0.42	-0.39 ±0.49	0.53 ±4.55	0.16 ±0.81
g_H^m	0.26 ±0.61	-0.08 ±0.52	-0.66 ±0.61	1.13 ±5.70	-0.85 ±1.02

*P<0.05; **P<0.01; ***P<0.001

Considerações finais

O cruzamento é uma ferramenta de melhoramento genético que possibilita ganhos em intervalos de gerações mais curtos, porém, a utilização requer um manejo mais complexo já que muitas vezes, dependendo da estratégia de cruzamento, há necessidade de produção ou aquisição de matrizes cruzadas, o que, muitas vezes, dificulta a utilização da ferramenta por parte dos produtores.

No presente estudo, o cruzamento entre taurinos e zebuínos, bem como a utilização de matrizes cruzadas, se mostrou interessante do ponto de vista produtivo, melhorando as principais características de interesse, tal como o peso a desmama, ganho pré e pós desmama, peso ao sobreano, peso ao abate e características de carcaça.

Os taurinos puros, em função da seleção feita ao longo dos anos, para desempenho em ambientes favoráveis, se mostraram mais eficientes para ganho de peso em confinamento, sendo que a raça Hereford, como já esperado, foi a que apresentou melhor eficiência alimentar em comparação as demais.

Já o Nelore, não apresentou desempenho favorável para utilização da raça pura em sistemas de produção a pasto tais quais o do presente estudo. Já o taurino adaptado, Caracu, pode ser utilizado em sistemas de cruzamento para explorar a rusticidade.

Mais estudos estão sendo conduzidos para verificar a viabilidade econômica de esquemas de cruzamento para bovinos criados a pasto. Esses estudos darão suporte para auxiliar na tomada de decisão dos produtores no momento de planejar um sistema de cruzamento.