UNIVERSIDADE FEDERAL DA BAHIA
PROGRAMA DE PÓS-GRADUAÇÃO EM ZOOTECNIA

QUALIDADE FÍSICO-QUÍMICA E SENSORIAL DE CARNES E PRODUTOS CÁRNEOS DE BOVINOS DE TRÊS GRUPOS ZOOTÉCNICOS

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SALVADOR - BAHIA
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Tese apresentada ao Programa de Pós-Graduação em Zootecnia, da Universidade Federal da Bahia, como requisito parcial para a obtenção do título de Doutora em Zootecnia.

Área de Concentração: Produção de Ruminantes e Forragicultura

Orientador: Prof. Dr. Ronaldo Lopes Oliveira

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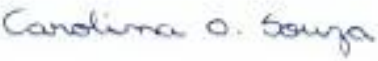

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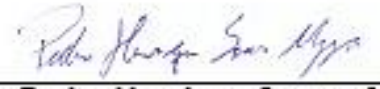

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AI	Atherogenicity index/índice de aterogenicidade
AL	Ácido linoléico
ALN	Ácido alfa linolênico
AMSA	American Meat Science Association
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
ATP	Adenosina trifosfato
CAPES	Coordenação de Aperfeiçoamento de Pessoal de Nível Superior
CIE	Commission International I'Eclarage
CL	Cooking loss
CLA	Conjugated linoleic acid/Ácido linoléico conjugado
DHA	Docosahexaenoic acid
DPA	Docosapentaenoic acid
EPA	Eicosapentaenoic acid
FA	Fatty acids
FAME	Fatty Acids Methyl Esters
FAPESB	Fundação de Amparo à Pesquisa do Estado da Bahia
FIS	Federal Inspection Service
HDL	High density lipoproteins
MAPA	Ministério da Agricultura, Pecuária e Abastecimento
MUFA	Monounsaturated fatty acids
NIR	Near Infrared
PUFA	Polyunsaturated fatty acids
SAS	Statistical Analysis System
SEM	Standard error of the mean
SFA	Saturated fatty acids
TI	Thrombogenicity index/índice de trombogenicidade
UFA	Unsaturated fatty acids
WBSF	Warner-Bratzler Shear Force
WHC	Water Holding Capacity

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INTRODUÇÃO GERAL

O Brasil se consolidou como o segundo maior produtor e o maior exportador mundial de carne bovina, contando com 202,78 milhões de cabeças de gado e um volume de abate de 42,31 milhões de cabeças, e um volume de exportação de cerca de 3,02 milhões de toneladas de carne bovina, sendo os principais países compradores a China (42,75%), os Emirados Árabes (7,72%) e os Estados Unidos (4,67%) (USDA, 2024; ABIEC, 2024).

Diante desta realidade, os produtores brasileiros, em meio aos mais diferentes tipos de ambiente e sistemas produtivos, enfrentam o grande desafio de produzir animais produtivos e rentáveis, e, ao mesmo tempo, alimentos cárneos que atendam aos requisitos de aceitação do consumidor (PEREIRA et al., 2015). Dentro das condições extensivas de criação a pasto no país, os bovinos pertencentes ao grupo zootécnico *Bos taurus indicus*, também denominados de *Bos indicus* ou, simplesmente, zebuínos, consolidaram-se como os principais representantes do rebanho comercial brasileiro (GORDO et al., 2018; AROEIRA et al., 2017).

Apesar de bovinos *Bos indicus* serem mais tolerantes às condições tropicais e aos parasitas, a carne destes animais é, tradicionalmente, considerada como de menor maciez e com baixa deposição de gordura quando comparada à carne de bovinos de raças *Bos taurus taurus* (também chamados de *Bos taurus*, ou taurinos) (RODRIGUES et al., 2017; WHEELER et al., 1990; JOHNSON et al., 1990), comprometendo, assim, a produção de carne de qualidade no país.

Dentro deste contexto, o melhoramento genético do rebanho se insere, portanto, como um fator de grande importância na determinação das características de qualidade da carne bovina, e, assim, os cruzamentos se tornaram um valioso aliado na busca por melhorias no perfil genético do rebanho nacional e, consequentemente, nos atributos de qualidade da carne produzida no país.

Além disso, como a carne é um produto altamente perecível, o seu processamento tornou-se necessário no sentido de preservar seus atributos de qualidade. Assim, diferentes processos de transformação de carne em produtos cárneos geram produtos mais ou menos modificados do que outros e com as mais diversas características sensoriais. Diversos tipos de processamento podem ser empregados, como salga, secagem, cozimento, marinação e defumação, entre outros (SEMAN et al., 2018; COLLIGNAN et al., 2001).

A carne de sol é um produto cárneo tradicionalmente consumido no Brasil, e seu processo de elaboração consiste, basicamente, na sua salga e desidratação parcial, tendo características físico-químicas muito próximas às da carne *in natura* e baixa vida de prateleira

(3 a 4 dias a temperatura ambiente). O seu processo de elaboração é considerado artesanal e está sujeito a variações de acordo com critérios regionais (ABRANTES et al., 2014; NORMAN e CORTE, 1985). Além disso, ainda não há legislação específica que regule suas características de identidade e qualidade.

O hambúrguer, de grande popularidade no Brasil e no mundo, é um produto cárneo industrializado com padrões de identidade e qualidade oficialmente regulados, obtido a partir da carne bovina moída, podendo ser adicionada gorduras e outros ingredientes, modelado e submetido a processo tecnológico adequado (RIBEIRO et al., 2023; BRASIL, 2022).

Dessa forma, considerando que os atributos físico-químicos da carne crua podem ter papel essencial na determinação da qualidade final do produto processado, a influência genética animal nos atributos físico-químicos e sensoriais da carne *in natura* também poderia ser perceptível nos atributos finais de qualidade de produtos cárneos. Portanto, hipotetizou-se que os cruzamentos entre as espécies de *Bos indicus* × *Bos taurus* podem atribuir melhorias nos atributos de qualidade físico-química e sensorial da carne e dos produtos cárneos de bovinos. O objetivo foi avaliar os efeitos dos grupos zootécnicos Nelore - Nell, ½ Nelore ½ Angus – NeAn e ¼ Nelore ¼ Angus ½ Senepol – NASe sobre os atributos físico-químicos e sensoriais da carne e dos produtos cárneos.

REVISÃO DE LITERATURA GERAL

2.1 Qualidade da carne e genética animal no contexto produtivo

Os atributos de qualidade da carne bovina estão relacionados a parâmetros específicos, como as proporções de massa magra e de gordura, a partir das quais são avaliados composição e perfil nutricional (CASSAR-MALEK e PICARD, 2016). Dentro destes parâmetros de qualidade da carne estão a aparência, o grau de retenção de água e gordura e os atributos de aroma, *flavor*, maciez e suculência (TORNBERG, 2005).

Alguns dos atributos de qualidade da carne tornaram-se grandes desafios para os produtores brasileiros, como a maciez, a deposição de gordura e a uniformidade de produção (LAGE et al., 2012). O rebanho bovino brasileiro é composto, em sua maior parte, por animais do grupo zootécnico *Bos indicus*, fator negativo no desenvolvimento destes atributos de qualidade, já que são conhecidos pela produção de carne com baixo índice de maciez quando

comparado com bovinos *Bos taurus*, e isso ocorre devido à maior atividade da enzima calpastatina no primeiro grupo, levando a uma menor atividade proteolítica miofibrilar (MACEDO et al., 2022; PRADO et al., 2008; PRINGLE et al., 1997). Considerando que a maciez é um atributo sensorial de maior importância no que diz respeito à satisfação proporcionada ao consumidor (VERBEKE et al., 2010; DELGADO et al., 2006), a carne dos zebuínos torna-se, portanto menos atrativa ao consumo.

As raças taurinas europeias britânicas, como a raça Angus, tornaram-se valiosos recursos genéticos para melhoria nos atributos de qualidade da carne, mas, ao mesmo tempo, apresentam, como características indesejáveis, a sua intolerância ao clima tropical, o que interfere negativamente no seu desempenho produtivo (OSU, 2015; BURROW et al., 2001). Para solucionar este problema, os cruzamentos tornaram-se aliados eficientes na melhora dos atributos de qualidade da carne no país (FERRAZ e FELÍCIO, 2010; GREGORY e CUNDIFF, 1980).

Entretanto, deve-se considerar que os animais cruzados ainda podem apresentar problemas de adaptabilidade e produtividade, bem como apresentar maiores necessidades nutricionais comparados aos zebuínos (NRC, 1996). Deve-se considerar que quanto maior a proporção de *Bos indicus* nos cruzamentos (½ ou mais), a qualidade da carne diminui, principalmente no que diz respeito à maciez, bem como quanto maior a proporção de *Bos taurus* (½ ou mais), piores são as características de adaptabilidade e produtividade do rebanho (PRINGLE et al., 1997; SHACKELFORD et al., 1995; JOHNSON et al., 1990; WHIPPLE et al., 1990; CROUSE et al., 1989).

Diante disso, os taurinos adaptados tornaram-se mais uma alternativa para a melhoria do rebanho brasileiro, sendo recomendados, inclusive, em cruzamentos com *Bos indicus* e *Bos taurus* para melhoria tanto dos atributos de qualidade da carne quanto na performance produtiva dos animais. Bovinos da raça Senepol são caracterizados como taurinos altamente adaptados às condições tropicais e com grande potencial para melhorar os atributos de carne e carcaça do rebanho (ABCB Senepol, 2024; MACEDO et al., 2022; PEREIRA e SILVA, 2004; HAMMOND et al., 1996; HUPP et al., 1978). Apesar disso, as informações na literatura acerca da caracterização zootécnica, bem como das características de qualidade da carne produzida por esta raça e seus cruzamentos permanecem escassas.

2.2 A importância dos produtos cárneos na alimentação humana

Devido à alta perecibilidade da carne, o seu processamento torna-se de fundamental

importância na preservação dos seus atributos de qualidade, além de possibilitar, assim, a produção de uma diversa gama de produtos cárneos, como carne de sol, charque, linguiça frescal e hambúrguer (BRASIL, 2000a; BRASIL, 2000b; COLLIGNAN et al., 2001; Norman & Corte, 1985). Geralmente, as carnes processadas podem ser fabricadas utilizando-se tanto os cortes íntegros obtidos das carcaças, quanto suas aparas e vísceras (LONERGAN et al., 2019). De acordo com o *American Meat Science Lexicon*, a carne pode ser processada de variadas formas, sendo que os processos de cominuição, secagem, salga, cura, marinação, defumação, acidificação e fermentação, por exemplo, modificam as características físico-químicas da carne crua (SEMAN et al., 2018).

A cocção é outro método de processamento da carne, com modificação das suas características físico-químicas. Além da desnaturação das proteínas, com destruição do seu conteúdo celular, ocorrem os processos de encurtamento das fibras musculares, agregação e formação de gel das proteínas sarcoplasmáticas, além de encurtamento e solubilização do tecido conectivo (ROWE, 1989; BENDALL e RESTALL, 1983; CHENG e PARRISH, 1976; JONES et al., 1977). A cominuição da carne, seguida de adição de sal e aquecimento, como ocorre nos processos de elaboração de hambúrgueres e linguiças e salsichas emulsionadas, modifica de forma substancial o arcabouço estrutural da carne, levando a um encurtamento ainda maior das fibras, ou pedaços de fibras musculares, podendo formar, inclusive, uma rede protéica densa (gel), com uma maior capacidade de reter água por capilaridade (TORNBERG, 2005).

As carnes processadas tornam-se fontes de proteínas, vitaminas e minerais, embora, muitas vezes, tenham um alto conteúdo em sal e gorduras, quando comparadas à carne fresca, e seu consumo pode ser influenciado por diversos aspectos, como aceitação sensorial e composição nutricional, custos, segurança alimentar, situação econômica, familiar e/ou influência educacional, dentre outros (JIMÉNEZ-COLMENERO et al., 2001; BRASIL, 2000a). Os embutidos, por exemplo, são ricos em lipídios e possuem características sensoriais desejáveis de sabor, maciez e suculência, sendo considerados alimentos de consumo frequente no Brasil, como linguiça e salsicha (26,5%) (COSTA et al., 2021).

A Organização Mundial de Saúde (OMS) recomenda que o consumo diário de sódio não ultrapasse 2g, o que equivale a 5g de sal de cozinha (WHO, 2012). Entretanto, dados da Global Burden of Diseases Nutrition and Chronic Diseases Expert Group (NUTRICODE), estimam que o consumo de sódio pela população mundial seja de 3,95 g/dia (MICHA et al., 2017) sendo que, no Brasil, este consumo pode chegar a mais de 8 g/dia (MILL et al., 2019). O consumo excessivo de sódio tem sido associado a problemas como aumento da pressão arterial, doença renal crônica e acidente vascular cerebral (CHOI et al., 2016; MA et al., 2015; KIM et

al., 2014; HE et al., 2013).

Um outro aspecto a ser considerado em carnes e produtos cárneos é a ocorrência de oxidação lipídica de triacilgliceróis e fosfolipídios durante o processamento e armazenamento, já que os lipídios podem ser oxidados por diversos sistemas catalíticos, como temperatura, enzimas, metais, metaloproteínas e microrganismos, ocasionando alterações deletérias em *flavor*, cor, textura e valor nutricional, o que compromete sua qualidade ao consumo (TSIKAS, 2017; JITTREPOTCH et al., 2006; GRAY et al., 1996; JUNG et al., 1996; FRANKEL, 1996; ST. ANGELO et al., 1996; BRADLEY e MIN, 1992; KORYCKA-DAHL e RICHARDSON, 1978). Assim, a indústria, com o objetivo de inibir estas reações bioquímicas, buscam diversos métodos para aumentar a vida de prateleira dos produtos, sendo um deles a aplicação de antioxidantes (Barbosa et al., 2019). Os antioxidantes sintéticos são os mais utilizados, como butil-hidroxi-anisol (BHA), butil-hidroxitolueno (BHT), terc-butil-hidroquinona (TBHQ) e propilgalato (PG), os quais apresentam efeitos adversos à saúde, devido ao seu potencial carcinogênico (LORENZO et al., 2018; AGREGÁN et al., 2017; MUNEKATA et al., 2017; ŞAHIN et al., 2017; FALOWO et al., 2014; LORENZO, et al., 2013; FAINE et al., 2006).

O teor de lipídios em produtos cárneos é considerado alto, podendo variar de 20% a 50%, enquanto que o teor de gordura da fração magra da carne de várias espécies animais normalmente não ultrapassa 5% (JIMÉNEZ-COLMENERO et al., 2000). O aumento nos níveis de ácidos graxos saturados da dieta, pode levar a enfermidades como doenças cardiovasculares, diabetes e obesidade (BINNIE et al., 2014; ALEXANDER, 2013; HENRY et al., 2013; ADA, 2012; WHO, 2009; DEMEYER et al., 2008). Além disso, o alto conteúdo de ácidos graxos ômega-6 (*n*-6) em relação aos ácidos graxos ômega-3 (*n*-3) presente na gordura animal pode aumentar a razão *n*-6:*n*-3, levando ao desenvolvimento de problemas como doenças cardiovasculares, aumento na taxa de multiplicação celular e reações alérgicas (VALENCAK et al., 2015; SIMOPOULOS, 2002; BEECHER, 1999).

Entretanto, ao mesmo tempo em que teor de cloreto de sódio (NaCl) e gorduras na carne são objeto de preocupação no que diz respeito à sua ingestão inadequada e ao desenvolvimento de doenças, ambos são importantes recursos para a melhoria dos aspectos de qualidade dos produtos cárneos, melhorando sua textura, sabor e vida de prateleira, pois melhoram a solubilização das proteínas miofibrilares da carne e a capacidade de retenção de água, diminuindo, com isso, sua perda durante o processo de cozimento, o que melhora a suculência e maciez, além de reduzir a atividade de água (a_w) e, consequentemente, a chance de crescimento microbiano (KWON et al., 2021; COSTA-CORREDOR et al., 2009; BIDLAS e LAMBERT, 2008; DESMOND, 2006; RUUSUNEN et al., 2005; HUGHES et al., 1997). Além

de contribuir para a formação de emulsões estáveis na carne moída, a ingestão de gorduras é importante para o desenvolvimento corporal e manutenção das suas atividades funcionais, pois ela é responsável pelo aporte de ácidos graxos e vitaminas lipossolúveis para o corpo, melhorando, também, os atributos sensoriais, a textura, o sabor e o aroma da carne (NUERNBERG et al., 2005; HUGHES et al., 1997). Assim, a carne pode ser convertida a uma grande variedade de produtos cárneos, sendo a maior fonte de energia e de proteínas e micronutrientes de alta qualidade, como as vitaminas B12 e D, além de ferro, selênio e zinco (PATHIRAJE et al., 2023).

2.2.1 Carne de sol

Nos países em desenvolvimento, a salga e secagem tornaram-se métodos tradicionais de conservação da carne, com destaque para a carne de sol, produto cárneo consumido desde tempos remotos no país, quando os recursos para refrigeração da carne eram escassos devido à baixa condição sócio-econômica da população (NORMAN e CORTE, 1985).

A carne de sol é descrita como a carne levemente salgada que foi submetida à desidratação parcial e que possui curta vida de prateleira (cerca de 3 a 4 dias à temperatura ambiente), sendo caracterizada como quase similar à carne fresca, diferente, portanto, da charque e do *Jerked beef* (OJHA et al., 2017; NORMAN e CORTE, 1985). A carne de sol é um produto cárneo tradicional da região nordeste do Brasil e sua fabricação é descrita como artesanal, onde a carne é submetida à salga e exposição ao sol e ao vento para secar, mas, em verdade, esta carne raramente é exposta ao sol; pelo contrário, ela é armazenada em ambiente coberto e bem ventilado.

Para fabricação da carne de sol utilizam-se normalmente as carnes bovina ou caprina (NORMAN e CORTE, 1985). Entretanto, apesar destas descrições técnicas, não existe nenhum protocolo oficial na legislação brasileira sobre a fabricação e as caracterização físico-química e sensorial de carne de sol. Em 2019, foi apresentada no Senado uma proposta para implementar padrões de fabricação e comercialização de carne de sol, a qual ainda está pendente de aprovação (BRASIL, 2019).

O processo de fabricação de carne de sol consiste, inicialmente, na utilização de corte de carne específico, especificamente aqueles localizados na região de quarto traseiro do animal, com destaque para os músculos coxão mole, ou chã de dentro (inclui os músculos semimembranoso, adutor, sartório, grácil, pectíneo, obturador interno, obturador externo, gêmeos e quadrado femoral), coxão duro, ou chã de fora (inclui o músculo glúteo bíceps,

patinho (inclui os músculos reto femoral, vasto lateral, vasto medial e vasto intermediário), alcatra (inclui os músculos tensor da fáscia lata, glúteo bíceps, glúteo médio, glúteo acessório e glúteo profundo) e lombo (contrafilé) (GOUVÊA e GOUVÊA, 2007; BRASIL, 1988).

Seguindo os princípios da metodologia de GOUVÊA e GOUVÊA (2007), com adaptações feitas por GOUVÊA et al. (2017), a elaboração da carne de sol é feita da seguinte forma: O corte de carne (coxão mole, músculos *Semimembranosus* e *Adductor femoris*) é submetido ao processo de adelgaçamento (elaboração da manta), que consiste num corte feito na carne de forma que a mesma fique com uma espessura de, no máximo, 5 centímetros. Depois, são feitos cortes no sentido das fibras musculares em somente um lado da manta, com espaços de 3 a 4 cm entre cada um deles. De outra forma, esses cortes podem ser feitos dos dois lados da peça, com espaços de 8 ou 9 cm entre eles, com o cuidado para que estes cortes não atinjam o outro na outra face da peça de carne.

Após a elaboração da manta e dos cortes, segue-se para o processo de salga. O teor de sal pode ser de 5% até um máximo de 8% em relação ao peso da carne utilizada. O sal é, então, distribuído ao longo da manta de carne e sua distribuição é feita por fricção da superfície da mesma, incluindo os cortes. Depois deste processo, cada peça de carne é colocada em uma bandeja plástica ou mesa inox perfuradas, as quais devem ter inclinação suficiente para que a salmoura escorra. Neste momento, a temperatura ambiente deve ser de 25 °C. As peças devem ser viradas duas vezes a cada 8h ou até 10h, para que ocorra a sua desidratação, e, assim, estarão prontas para serem comercializadas e consumidas.

Opcionalmente, as peças podem ser ligeiramente lavadas com água para retirar o excesso de sal e serem penduradas em ganchos de metal com espaços entre si para permitir a circulação homogênea de ar e colocadas por mais 8h a uma temperatura ambiente de cerca de 25 °C para remoção do excesso de água da lavagem. Além disso, pode-se optar por colocar as peças de carne sob o sol da manhã (evitando-se os horários mais quentes) por 30 a 40 min, com a parte gordurosa voltada para o sol, sendo que esta etapa tem como único objetivo dourar a gordura da carne. Todo o processo de elaboração de carne de sol pode durar cerca de 24 h a 30 h.

A carne de sol é diferente da Charque, a qual é um produto largamente consumido e com parâmetros de qualidade regulados por legislação específica, sendo o produto cárneo dessecado mais comum na América do Sul (ABRANTES et al., 2014; NORMAN e CORTE, 1985). Enquanto a charque sofre processos mais intensos de salga seca e úmida e secagem, resultando num produto com 44-45% de umidade e 12-15% de NaCl, a carne de sol passa por um processo mais suave de salga seca e secagem, resultando em um produto com 64-70% de

umidade e 5-6% de NaCl (LIRA et al., 1998). Os diferentes processos de elaboração da carne de sol e charque determinam suas diferenças no que diz respeito à vida de prateleira. Enquanto a charque normalmente é comercializada a vácuo e tem vida de prateleira de aproximadamente 180 dias, a carne de sol é comercializada sem atmosfera a vácuo, e, assim, possui uma vida de prateleira menor que 7 dias (OJHA et al., 2017; FERREIRA, 2008; NORMAN e CORTE, 1985).

2.2.2 Hambúrguer

Acredita-se que o hambúrguer tenha se originado na Alemanha, cujo nome (*hamburger*) deriva da cidade de Hamburgo, localizada naquele país, e chegado aos Estados Unidos da América por volta de 1904, onde se popularizou (USDA, 2023; RANKEN, 2000). Assim, o hambúrguer tornou-se um produto cárneo largamente consumido ao redor do mundo devido à sua preparação simples, baixo custo, composição em nutrientes importantes como proteínas de alto valor biológico, vitaminas e minerais, além de possuir atributos sensoriais atrativos, e, além disso, seu consumo, juntamente com o da salsicha, vem crescendo progressivamente no Brasil, com um aumento de cerca de 83% entre 2015 e 2020 (RIBEIRO et al., 2023; ZIEGLER et al., 2020; RIOS-MERA et al., 2019; HAUTRIVE et al., 2019; OLIVEIRA et al., 2016; RAMADHAN et al., 2011; BENDER, 1992).

O processo de elaboração de hambúrguer envolve, basicamente, os seguintes passos (GOUVÊA et al., 2016; GUERREIRO, 2006): Primeiro a carne é moída, e adicionada de gordura animal (toucinho) moída. As duas matérias-primas são misturadas manualmente e acrescidas de sal a 1,5% e condimentos, como alho, açúcar e pimenta. A massa com os ingredientes é, então, misturada manualmente por 20 minutos e colocada em refrigerador a 4°C por 12h. Após esse período, a massa é moldada em equipamento específico para hambúrguer (a massa deve estar em temperatura de, no máximo, 10°C) e o produto pronto é então embalado e congelado abaixo de 0°C, até o momento de seu uso.

Ao contrário do que ocorre com a carne de sol, onde não há legislação específica que caracterize os seus padrões de identidade e qualidade, as características de qualidade do hambúrguer são oficialmente reguladas. De acordo com o Regulamento Técnico de Identidade e Qualidade de Hambúrguer, o hambúrguer é um produto cárneo industrializado obtido a partir da carne moída dos animais de açougue, com ou sem adição de gorduras e outros ingredientes, moldado e submetido a processos tecnológicos, sendo classificado como um produto cru, cozido, congelado ou resfriado (BRASIL, 2022). Como características físico-químicas, a

legislação brasileira estipula ainda que a composição do hambúrguer inclua, obrigatoriamente, carnes de diferentes espécies de animais de açougue, sendo os demais ingredientes (água, sal, gordura animal, gordura vegetal, condimentos, etc) opcionais.

O hambúrguer constitui-se em um produto fonte de altos níveis de lipídios e sódio, os quais, em excesso, podem levar a doenças cardiovasculares e obesidade (RIOS-MERA et al., 2019; ZHOU et al., 2019; BARBOSA et al., 2017; SELANI et al., 2016; ABURTO et al, 2013). No Brasil, o teor de sódio do hambúrguer (701 mg/100 g de produto) chega a ser maior que na Austrália (480 mg/ 110 g de produto) e Estados Unidos (290-400 mg/100 g de produto) (INGUGLIA et al., 2017; ANVISA, 2012; WEBSTER et al., 2010).

A gordura animal adicionada à massa de hambúrguer tem como objetivo melhorar o paladar do produto, sendo os toucinhos a fonte principal de gordura, com destaque para o toucinho suíno, de cor branca, firme e sem cheiro (GUERREIRO, 2006). Normalmente, os teores de gordura animal do hambúrguer podem variar de 9 a 20%, contendo um nível alto de ácidos graxos saturados (31 a 42%), os quais estão relacionados a doenças coronarianas, e, dessa forma, o consumo excessivo deste produto cárneo pode ser prejudicial à saúde (HECK et al., 2019; ALEJANDRE et al., 2017; SELANI et al., 2016; WHO, 2003). O Regulamento Técnico de Identidade e Qualidade de Hambúrguer estabelece um teor de gordura máximo no produto de 25% (BRASIL, 2022). Segundo a OMS, o teor de gorduras ingerido não deve ultrapassar 30% do total de energia ingerida por um adulto (WHO, 2023).

Em suma, a elaboração de produtos cárneos visa não só preservar as características de qualidade físico-química e microbiológica da carne, preservar sua vida útil e aumentar sua segurança ao consumo, mas também é uma forma de agregar valor aos produtos comercializados (NARDOCCI et al., 2019; BARBOSA et al., 2019; SEMAN et al., 2018), aliado ao fato de que, até os dias atuais, a carne e os produtos cárneos, além de promover uma alta saciedade quando do seu consumo, se consolidaram como os mais completos em termos de aporte de nutrientes importantes (WESTERTERP-PLANTENGA et al., 2009).

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CHAPTER I

PHYSICOCHEMICAL COMPOSITION, FATTY ACID PROFILE AND SENSORY ATTRIBUTES OF MEAT (*LONGISSIMUS LUMBORUM* MUSCLE) FROM NELLORE AND NELLORE-CROSS BULLS

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Composição físico-química, perfil de ácidos graxos e atributos sensoriais de carne (músculo *longissimus lumborum*) de bovinos Nelore e cruzados de Nelore

RESUMO

O presente estudo teve como objetivo comparar as características físico-químicas, o perfil de ácidos graxos e os atributos sensoriais da carne de bovinos dos seguintes grupos genéticos: Nelore (Nell), ½ Nelore × ½ Angus (NeAn), and ¼ Nelore × ¼ Angus × ½ Senepol (NASe). Foi utilizado o músculo *Longissimus lumborum* de 30 bovinos abatidos com peso corporal de 549 ± 32.5 kg. A capacidade de retenção de água foi maior em carnes dos grupos Nell e NeAn do que no grupo NASe. As amostras de carne do grupo NASe tiveram maior índice *L** do que carnes do grupo NeAn e menores índices *a** e *b** do que as carnes do grupo Nell. O perfil de ácidos graxos mostrou que o grupo Nell obteve maiores concentrações de 12:0, 14:0, 18:1 *t*11, 14:1 *c*9, 16:1 *c*9, 18:1*c*9, 18:1 *c*11, 18:2 *c*9, *t*11 (ácido linoléico conjugado (CLA)), e 20:3 *n*-6 do que as carnes dos grupos NeAn e NASe. As concentrações totais de ácidos graxos saturados, insaturados e monoinsaturados (ΣSFA, ΣUFA e ΣMUFA) foram maiores e a razão ΣPUFA:ΣSFA foi menor no grupo Nell do que no grupo NeAn. A atividade de Δ^9–desaturase para C16 foi significativamente maior nos grupos Nell e NASe do que no grupo NeAn. O índice de aterogenicidade (IA) teve tendência de decréscimo nos animais cruzados do que no grupo Nelore. O grupo NASe apresentou carnes com melhores escores de maciez, suculência e aceitação global do que os grupos Nell e NeAn, e, assim, foi o melhor grupo genético para a produção de carne bovina dentre todos os grupos testados.

Palavras-chave: *Bos indicus*, *Bos taurus*, cruzamentos, genética, produção, ruminantes

Physicochemical composition, fatty acid profile and sensory attributes of meat (*longissimus lumborum* muscle) from Nellore and Nellore-cross bulls

ABSTRACT

This study aimed to compare the physicochemical characteristics, fatty acid composition, and sensory attributes of the meat from three genetic groups: Nellore (Nell), ½ Nellore × ½ Angus (NeAn), and ¼ Nellore × ¼ Angus × ½ Senepol (NASe). *Longissimus lumborum* muscle from 18 slaughtered bulls with a body weight of 549 ± 32.5 kg was used. The water holding capacity was greater for the Nell and NeAn groups than for the NASe group. Meat samples from the NASe group exhibiteda higher L* index than those from the NeAn group and lower a* and b* color indexes than those from the Nell group. The meat fatty acid profiles showed that the Nell group had higher concentrations of 12:0, 14:0, 18:1 *t*11, 14:1 *c*9, 16:1 *c*9, 18:1*c*9, 18:1 *c*11, 18:2 *c*9, *t*11 (conjugated linoleic acid (CLA)), and 20:3 *n*-6 polyunsaturated fatty acid (PUFA) than the NeAn and NASe groups. The total saturated (ΣSFA), unsaturated (ΣUFA), and monounsaturated (ΣMUFA) fatty acid concentrations were higher and the ΣPUFA:ΣSFA ratio was lower in the Nell group than in the NeAn group. The Δ^9–desaturase C16 activity was significantly higher in the Nell and NASe groups than in the NeAn group. The atherogenicity index (AI) tended to be lower in the crossbreeds than in the Nell breed. The NASe group presented meat with better tenderness, juiciness, and overall acceptance than the Nell and NeAn groups and was therefore the best genetic group for beef production of the tested groups.

Keywords Atherogenicity index · Beef · Genetic · *Longissimus* muscle · Water holding capacity

Introduction

The concept of meat quality is very broad and can be influenced by several factors that are interrelated within the meat production chain. One of the main factors is the choice of genetic material because the meat quality varies on the basis of the breed (Rotta et al. 2009). Thus, genetic improvement is an important tool for increasing meat quality, which can cause problems in production systems when fat deposition or tenderness is low (Lage et al. 2012). The genotype Bos indicus is commonly used in meat production (Aroeira et al. 2017) but suffers from the abovementioned quality deficit (Prado et al. 2008). Taurine breeds have great characteristics when raised in temperate climates but do not present the same productive attributes when raised in tropical regions due to environmental stressors, which include hot temperatures and parasites.

In this sense, crossbreeding has been fundamental to improving the beef cattle production system. Crossbreeding aims to exploit differences to find combinations (crosses) that best fit the type of production (breeding, rearing, or fattening), as well as the environmental conditions and market requirements of each region. Thus, beef cattle producers began to explore genotypes best suited for their production system; that is, genotypes that are more efficient at converting consumed food into body mass and meeting market demand, especially in terms of carcass and meat quality, are utilized (Koetz Junior et al. 2019).

Bos taurus and *Bos indicus* were crossbred to explore complementarity between breeds and the benefit of heterosis (Gama et al. 2013) in addition to improvements in carcass and meat traits, such as tenderness (Lage et al. 2012). *B. indicus* meat was shown to be less tender than *B. taurus* meat (Wheeler et al. 1990), and as the proportion of *B. indicus* increases in the crossbreed, meat tenderness decreases (Crouse et al. 1989; Johnson et al. 1990; Rubensam et al. 1998). The difference in shear force between meat from *B. taurus* and *B. indicus* is attributed to the behavior of the calpain/calpastatin complex during maturation (Whipple et al. 1990; Lana and Zolla 2016), where calpains partially rupture the myofilaments, rendering the meat softer (Muroya et al. 2006). However, the catalytic activity of these enzymes is inhibited by calpastatin (Koohmaraie et al. 2002), whose activity in the muscles of *B. indicus* is higher than that in the muscles of *B. taurus* (Rubensam et al. 1998).

The Nellore breed is most frequently chosen for crossbreeding due to its rusticity, good performance, and remarkable precocity in relation to other Zebu breeds; additionally, the Nellore breed presents a higher slaughter carcass yield than other Zebu and Taurus breeds (Perotto et al. 2009; Carvalho et al. 2019). In addition, between Nellore and Red Angus crossbreeds show a higher warm carcass yield, higher longissimus dorsi area, higher carcass

musculature degree, lower bone content (Perotto et al. 2009), and higher fat thickness (Leme et al. 2000) than other crossbreeds. Thus, three cross-breeds can yield further improvements in carcass quality, meat production, and animal quality if an adapted Bos taurus animal is used. In this sense, the Senepol (Hammond et al. 1996)breed stands out due to its high tolerance of a tropical climate compared to that of other Taurus breeds, but data related to the genetic characterization of this breed are still sparse (Floriet al. 2012). Furthermore, there is a lack of information on the physicochemical and sensory meat attributes of this breedand its crosses.

In this context, meat quality improvement is related to the knowledge and control of meat attributes (Joo et al. 2013). For the meat industry, knowledge about customer meat quality preferences at the moment of purchase is of great importance(Vimiso et al. 2012). Therefore, the present study was conducted to test the hypothesis that animals of the genetic group ¼ Nellore × ¼ Angus × ½ Senepol have a longissimus musclewith improved physicochemical and sensory traits.

Materials and methods

Ethical considerations, treatment, animals, and management

The experimental trial was conducted at the Veterinaryand Animal Science School of Federal University of Bahia (UFBA), located in Salvador, Bahia, Brazil. All procedures followed the guidelines recommended by the AnimalCare and Use Committee of the same institution (CEUA/ UFBA Process number 043/2019).

The *longissimus lumborum* muscle from 30 uncastrated, pasture-finished bulls averaging 24 ± 3 months of age was used. The average daily gain was 0.955 ± 0.100 kg (producer farm data). Of the 30 muscle samples, ten were from the genetic group Nellore (Nell), ten from ½ Nellore × ½ Angus (NeAn), and ten from ½ Senepol × ¼ Nellore × ¼ Angus (NASe). The body weight of the slaughtered animals was 549 ± 32.5 kg, and the muscle pieces were purchased directly from the producer farm.

The animals that were born and raised on the same producer farm from where they were finished were separated by genetic group, kept in different paddocks (one 24-hectare paddock for each genetic group) containing *Brachiaria brizantha* cv. Marandu, and provided with drinking water sources and collective feeders nine meters in length for mineral supplementation

specific to each category. Feeding was similar for all genetic groups. Animals that were kept in pasture were supplemented with a 20% crude protein concentrate, offered at 1% of the body weight (BW). The concentrate consisted of ground corn (54%), soybean meal (40%), and a mineral mixture (6%). The animals remained separated by group until the predetermined BW for slaughter (500 to 600 kg) was reached.

Slaughter and physicochemical properties of meat

At the end of the finishing period, the animals were fasted for 16 h and weighed to obtain body weight at slaughter (BWS); then, they were sent to a commercial slaughterhouse located 1000 m away from the experimental farm. The animals were slaughtered following the guidelines of the Federal Inspection Service (FIS) of humane slaughter in accordance with the Brazilian Ministry of Agriculture and Livestock regulations (Normative no 03/00, MAPA, Brazil). At slaughter, after skinning and evisceration, the carcasses were cut into two halves, and the initial pH (pH_0)was measured in the *longissimus dorsi* muscle between the 6^{th} and 7^{th} ribs using a digital pH meter (model HI99163, HANNA Instruments, São Paulo, Brazil). Then, the carcasses were sent to the cold chamber where they remained at 4 °C for 24 h. After 24 h, the final pH (pH_{24h}) of the carcasses was measured using the same procedure previously described for pH_0, both according to the AOAC (2012). A transverse cut was made between the 12^{th} and 13^{th} ribs, section HH (Greiner et al. 2003). Then, samples of the *longissimus lumborum* muscle, approximately 2.5 cm thick, were collected, packed in aluminum foil and plastic film, and frozen in a freezer (− 18 °C) until analysis of the physicochemical properties, fatty acid composition, and sensory attributes. Before starting the analysis, the meat samples were thawed in plastic bags in a refrigerator at 10 °C for 20 h.

The water holding capacity (WHC) was determined in triplicate by the pressure method described by Hamm (1986), based on the difference in weight of a rectangular meat sample (2.0 g) before and after roasting. The sample was then subjected to a force equivalent to 10 kg for 5 min. The amount of water loss from the sample was expressed as a % of water retention in the initial sample weight.

To determine the cooking weight loss (CWL), meat samples with cm^3 dimensions and weighing approximately 15 g were weighed before and after cooking. A stainless-steel thermocouple (Gulterm 700; Gulton of Brazil) was positioned in the center (geometric) of each sample to monitor the internal temperature. During cooking, when the internal temperature

reached 71 °C, the samples were removed from the grill (George Foreman Jumbo Grill GBZ6BW, Rio de Janeiro, Brazil), placed in plastic packaging, and submergedin an ice water bath until the sample reached room temperature. The weight loss of each sample was determined from the difference between the weights before and after cooking and expressed as a percentage. After being weighed, thesamples remained at 4 °C overnight for subsequent texture analysis according to the American Meat Science Association (AMSA 2016). The cooking yield was calculated using the following equation: yield = (weight of cooked sample/ weight of raw sample) × 100.

A texture analyzer (Texture Analyzer TX-TX2, Mecmesin, NV, USA) fitted with a Warner–Bratzler-type shear blade with a load of 25 kg*f* and a cutting speed of 20 cm/min (Shackelford et al. 1999) was used to determine the shear force. Meat samples were brought to room temperature priorto Warner–Bratzler shear force (WBSF) analysis. At least three cores with a 1.27 cm diameter and 2.0 cm length that were parallel to the muscle fibers were removed from each sample using a cork borer. Each core was sheared perpendicularly to the fiber direction.

Longissimus lumborum samples were exposed to air for 30 min. After this period, color measurements were taken on the surfaces of the samples with a handheld CR-410 Minolta colorimeter (Chroma Meter CR-410, Konica Minolta, Tokyo, Japan), according to the Commission International I'Eclarage (CIE) system, using L^*, a^*, and b^* coordinates; illuminant D65; and a 10° standard observer angle (Miltenburg et al. 1992). The saturation index (chroma, C^*) was calculated as $C^* = (a^{*2} + b^{*2})^{1/2}$ according to Hunt and King (2012).

The protein, lipid, moisture, ash, and collagen contents of *longissimus lumborum* samples were determined by near-infrared spectroscopy (NIR) in a FoodScan™ apparatus (FOSS Analytical A/S, Hillerod, Denmark) according to methods approved by the AOAC (2007). The *longissimus* water activity (A_W) was assessed by using an Aqualab LITE® device (Decagon Devices Inc., Pullman, WA, USA).

Fatty acid profile

The fatty acid composition was analyzed according to O'Fallon et al. (2007), with adaptations. Briefly, 0.5 g of the freeze-dried samples was weighed into 12-mL tubes, and 1 mL of internal standard solution in methanol (1 mg 19:0/mL), 5.3 mL of methanol, and 0.7 mL of 10 N aqueous potassium hydroxide were added to each tube. Then, the tubes were incubated in a water bath at 55 °C for 1.5 h, and every 20 min, they were vigorously hand-shaken for 5 s.

The tubes were then cooled in a tap water bath, and 0.58 mL of 24 N aqueous sulfuric acid was added for a second water bath cycle, as described. The tubes were cooled again in a cold tap water bath, and 3 mL of hexane was added to each tube.

The tubes were vortexed (Fisatom 772, São Paulo, Brazil) for 5 min and centrifuged (Centribio 80-2B, Equipar®, Paraná, Brazil) for 5 min. The supernatants were collected and placed in GC vials.

Fatty acid methyl ester (FAME) separation was carried out using a gas chromatograph (Focus GC Thermo Electron S.P.A., Milan, Italy) fitted with a flame ionization detector and an SP-2560 column (100 m × 0.25 mm × 0.20 µm; Supelco Inc., Bellefonte, PA, USA). The oven temperature was initially set to 140 °C for 5 min, increased at a rate of 1 °C.min^{-1} to 220 °C, and held for 25 min. The carrier gas was hydrogen, with a 1.3 mL.min^{-1} flow rate. The injector temperature was 250 °C, and the detector temperature was 280 °C. The injection volume was 1 µL, and the split ratio was 30:1.

Identification of FAMEs was performed by comparing the methyl ester retention times in the samples to those of the GLC-674 Standard Mixture (Nu-Chek Prep Inc. Elysian, USA), containing 52 fatty acids. Quantification was based on the Sukhija and Palmquist (1988) method and was performed with the following formula: [(total area under the peak) − (area under the internal standard peak/area of the internal standard) × (internal standard concentration/dry weight of the sample)]. The results were expressed in miligrams of fatty acid per 100 g of beef (mg/100 g beef) and as percentages (%) of the total fatty acids as g/100 g FAMEs.

The sums of the total saturated (ΣSFAs), unsaturated (ΣUFAs), monounsaturated (ΣMUFAs), and polyunsaturated (ΣPUFAs) fatty acids, Σ*n*–6, and Σ*n*–3 were calculated, as well as the ΣUFA:ΣSFA, ΣMUFA:ΣSFA, PUFA:SFA, ΣPUFA:ΣMUFA, and Σ*n*–6:Σ*n*–3 ratios. To evaluate the nutritional quality of the lipid fraction of the *longissimus lumborum* muscle, the atherogenicity index (AI) and thrombogenicity index (TI) according to Ulbricht and Southgate (1991) and the relationship between hypocholesterolemic and hypercholesterolemic fatty acids (h:H) (Santos-Silva et al. 2002) were calculated. The stearoyl Co-A desaturase (Δ^9 desaturase) activities for 6:0 (palmitic acid) and 18:0 (stearic acid) as well as the elongase activity (De Smet et al. 2004) were also estimated.

Sensory attributes

Consumer appeal was evaluated using the affective method or hedonic scale of nine points, evaluating the parameters of flavor, aroma, softness, juiciness, and overall acceptance.

The panel was composed of 80 untrained testers. Duringa sensory evaluation, four samples per treatment, without additional condiments, were provided to each taster in plastic containers with coded lids; each taster also received water and crackers for intake between tastings to remove the residual flavor.

Raw meat samples of each genetic group were cut into cubes of approximately 2.0 cm^3 in size and approximately 16 g in weight. The samples were then grilled on a preheatedelectric grill (George Foreman Jumbo Grill GBZ6BW, Rio de Janeiro, Brazil) at 170 °C until the temperature of the geometric center reached 71 °C. The samples were then transferred to preheated, coded beakers covered with aluminum foil to ensure minimum loss of heat and aroma volatiles, and the beakers were kept in a water bath (Marconi-Piracicaba-SP, Brazil) at 75 °C so that the temperature of the samples remained between 65 and 70 °C until distribution to the tasters. No salt or condiments were added. Waterand cream crackers were provided to remove any aftertastebetween tastings.

Sensory attribute analyses were performed between 09:00 h and 11:00 h in individual compartments. Sensory attributes were determined using a structured scale of nine points, with 1 meaning disliked very much; 2, very displeased; 3, disliked moderately; 4, slightly disliked; 5, indifferent; 6, liked slightly; 7, liked moderately; 8, liked a lot; and 9, liked very much. The evaluated attributes were flavor, aroma, tenderness, juiciness, and overall acceptance.

Statistical analysis

Statistical analysis was carried out with the Statistical Analysis System (SAS Institute Inc., Cary, NC, USA) using analysis of variance (ANOVA) of data from the completely randomized study design of the three genetic groups (Nellore (Nell), ½ Nellore × ½ Angus (NeAn), and ½ Senepol × ¼Nellore × ¼ Angus (NASe), which included the effects ofthe genetic group. Tukey's test was used to compare least square means. The means were significantly different when $P < 0.05$, and trends were discussed at the level of $P < 0.10$. The following statistical model was used: $Yij = \mu + si + eij$, where Yij = the observed value, μ = the general mean, si = the effect of the genetic group, and eij = the effect of the experimental error in the plots.

Results

Animal and carcass traits

Slaughter weights (SW; $P < 0.001$; Table 1) as well as hot carcass weights (HCW; $P < 0.001$) were significantly different among groups. Hot carcass yield (HCY) ($P = 0.041$) was similar among Nell and NeAn groups and differed significantly from NASe. Subcutaneous fat thickness (SFT)($P = 0.104$) was statistically similar among groups. Regarding crossbreds, it was possible to observe that NASe, whichwas the lighter, was earlier in SFT compared to NeAn. Loineye area (LEA) was not statistically different among groups($P = 0.838$). However, it was observed an advantage to crossbreds, in which SW was lower. This was especially perceived in NASe, which achieved the same score as Nell, althoughhaving the lighter SW.

Table 1. Animal, carcass, and *Longissimus lumborum* traits from Nellore (Nell), ½ Nell × ½ Angus (NeAn), and ¼ Nell × ¼ Ang × ½ Sen (NASe)

Trait	Genetic groups			SEM$^{\Sigma}$	p - value†
	Nell	NeAn	NASe		
Slaughter weight (kg)	615.7^{a}	531.7^{b}	473.3^{c}	11.733	< 0.001
Hot carcass weight (kg)	311.2^{a}	270.5^{b}	229.9^{c}	7.740	< 0.001
Hot carcass yield (%)	50.5^{a}	50.8^{a}	48.6^{b}	0.594	0.041
Subcutaneous fat thickness (mm)	3.33	2.08	2.33	0.384	0.104
Loin eye area (cm^2)	64.6	67.8	64.6	4.257	0.838

$^{\Sigma}$*SEM* standard error of the mean

†Means with different superscript letters in the same row differ ($P < 0.05$; $P < 0.10$)

Physicochemical properties

There was no difference among groups ($P > 0.05$) in the initial and final (24 h) pH; C^* (saturation) color parameter; shear force; cooking loss; protein, lipid, moisture, ash, or collagen contents; or water activity of the *longissimus lumborum* samples (Table 2). The WHC ($P = 0.002$) of all groups was high, with significantly higher scores for the Nelland NeAn groups (averaging 83.4% and 82.2%, respectively) than for the NASe group (78.3%). Meat samples from the NASe group exhibited a trend of higher L^* ($P = 0.070$) thanthose from the NeAn group and lower a^* ($P = 0.091$) and b^* ($P = 0.085$) values than those from the Nell group; that is, the NASe meat was brighter and less intensely red and yellow than the meat from the other groups.

Table 2. Physicochemical composition of *Longissimus lumborum* from Nellore (Nell), ½ Nell × ½ Angus (NeAn), and ¼ Nell × ¼ Ang × ½ Sen (NASe)

Attribute	Genetic group			SEM[A]	*p*- value[B]
	Nell	NeAn	NASe		
pH_0 (initial pH)	6.98	6.70	6.80	0.118	0.276
$pH_{24\ h}$ (final pH)	5.90	5.72	5.85	0.082	0.379
Water holding capacity (%)	83.4[a]	82.2[a]	78.3[b]	1.153	0.002
Color parameters					
*L** (lightness)	37.8	37.2	39.0	0.827	0.070
*a** (redness)	23.1	22.9	22.4	0.336	0.091
*b** (yellowness)	7.37	7.04	6.92	0.288	0.085
Chrome*(saturation)	24.2	23.9	23.5	0.408	0.117
Shear force (kg*f*/cm^2)	7.46	6.84	7.62	0.938	0.527
Cooking loss (%)	28.4	32.9	31.2	1.673	0.192
Protein (%)	22.9	22.9	23.3	2.442	0.501
Lipid (%)	1.51	1.02	1.07	0.187	0.236
Moisture (%)	73.0	73.5	73.3	0.406	0.671
Ash (%)	2.45	2.55	2.30	0.193	0.707
Collagen (%)	1.34	1.47	1.16	0.104	0.151
Water activity	0.983	0.982	0.981	0.002	0.780

[A]*SEM* standard error of the mean

[B]Means with different superscript letters in the same row differ at $p < 0.05$, and trends are discussed at the level of $p < 0.10$

Fatty acid composition

The *longissimus lumborum* fatty acid profile in g/100 g beef (Table 3) showed that the muscle from the Nell group had the highest amount of ΣSFAs, with higher trend for concentrations of 12:0 ($P = 0.068$) and 14:0 ($P = 0.009$) than those in the meat from the NeAn and NASe groups, which were similar in the composition of these fatty acids. The Nell group had significantly higher amounts of 18:1 *t*11($P = 0.026$), 14:1 *c*9 ($P = 0.042$), 16:1 *c*9 ($P = 0.029$), and 18:1 *c*9 ($P = 0.023$), and a trend to 18:1 *c*11 ($P = 0.076$) than the NeAn and NASe groups, which were similar in the composition of these fatty acids. The PUFAs 18:2 *c*9 and *t*11 (conjugated linoleic acid (CLA)) in *longissimus lumborum* samples from the Nell breed were higher than those in samples from the NeAn breed but similar to those in the NASe samples. For the 20:3 *n*-6 fatty acid, the Nell breed samples also had higher levels than the other two genetic groups. However, the 20:5 *n*-3 concentration was higher in the NeAn breed than in the Nell breed. The SFAs 15:0, 16:0, 17:0, and 18:0; MUFA 15:1 *c*10; and PUFAs 18:2 *n*-6, 18:3

386 *n*-3, 20:4 *n*-6, and 22:5 *n*-3 did not differ among the compared genetic groups.

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389 **Table 3.** Fatty acid composition of *Longissimus lumborum* from Nellore (Nell), ½ Nell × ½
390 Angus (NeAn), and ¼ Nell × ¼ Ang × ½ Sen (NASe) in mg/100 g beef

Fatty acid (mg/100 beef)	Genetic group			SEM[A]	*p*- value[B]
	Nell	NeAn	NASe		
Saturated fatty acids (SFAs)					
12:0	2.80	0.79	1.21	0.199	0.068
14:0	47.33[a]	19.05[b]	22.66[b]	5.660	0.009
15:0	9.85	5.39	7.39	1.454	0.168
16:0	361.5	232.0	246.5	40.87	0.120
17:0	19.45	12.61	14.06	2.406	0.225
18:0	336.3	260.3	248.9	38.00	0.333
Monounsaturated fatty acids (MUFAs)					
18:1 *t*11	45.15[a]	19.65[b]	25.37[b]	5.682	0.026
14:1 *c*9	4.47[a]	1.42[b]	2.50[ab]	0.527	0.042
15:1 *c*10	1.61	1.99	1.81	0.232	0.673
16:1 *c*9	38.34[a]	20.91[b]	25.42[b]	4.079	0.029
18:1 *c*9	489.5[a]	280.0[b]	303.0[b]	49.45	0.023
18:1 *c*11	15.34	11.08	11.90	1.214	0.076
Polyunsaturated fatty acids (PUFAs)					
18:2 *n*-6	68.6	57.4	55.4	4.844	0.153
18:3 *n*-3	20.61	16.39	16.48	1.622	0.158
18:2 *c*9, *t*11	4.08	1.54	3.04	0.506	0.067
20:3 *n*-6	4.72	3.46	3.45	0.359	0.057
20:4 *n*-6	18.89	20.10	18.45	1.154	0.605
20:5 *n*-3	5.55[b]	7.16[a]	6.28[ab]	0.365	0.041
22:5 *n*-3	12.38	13.51	12.76	0.613	0.513

391 [A]*SEM* standard error of the mean

392 [B]Means with different superscript letters in the same row differ at $p < 0.05$, and trends are
393 discussed at the level of $p < 0.10$

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396 FAMEs (Table 4), the SFA C14:0 was affected by the genetic group ($P = 0.0069$), being
397 greater in the Nell groups, followed by the NeAn and NASe groups, which were similar in the
398 composition of this fatty acid ($P > 0.05$). The SFAs C12:0, C15:0, C16:0, C17:0, and C18:0
399 were not affected by the genetic group ($P > 0.05$). The MUFA C14:1 *c*9 also showed a genetic
400 group effect, being greater in the Nell group than in the NeAn and NASe groups, which were
401 similar in the composition of this fatty acid ($P > 0.05$). MUFAs C18:1 *t*11, C14:1 *c*9, C15:1
402 *c*10, C16:1 *c*9, C18:1 *c*9, and C18:1 *c*11 were not affected by the genetic group, and PUFAs

C18:2 *n*-6, C18:3 *n*-3, C18:2 *c*9, t11, C20:3 *n*-6, C20:4 *n*-6, C20:5 *n*-3, and C22:5 *n*-3 did not differ among the genetic groups evaluated ($P > 0.05$).

Table 4 Fatty acid composition of *Longissimus lumborum* from Nellore (Nell), ½ Nell × ½ Angus (NeAn), and ¼ Nell × ¼ Ang × ½ Sen (NASe) in mg/100 g FAME (fatty acid methyl esters)

Fatty acid	Genetic group			SEM[A]	*p*- value[B]
	Nell	NeAn	NASe		
Saturated fatty acids (SFAs)					
C12:0	0.22	0.07	0.11	0.03	0.1799
C14:0	3.29[a]	2.17[b]	1.70[b]	0.27	0.0069
C15:0	3.51	0.68	2.65	1.69	0.6110
C16:0	17.85	22.25	21.35	2.43	0.5029
C17:0	1.32	1.30	1.19	0.09	0.5031
C18:0	25.21	22.50	26.59	1.92	0.3578
Monounsaturated fatty acids (MUFAs)					
C18:1 *t*11	5.74	5.21	2.11	2.16	0.5452
C14:1 *c*9	0.34[a]	0.21[b]	0.13[b]	0.03	0.0353
C15:1 *c*10	0.18	0.18	0.25	0.05	0.5949
C16:1 *c*9	2.41	2.44	4.19	0.86	0.5276
C18:1 *c*9	28.89	27.90	26.14	2.52	0.7117
C18:1 *c*11	1.56	2.11	1.15	0.47	0.5603
Polyunsaturated fatty acids (PUFAs)					
C18:2 *n*-6	4.47	5.89	5.86	0.89	0.4807
C18:3 *n*-3	1.37	1.54	1.82	0.19	0.2981
C18:2 *c*9, *t*11	0.33	0.29	0.21	0.05	0.2624
C20:3 *n*-6	0.71	0.90	0.34	0.23	0.3384
C20:4 *n*-6	1.33	1.92	2.07	0.26	0.1787
C20:5 *n*-3	0.41	0.96	0.72	0.15	0.1233
C22:5 *n*-3	0.86	1.50	1.43	0.20	0.1463

[A]*SEM* standard error of the mean

[B]Means with different superscript letters in the same row differ at $p < 0.05$, and trends are discussed at the level of $p < 0.10$

The ΣPUFA, ΣUFA:ΣSFA, ΣMUFA:ΣSFA, Σ*n-6*, Σ*n-3*, and Σ*n-6*:Σ*n-3* values and the Δ^9–desaturase C18 and elongase enzymatic activities did not differ among the genetic groups (Table 5). Trends were observed for the ΣSFA ($P = 0.077$), ΣUFA ($P = 0.086$) and ΣMUFA ($P = 0.057$) concentrations were higher and the ΣPUFA:ΣSFA ratio was lower ($P = 0.053$) in

the Nell group than in the NeAn and NASe groups, which were similar in these fatty acid indices. The Δ^9–desaturase C16 activity ($P = 0.082$) was significantly higher in the Nell and NASe groups than in the NeAn group. The AI ($P = 0.070$) of the *longissimus lumborum* tended to be lower in the crossbreeds than in the Nell breed. There was no difference among the groups in terms of the TI index ($P = 0.401$) or h:H index ($P = 0.386$).

Table 5. Sums, ratios of fatty acid groups, enzymatic activity, and health-promoting compounds in *Longissimus lumborum* of Nellore (Nell), ½ Nell ½ Angus (NeAn) and ¼ Nell ¼ Angus ½ Sen (NASe)

Item (mg/100g beef)	Genetic group			SEM[A]	*p*- value[B]
	Nell	NeAn	NASe		
Sum of groups and ratios					
ΣSFA	767.7[a]	529.6[b]	539.9[b]	84.67	0.017
ΣUFA	685.0	466.8	501.8	60.40	0.086
ΣMUFA	552.8	347.8	386.9	55.00	0.057
ΣPUFA	127.9	119.0	114.9	7.798	0.509
ΣUFA: ΣSFA	0.899	0.912	0.988	0.048	0.448
ΣMUFA: ΣSFA	0.732	0.670	0.733	0.026	0.209
ΣPUFA: ΣSFA	0.125	0.157	0.163	0.023	0.053
Σ*n*-6	88.7	80.9	77.3	5.315	0.367
Σ*n*-3	39.6	38.1	37.6	3.148	0.890
n-6:*n*-3	2.08	2.13	2.09	0.080	0.919
Enzymatic activity					
Δ^9 – desaturase C16	8.94	8.29	9.44	0.277	0.082
Δ^9 – desaturase C18	56.7	52.2	55.6	1.481	0.150
Elongase	66.5	68.3	67.2	0.890	0.368
Health indexes					
Atherogenicity Index (AI)	0.795	0.647	0.642	0.045	0.070
Thrombogenicity Index (TI)	1.68	1.53	1.43	0.101	0.401
h:H[C] Index	1.26	1.39	1.40	0.077	0.386

[A]*SEM* standard error of the mean

[B]Means with different superscript letters in the same row differ at $p < 0.05$, and trends are discussed at the level of $p < 0.10$

[C]Hypocholesterolemic:hypercholesterolemic fatty acid ratio

Sensory attributes

The NASe group presented meat with better tenderness ($P = 0.001$), juiciness ($P = 0.023$), and overall acceptance ($P = 0.018$) than the Nell and NeAn groups, which were not different in terms of these attributes. There was no difference among the groups in terms of the aroma ($P = 0.786$) and flavor ($P = 0.315$) of the *longissimus lumborum* samples (Table 6).

Table 6. *Longissimus lumborum* sensory evaluation results from Nellore (Nell), ½ Nell ½ Angus (NeAn) and ¼ Nell ¼ Angus ½ Sen (NASe)

Attributes[A]	Genetic group			SEM[B]	*p*- value[C]
	Nell	NeAn	NASe		
Aroma	6.61	6.48	6.51	0.144	0.786
Flavor	6.75	6.43	6.56	0.150	0.315
Tenderness	5.83[b]	5.91[b]	6.86[a]	0.207	0.001
Juiciness	5.90[b]	6.04[b]	6.56[a]	0.178	0.023
Overall acceptance	6.29[b]	6.20[b]	6.81[a]	0.163	0.018

[A]Hedonic scale (1 meaning disliked very much; 2 very displeased; 3 disliked moderately; 4 slightly disagree; 5 indifferent; 6 liked slightly; 7 liked moderately; 8 liked very much; and 9 liked very much)

[B]*SEM* standard error of the mean

[C]Means with different superscript letters in the same row differ at $p < 0.05$, and trends are discussed at the level of $p < 0.10$

Discussion

Animal and carcass traits

Slaughter (SW) and carcass (HCW) weights differed significantly among groups and were greater as higher was the *Bos indicus* genetic inclusion. Zebu is considered late to body growth compared to crossbreds (Perotto et al. 2000), with lower intramuscular fat deposition (marbling) (Maggioni et al. 2010) and tenderness of meat (Johnson et al. 1990). Considering the absence of information on literature about NASe animals, its weights were slightly increased the observed in literature for purebreds Senepol (452 kg) under hot environments

(Chase et al. 1993). Higher hot carcass yield (HCY) in Nell and NeAn groups followedthe described by Maggioni et al. (2010), in Nell (52.6%) and ½ Nell ½ European (52.6%), with a slight decreasein ¼Nell ¾European. This trait is related to the internal organs' weights (respiratory and gastrointestinal), whichare removed during slaughtering procedures (Miguel et al. 2014). Nellore is known as having a small digestive trait than*Bos taurus*, which contributes to its higher HCY, comparedto taurine breeds (Lopes et al. 2012). So, *Bos indicus* presence in crossbreeding promotes an increase in HCY (Rotta et al. 2009). Therefore, this fact probably contributed to thelack of differences between Nell and NeAn in the present study. In general, LEA was proportionally low in Nell and increased in crossbreds. NASe, which achieved the lowest weights, reached similar measurements of Nell. Miguel et al.(2014) also found higher LEA in ½ Nel ½ Angus than in Nell breeds.

Physicochemical properties

The average initial and final pH (24 h) in the *longissimus lumborum* samples observed in the present study did not differ between the evaluated genetic groups. An appropriate reduction in the final pH in relation to slaughter was observed, and the pH values 24 h after slaughter remained in the range of 5.4 to 5.9, which is considered adequate for maintaining quality and shelf life (Matarneh et al. 2017). Acidification of the muscle is caused by the accumulation of lactic acid from ATP resynthesis of glucose from glycogen stores (Duarte et al. 2011). The final pH of the three genetic groups was close to the upper limit because cattle kept exclusively on pasture normally have relatively low glycogen availability at slaughter and therefore a relatively low final meat pH (Neath et al. 2007). Thus,the average values found in the present study (close tothe upper limit of the acceptable range) were possibly a reflection of the diet (pasture finishing) associated with the appropriate antemortem conditions.

The results of the *C** color parameter, shear force, cooking loss, protein, lipid, moisture, ash, and collagen contents and water activity of *longissimus lumborum* showed no differences among the genetic groups. In this work, the average shear force was not influenced by the genetic group, nor was the average cooking loss, which was not expected since *B. taurus* and *B. taurus* × *B. indicus* crossbred animals show lower values of shear strength than Nellanimals (Wulf et al. 2002; Belew et al. 2003; Bianchiniet al. 2007). On a centesimal scale, fat is the component of muscle in *Bos* sp. with the greatest variation, and

usually, the amount of deposited fat is determined by the balance between dietary energy and metabolic requirements (NRC 1996). In the present study, the absence of an effect of the genetic group on the fat content may be justified by the possible similarities between these animals in terms of their rates of intake and nutrient requirements.

However, the *longissimus lumborum* samples from the Nell and NeAn groups had higher WHC values and were darker than the NASe samples. Wulf et al. (1997) found a darker color of meat from *B. indicus* than from *B. taurus* breeds, indicating a trend toward a darker color in Zebu animals. Highly temperamental cattle can develop a relatively dark meat color (Voisinet et al. 1997a) due to their water metabolism, and as the *B. indicus* percentage in crossbreeding increases, cattle temperament becomes more undesirable, which can promote beef darkening (Voisinet et al. 1997b).

The results indicated lower *L** (luminosity) and higher *a** (redness) and *b** (yellowness) values in Nell and NeAn meat than in NASe meat, which agrees with the findings of Voisinet et al. (1997a), who found that cattle with darker meat exhibited a more excitable temperament. In general, the mean *L** values found in the meat of both the Nell and NeAn genetic groups were low, demonstrating that these meats were darker than the typical averages. Factors reported in the literature to influence the luminosity of meat are the animal diet, age, and physical activity and the amount of color pigments, amount of fat, and final pH of the meat (Muchenje et al., 2009). In the present study, the animals used were not castrated, and the meat presented a lower *L** intensity than did meat from castrated animals, possibly due to a lower amount of intramuscular fat in the former. Muchenje et al. (2009) describe that, in cattle, the average brightness varies between 33.2 and 41.0, the average *a** value varies between 11.1 and 23.6, and the average *b** value varies between 6.1 and 11.3. Abularach et al. (1998) classified meat as dark when $L^* < 29.68$ and meat as light when $L^* > 38.51$. Regarding the intensity of a red color, they considered an $a^* < 14.83$ as low and an $a^* > 29.27$ as high; for the intensity of a yellow color, $b^* < 3.40$ was low and $b^* > 8.28$ was high. Thus, it can be inferred that the only meat considered satisfactory in terms of this classification was from the NASe group.

Fatty acid composition

The higher concentrations of 14:0, 16:0, and 18:0 in the Nell meat than in the NeAn and NASe meat were in accordance with Rossato et al. (2010) and Bressan et al. (2011), who also

observed higher concentrations of these SFAs in *B. indicus* animals. These results can indicate a tendency for Zebu breeds to accumulate more SFAs than European breeds, which probably influenced the differences found between the Nell and crossbred groups.

The increased content of ΣMUFAs, especially 18:1 *c*9, in meat from the Nell group compared to that in meat from the crossbred groups may be related to the breed type. Bressan et al. (2016) found few differences in MUFA concentrations according to the genetic group, with higher concentrations in *B. indicus* than in *B. taurus* × *B. indicus*. According to Smith et al. (2009), the breed type may affect desaturase activities and, hence, the concentration of MUFAs. The Nell meat had a significantly higher concentration of 18:1*t*–11 than the meat from the other groups, which was probably related to the higher intake of 18:2*n*–6 and 18:3*n*–3 by the Zebu breed than by the crossbreeds, with increased intermediate fatty acid production (incomplete biohydrogenation) (Rossato et al. 2010).

The Δ^9–desaturase activities were similar between the NASe and Nell groups. Gama et al. (2013) also observed no significant genetic influence on Δ^9–desaturase–C16 activity and no difference in Δ^9–desaturase–C18 activity among *B. indicus* and crossbreeds.

In addition to 18:1*t*–11, CLA was primarily present in meat from the Nell group, followed by that in the meat of the NASe group. CLA can be synthetized by the conversion of 18:1*t*–11 in tissues (Bauman et al. 1999), and this process is also initiated by desaturases (Smith et al. 2009). The fatty acids 18:1 *t*11 and CLA are primarily formed in triacylglycerols, and their concentrations increase as the fat content increases (Wood et al. 2008). Thus, the differences found in the 18:1*t*–11 and CLA contents are also probably due to the differences in Δ^9–desaturase activities, which are described as more active in animals with a higher fat content (Aldai et al. 2006). This fact can also explain the decreased Δ^9–desaturase activities in the NeAn group, which had lower lipid proportions, indicating no influence of the genetic group.

Meat from animals with only Nellore genetics (Nell) showed a higher ΣSFA content than meat from the crossbred groups, and SFAs are more harmful to human health than other fatty acids (Scientific Review Committee 1990). Metz et al. (2009) also observed that the ΣSFA content is higher in animals with a predominance of Zebu over taurine in their genetics.

The ΣPUFA:ΣSFA ratio was lower in the Nell genetic group than in the other groups (0.125) but was low in all three genetic groups, ranging from 0.125 to 0.163, similar to that observed by Climaco et al. (2011) in a study with a *B. taurus* × *B. indicus* crossbreed. According to the Department of Health (DHA 1994), a diet is considered unhealthy if the ΣPUFA:ΣSFA ratio is less than 0.4. Additionally, according to the DHA (1994), the Σ*n–6:*Σ*n–3* ratio should be

less than4:1. Although there were no significant differences among the groups, the ratio in all three genetic groups was approximately 2:1; that is, the ratios were in compliance with the recommendations of the DHA and well below the average ratio found in the Western diet, which is 17:1 (Wood et al. 2008). However, according to these authors, a 1:1 ratio is currently recommended for a healthy diet.

The lack of significant differences in most of the fatty acid composition parameters among the genetic groups corroborates the findings of Pires et al. (2008), who also did not observe differences in fatty acid composition between four genetic groups (Nellore, Nellore × Canchim, Nellore × Limousin and Aberdeen Angus × Nellore) and commented thatone of the main factors affecting the lipid composition of meat is feed. In this study, the AI found in Nell (0.79) was above the range stated by Ulbricht and Southgate (1991) forbeef (0.70), and the AI was decreased significantly in the crossbreeds. SFAs 12:0, 14:0, and 16:0 have the most pro-atherogenic potential, whereas ΣMUFAs and ΣPUFAs haveantiatherogenic effects (Ojha et al. 2017).

Conversely, the TI gradually decreased as the *B. indicus* percentage decreased, indicating the ability of crossbreeding to decrease the accumulation of undesirable ΣSFAs compared to that in the Nell group. The h:H index evaluates cholesterol metabolism: as h:H increases, the cholesterol content decreases, and while 12:0 and 14:0 lead to a hypercholesterolemic index, PUFAs lead to an increase in the hypocholesterolemic effect (Ojha et al. 2017). The cross breed groups tended to have increased hypocholesterolemic activity, related to their significantly lower undesirable SFAcontents. As described earlier, the Nell meat had the highest SFA content, especially the contents of 14:0, 16:0, and 18:0, reflecting an increased accumulation of these undesirable fatty acids, which negatively impacted the Zebu meat health indexes.

Sensory attributes

As the percentage of Nell genetics increased, tenderness decreased. Thus, the Nell and NeAn groups (100% and 50% of *B. indicus*) had the lowest acceptance scores. This was related to their increased tendency to produce lesstender meat, as stated by Johnson et al. (1990) and Crouse et al. (1989), and the resulting lower sensory acceptance, as found by Elzo et al. (2012) and Phelps et al. (2017). However, despite the NASe group achieving the highest sensory rating, this parameter was not in line with thehigher SF achieved by this group. These opposing results

probably occurred due to intrinsic *longissimus* traits, since, according to Shackelford et al. (1995), this muscle presents a high variation in tenderness from carcass to carcass. *Longissimus* was described as having both glycolytic and intermediate fibers, and according to Ashmore et al. (1972), the proportions of these fiber types are highly variable even in the same muscle. Moreover, glycolytic fibers are more common in the muscle surface, whereas oxidative fibers are often found in the deepest fraction of the muscle (Armstrong and Phelps 1984). This distribution probably affected the results found in this study, since there was no standardization related to the fiber distribution during the sampling protocol, thus leading to variable results.

In addition to its increased tenderness, the meat from the NASe group was juicier, with a value that was near that found by Phelps et al. (2017) for ½ Angus × ½ Brahman. Similarly, Elzo et al. (2012) found intermediate sensory acceptance of ½ Angus × ½ Brahman. In both works, as well as in the present study, the authors observed that as the Zebu genetic proportion increased, the sensory ratings decreased, which indicated that crossbreeding was effective at improving this sensory parameter.

Despite the absence of data related to the NASe group in the literature, the results demonstrated the higher performance of this genetic group than of the other genetic groups in terms of sensory acceptance. According to Nassu et al. (2017), sensory evaluation is more effective at measuring tenderness, juiciness, aroma, and flavor than is instrumental analysis, since human sensory perception is more effective at detecting differences than are instruments. Thus, sensory acceptability is a highly important aspect of rating beef quality in terms of consumer purchasing decisions (Destefanis et al. 2008).

Conclusions

The NASe crossbreed was preferred over Nellore and Nellore × Angus for beef production. This genotype had the most desirable color and best fatty acid profile, characterized by a low undesirable SFA content. NASe produced the most attractive meat for consumers, with the best tenderness and juiciness.

Author contribution VPM, MNSS, and SAA: data curation, formal analyses, investigation, writing – original draft;
RDXR and EAA: supervision, investigation, methodology;
CVDMR, COS, TMS, AMB: data curation, formal analyses, investigation;
JMSJ: supervision, investigation, methodology, writing—original draft;
LRB and RLO: conceptualization, supervision, funding acquisition, methodology.

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Data availability Not applicable.
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Declarations

Ethical approval and consent to participate The experimental trial conducted at the Veterinary and Animal Science School of Federal University of Bahia (UFBA), located in Salvador, Bahia, Brazil. All procedures followed the guidelines recommended by the Animal Care and Use Committee of the same institution (CEUA/UFBA Process number 043/2019). All the authors consent to participate in publication.

Consent for publication All the authors consent to publication of this manuscript.

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CHAPTER II

EFFECTS OF PROCESSING METHODS ON PHYSICOCHEMICAL CHARACTERISTICS OF *CARNE DE SOL* FABRICATED WITH BEEF FROM DIFFERENT CATTLE ZOOTECHNICAL GROUPS

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Efeitos dos métodos de processamento sobre as características físico-químicas e sensoriais de *Carne de sol* fabricada com carne bovina de diferentes grupos zootécnicos

RESUMO

O conjunto de propriedades determinantes dos atributos de qualidade da carne está associado com a percepção dos atributos sensoriais e o perfil nutricional da carne magra. No que diz respeito aos produtos cárneos, a complexidade e intensidade dos processos aplicados para modificar as propriedades físico-químicas da carne fresca exercem papel essencial na determinação da qualidade final do produto processado. Carne de sol é um produto cárneo tradicional brasileiro elaborado de forma artesanal, não havendo nenhum protocolo oficial na legislação do país relacionado à caracterização de sua fabricação e de seus atributos físico-químicos e sensoriais. Neste estudo, o objetivo foi avaliar a extensão das mudanças físico-químicas e sensoriais da carne bovina para sua conversão em Carne de sol e os efeitos de três grupos zootécnicos sobre os atributos de qualidade de carne e Carne de sol. Os grupos genéticos foram Nelore (Nell), ½ Nelore ½ Angus (NeAn), e ½ Senepol ¼ Nelore ¼ Angus (NASe). A Carne de sol melhorou os atributos de capacidade de retenção de água, força de cisalhamento, perdas por cocção e atividade de água. Entretanto, este produto cárneo diminuiu o teor de ácidos graxos poliinsaturados e piorou os seus parâmetros nutricionais. O grupo genético NASe apresentou carne com melhor atividade da enzima Δ^9-dessaturase para C16 na carne fresca e aumentou os teores de 22:5 *n*-3 e total *n*-3 total em Carne de sol. A inclusão de *Bos taurus* não alterou a qualidade sensorial de Carne de sol.

Palavras-chave: Angus, atributos de qualidade, Nelore, Angus, Senepol, produtos cárneos

Effects of processing methods on physicochemical characteristics of *Carne de sol* fabricated with beef from different cattle zootechnical groups

ABSTRACT

The set of properties that determine meat quality is associated with the perception of sensory attributes and the nutritional profile of the lean. For processed meats, the complexity and intensity of processes applied to modify the physicochemical properties of the fresh source play an essential role in determining the final quality of the processed product. *Carne de sol* is a brazilian traditional meat product made in an artisanal way, and there are not any official protocols on brazilian legislation related to the manufacturing, physicochemical and sensory characterization of this meat product. In this study, our goal was to evaluate the extent of biochemical transformation of fresh beef into *Carne de sol* and the effects of three crossbred groups on the quality attributes of fresh beef and *Carne de sol*. Genetic groups included Nellore (Nell), ½ Nellore ½ Angus (NeAn), and ½ Senepol ¼ Nellore ¼ Angus (NASe). *Carne de sol* increased water activity and hence its shelf life than fresh meat. *Carne de sol* improved the physicochemical properties of water holding capacity, shear force, cooking loss and water activity, however, this meat product had impaired PUFA contents and FA health indexes. NASe provide better Δ^9-C16 activity to fresh meat and increased 22:5 *n*-3 and total *n*-3 content in *Carne de sol*. The inclusion of *Bos taurus* did not alter the sensory quality of *Carne de sol*.

Keywords: Angus, crossbreeding, meat products, Nellore, quality attributes, Senepol

Introduction

Beef quality is related to specific parameters, such as lean and fat proportions, in which composition and nutritional profile can be evaluated, as well as sensory aspects, especially tenderness and juiciness (Cassar-Malek & Picard, 2016). Some quality attributes became a big challenge for Brazilian producers, as tenderness, fat deposition and uniformity, and cattle genetic improvement can be an important alternative to solve these problems (Lage et al., 2012).

The commercial beef herd in Brazil is mainly represented by *Bos indicus* animals (Aroeira et al., 2017). Although *Bos indicus* breeds are more tolerant to tropical conditions and parasites, the meat of those animals is usually tougher and leaner when compared with the meat of *Bos taurus* breeds (Johnson et al., 1990).

Bos taurus breeds, such as Angus, are a great resource to improve meat traits, however, they are intolerant to tropical conditions, impairing the productivity attributes (Burrow et al., 2001; OSU, 2015). Regarding this situation, crossbreeding was established as an efficient tool to improve these quality parameters. The introduction of Angus breed in South of Brazil improved beef quality, producing tender and marbled meat, but, in other regions of the country, crosses with Zebu herd (especially Nellore) became predominant in order to improve Brazilian cattle genetics, since crossbreds have better carcass and meat traits than Zebu (Ferraz & Felício, 2010; Miguel et al., 2014; Aroeira et al., 2016).

However, over the years, many authors had observed that the crossbreeding among these two genetic groups produces cattle with high nutritional needs, and, furthermore, as the proportion of *Bos indicus* increases (½ or more), beef quality decreases, especially tenderness, and ½ *Bos taurus* or more may impair adaptability traits, since *Bos indicus* breeds uses to better regulate their body temperature under heat stressed conditions compared to *Bos indicus* × *Bos taurus* crosses (Masroor et al., 2022; Macedo et al., 2022; Deb et al., 2014; Pringle et al., 1997; NRC, 1996; Shackelford et al. 1995; Johnson et al., 1990; Whipple et al., 1990; Crouse et al., 1989).

Adapted *Bos taurus* is recommended to be used in crossbreeding involving *Bos indicus* and *Bos taurus* in order to improve both productivity and adaptability of this group (Burrow, 2006). Senepol breed is a tropically adapted taurine with great potential to improve carcass and meat traits (Hupp, 1978; Hammond et al., 1996). Despite this, information about its genetic characterization as well as the physicochemical and sensory attributes of meat from this breed and its crosses remain sparse.

Regarding beef quality, meat is a highly perishable food, and its processing is an

important tool for its preservation (Norman & Corte, 1985). Processing includes salting, drying, cooking, marinating, smoking and anothers, and some traditional products around the world use these processing methods, such as Carne *de sol* (meat of the sun) in Brazil (Collignan et al., 2001).

In developing countries, salting and drying became traditional methods for meat preservation, and *Carne de sol* was consumed since ancient times in Brazil, being developed as an alternative to the lack of access to refrigeration systems due socioeconomics difficulties of population (Norman & Corte, 1985). Sodium chloride (NaCl) is an important resource for maintenance of quality attributes of meat and meat products, by increasing their shelf life and contributing to improved taste and flavor (Ruusunen et al., 2005; Bidlas & Lambert, 2008), and, furthermore, contributes with lowering of water losses during cooking (Vandendriessche, 2008).

Carne de sol is described as a slightly salted meat submitted to partial dehydration, which leads it to have a short shelf-life (about 3 to 4 days at room temperature), being described as almost similar to fresh meat, different from *charque* (Charqui) and jerked beef (Norman & Corte, 1985; Ojha et al., 2017). It is a traditional meat product from north-east region of Brazil, and its manufacturing is typically an artisanal technique, where meat was primarily submitted to salting and exposure to the sun and wind in order to dry, and, in truth, it is seldom exposed to sun nowadays, being rather placed in covered and well-ventilated environments. The resources for its manufacturing are mainly meats from bovines or goats (Norman & Corte, 1985). However, despite these technical descriptions, there are not any official protocols on Brazilian legislation related to the manufacturing and physicochemical and sensory characterization of *Carne de sol*.

On the other hand, Charqui is a widely consumed, regulated, and the most common dry meat product in South America (Abrantes et al., 2014; Norman & Corte, 1985). While Charqui goes through a very intense dry and wet-salting and drying process, resulting in a product with 44-45% of moisture and 12-15% of NaCl, *Carne de sol* goes through lighter dry-salting and drying processes, resulting in a product with 64-70% of moisture and 5-6% of NaCl (Lira et al., 1998).

Nowadays, *Carne de sol* produced for commercialization purposes is fabricated in butcher stores, where the drying process differs from the process performed during the colonial period. *Carne de sol* is dried in closed and ventilated rooms instead of under the sun. The different manufacturing processes used for Charqui and *Carne de sol* also determine different shelf stability. While Charqui is usually commercialized under vacuum conditions and has a

shelf life of approximately 180 days, *Carne de sol* is commercialized with no vacuum and has a shelf life of 3 to 4 days at room temperature (Ferreira 2008; Norman & Corte, 1985; Ojha et al., 2017).

Therefore, due to the mild drying and dry-salting processes used to fabricate *Carne de sol*, we hypothesized that the genetic composition of animals affects the quality of meat and its does not occur equally for all meat products.

In this study, we evaluated the effect of processes used to manufacture *Carne de sol* on initial physicochemical attributes of fresh beef and the effects of three zootechnical groups, including a *Bos indicus* breed (Nellore - Nell), a *Bos indicus* (Nellore) and *Bos taurus* (Angus) cross (½ Nellore and ½ Angus - NeAn), and a three-way cross of *Bos indicus* and *Bos taurus* cross (Senepol), *Bos indicus* (Nellore) and *Bos taurus* (Angus) (½ Senepol ¼ Nellore ¼ Angus – NASe) on physicochemical attributes and sensory attributes of *Carne de sol*.

Materials and Methods

Ethical, animal and research description

The present study was conducted at the Veterinary and Animal Science School of the Federal University of Bahia (UFBA), Salvador, Bahia, Brazil. Ethical animal procedures were performed in accordance to the Guidelines stated by the Animal Care and Use Committee of the same institution (CEUA/UFBA, Process number 043/2019).

Eighteen steers, averaging 24 months, from the groups Nellore (Nell), ½ Nellore ½ Angus (NeAn) and ½ Senepol ¼ Nellore ¼ Angus (NASe), pasture finished, were used. All the animals were finished in two paddocks, each of them measuring 24 hectares, containing *Brachiaria brizantha* cv. Marandu. Drinking sources and mineral supplementation were also offered. Furthermore, the animals received concentrate of ground corn (54%), soybean meal (40%) and mineral mixture (6%) at 1% of body weight (BW). The BW to slaughter was predetermined when the steers reached about 500 to 600 kg.

Thus, the animals were fasted for 16 h solids and then sent to the slaughter in a commercial slaughterhouse. The slaughter procedures also followed the guidelines of the Federal Inspection Service (SIF) of humane slaughter, in accordance with Brazilian Ministry of Agriculture, Cattle and Supplying (Ministério da Agricultura, Pecuária e Abastecimento - MAPA) regulations (Normative nº 03/00, MAPA, Brazil, 2000).

Physicochemical properties

After slaughter, skinning and evisceration, the carcasses were cut into two halves and the initial pH (pH_0) was measured in *Longissimus dorsi* muscle, between the 6^{th} and 7^{th} ribs, using a digital potentiometer model HI99163 (HANNA Instruments, São Paulo, Brazil). Then the carcasses were sent to the cold chamber where they remained cooled for 24 hours at 4 °C. After 24 h, the carcasses final pH (pH_F) was measured using the same procedure early described for pH_0. Portions of *Semimembranosus* muscle and *Adductor femoris* muscle samples were collected and placed into plastic bags for physicochemical and sensory evaluation, as well as the manufacturing of salted and sun-dried meat to be submitted to the same analysis.

The pH of fresh meat (*Semimembranosus* muscle and *Adductor femoris* muscles) was measured in three different parts of the samples using a digital potentiometer model HI99163 (HANNA Instruments, São Paulo, Brazil).

The manufacturing process of salted and sun-dried meat followed Gouvêa & Gouvêa (2007), with adaptations. About three kilograms (3 kg) of *Semimembranosus* muscle were used, and the excess of connective tissue and fat was removed in order to allow better salt penetration. Following this step, each sample was divided in half, and four parallel cuts of about 5 cm thick were made in direction to muscle fibers. After this, salt was added at a proportion of 5% (±150 g), and thus it was rubbed onto the meat surfaces and cut on both sides. The samples thus were kept at 25° C in white plastic trays and turned at every 8 h, and when meat exudate drainage occurred (after 16h) they were washed in potable water. Each sample was suspended on stainless metal hooks, with enough space to allow air circulation between them, remaining for 8h to dry at 25 °C in order to allow the release of excess water. This process was finished after 24 h, when the salted sun-dried meat samples were placed into labeled plastic bags and submitted to refrigeration (4 °C) for further physical-chemical and sensory analysis. Other portions of fresh and salted and sun-dried meats were chilled at -20 °C for fatty acids profile and centesimal composition.

After manufacturing procedures, the pH of *Carne de sol* was measured in triplicate using a digital potentiometer model HI99163 (HANNA Instruments, São Paulo, Brazil).

The water holding capacity (WHC) evaluation was performed in triplicate using the pressure method described by Hamm (1986) and Xie et al. (2023). The fresh and salted and sun-dried meat samples (2 g) were subjected to a force equivalent to 10 kg for 5 min, and the difference in weight before and after the pressure force was calculated. The amount of water loss of the sample was expressed in percentage of water expressed.

After samples had been exposed to the air for 30-min, Lightness (L^*), Redness (a^*), Yellowness (b^*) and Color saturation (C^*) were measured on the surfaces of the samples, with a handheld CR-410 Minolta Colorimeter (Chroma Meter CR-410, Konica Minolta, Tokyo, Japan), according to the Commission International I'Eclarage (CIE) system, using L^*, a^*, b^* coordinates, iluminant D65 and 10° standard observer. Previous calibration was carried out using white and black tiles. L^*, a^*, b^* and C^* [$C^* = (a^{*2} + b^{*2})^{1/2}$] were assessed (Hunt & King, 2012).

Sections of the samples were cut into 2.5 × 2.5 cm thick cubes and weighed before cooking. The samples were cooked on a grill (George Foreman Jumbo Grill GBZ6BW, Rio de Janeiro, Brazil) at 170 °C. The geometric center temperature of the slices was measured with portable digital thermometers (Gulterm 700-10S, São Paulo, Brazil). When the temperature reached 71 °C, the samples were cooled at room temperature, and following weighed. The cooking loss was calculated by the difference between initial and final weights being expressed as percentage (AMSA, 2016).

The cooked samples were wrapped into aluminum foil and stored at 4 °C for 12 h. In the following day, samples were brought to room temperature prior to Shear Force (SF) analysis. The SF was measured by a texture analyzer (Texture Analyser TX-TX2, Mecmesin, Nevada, United States) fitted with a Warner–Bratzler type shear blade with load of 25 kg*f* and a cutting speed of 20 cm/min (Shackelford et al., 1999). At least three cores with about 1.27 cm diameter and 2.0 cm length that were parallel to the muscle fibers were removed from each sample using a cork borer. Each core was sheared perpendicularly to the fiber direction.

Protein, lipid, moisture, ash and collagen were determined by using Near Infrared Spectroscopy (NIR) in FoodScan™ apparatus (FOSS Analytical A/S, Hillerod, Denmark) according to the method approved by AOAC (2007).

The water activity (a_w) of the samples was assessed by using the Aqualab LITE® (Decagon Devices Inc., Pullman, WA, USA) device.

Fatty acids composition

The fatty acids composition was carried out according to O'Fallon et al. (2007), with adaptations. Briefly, 0.5 g of freeze-dried samples were weighed into 12-mL tubes, and 1 mL of internal standard (N5252-1G; Sigma-Aldrich) solution in methanol (1mg19:0/mL), 5.3 mL of methanol and 0.7 mL of 10N potassium hydroxide in aqueous solution were added. Then, the tubes were incubated in a water bath under 55 °C for 1.5 h, and at each 20 min., they were

handshaking in a vigorous way for 5 seconds. The tubes were then cooled in a tap water bath, and 0.58 mL of 24*N* sulfuric acid in aqueous solution was added for a new water bath cycle, as described. Then, the tubes were cooled again in a cold tap water bath, and 3 mL of hexane was added. The test tubes were mixed with a vortex (Fisatom 772, São Paulo, Brazil) for 5 min and centrifuged for 5 min (CENTRIBIO 80-2B, EQUIPAR Ltda., Paraná, Brazil). The supernatant was collected and placed into GC vials.

The fatty acid methyl esters (FAME) separation was carried out using a gas chromatograph (Focus GC Thermo Electron S.p.A, Milan, Italy) fitted with a flame ionization detector and SP-2560 column (100 m x 0.25 mm x 0.20 µm; Supelco Inc., Bellefonte, PA, USA). The initial oven temperature was set to 140 °C for 5 min., and increased at a rate of 1 °C.min^{-1} to 220 °C, held for 25 min. The carrier gas was hydrogen, with a 1.3 mL.min^{-1} flow rate. The injector temperature was 250 °C and the detector temperature was 280 °C. The injection volume was of 1µL, and the split ratio was of 30:1.

The identification of the FAME was done by comparing sample methyl esters retention times against the GLC-674 Standard Mixture (Nu-Chek Prep Inc. Elysian, USA), containing 52 fatty acids. The quantification was based on Sukhija & Palmquist (1988) method, using the formula:$[(total\ area\ under\ peaks) - (area\ under\ internal\ standard)/ (area\ of\ internal\ standard) \times (internal\ standard\ concentration/ dry\ weight\ of\ the\ sample)]$. The results were expressed in milligrams of fatty acid per 100 grams of beef (mg/100g).

The sum of total saturated (SFA), unsaturated (UFA) monounsaturated (MUFA) and polyunsaturated fatty acids (PUFA), *n*-6 and *n*-3 were calculated, as well as UFA:SFA, MUFA:SFA, PUFA:SFA, PUFA:MUFA and *n*–6:*n*–3 ratios. To evaluate the nutritional quality of the lipid fraction of the samples, the Atherogenicity index (AI), Thrombogenicity index (TI) (Ulbricht & Southgate, 1991) and the relationship between hypocholesterolemic and hypercholesterolemic fatty acids (h:H) (Santos-Silva et al., 2002) were calculated. The stearoyl Co-A desaturase (Δ^9 desaturase) activities for 16:0 (palmitic acid) and 18:0 (stearic acid) as well as the elongase activity (De Smet et al., 2004) were also estimated.

Sensory attributes

The *Longissimus* sensory evaluation was carried out according to American Meat Science Association guidelines (AMSA, 2016), using a panel of 70 consumers and a 9 points

hedonic scale, the evaluated scores meaning: 1: desliked extremely; 2: desliked very much; 3: desliked moderately; 4: desliked slightly; 5: indifferent; 6: liked slightly; 7: liked moderately; 8: liked very much; 9: liked extremely.

The samples, without any condiments, were pooled by a zootechnical group, and cooked at 170 °C on a grill (George Foreman Jumbo Grill GBZ6BW, Rio de Janeiro, Brazil). When the geometric center reached 71°C, the samples were cut into 2 cm cubes, coded, covered in an aluminum foil and placed in a water bath at 75 °C, in order to maintain them heated and to prevent volatile aroma compounds losses. The sensory panel was conducted from 9:00 to 12:00 h. Each consumer received three samples, representing the three genetic groups, and was offered Water and Salt type biscuits and water between the tastings, in order to remove aftertaste. The sensory attributes evaluated were flavor, aroma, tenderness, juiciness, overall acceptance and preference.

Statistical analysis

Statistical analysis was carried out by the Statistical Analysis System 9.4 (SAS Institute Inc., Cary, NC, USA) using Analysis of Variance for a completely randomized design and three treatments (zootechnical groups), where the effects of zootechnical groups were included. Tukey's test was used in order to compare least squares means. The means were significantly different when $P < 0.05$. The statistical model used was the following:

$$Y_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + e_{ij},$$

Where Y_{ij} = the observed value, μ = the general mean, α_i = the effect of the zootechnical group, β_j = the effect of the type of meat, $(\alpha\beta)_{ij}$ = the interaction effect of the zootechnical group and the type of meat, and e_{ij} = the effect of the experimental error in the plots. The model also included zootechnical groups and types of meat (Fresh meat and *Carne de sol*) along with their interactions as fixed effects. For sensory analysis, the statistical model used was $Y_{ij} = \mu + s_i + e_{ij}$., where: Y_{ij} = the observed value, μ = the general mean, s = the effect of the zootechnical group, and e_{ij} = the effect of the experimental error in the plots.

Results

Physicochemical traits

Physicochemical results are presented in Table 1. Regarding meat type, *Carne de sol* had the lowest pH values ($P < .001$) compared to fresh meat. It was observed that NASe reached the lowest pH, being significantly different from the Nell group ($P = 0.008$). It was observed an interaction effect ($P = 0.021$) between type of meat and genetic group, where *Carne de sol* was associated with the more intense pH dropping by NASe.

Carne de sol had lower lightness (L^*) ($P < .001$), redness (a^*) ($P < .001$) and Chroma (C^*) ($P < .001$) than fresh meat. For *Carne de sol*, NASe had significantly higher L^* ($P = 0.005$) compared to Nell and NeAn. For the fresh meat, crossbreeds had lower a^* than Nell group ($P = 0.008$). For C^*, *g*enetic differences were observed for fresh meat, where NASe was significantly different from Nell ($P = 0.004$), reaching the highest value.

Significant differences in WHC were observed between the two types of meat ($P < .001$), with significantly lower expressed water to *Carne de sol* (higher water holding capacity) compared to fresh meat. Genetic differences were observed only for fresh meat, and the NeAn group had the highest water retention (lower water expressed) compared to Nell ($P = 0.026$). These differences in fresh meat were statistically associated ($P = 0.018$).

Carne de sol had significantly lower CL ($P < .001$) and SF ($P < .001$), and the lowest contents in Protein ($P < .001$) and Moisture ($P < .001$) compared to fresh meat. On the other hand, this meat product obtained significantly higher ashes ($P < .001$) and collagen ($P < .001$) contents. *Carne de sol* significantly had lower values of a_w compared to fresh meat ($P < .001$). Genetic differences for a_w were only observed in *Carne de sol*, where NeAn had the lowest values compared to Nell ($P = 0.011$). There was an interaction effect between the lowering of a_w by NeAn and *Carne de sol* ($P = 0.045$).

Table 1. Physicochemical traits of fresh beef (FR) and *Carne de sol* (*CS*) from Nellore (Nell), ½ Nellore ½ Angus (NeAn) and ½ Senepol ¼ Nellore ¼ Angus (NASe)

mt	Attribute	Genetic groups			Mean	SEM	*P*-value		
		Nell	NeAn	NASe			mt	G	mt*G
FR	pH	5.49	5.41	5.49	5.46^{A}	0.054	<.001	0.119	0.021
CS		5.37^{a}	5.35^{ab}	5.27^{b}	5.33^{B}	0.036		0.008	
FR	*L**	36.7	37.7	38.6	37.68^{A}	1.020	<.001	0.137	0.372
CS		31.2^{b}	31.3^{b}	34.0^{a}	32.15^{B}	0.794		0.005	
FR	*a**	20.7^{b}	21.8^{a}	22.0^{a}	21.48^{A}	0.387	<.001	0.008	0.428
CS		18.0	18.0	19.6	18.54^{B}	0.923		0.226	
FR	*b**	5.68	6.24	6.42	6.12	0.320	0.109	0.076	0.595
CS		6.14	6.29	7.03	6.49	0.528		0.228	
FR	*C**	21.4^{b}	22.6^{ab}	23.1^{a}	22.40^{A}	0.479	<.001	0.004	0.524
CS		19.10	19.04	20.90	19.67^{B}	1.025		0.207	
FR	WHC (%)	23.63^{a}	18.73^{b}	22.79^{ab}	21.72^{A}	1.656	<.001	0.026	0.018
CS		10.98	11.92	12.19	11.70^{B}	0.587		0.325	
FR	CL (%)	33.4	32.5	33.3	33.11^{A}	1.131	<.001	0.932	0.483
CS		20.6	22.9	25.2	22.91^{B}	1.375		0.626	
FR	SF (kfc/cm^2)	6.38	5.79	6.55	6.24^{A}	0.631	<.001	0.463	0.496
CS		3.70	3.16	3.19	3.35^{B}	0.245		0.059	
FR	Protein (%)	22.9	22.7	23.1	22.88^{A}	0.275	<.001	0.701	0.965
CS		21.5	21.3	21.5	21.43^{B}	0.217		0.646	
FR	Lipid (%)	1.18	1.13	0.782	1.03	0.132	0.498	0.256	0.690
CS		1.41	1.04	1.02	1.16	0.175		0.895	
FR	Moisture (%)	72.5	73.0	73.3	72.92^{A}	0.250	0.004	0.227	0.527
CS		71.8	72.1	72.0	71.98^{B}	0.180		0.842	
FR	Ashes (%)	3.44	3.19	2.87	3.17^{B}	0.131	<.001	0.084	0.327
CS		5.26	5.59	5.46	5.44^{A}	0.257		0.907	
FR	Collagen (%)	1.59	1.38	1.37	1.45^{B}	0.083	<.001	0.286	0.058
CS		1.77	2.04	1.78	1.87^{A}	0.064		0.062	
FR	a_w	0.979	0.977	0.977	0.978^{A}	0.001	<.001	0.125	0.045
CS		0.944^{a}	0.937^{b}	0.940^{ab}	0.940^{B}	0.003		0.011	

Means with different letters in the same row differ ($P < 0.05$). Means with different superscripted letters in the same column differ ($P < 0.05$). SEM: standard error of the mean. WHC: water holding capacity; CL: cooking loss; SF: shear force; a_w: water activity. mt: meat type. G: genetic group.

Fatty acid composition

The results of the main fatty acid composition of fresh meat and *Carne de sol* are presented in Table 2.

Regarding SFA concentration, the significant differences were observed only for meat type. *Carne de sol* presented the highest concentrations of C14:0 ($P = 0.030$), C17:0 ($P = 0.031$) and C18:0 ($P = 0.021$) compared to fresh meat.

Regarding MUFA content, *Carne de sol* significantly had the lowest concentration of C15:1 *c*10 ($P < .001$). In fresh meat, there were observed genetic differences in C18:1 *c*9 concentration ($P = 0.013$), where Nell significantly had the highest values of C18:1 *c*9 compared to NASe.

There were significant differences in some long chain PUFA concentrations regarding meat type. Fresh meat presented the highest concentrations of C20:4 *n*-6 ($P < .001$), C20:5 *n*-3 ($P < .001$) and C22:5 *n*-3 ($P < .001$) compared to *Carne de sol*. Regarding genetic differences found in *Carne de sol*, the C18:2 *n*-6 concentration was significantly higher for NASe ($P = 0.010$) compared to NeAn. Regarding C20:3 *n*-6 concentration, there were observed genetic differences in fresh meat ($P < .001$), where Nell group had the highest values compared to crossbreds, and in *Carne de sol* ($P = 0.001$), where Nell had higher concentration compared only to NeAn. In *Carne de sol*, there were significant differences in the concentrations of C20:5 *n*-3 ($P = 0.001$), where NASe had higher values compared only to Nell, and C22:5 *n*-3 ($P < .001$), where NASe had the highest values ($P < .001$) compared to the other groups. There were interaction effects between *Carne de sol* and these genetic differences found for C22:5 *n*-3 content ($P = 0.018$).

Table 2. Fatty acid concentration (mg/100g fresh beef (FR)/*Carne de sol* (*CS*)) from Nellore (Nell), ½ Nellore ½ Angus (NeAn) and ½ Senepol ¼ Nellore ¼ Angus (NASe)

mt	FA	Genetic groups			Mean	SEM	*P*-value		
		Nell	NeAn	NASe			mt	G	mt*G
Saturated Fatty Acids (SFA)									
FR	14:00	19.43	14.71	10.18	14.50^{B}	4.111	0.030	0.110	0.917
CS		25.39	18.76	19.01	21.05^{A}	3.771		0.124	
FR	15:00	4.22	4.29	4.85	4.42	1.490	0.080	0.914	0.881
CS		5.70	5.70	7.21	6.20	1.344		0.521	
FR	16:00	232.0	195.0	151.9	190.7	35.80	0.075	0.117	0.988
CS		273.3	232.7	229.7	245.2	34.76		0.341	
FR	17:00	10.63	10.01	6.87	9.09 ^{B}	2.363	0.031	0.244	0.616
CS		13.40	13.26	12.22	12.96^{A}	2.276		0.895	
FR	18:00	194.9	196.7	129.2	172.4^{B}	34.91	0.021	0.098	0.716
CS		237.6	244.4	209.2	230.4^{A}	37.64		0.623	
Monounsaturated Fatty Acids (MUFA)									
FR	18:1 *t*11	17.00	14.29	12.13	14.33	4.732	0.167	0.625	0.878
CS		19.37	20.56	15.16	18.50	2.634		0.102	
FR	15:1 *c*10	2.22	2.75	2.85	2.61^{A}	0.262	<.001	0.052	0.643
CS		1.78	1.88	2.00	1.89^{B}	0.155		0.071	
FR	16:1 *c*9	23.52	21.37	19.99	21.52	4.168	0.175	0.716	0.896
CS		28.58	23.68	22.36	25.02	3.132		0.297	
FR	18:1 *c*9	397.1^{a}	281.8^{ab}	240.5^{b}	306.5	51.28	0.355	0.013	0.323
CS		385.1	318.3	329.9	344.5	47.37		0.549	
FR	18:1 *c*11	14.68	12.22	11.68	12.86	1.651	0.975	0.174	0.791
CS		13.13	11.89	12.30	12.45	1.025		0.434	
Polyunsaturated Fatty acid (PUFA)									
FR	18:2 *n*-6	76.63	73.11	68.75	72.83	7.099	0.073	0.549	0.131
CS		65.23^{ab}	56.94^{b}	71.13^{a}	64.43	4.179		0.010	
FR	18:3 *n*-3	21.64	20.11	19.00	20.25	2.432	0.128	0.550	0.312
CS		17.94	15.98	19.43	17.89	1.387		0.085	
FR	18:2 *c*9,*t*11	4.99	1.59	3.55	3.35	1.052	0.125	0.059	0.316
CS		2.43	1.60	3.29	2.37	0.462		0.126	
FR	20:3 *n*-6	6.43^{a}	4.24^{b}	4.49^{b}	5.05	0.466	0.072	<.001	0.175
CS		5.12^{a}	3.49^{b}	4.36^{ab}	4.32	0.393		0.001	
FR	20:4 *n*-6	27.88	26.65	26.64	27.06^{A}	1.731	<.001	0.764	0.080
CS		21.50	20.80	22.96	21.68^{B}	1.062		0.087	
FR	20:5 *n*-3	8.94	9.81	9.19	9.31 ^{A}	0.713	<.001	0.504	0.124
CS		6.80^{b}	7.66^{ab}	8.69^{a}	7.71 ^{B}	0.390		<.001	
FR	22:5 *n*-3	15.74	16.74	16.66	16.38^{A}	0.886	<.001	0.997	0.018
CS		12.09^{b}	13.04^{b}	15.76^{a}	13.63^{B}	0.583		<.001	

Means with different letters in the same row differ ($P < 0.05$). Means with different superscripted letters in the same column differ ($P < 0.05$). SEM: standard error of the mean. FA: fatty acid. mt: meat type. G: genetic group.

The results for fatty acids sums, ratios, enzymatic and nutritional quality parameters for fresh meat and *Carne de sol* are presented in Table 3. Fresh meat presented significantly the highest PUFA ($P < .001$) and Σ *n*-6 ($P = 0.016$), as well the highest Σ UFA: Σ SFA ($P < .001$), Σ MUFA: Σ SFA ($P < .001$), Σ PUFA: Σ SFA ($P < .001$) and *n*-6:*n*-3 ($P < .001$) ratios compared to *Carne de sol*.

The genetic differences were observed only for *Carne de sol*. PUFA ($P = 0.002$), Σ *n*-6 ($P = 0.015$) and Σ UFA: Σ SFA ($P = 0.026$) were higher in NASe compared to NeAn. Σ PUFA: Σ SFA ($P = 0.004$) ratio and Σ *n*-3 ($P = 0.002$) were higher only in the NASe group compared to those with higher Nellore degree. For Σ MUFA: Σ SFA ratio, NASe and Nell were statistically similar, obtaining higher values when compared to NeAn ($P = 0.040$). Furthermore, crossbreds lowered the *n*-6:*n*-3 ratio compared to Nell ($P = 0.001$). The use of *Carne de sol* and the genetic differences found on PUFA content ($P = 0.033$) and Σ UFA: Σ SFA ($P < .001$) and *n*-6:*n*-3 ($P < .001$) ratios were statistically associated.

Regarding enzymatic activity, differences related to meat type were observed. Fresh meat had the highest Δ^9-C16 ($P < .001$), Δ^9-C18 ($P = 0.002$) and Elongase ($P < .001$) activities compared to *Carne de sol*. There were observed genetic differences in Δ^9-C16 and Δ^9-C18 activities for both fresh meat and *Carne de sol*. For fresh meat ($P < .001$), the Δ^9-C16 activity was higher for NASe compared to the other groups, and for *Carne de sol* ($P = 0.018$) the Δ^9-C16 activity was higher in NASe when only compared to NeAn. The Δ^9-C18 activity was the same in fresh meat ($P = 0.001$) and *Carne de sol* ($P < .001$), with NASe and Nell being statistically similar, reaching the highest activities compared to NeAn. The elongase showed genetic differences ($P = 0.046$) only for *Carne de sol*, with increased activity for NASe compared to Nell.

Regarding nutritional quality parameters, differences for meat type were found. AI ($P < .001$) and TI ($P < .001$) were higher in *Carne de sol* than in fresh meat. On the other hand, the h:H index was higher in fresh meat than in *Carne de sol* ($P < .001$). It was also observed genetic differences in TI and h:H. The TI for *Carne de sol*, was lower in the NASe group compared to NeAn ($P = 0.039$). The h:H ratio in fresh meat was higher in NASe compared to Nell. Furthermore, the results in genetic traits found in Δ^9-C16 ($P < .001$), Δ^9-C18 ($P = 0.003$) and elongase ($P < .001$) activities, as well in AI ($P = 0.003$), TI ($P = 0.022$), h:H ($P < .001$) were associated with the type of meat used (*Carne de sol* or fresh meat).

Table 3. Sums, ratios, enzymatic activities and nutritional quality parameters of fresh beef (FR) and *Carne de sol* (*CS*) from Nellore (Nell), ½ Nellore ½ Angus (NeAn) and ½ Senepol ¼ Nellore ¼ Angus (NASe)

mt	trait	Genetic groups			Mean	SEM	*P*-value		
		Nell	NeAn	NASe			mt	G	mt*G
Sum of groups and ratios									
FR	Σ SFA	471.9	474.2	434.1	464.0	87.02	0.385	0.999	0.739
CS		514.9	529.9	489.2	512.6	54.77		0.902	
FR	Σ UFA	620.8	521.9	567.0	573.9	72.34	0.769	0.401	0.113
CS		513.3	518.6	578.9	534.4	45.94		0.482	
FR	Σ MUFA	462.3	372.4	403.2	417.5	62.24	0.796	0.376	0.142
CS		382.7	402.2	435.0	404.9	44.55		0.685	
FR	Σ PUFA	158.6	149.5	163.8	156.5^{A}	13.11	<.001	0.601	0.033
CS		130.5^{ab}	116.4^{b}	143.9^{a}	129.5^{B}	6.551		0.002	
FR	ΣUFA:ΣSFA	1.18	1.11	1.31	1.26^{A}	0.092	<.001	0.091	<.001
CS		1.13^{ab}	0.872^{b}	1.18^{a}	1.04^{B}	0.097		0.026	
FR	ΣMUFA:ΣSFA	0.849	0.783	0.924	0.836^{A}	0.051	<.001	0.131	0.525
CS		0.852^{a}	0.772^{b}	0.845^{a}	0.822^{B}	0.034		0.040	
FR	ΣPUFA:ΣSFA	0.226	0.218	0.232	0.224^{A}	0.025	<.001	0.941	0.441
CS		0.172^{b}	0.147^{b}	0.223^{a}	0.178^{B}	0.017		0.004	
FR	Σ *n*-6	110.9	104.0	99.88	104.9^{A}	8.244	0.016	0.434	0.085
CS		91.85^{ab}	81.27^{b}	92.63^{a}	88.58^{B}	4.811		0.015	
FR	Σ *n*-3	47.61	47.38	45.96	46.98	4.184	0.081	0.913	0.108
CS		38.69^{b}	34.82^{b}	45.52^{a}	39.68	2.641		0.002	
FR	*n*-6:*n*-3	2.29	2.18	2.19	2.221^{A}	0.073	<.001	0.571	<.001
CS		2.39^{a}	2.16^{b}	2.05^{b}	2.198^{B}	0.064		0.001	
Enzimatic activity									
FR	Δ^{9}– C16	9.07^{b}	9.95^{b}	11.84^{a}	10.36^{A}	0.429	<.001	<.001	<.001
CS		9.50^{ab}	9.35^{b}	10.49^{a}	9.74^{B}	0.363		0.018	
FR	Δ^{9}– C18	63.90^{a}	59.73^{b}	66.15^{a}	63.22^{A}	1.582	0.002	0.001	0.003
CS		62.69^{a}	56.97^{b}	62.00^{a}	60.56^{B}	1.386		<.001	
FR	Elongase	67.70	69.29	69.22	68.79^{A}	0.743	<.001	0.082	<.001
CS		67.01^{b}	68.83^{a}	68.29^{ab}	68.04^{B}	0.635		0.046	
Nutritional quality parameters									
FR	AI	0.540	0.529	0.600	0.550^{A}	0.047	<.001	0.683	0.003
CS		0.628	0.603	0.576	0.604^{B}	0.037		0.230	
FR	TI	1.10	1.16	1.01	1.10^{B}	0.081	<.001	0.467	0.022
CS		1.34^{ab}	1.45^{a}	1.21^{b}	1.34^{A}	0.099		0.039	
FR	h:H	1.69^{b}	1.83^{ab}	2.15^{a}	1.90^{A}	0.149	<.001	0.016	<.001
CS		1.52	1.49	1.62	1.54^{B}	0.068		0.082	

Means with different letters in the same row differ ($P < 0.05$). Means with different superscripted letters in the same column differ ($P < 0.05$). SEM: standard error of the mean. SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; Δ^9– C16: desaturase activity for palmitic acid; Δ^9– C18: desaturase activity for stearic acid; AI: atherogenicity index; TI: thrombogenicity index; h:H: hypocholesterolemic/hypercholesterolemic ratio. mt: meat type. G: genetic group.

Sensory attributes

Regarding the taste panel of *Carne de sol*, panelists did not detect significant differences when evaluating the effects of zootechnical groups on sensory attributes (Table 4). No significant effects were observed for any attribute when evaluating the interaction between genetic groups and processing.

Table 4. Sensory attributes of *Carne de sol* from Nellore (Nell), ½ Nellore ½ Angus (NeAn) and ½ Senepol ¼ Nellore ¼ Angus (NASe).

Attribute	Genetic groups			SEM	*P* - value
	Nell	NeAn	NASe		
Aroma	7.56	7.60	7.49	0.107	0.777
Flavor	7.89	7.77	7.70	0.097	0.444
Tenderness	7.66	7.27	7.30	0.137	0.120
Juiciness	7.57	7.50	7.23	0.123	0.156
Overall desirability	7.71	7.40	7.70	0.106	0.091

SEM: standard error of the mean.

Discussion

Physicochemical traits

The methods employed during fabrication lowered pH values from 5.46 to 5.33 ($P < .001$), and these values was within the range found by Gesteira et al. (2019) on the same meat product. Adding 2% NaCl in meat matrices lowers the isoelectric point of the myofibrillar system from pH 5.0 to 4.0 (Hamm, 1962). In this study, this slight decrease in pH was expected since NaCl was applied superficially, not into the deeper layers of the lean. Filgueras et al. (2016) demonstrated that when NaCl is used on muscle surfaces simulating a dry salting process, the

penetration of both ions into the interior is slow, and the maximum depth is reached in 5 or 30 min. Therefore, whatever the dry salting time, the penetration of NaCl into the muscle will eventually reach a maximum and limited depth. Although significant, the slight difference in pH values (0.1) is due to the superficial process of dry salting, which limited NaCl diffusion into the lean. Conversely, the pH of *Carne de sol* was similar to the pH values reported for Charqui, a product that undergoes a lengthy wet (brining) and dry salting process of about 5 days (Lara et al., 2003). Although brining the fresh meat with NaCl may lead to an improved linear diffusion of those ions into the lean and even into the perimysium (Filgueras et al., 2016), it seems that the effects of dry and wet salting on pH are similar when methods are used to fabricate Charqui or *Carne de sol*.

Genetic differences were observed for *Carne de sol*, where NASe reached the lowest pH compared to de zebu group Nell. *Bos taurus* genotype promotes faster maturation process than *Bos indicus* genotype into the 24 h *postmortem* (Whipple et al., 1990) because of the higher calpastatin activity of zebu breeds, which leads to inhibition of calpain and therefore impairing the drop of pH (Bridi & Constantino, 2009). Therefore, this fact can explain the significant differences between Nell (*Bos indicus*) and NASe (25% *Bos indicus*, 75% *Bos taurus*). Another explanation can be the effect of salt addition on the samples, altering the water behavior inside meat cells and hence leading to unspecific differences between the three groups of cattle, excluding thus a genetic influence in this parameter, since the fresh meat did not showed any genetic differences between samples. Macedo et al. (2022) also did not find any genetic difference in pH of fresh meat *Longissimus* from the same genetic groups studied.

The superficial salting and drying processes altered instrumental color, producing *Carne de sol* with lower lightness (L^*), Redness (a^*), and Chroma. Applying NaCl on the meat surface induces changes in the heme structure and hydrophobic portions of the myoglobin and increases concentrations of metmyoglobin (Liu et al., 2022; Torres et al., 1988). Allied with the drying process, NaCl speeds up water loss via osmotic dehydration, changes the shape and volume of muscle fibers, and partially impregnates the tissue with its solid particles (Raoult-Wack, 1994; Rastogi et al., 2002). Those biochemical and physical changes on myoglobin and myofibrils directly affect color reflection when light is emitted on the meat's surface. While the darkening effect of drying and salting limited the overall reflection of all wavelengths emitted by the colorimeter, the wavelength associated with red color was absorbed by the surface, leading to less reflection and consequently lower a^* values (AMSA, 2012). Hence, the lower values of L^* and a^* decreased values of Chroma, indicating less color intensity and discoloration (Møller & Skibsted, 2006).

Carne de sol from NASe were lighter than products from Nell and NeAn. Although a statistical trend (P = 0.07) reported by Macedo et al. (2022) suggested that fresh strip loins obtained from NASe steers were lighter than loins from Nell, there is still minimal research detailing the effects of Senepol inheritance on beef quality attributes. Previous research evaluating color attributes of beef from Senepol-crossed steers showed no significant differences in L^* when evaluating Senepol inheritance within genetic groups containing Angus, Nellore, and native breeds (Afonso et al., 2020).

Carne de sol had the lowest expressed water (highest WHC) and the lowest values of CL. The addition of salt promotes an increase in the myofibrillar protein hydration and hence a higher water retention capacity, thus reducing the cooking losses (Vandendriessche, 2008). The stronger binding of Cl^- ions to the positively charged myofibrillar proteins leads to the exposition of the negatively charged proteins and to a repulsion between them, thus leading to an increase in their swelling and water retention capacity (Hamm, 1986).

In fresh meat, WHC was significantly higher for NeAn than for Nell. Macedo et al. (2022) found that NASe had a tendency to have less WHC than cattle with higher proportion of Nellore genotype. The genetic differences between the three groups disappeared in the *Carne de sol* group, probably due to the homogeneous application of NaCl for all the samples during manufacturing, which may have offset the genetic effect of these groups.

The mean values of Protein, Moisture, Ashes, SF, a_w and collagen parameters found for *Carne de sol* in the present study were near the found by Ishihara et al. (2013) and Gesteira et al. (2019) for this partially dehydrated meat product. The values of a_w were within the expected to fresh meat (0.98 to 0.99) and *Carne de sol* (about 0.94) (Norman & Corte, 1985; Leistner & Rödel, 1975), and these results showed that *Carne de sol* had higher chemical and microbiological stability than fresh meat. However, lower values (0.86 to 0.88) were found by Araújo et al. (2022), when evaluating *Carne de sol* (salted and sun-dried beef) from Nellore fed different levels of lauric acid on their diets, applying the same proportion of salt of the present study (5%). Regarding the genetic differences found in *Carne de sol* between NeAn and Nell and the absence of these differences in fresh meat, Macedo et al. (2022) also did not find any genetic differences in a_w of fresh meat when they evaluated these three genetic groups of cattle. It is needed to consider some possible unspecific interference of NaCl in the samples, affecting the water behavior into them and thus leading to the differences found.

A lower moisture value is the primary desirable outcome when dehydration and salting processes are used to manufacture cultural dry and semi-dry meat products such as Jerky, Biltong, Charqui, Cecina, Cabanossi, and Pemmican (Cheng et al., 2022; Ngapo et al., 2021;

Swanepoel et al., 2016; Petit et al., 2014; Garcia et al., 1997; Norman & Corte, 1985). Communities around the globe have historically used drying and salting processes to minimize microbial growth and increase product shelf life (Mediani et al., 2022). However, although countries have different regulations regarding moisture levels for dry and semi-dry products, the moisture value and a_w of *Carne de sol* were 71.98% and 0.94 when compared with 72.92% and 0.98 of fresh beef, respectively. Although those reported values differed statically, this research suggests that the literature characterization of *Carne de sol* as a dry product (Aykın Dinçer, 2021; Costa &Silva, 2001; Norman & Corte, 1985) conflicts with its moisture content. Values of moisture for fresh beef varying from 68 to 74% have been widely reported in the literature (Pouzo et al., 2023; Yeh et al., 2018; Hunt et al., 2014; Rubio et al., 2007; Pietrasik & Shand, 2005), whereas for traditional semi-dry and dry intact products, values of moisture vary from 21 to 50% (Cheng et al., 2022; Ngapo et al., 2021; Swanepoel et al., 2016; Petit et al., 2014; Garcia et al., 1997; Norman & Corte, 1985). However, the lack of official manufacturing patterns for *Carne de sol* impairs the correct comparisons between this meat product and the fresh meat.

As mentioned, the Brazilian government does not officially regulate *Carne de sol* production and handling. In 2019, a bill was presented to the Brazilian Senate to implement manufacturing and commercialization standards for *Carne de sol* (BRASIL, 2019). While the bill approval is still pending, future regulatory efforts must ensure that *Carne de sol* is produced by following good manufacturing practices (GMPs) and that the final product re-enters the cold chain for further handling and distribution. The moisture values for *Carne de sol*, even undergoing mild salting and drying processes, were around 72%, similar to fresh beef. Therefore, based on its moisture content and lack of standard production processes, it is imperative that after the bill passes the Senate, regulatory documents detailing manufacturing and handling procedures are elaborated to ensure product wholesomeness at commercial retail.

Regarding the increased collagen content in *Carne de sol* than in fresh meat, Youssef et al. (2007) reported similar results for salted dry products, showing an increase in insoluble collagen in Charqui compared with fresh beef. Despite the fact that there is a direct relationship between SF and collagen (Christensen et al., 2011), the higher collagen content did not detrimentally affect SF of *Carne de sol*, which was significantly lower when compared with cooked fresh beef. The lower values of SF in *Carne de sol* can be attributed to the addition of NaCl, which loses collagen fibers by breaking H bonds of the molecule lysing their polysaccharide complexes (Li et al., 2016; Krasulya et al., 2019). *Carne de sol* had a significantly better SF score than fresh meat. From the information in Belew et al. (2003), it

608 can be concluded that this meat product was considered “tender” (values between 3.2 and 3.9
609 kgf), while fresh meat was considered “hard”, since its score was above 4.6 kgf.
610 For the fixed effect of the genetic group, we initially hypothesized that including *Bos*
611 *taurus* could improve some of the quality attributes of fresh beef and *Carne de sol*. Moraes et
612 al. (2011) demonstrated that beef from ½ Nellore ½ Angus and ½ Nellore ½ Simmental steers
613 had lower SF when compared with beef obtained from pure Nellore. Therefore, due to higher
614 calpastatin activity in *Bos indicus* beef (Rodrigues et al., 2017; Pringle et al., 1997; Whipple et
615 al., 1990; Johnson et al., 1990), we expected to observe lower SF in meat products from NeAn
616 and NASe. In fact, the effects of genetics were observed only for *L**, *C**, WHC and a_w. The
617 similar SF values across all genetic groups were mainly driven by the *Bos indicus* (Nellore)
618 inheritance. Thrift and Thrift (2002) reported that beef obtained from *Bos indicus* and its
619 derivatives usually show higher instrumental tenderness; however, lower values can be
620 achieved when *Bos taurus* breeds account for ⅝ of total inheritance.
621 Regarding the fact *Carne de sol* had lower protein than fresh meat, it is important to
622 emphasize that *Carne de sol* is a meat product partially dehydrated (Gouvêa & Gouvêa, 2007),
623 thus water, protein and other substances can be lost from the meat. The increased ash content
624 in *Carne de sol* was also observed by Gouvêa et al. (2017). It is important to consider the
625 addition of salt (NaCl) during *Carne de sol* manufacturing, which probably increased the ash
626 content observed, since salt is an additional source of minerals.
627 When compared with fresh beef, *Carne de sol* showed significantly higher WHC (lower
628 expressed water) and lower CL. In the raw product, the lower moisture loss observed while
629 evaluating WHC was possibly determined by the barrier resulting from the surface dehydration
630 led by salting and drying. This barrier prevented water from being released from deeper layers
631 of the lean (Vidal et al., 2019). The CL was higher in fresh beef than in *Carne de sol*. Although
632 the moisture content of *Carne de sol* and fresh beef was about 71±1% before cooking, the CL
633 of fresh beef was about 1.4-fold higher than *Carne de sol*. This is due to the incorporation of
634 NaCl in the surface of the lean and the propagation of its ions towards the inner layers, which
635 increases the ionic strength of *Carne de sol*. According to Puolanne and Peltonen (2013), high
636 ionic strength and a higher pH (5.34) compared with an average isoelectric pH value of
637 structural proteins (5.0) increase the WHC of meat matrices. Results of this study suggested
638 that the higher ionic strength played a decisive role in retaining more moisture in *Carne de sol*
639 than in fresh beef during cooking.
640
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Fatty acid composition

Regarding the decreasing in PUFA concentration and the increasing in SFA concentration for *Carne de sol*, it is known that salt is considered as pro-oxidant, and phospholipids are the most susceptible FA to suffer lipid oxidation. Thus, it is important to emphasize that SFA is less susceptible to oxidation than UFA (Resconi et al., 2013; Mottram, 1998; Marmer et al., 1984; Mottram & Edwards, 1983), and thus this fact probably affected the opposite concentrations found for SFA and PUFA. The genetic differences detected in *Carne de sol* for C18:2 *n*-6, C20:3 *n*-6 (differences also for fresh meat), C20:5 *n*-3 and C22:5 *n*-3 were very unspecific, and it was possible that salt influenced these results considering the lipolytic effect of salt on triglycerides and phospholipids due to hydrolysis or enzymatic activity, leading to the release of glycerol and free fatty acids (FFA), highly susceptible to oxidation (Nachtigall et al., 2019; Demeyer, 2004). Thus it is possible that the application of salt during *Carne de sol* manufacturing randomly affected the results found in the present study.

In *Carne de sol*, there were observed significant genetic differences for Σ PUFA, sums and ratios, whereas in fresh meat these genetic differences were not found. Macedo et al. (2022) also did not find in fresh meat any statistic differences in Σ PUFA, Σ UFA: Σ SFA and Σ MUFA: Σ SFA, as well Σ *n*-6, Σ *n*-3 and *n*-6:*n*-3, suggesting a possible random effect of addition of NaCl on the parameters studied in the present work. The authors only found a significant increase in Σ PUFA: Σ SFA, where crossbreeds had higher ratios, and this was the only difference found for fresh meat compared to the present study. *Carne de sol* significantly decreased n-6:*n*-3 ratio compared to fresh meat, and crossbreds of *Carne de sol* lowered the n-6:*n*-3 ratio in this meat product, which is a positive result, since the ideal ratio for a healthy diet is in the 1:1 range, despite 2:1 being recommended (Wood et al., 2008; DHA, 1994).

These reductions on PUFA content and their ratios was accomplished by the reduction of some enzymatic activities, as shown by Δ^9-C18, which decreased for *Carne de sol*. It was also observed genetic differences in Δ^9-C16 e Δ^9-C18 activities for both types of meat, with improved activity for NASe and lower activity for NeAn. Evaluating fresh meat of the same groups of cattle, Macedo et al. (2022) found genetic differences only for Δ^9-C16, with the same increased activity for NASe and lower activity for NeAn. In *Carne de sol*, elongase achieved better activities for NASe than Nell. These results showed non specific values and it was possible they may have been influenced by salt during *Carne de sol* manufacturing.

Nutritional quality parameters also followed the decrease in PUFA's contents and sums, with increased AI and TI and decreased h:H for *Carne de sol*. These findings may have been

related to the decreasing in PUFA contents and the increasing in C14:0, since salt promotes lipid oxidation and phospholipids have high tendency to be oxidized compared to triglycerides (Resconi et al., 2013; Mottram, 1998; Mottram & Edwards, 1983). Considering that many PUFA are antithrombogenic and hipocholesterolemic, they can reduce the risk of heart diseases, as EPA and DHA (Wijendran & Hayes, 2004; Enser et al., 2001; McDonald et al., 1989; Mattson & Grundy, 1985), and, at the same time, many SFA, as C12:0, C14:0 and C16:0, are thrombogenic and hipercholesterolemic, increasing the risk of heart attack (Ojha et al., 2017; Yu et al., 1995; Hornstra & Lussenburg, 1975), the results found in the present study demonstrates the increased risk of the elevated consume of *Carne de sol* with high levels of salt. Regarding genetic differences for nutraceutical compounds, the results in the present study differed from the results reported by Macedo et al. (2022) for fresh beef from the same groups of cattle. The authors found a trend in crossbreds in to have lower AI compared to Nell. However, no statistical differences in TI and h:H parameters of the same group of cattle were found.

Sensory attributes

The genetic composition of the experimental units used in this research did not affect the sensory attributes for *Carne de sol* probably due the effect of manufacturing of this meat product, and thus offset any breed difference found in the panel. The absence of studies on literature about genetic groups and quality traits of meat products is a negative factor to correctly discuss the present results.

The scores reached by *Carne de sol* were about 7 (liked moderately) and demonstrated good sensory acceptance. Studies about *Carne de sol* from Nellore breeds found scores near to the found in the present study: (Araújo et al., 2022; Gesteira et al., 2019; Gouvêa et al., 2017). Gouvêa et al. (2017) compared *Carne de sol* and fresh meat and observed improved scores for *Carne de sol* compared to the fresh meat. Although no genetic effect have been studied, these results indicated a possibly pattern in *Carne de sol* to have sensory scores around 7, at least in beef from Nellore.

Conclusions

Carne de sol improved physicochemical attributes of the meat, with better shear force, lower cooking loss and water activity compared to fresh meat. However, this meat product

710 negatively affected FA profile, impairing PUFA content and the health indexes. *Carne de sol*
711 reached good sensory scores, showing great acceptability by the consumers. In its turn, fresh
712 meat had the best composition of Σ PUFA, Σ UFA: Σ SFA, Σ MUFA: Σ SFA, Σ PUFA: Σ SFA,
713 Σ *n*-3 and *n*-6:*n*-3 ratio, and thus it is still a better source of these nutrients, improving health
714 compounds compared to *Carne de sol*.

715 The differences between genetic groups found in this study were more accurate for fresh
716 meat than for *Carne de sol*, since salt application appeared to offset the changes in the quality
717 attributes evaluated. NASe produced beef with better lightness, the highest C22:5 *n*-3 and Δ^9-
718 C16 activity. Overall, including *Bos taurus* breeds did not alter the sensory attributes of *Carne*
719 *de sol*. More research is necessary to study the influence of the genetic group on the changes in
720 physicochemical attributes of meat products, as well the interaction effects found between them
721 and the genetic groups on these traits.

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728 **Declaration of Competing Interest**

729 The authors declare no conflict of interest associated with this publication and no
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731

732 **Author Contributions**

733 **Ronaldo L. Oliveira, Analívia M. Barbosa, and Leilson R. Bezerra**: Conceptualization,
734 Methodology, Funding acquisition.
735 **Vanessa P. Macedo and Thadeu M. Silva**: Data curation.
736 **Amilton S. de Mello**: Formal analysis, Software.
737 **Ronaldo L. Oliveira and Amilton S. de Mello**: Visualization.
738 **Vanessa P. Macedo**: Writing - Original draft.
739 **Amilton S. de Mello**: Writing - Reviewing & Editing.

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CHAPTER III

SENSORY ACCEPTANCE, PHYSICOCHEMICAL TRAITS AND FATTY ACID PROFILE OF BEEF BURGERS FROM THREE BEEF CATTLE ZOOTECHNICAL GROUPS

Aceitação sensorial, atributos físico-químicos e perfil de ácidos graxos de hambúrgueres de bovinos de três grupos zootécnicos

RESUMO

Bovinos da espécie *Bos indicus* tornaram-se um valioso recurso em países de climas tropical e subtropical; entretanto, estes animais produzem carne com grau de dureza indesejável quando comparados com bovinos *Bos taurus*, os quais, por sua vez, não conseguem ter desempenho satisfatório quando inseridos em ambiente tropica e, neste caso, os cruzamentos podem ser utilizados como uma grande ferramenta de melhoria do perfil genético do rebanho. Os produtos cárneos são importantes fontes de proteína em países em desenvolvimento, e o hambúrguer é um produto amplamente consumido ao redor do mundo. Três grupos genéticos de bovinos, (Nelore (Nell), ½ Nelore × ½ Angus (NeAn), and ¼ Nelore × ¼ Angus × ½ Senepol (NASe)) foram utilizados para avaliar os atributos físico-químicos e sensórias de hambúrgueres de carne bovina. Os animais cruzados afetaram positivamente os parâmetros de qualidade dos hambúrgueres, especificamente luminosidade e umidade ($P < 0.05$), e diminuíram as concentrações dos ácidos graxos saturados indesejáveis ($P < 0.05$) quando comparados ao grupo Nell. Os animais cruzados também obtiveram melhores escores de maciez ($P = 0.005$) e suculência ($P = 0.006$) do que o grupo Nell. Entretanto, o processamento pode modificar os atributos físico-químicos da carne, resultando em mudanças inespecíficas no produto cárneo que podem interferir negativamente na interpretação dos resultados. Assim, mais estudos envolvendo grupos zootécnicos e atributos de qualidade de hambúrgueres tornam-se necessários.

Palavras-chave*:* atributos de qualidade, cruzamentos, *Bos indicus*, *Bos taurus*, produtos cárneos

Sensory acceptance, physicochemical traits and fatty acid profile of beef burgers from three beef cattle zootechnical groups

ABSTRACT

Bos indicus is a valuable resource in tropical and subtropical countries; however, they produce meat with an undesirable degree of toughness compared to *Bos taurus*, which cannot perform efficiently under tropical conditions, and thus crossbreeding can be used as a genetic tool. Meat products are important protein sources in developing countries, and beef burgers are a widely consumed meat product worldwide. Three different zootechnical groups of cattle, Nellore (Nell), ½ Nellore ½ Angus (NeAn) and ½ Senepol ¼ Nellore ¼ Angus (NASe) were used to evaluate the physicochemical and sensory attributes of beef burgers. Crossbreeds positively affected the parameters of beef burgers, specifically lightness and moisture ($P < 0.05$), and decreased undesirable saturated fatty acids ($P < 0.05$) compared to Nell. Crossbreeds also had better ratings of tenderness ($P = 0.005$) and juiciness ($P = 0.006$) than Nell. However, the manufacturing of beef burgers can change the physicochemical attributes of meat, leading to possibly unspecific effects, which can affect the interpretation of the results found. Thus more studies involving zootechnical groups of cattle and the quality traits of beef burgers are necessary.

Keywords*:* *Bos indicus*, *Bos taurus*, atributos de qualidade, crossbreeding, meat products, quality atributes

1. Introduction

In tropical and subtropical countries, *Bos indicus* breeds are valuable resources since they can be produced in rural environments due to their adaptable capacity (greater resistance to parasites, poor-quality food, and high temperature). This contributed to the spread of these breeds in tropical regions, especially in Brazil (Santana Junior et al., 2016), with the Nellore breed being the predominant breed raised (Aroeira et al., 2017). Furthermore, *Bos indicus* produce meat with lower fat deposition (Lage et al., 2012; Johnson et al., 1990; Wheeler et al., 1990). On the other hand, taurine breeds cannot perform efficiently under tropical conditions, due environmental stressors (e.g. high temperature and ectoparasites).

Bos indicus produces meat with undesirable toughness due to the high calpastatin activity in this species. This enzyme impairs calpain activity in the proteolytic process and blocks the tenderizing (Whipple et al., 1990; Pringle et al., 1997; Johnson et al., 1990). In the *postmortem* carcass, calpains are responsible for the partial rupture of myofilaments during the maturation process, which improves tenderness (Whipple et al., 1990; Muroya et al., 2006; Lana & Zolla, 2016); however, their activity can be impaired by calpastatin activity (Koohmaraie et al., 2002). *Bos taurus* has lower calpastatin activity than *Bos indicus*, which means more tender meat (Rubensam et al., 1998).

Crossbreeding can be used as a genetic tool to improve meat quality and adaptation capacity. Crossbreeding improves genetic traits using the effects of heterosis and the complementarity between breeds traits, especially in the case of crosses between *Bos taurus* and *Bos indicus* (Gama et al., 2013; Leroy et al., 2016). However, it is important to note that meat tenderness and juiciness decrease as the *Bos indicus* proportion in crossbreeding (½ or more) increases (Johnson et al., 1990; Phelps et al., 2017).

In addition to meat, meat products (processed foods) are important protein sources in developed countries, and several aspects can influence their consumption: sensory acceptance and nutritional profile, costs, safety, economic situation, familiar and/or educational influences, and others (Jiménez-Colmenero et al., 2001). Additionally, beef is a high perishable food, and thus, some processing methods have been developed to maintain its quality during storage, such as salting, cooking, drying, smoking, marinating and curing (Norman & Corte, 1985; Collignan et al., 2001).

Despite their undesirable high content of salt, fat, saturated fatty acids, and cholesterol, meat products are important sources of minerals, vitamins and proteins (Jiménez-Colmenero et al., 2001). Fat and sodium chloride (NaCl) are important meat quality enhancers (Hughes et al.,

1997; Bidlas & Lambert, 2008). NaCl improves meat's shelf life, taste and texture of meat and meat products (Ruusunen et al., 2005; Bidlas & Lambert, 2008). Furthermore, NaCl reduces water activity (a_w) and microbial growth (Costa-Corredor et al., 2009), contributes to the solubilization of myofibrillar proteins, enhancing their water-holding capacity, and leading to the reduction of cooking loss and improved texture of the meat product, specifically juiciness and tenderness, as well facilitating fat binding (Desmond, 2006). Fat contributes to stable emulsions in comminuted meat products (Hughes et al., 1997).

One meat product is beef burgers patties obtained from ground meat (Bender, 1992). This meat product is widely consumed worldwide due to its simple preparation and sensory traits (Ziegler et al., 2020). According to Brazilian legislation, beef burger (*hambúrguer*) is an industrialized meat product obtained from ground beef with or without the addition of fat and other ingredients, molded and submitted to technological proceedings (Brasil, 2022).

From the information described above and considering the absence of data in the literature concerning the direct influence of different genetic groups of cattle on beef burger quality traits, this study aimed to evaluate the physicochemical and sensory quality of beef burgers from three genetic groups of bovines: Nellore (Nell), ½ Nellore ½ Angus (NeAn) and ½ Senepol ¼ Nellore ¼ Angus (NASe). The hypothesis tested in the present work is that taurine breeds can contribute to genetic crossing programs, impacting the quality of the bovine burger (physicochemical properties and sensory attributes), being an innovative resource for production systems in tropical and subtropical conditions.

2. Materials and methods

2.1 Ethical considerations, animals, and general procedures

The present experiment was conducted at the Veterinary and Animal Science School of Federal University of Bahia (UFBA), located in Salvador, Bahia, Brazil. Animal procedures followed the guidelines recommended by the institutional Animal Care and Use Committee (CEUA/UFBA, Protocol number 043/2019).

Eighteen steers, averaging 24 months, from the Nellore (Nell), ½ Nellore ½ Angus (NeAn) and ½ Senepol ¼ Nellore ¼ Angus (NASe), pasture finished groups were used. They were finished in two paddocks of approximately 24 hectares each one, containing *Brachiaria brizantha* cv. Marandu, also receiving mineral supplementation and having free access to water.

The concentrate offered included ground corn (54%), soybean meal (40%) and mineral mixture (6%) at 1% of body weight (BW). The animals were separated by the group until they reached the predetermined BW of slaughter (500 to 600 kg).

After reaching the BW for slaughter, the animals have fasted for 16 h, and then sent to be slaughtered in a commercial slaughterhouse. The slaughtering procedures followed the guidelines of the Federal Inspection Service (SIF), in accordance with the official legislation (Normative nº 03/00) (Brazil, 2000).

After skinning and evisceration, the carcasses were cut in two halves, and the initial pH (pH_0) was measured in the *Longissimus dorsi* muscle between the 6^{th} and 7^{th} ribs using a digital potentiometer model HI99163 (HANNA Instruments, São Paulo, Brazil). Then, the carcasses were sent to the cold chamber, where they cooled for 24 hours at 4 °C. After 24 h, the final carcass pH (pH_U) was measured using the procedure previously described for pH_0. *Semimembranosus* and *Adductor femoris* samples were collected from half of the carcass, placed into labeled plastic bags and submitted to refrigeration (4°C), for further beef burger manufacturing followed by physicochemical and sensory analysis.

2.2 Beef burger manufacturing

Beef burger manufacturing was carried out according to Gouvêa et al. (2016) with modifications. *Semimembranosus* and *Adductor femoris* samples were first prepared by removing excess fat and connective tissue. The beef samples were ground in an 8 mm disc of a Skymsen PS-10 grinder (Metalúrgica Siemsen ltda., Brusque, SC, Brazil), mixed and passed through the same device to homogenize the mass. Pork fat was submitted to the same grounding process and added to the meat mass. The proportions of ground pork fat and ground meat calculated for each 1 kg of beef burger were 15% (150 g) and 81,3% (813 g), respectively. In the mixture, 1.5% (15 g) salt, 0.2% (2 g) sugar, 0.3% (3 g) garlic paste and 0.2% (2 g) ground black pepper were also added. The mass and ingredients were manually mixed for 20 minutes and then placed in a refrigerator at 4°C for 12 hours. Then, the beef burgers were manufactured by molding in a 9.5 cm hand press. The burgers were packaged in cling film and stored at -18 °C until the physicochemical and sensory evaluations.

2.3 Physicochemical properties

The pH of beef burgers was measured in triplicate using a digital potentiometer model

HI99163 (HANNA Instruments, São Paulo, Brazil). The lightness (L*), redness (a*), yellowness (b*) and chrome color saturation (C*) of the beef burgers were evaluated after beef burger samples were exposed to air for 30 min according to the method described by Miltenburg et al. (1992). Color measurements were taken on the surfaces of the samples with a handheld CR-410 Minolta Colorimeter (Chroma Meter CR-410, Konica Minolta, Tokyo, Japan), according to the Commission International I'Eclarage (CIE) system, using the L*, a*, b* coordinates, an iluminant D65 and a 10° standard observer. Calibration was carried out using white and black tiles, and the lightness (L*), redness (a*), yellowness (b*) and chrome color saturation [$C^* = (a^{*2} + b^{*2})^{1/2}$] were assessed (Hunt & King, 2012).

Sections of the beef burger samples were cut into 2.5 × 2.5 cm thick cubes and weighed before cooking. Then, the samples were cooked on a grill (George Foreman Jumbo Grill GBZ6BW, Rio de Janeiro, Brazil) at 170 °C, and the geometric center temperature of the slices was measured with portable digital thermometers (Gulterm 700-10S, São Paulo, Brazil). When the temperature reached 71 °C, the samples were cooled to room temperature and weighed. The cooking loss was calculated by the difference between the initial and the final weights was expressed as a percentage (AMSA, 2016).

The cooked beef burger samples were wrapped in aluminum foil and stored at 4 °C for 12 h (Consul CHB53C®, Salvador, Brazil). Then, the samples were brought to room temperature prior to Shear Force (SF) analysis. At least three cores were removed from each sample using a cork borer. The SF was measured with a texture analyzer (Texture Analyser TX-TX2, Mecmesin, Nevada, United States) fitted with a Warner–Bratzler type shear blade with a load of 25 quiloforces (kg*f*) and a cutting speed of 20 cm/min. Following the Meat Animal Research Center, the values obtained were expressed in kg*f* (Shackelford et al., 1999).

The protein, lipid, moisture, ashes and collagen contents of the beef burgers were determined by near infrared spectroscopy (NIRS) in a FoodScan™ Apparatus (FOSS Analytical A/S, Hillerod, Denmark) according to AOAC (2007). The beef burgers' water activity (a_w) was assessed with an Aqualab LITE® (Decagon Devices Inc., Pullman, WA, USA) device.

2.4 Fatty acids composition

The fatty acid composition of the beef burgers followed O'Fallon et al. (2007), with adaptations. First, 0.5 g of each freeze-dried sample was placed in an individual 12-mL tube, 1 mL of internal standard solution (N5252-1G; Sigma-Aldrich) in methanol (1mg19:0/mL), 5.3

mL of methanol and 0.7 mL of 10N potassium hydroxide in an aqueous solution were added. Then, the tubes were incubated in a water bath at 55 °C for 1.5 h, and every 20 min., they were handshake vigorously for 5 seconds. The tubes were then cooled in a tap water bath, and 0.58 mL of 24*N* sulfuric acid in an aqueous solution was added for a new water bath cycle, following the same procedure. Then, the tubes were cooled again in a cold tap water bath, and 3 mL of hexane was added. The test tubes were mixed with a vortex (Fisatom 772, São Paulo, Brazil) for 5 min and centrifuged for 5 min (CENTRIBIO 80-2B, EQUIPAR Ltda., Paraná, Brazil). The supernatant was collected and placed into a GC vial.

Fatty acid methyl esters (FAME) separation was carried out using a gas chromatograph (Focus GC Thermo Electron S.p.A, Milan, Italy) fitted with a flame ionization detector and SP-2560 column (100 m x 0.25 mm x 0.20 µm; Supelco Inc., Bellefonte, PA, USA). The initial oven temperature was set to 140 °C for 5 min., and increased at a rate of 1 °C.min^{-1} to 220 °C, held for 25 min. The carrier gas used was hydrogen, with a 1.3 mL.min^{-1} flow rate. The injector temperature was 250 °C and the detector temperature was of 280 °C. The injection volume was 1µL, and the split ratio was 30:1.

The identification of the FAMEs was performed by comparing the samples methyl esters retention times against the GLC-674 Standard Mixture (Nu-Chek Prep Inc. Elysian, USA), containing 52 fatty acids. The quantification was carried out using the formula: [(total area under peaks) – (area under internal standard)/(area of internal standard) × (internal standard concentration/dry weight of the sample)], which was based on the Sukhija & Palmquist (1988) method. The results were expressed in milligrams of fatty acid per 100 grams of beef burger (mg/100g).

The sum of total saturated (SFA), unsaturated (UFA) monounsaturated (MUFA) and polyunsaturated fatty acids (PUFA), *n*-6 and *n*-3, as well as UFA:SFA, MUFA:SFA, PUFA:SFA, PUFA:MUFA and *n*–6:*n*–3 ratios were calculated. The nutritional quality of the lipid fraction of the samples was estimated by the atherogenicity index (AI), thrombogenicity index (TI) (Ulbricht & Southgate, 1991) and the relationship between hypocholesterolemic and hypercholesterolemic fatty acids (h:H) (Santos-Silva et al., 2002). Furthermore, the stearoyl Co-A desaturase (Δ^9 desaturase) activities for 16:0 (palmitic acid) and 18:0 (stearic acid), as well as the elongase activity (De Smet et al., 2004) were also calculated.

2.5 Sensory attributes

Beef burger sensory evaluation was carried out according to American Meat Science

Association guidelines (AMSA, 2016), using a panel of 70 consumers and a 9-point hedonic scale: 1: desliked extremely; 2: desliked very much; 3: desliked moderately; 4: desliked slightly; 5: indifferent; 6: liked slightly; 7: liked moderately; 8: liked very much; 9: liked extremely. The sensory attributes evaluated were flavor, aroma, tenderness, juiciness, overall acceptance and preference.

The beef burger samples were classified by genetic group and cooked at 170 °C on a grill (George Foreman Jumbo Grill GBZ6BW, Rio de Janeiro, Brazil). When the geometric center reached 71°C, the samples were cut into 2 cm^3 cubes, coded, and placed in a water bath at 75 °C. At this moment, the samples were covered in aluminum foil, to maintain their heat and to prevent volatile aroma compounds losses. The sensory panel was conducted from 9:00 to 12:00 h. Each consumer received three samples representing the three genetic groups, and was offered water- and salt-type biscuits and water between the tastings to remove the aftertaste.

2.6 Statistical analysis

Statistical analysis was carried out using 38Statistical Analysis System version 9.4 (SAS Institute Inc., Cary, NC, USA) with analysis of variance for a completely randomized design and three treatments (zootechnical groups Nell, NeAn and NASe), which included the effects of genetic group. Tukeys's test was used to compare the least square means, and significant differences ($P < 0.05$) were evaluated. The statistical model was the following:

$$Yij = \mu + si + eij,$$

where Yij = the observed value, μ = the general mean, si = the effect of the zootechnical group, and eij = the effect of the experimental error in the plots.

3. Results

3.1 Physicochemical properties

There were no significant differences in pH, cooking loss, protein, lipid, ash, collagen, or water activity among the groups ($P > 0.05$). L^* value presented significant differences between genetic groups ($P = 0.002$), with beef burger from NASe being lighter than those from Nell and NeAn. Moisture ($P = 0.002$) was significant higher in crossbred than Nell.

Table 1. Physicochemical traits of beef burgers from Nellore (Nell), ½ Nellore ½ Angus (NeAn) and ¼ Nellore ¼ Angus ½ Senepol (NASe)

Attribute	Genetic group			SEM	*P* value
	Nell	NeAn	NASe		
pH	5.98	5.95	5.95	0.025	0.381
*L**	44.1[b]	44.6[b]	46.4[a]	0.618	0.002
*a**	8.54	8.82	8.49	0.263	0.379
*b**	12.0	11.9	12.2	0.144	0.292
*C**	14.80	14.79	15.04	0.200	0.515
Cooking loss (%)	24.4	22.6	23.6	1.305	0.884
Shear force (kfc cm^{-2})	1.08	1.07	1.02	0.073	0.922
Protein (g 100 g^{-1})	19.6	19.5	19.6	0.144	0.922
Lipid (g 100 g^{-1})	9.99	8.98	9.49	0.188	0.154
Moisture (g 100 g^{-1})	68.7[b]	70.3[a]	70.2[a]	0.144	0.002
Ashes (g 100 g^{-1})	1.70	1.64	1.48	0.206	0.889
Collagen (g 100 g^{-1})	1.45	1.34	1.24	0.080	0.517
Water activity	0.969	0.972	0.970	0.002	0.251

Means with different letters in the same row differ ($P < 0.05$). SEM: standard error of the mean.

3.2 Fatty acid composition

The fatty acid profile of the beef burgers (Table 2) showed significant differences among the Nellore and crossbreds in both saturated and unsaturated fatty acids (FAs) and their sums. The Nell group had the major content of saturated fatty acids (SFA) compared to the other groups, as well as the highest monounsaturated fatty acids (MUFA) content. These differences became to decrease in the content of polyunsaturated fatty acids (PUFA). The FA's 18:1 *c*9 (oleic), 16:00 (palmitic), 18:00 (stearic) and 18:2 *n*-6 (linoleic) were the most abundant. In the same way, Nell group had significantly the major content in total SFA ($P = 0.003$) and MUFA ($P < .001$) compared to the other groups, decreasing this difference in total PUFA, as well as in the sums of *n*-6 and *n*-3. However, these differences did not affect their ratios.

Table 2. Fatty acid composition (mg 100 g^{-1} edible product) and health indexes of beef burgers from Nellore (Nell), ½ Nellore ½ Angus (NeAn) and ¼ Nellore ¼ Angus ½ Senepol (NASe)

Fatty acid	Genetic group			SEM	*P* value
	Nell	NeAn	NASe		
12:00	6.31	6.08	5.96	0.148	0.280
14:00	116.0[a]	104.3[b]	103.6[b]	3.808	0.029
15:00	11.62	10.17	10.0	0.591	0.103
16:00	1930.2[a]	1779.6[b]	1694.6[b]	39.281	<.001
17:00	55.79[a]	49.52[b]	49.56[b]	1.664	0.031
18:00	1028.3[a]	971.9[b]	933.0[b]	21.578	0.005
16:1 *c*9	162.0[a]	149.5[b]	146.3[b]	3.571	0.002
17:1 *c*10	38.74[a]	36.37[ab]	34.32[b]	1.259	0.037
18:1 *t*11	24.41[a]	11.22[b]	19.11[a]	2.583	0.011
18:1 *c*9	3227.6[a]	3012.6[b]	2842.9[c]	56.104	<.001
18:1 *c*11	177.4[a]	170.5[a]	159.1[b]	3.642	0.001
18:2 *n*-6	971.2[a]	974.8[a]	889.7[b]	25.018	0.006
18:3 *n*-3	59.21[a]	58.87[a]	54.33[b]	1.274	0.004
18:2 *c*9, *t*11	2.69	2.67	2.55	0.040	0.137
20:3 *n*-6	9.57[a]	8.32[b]	8.06[b]	0.241	<.001
20:4 *n*-6	28.08	28.94	27.07	0.801	0.121
20:5 *n*-3	5.63	6.12	5.47	0.270	0.162
22:5 *n*-3	12.16	12.78	11.94	0.377	0.131
Σ SFA	3091.2[a]	2920.9[b]	2794.2[b]	59.341	0.003
Σ UFA	4629.5[a]	4446.0[a]	4206.9[b]	72.492	<.001
Σ MUFA	3538.5[a]	3352.7[b]	3202.4[b]	50.527	<.001
Σ PUFA	1091.0[a]	1093.3[a]	1004.5[b]	28.041	0.005
Σ UFA: Σ SFA	1.51	1.52	1.51	0.015	0.588
Σ MUFA: Σ SFA	1.15	1.15	1.15	0.009	0.896
Σ PUFA: Σ SFA	0.35	0.37	0.36	0.008	0.237
Σ *n*-6	1015.6[a]	1019.1[a]	931.2[b]	25.767	0.005
Σ *n*-3	78.35[a]	80.19[a]	73.27[b]	1.742	0.004
n-6:*n*-3	12.95	12.67	12.73	0.123	0.135
Δ^9 desaturase C16	7.86	7.76	7.95	0.092	0.150
Δ^9 desaturase C18	75.62	75.61	75.31	0.202	0.198
Elongase	67.06	67.41	67.24	0.118	0.161
AI	0.490	0.496	0.502	0.008	0.659
TI	1.21	1.17	1.19	0.012	0.259
h:H	2.07	2.12	2.08	0.019	0.127

Means with different letters in the same row differ ($P < 0.05$). SEM: standard error of the mean. SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; AI: atherogenicity index; TI: thrombogenicity index; h:H: hypocholesterolemic/hypercholesterolemic ratio.

366 *3.3 Sensory attributes*

367

368 The sensory attributes of beef burgers are in Table 3. In general, all the parameters
369 received grades from 7 to 8 (from "liked moderately" to "liked very much"), with tenderness
370 being significantly better rated in NASe than in Nell group (P = 0.005), and juiciness better
371 rated in crossbreds compared to Nell (P = 0.006).

372

373

374 **Table 3.** Sensory ratings of beef burgers from Nellore (Nell), ½ Nellore ½ Angus (NeAn) and
375 ¼ Nellore ¼ Angus ½ Senepol (NASe)

Attribute	Genetic group			SEM	*P* value
	Nell	NeAn	NASe		
Aroma	7.53	7.47	7.61	0.117	0.718
Flavor	7.93	8.11	8.07	0.090	0.363
Tenderness	7.79^{b}	8.01^{ab}	8.26^{a}	0.094	0.005
Juiciness	7.67^{b}	8.03^{a}	8.09^{a}	0.090	0.006
Overall acceptance	7.77	7.97	8.04	0.087	0.107

376 Means with different letters in the same row differ (P<0.05). SEM: standard error of the mean.

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378

379 **4. Discussion**

380

381 *4.1 Physicochemical properties*

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383 The content of protein and lipid are within the expected for Brazilian regulations of
384 burgers (BRASIL, 2022), in which is stated a minimum protein content of 15% and a maximum
385 lipid content of 25%.

386 The fact NASe group produced significantly lighter burgers patties (L*) than Nell and
387 NeAn groups may be explained by the influence of Nellore genetics, since as higher is the
388 percentage of zebu in crosses, darker the beef is due the excitable temperament of this breed
389 (Voisinet et al., 1997a; Voisinet et al., 1997b; Wulf et al., 1997), leading to faster decrease in
390 glycogen stores while the pH is still high during the conversion of muscle to meat (Warner,
391 2017; Matarneh et al., 2017). Hence, it can trigger changes in pH and retention of water, which
392 accumulates into the cells, decreasing the reflection of the light (Braden, 2013). The pH of the
393 burgers ranged from 5.72 to 5.90, which is near to the upper limit. Macedo et al. (2022) found
394 darker meat in Nell and NeAn and a trend in these breeds in to have meat with lower L*

compared to NASe. Despite their results were similar to the present study, Macedo et al. (2022) used the whole muscle (*Longissimus*), while the present study evaluated beef patties. This fact can impair the comparisons made, since the beef burger manufacturing included the grinding of the meat and de addition of fat and spices.

Moisture decreased significantly in beef burgers from Nell breed compared to crossbreeds and, as reported by many authors, variations in moisture are inversely related with percentage of lipids, and when total lipids increase, moisture decrease (Barros et al., 2020; Pereira et al., 2013; Prado et al., 2008b; Carballo et al., 1995; Roland et al., 1981). In studies with beef samples, moisture presented little variation according genetic groups, ranging from 72.8% to 74.2% among zebu and its crosses with taurine breeds (Rotta et al., 2009; Prado et al., 2008a; Prado et al., 2008b; Prado et al., 2008c).

4.2 Fatty acids composition

The composition of fatty acids (FA) in beef burgers showed the most numerous FA found in the present study were the same found in higher concentration in pork fat, that is, the FA 18:1 *c*9 (oleic), 16:00 (palmitic), 18:00 (stearic) and 18:2 *n*-6 (linoleic) (Wood et al., 1989). Additionally, it is important to consider the spices used, as garlic and black pepper, reported as great sources of 12:00, 14:00, 16:00, 18:00, 18:1 *c*9, 16:1 *c*9 and 18:2 *n*-6 (Hossain et al., 2014; Kamanna & Chandrasekhara, 1980). Nell produced the most saturated burgers, having significantly higher SFA content than crossbreds, especially 14:00, 16:00 and 18:00, and this may occur due influence of zebu genetics, since studies have reported *Bos indicus* as having a trend to accumulate these FA (Bressan et al., 2011; Rossato et al., 2009).

The higher content in UFA than SFA were in line with the results found by many authors for beef burgers (Barros et al., 2020; Selani et al., 2016b; Rodríguez-Carpena et al., 2012; Scheeder et al., 2001). The higher MUFA content was influenced by the higher concentration of 18:1 *c*9, which is also the main FA in pork fat (Wood et al., 1989). While SFA 12:00, 14:00 and 16:00 are pro-atherogenic, MUFA and PUFA have antiatherogenic effects, which is important to maintenance of health indexes (Ojha et al., 2017).

PUFA:SFA ratio did not reach the recommended by the Department of Health (DHA, 1994), which is 0.4, the values were quite near to that, indicating a better percentage of PUFA, probably due the increased content of 18:2 *n*-6, which is highly present in pork fat and spices, as discussed earlier. However, the *n*-6:*n*-3 ratio was higher than the recommended by DHA (1994), which is 4:1, and hence the results found represents risk of health diseases (Simopoulos,

2002).

Atherogenicity index (AI) was low and not significant among groups, being lower than the range found by Ulbricht & Southgate (1991) for beef and beef products, as grilled sausages (0.72 to 0.74). On the other hand, thrombogenicity index (TI) ranged within the index stated for beef and beef products (1.06 to 1.39) (Ulbricht; Southgate, 1991). The addition of ingredients possibly increased the MUFA and PUFA content, which improved this index, MUFA and PUFA have antiatherogenic and antithrombogenic effects (Ojha et al., 2017). Finally, the hipocholesterolemic:hypercholesterolemic index (h:H) did not differ among groups, and, despite not having a standard value for this index, Santos-Silva et al. (2002) stated as desirable a value above 2.0, and the results found for this parameter were in that range, which occurred probably due the addition of ingredients rich in MUFA and PUFA, improving the health indexes.

4.3 Sensory attributes

The ratings made by panelists in tenderness and juiciness showed preference for burgers from crossbreds, especially from NASe, which had the tender beef burger. These results showed that, although the interference of manufacturing protocol, it is possible to observe significant differences among groups. There were no studies involving effects of genetic groups of bovines on beef burger sensory quality, which hence impairs the discussion in respect to this aspect. However, authors showed beef burgers have been rated from 5 to 7 (Barros et al., 2020; Gouvêa et al., 2016), less than the reached in the present study.

5. Conclusions

NASe produced beef burgers with better lightness than cattle with higher Nellore degree. Crossbreeds produced beef burgers with higher moisture parameters, decreased saturated fatty acid content and improved tenderness and juiciness compared to Nellore. However, the effects of manufacturing can change the physicochemical attributes of meat, leading to possibly unspecific effects. Thus, further studies involving the effects of zootechnical groups of cattle on physicochemical and sensory quality of beef burgers are necessary.

Author contributions

Vanessa P. Macedo: investigation, formal analyses, investigation, data curation, writing - original draft.

Ronaldo L. Oliveira: conceptualization, supervision, validation, writting review.

Leilson R. Bezerra: validation, visualization, writting review & editing.

Conflict of interest statement

The authors declare no competing interests.

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CONSIDERAÇÕES FINAIS E IMPLICAÇÕES

A utilização de *Bos taurus* adaptado em cruzamentos *Bos indicus* × *Bos taurus* mostrou-se eficiente para a produção de carne bovina de melhor qualidade. Dessa forma, o grupo genético ¼ Nelore ¼ Angus ½ Senepol melhorou os atributos de retenção de água e cor, bem como melhorou o perfil de ácidos graxos da carne, diminuindo a concentração dos ácidos graxos saturados indesejáveis. Além disso, este genótipo produziu carne com maior maciez e suculência, levando a uma maior aceitação ao consumo.

Entretanto, o efeito da genética sobre as características de qualidade em produtos cárneos permanece incerto devido à interferência dos métodos de processamento da carne sobre as características de qualidade da mesma, fazendo com que ocorram mudanças nos parâmetros físico-químicos e sensoriais por conta da ocorrência dos processos de salga, cominuição e adição de sal, gorduras e demais ingredientes, o que pode gerar erros durante a interpretação dos resultados. Assim, embora diferenças entre grupos zootécnicos tenham sido observadas nos parâmetros físico-químicos e sensoriais do hambúrguer e que essas diferenças estivessem alinhadas com os resultados encontrados para carne, devem ser considerados os efeitos do processamento nas mudanças ocorridas.

Assim, mais estudos são necessários para atestar a influência do perfil genético animal sobre as características de qualidade de produtos cárneos, dadas às suas características diversas de processamento.