COPRODUTOS DA INDÚSTRIA DE BIOCOMBUSTÍVEIS EM DIETAS PARA RUMINANTES

TIAGO BRANDÃO FREITAS

2016

UNIVERSIDADE ESTADUAL DO SUDOESTE DA BAHIA
PROGRAMA DE PÓS-GRADUAÇÃO EM ZOOTECNIA

COPRODUTOS DA INDÚSTRIA DE BIOCOMBUSTÍVEIS EM DIETAS PARA RUMINANTES

Autor: Tiago Brandão Freitas
Orientador: Prof. Dr. Márcio dos Santos Pedreira

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Março de 2016

TIAGO BRANDÃO FREITAS

COPRODUTOS DA INDÚSTRIA DO BIOCOMBUSTÍVEL NA COMPOSIÇÃO DE DIETAS PARA RUMINANTES

Tese apresentada como parte das exigências para obtenção do título de DOUTOR EM ZOOTECNIA, no Programa de Pós-Graduação em Zootecnia da Universidade Estadual do Sudoeste da Bahia.

Orientador: Prof. Dr. Márcio dos Santos Pedreira
Coorientadores: Prof. Dr. Robério Rodrigues Silva e Dr. Herymá Giovane de Oliveira Silva

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PROGRAMA DE PÓS-GRADUAÇÃO EM ZOOTECNIA
Área de Concentração: Produção de Ruminantes

Campus Itapetinga-*BA*

D E C L A R A Ç Ã O D E A P R O V A Ç Ã O

Título: "Coprodutos da Indústria de biocombustíveis em dietas para ruminantes".

Autor (a): Tiago Brandão Freitas
Orientador (a): Prof. Dr. Márcio dos Santos Pedreira
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Aos meus queridos pais,
à minha amada esposa,
e ao mais novo amor, minha filha Luna,

DEDICO.

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"Tudo é uma questão de manter a mente quieta, a espinha ereta e o coração tranquilo."
(Walter Franco)

"Se queremos chegar ao Despertar da Consciência, à Autoconsciência, temos que trabalhar com a Consciência aqui e agora. É precisamente aqui, neste mundo físico, onde devemos trabalhar para Despertar a Consciência. Quem desperta aqui, desperta em todas as partes, em todas as dimensões do Universo." (Samael Aun Weor)

"Só há um tempo em que é fundamental despertar. Esse tempo é agora" (Buda)

"A dificuldade não está em aceitar novas ideias, mas em se libertar das velhas". (John Maynard Keyne)

O autoconhecimento busca o equilíbrio entre o cérebro e o coração. Procuremos sempre manter nosso centro de gravidade psicológico. Aprender a transformar as impressões é um esforço de alerta contínuo.

O objetivo do conhecimento é nos libertar do materialismo, despertar a consciência. Meditação liberta a mente. Quanto mais egos, mais ignorante de si mesmo.

Se queres uma vida diferente, vire-se para dentro. Base para a expansão da consciência: auto-observação, autoanálise, e autocrítica.

Precisamos nos sutilizar energeticamente para nos desprendermos dos egos.

Tudo é causa e efeito. Não existe casualidade, mas sim causalidade. As leis que regem o mesocosmos regem também os macro e microcosmos.

A dificuldade de mudança radica na débil vontade. A vontade de ser melhor é a melhor arma que temos para combater as doenças psicológicas de fundo e forma, até lograr êxito. A essência só se desenvolve com disciplina, dedicação, perseverança e foco.

BIOGRAFIA

TIAGO BRANDÃO FREITAS, filho de José Lima Freitas e Liana Santiago Brandão, nasceu em 20 de novembro de 1979, em Salvador, Bahia.

Em 1998, iniciou o curso de Medicina Veterinária na Universidade Federal de Viçosa, concluindo em março de 2003.

Em março de 2003, iniciou o curso de Mestrado em Zootecnia – concentração em Nutrição e Produção de Ruminantes, na Universidade Federal de Viçosa, concluindo em janeiro de 2005.

Em março de 2005, viajou para os Estados Unidos pela primeira vez para participar de um programa de intercâmbio agricultural para trainees, o MAST – *Minnesota Agricultural Student Trainee*. No primeiro ano, ainda em 2005, Tiago teve a oportunidade de conhecer e trabalhar em fazendas de gado de corte que criam gado Angus puro, morar em Oklahoma, viajar para conhecer e trabalhar no Texas e vivenciar a cultura americana. Ainda como trainee, teve a excelente oportunidade de se mudar para morar em Minnesota e trabalhar em uma fazenda de gado de leite com vacas Holandês puras, produzindo 5 mil litros de leite por dia. No segundo ano nos EUA, em 2006, Tiago estudou na *University of Minnesota*, onde cursou disciplinas na área de Ciência Animal e Agricultura.

De volta ao Brasil, trabalhou como médico veterinário durante quase 2 anos na Secretaria de Agricultura do Estado da Bahia, de onde saiu para dar início aos trabalhos como nutricionista de ruminantes na empresa Matsuda, onde trabalhou por 3,5 anos.

Em abril de 2012, iniciou o curso de Doutorado em Zootecnia – concentração em Nutrição e Produção de Ruminantes, já com planos de fazer o doutorado sanduíche e morar nos Estados Unidos pela segunda vez. Durante o ano dos seus trabalhos de doutorado que realizou nos EUA, Tiago teve a felicidade de trabalhar na *University of Illinois at Urbana-Champaign*, sob a supervisão da professora Dra. Tara Felix. Fez parte do grupo de pesquisas em Gado de Corte "*The Beef Group*", onde realizou pesquisas de ponta nas áreas de nutrição de gado de corte, nutrigenômica e metabolismo animal. Tiago ainda trabalhou como *teaching assistant* na disciplina *Feeds and Feeding* de sua orientadora na universidade norte-americana e foi convidado a ministrar aula para alunos de graduação sobre Produção de Gado de Corte no Brasil. De volta ao Brasil, completou os requisitos do Programa de Doutorado, escrevendo 4 artigos científicos para serem publicados em periódicos internacionais. Em março de 2016, submeteu-se à defesa de tese junto à Universidade Estadual do Sudoeste da Bahia.

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FREITAS, Tiago Brandão. **Coprodutos da indústria de biocombustíveis em dietas para ruminantes.** Itapetinga, BA: UESB, 2016. 97 p. Tese. (Doutorado em Zootecnia, Área de Concentração em Produção de Ruminantes). *

Dois experimentos foram realizados na *University of Illinois at Urbana-Champaign*, no Estado de Illinois, nos Estados Unidos, durante o Programa de Doutorado Sanduiche. Os outros dois experimentos foram realizados na Universidade Estadual do Sudoeste da Bahia (UESB), campus Itapetinga, na Bahia. O experimento 1 foi o primeiro a ser desenvolvido na *University of Illinois*. Objetivou-se determinar o nível ótimo de hidróxido de sódio (NaOH) necessário para tamponar a acidez do DDGS (grãos de destilaria, sigla em inglês para *Dried Distillers Grains plus Solubles*) e seus efeitos sobre a digestibilidade, metabolismo ruminal e acidose metabólica em novilhos em confinamento. Foram utilizados 8 novilhos cruzados com genética Aberdeen Angus, com cânulas ruminais, individualmente confinados e separados em dois blocos de acordo com o PV (Pequenos, n = 4, PV = 555 kg; Grandes, n = 4, PV = 703 kg) em quatro períodos de 21 dias cada, em um delineamento Quadrado Latino 4 × 4. Os animais foram separados em 4 dietas: 1) 50% DDGS sem tratamento; 2) 50% DDGS, tratado com 0,5% (na MS) de NaOH; 3) 50% DDGS, tratado com 1,0% (na MS) de NaOH; e 4) 50% DDGS, tratado com 1,5% (na MS) de NaOH. Além do DDGS, as dietas foram constituídas (na MS) por 20% de silagem de milho, 20% de milho moído e 10% de suplemento. Neste experimento, tratar o DDGS com NaOH não aumentou a digestibilidade da fibra, nem foi necessário para aliviar uma possível acidose metabólica. O tratamento do DDGS com a base não elevou o pH ruminal médio nem o pH sanguíneo. No experimento 2, trabalhou-se com a aplicação em larga escala do experimento 1, e o objetivo foi determinar qual inclusão de NaOH (usadas no experimento 1) resultaria na melhor eficiência alimentar, ingestão de MS, ganho médio diário, e características de carcaça em novilhos em confinamento. Foram utilizados 120 bovinos, castrados, alocados em 20 baias (cada baia com 6 novilhos) em um experimento de 137 dias. Baias dentro de um mesmo bloco recebiam 1 dos 4 tratamentos (os mesmos do experimento 1). Este segundo estudo sugere que DDGS com baixa quantidade de ácido pode ser fornecido aos animais, mesmo sem tratamento com NaOH, sem risco de afetar o desempenho animal ou características de carcaça. Com o experimento 3, objetivou-se avaliar os efeitos da inclusão de níveis de torta de dendê na composição de suplementos para borregos a pasto sobre o consumo, digestibilidade, desempenho, características da carcaça e perfil de ácidos graxos na carne destes animais. Foram utilizados 31 borregos mestiços da raça Santa Inês, machos não-castrados, com peso vivo inicial de 20 kg e idade média de quatro meses, divididos em quatro lotes, seguindo um delineamento inteiramente casualizado. Os tratamentos foram: 0%, 10%, 20% e 30%, referentes aos tratamentos sem substituição, com 10%, 20% e 30% de substituição da torta de dendê em relação aos farelos de milho e de trigo. A dieta dos animais foi composta por farelo de soja, farelo de trigo, milho moído, torta de dendê, ureia, sal mineral, além de forragem em pastejo direto. O nível de suplementação foi de 1,6% do PV por animal/dia. A inclusão de até 30% da torta de dendê em substituição ao milho moído e farelo de trigo na composição de suplementos para ovinos a pasto mostrou-se viável por proporcionar manutenção de ganho de peso dos animais, assim como por não modificar características de carcaça ou perfil de ácidos graxos do músculo *Longissimus dorsi* dos borregos suplementados. No experimento 4, objetivou-se avaliar o consumo e a digestibilidade de nutrientes, ganho de peso e características de carcaça de borregos alimentados a pasto e suplementados com níveis de farelo de mamona em substituição ao farelo de soja na composição dos suplementos. Foram utilizados 36 borregos mestiços da raça Santa Inês, machos não-castrados, com peso inicial de 21,8 kg e idade média de quatro meses, divididos em quatro lotes, seguindo um delineamento inteiramente casualizado, onde cada lote recebeu um dos quarto tratamentos, com 9 animais em cada. Os tratamentos foram: 0%, 33%, 67% e 100%, referentes aos tratamentos sem substituição, com 33%, 67% e 100% de substituição do farelo de soja com o farelo de mamona no suplemento múltiplo, respectivamente. O nível de suplementação foi de 1,6% do PV por animal/dia. Deste experimento, conclui-se que apesar de haver alguns efeitos negativos sobre consumo e digestibilidade de nutrientes, o aumento no nível de farelo de mamona no suplemento não afetou o desempenho dos borregos a pasto, assim como não houve efeito sobre as características de carcaça destes animais.

Palavras-chave: características de carcaça, coprodutos, dieta, ruminantes

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* Orientador: Márcio dos Santos Pedreira, Dr. UESB; e Coorientadores: Robério Rodrigues Silva, Dr. UESB; e Herymá Giovane de Oliveira Silva, Dr. UESB.

ABSTRACT

This dissertation was written after four experiments, which produced four scientific articles. Two experiments were conducted at the University of Illinois at Urbana-Champaign, in Illinois, in the United States during a Sandwich Doctoral Program. The other two experiments were conducted at the State University of Southwest Bahia (UESB), Itapetinga, Bahia. Experiment 1 was the first to be held at the University of Illinois, and the objectives were to determine the optimum inclusion of sodium hydroxide (**NaOH**) necessary to buffer the acidity of DDGS and its effects on digestibility, ruminal metabolism, and metabolic acidosis in feedlot steers. Rumen cannulated Angus-crossed steers were blocked by BW (small, initial BW = 555 ± 42 kg, n = 4; and large, initial BW = 703 ± 85 kg, n = 4) over four 21-d periods in a replicated 4 × 4 Latin square design. Steers were assigned to 1 of 4 dietary treatments: 1) 50% DDGS, untreated; 2) 50% DDGS, treated with 0.5% (DM basis) NaOH; 3) 50% DDGS, treated with 1.0% (DM basis) NaOH; and 4) 50% DDGS, treated with 1.5% (DM basis) NaOH. The remainder of the diets, on a DM basis, were composed of 20% corn silage, 20% dry rolled corn, and 10% supplement. In this study, feeding NaOH-treated DDGS did not increase fiber digestibility, nor was it necessary to alleviate a possible metabolic acidosis. Alkali treatment of DDGS did not increase average ruminal pH or blood pH. In experiment 2, we have worked with large-scale application of experiment 1, and the objective was to determine which inclusion of NaOH (used in experiment 1) would result in best feed efficiency, dry matter intake, average daily gain and carcass characteristics of feedlot steers. One hundred and twenty Angus-cross steers were blocked into two BW blocks (light, BW = 211 ± 27 kg; and heavy, BW = 261 ± 27 kg) and housed in 20 pens (6 steers per pen) in a 137-d trial. Pens within block were randomly allotted to 1 of 4 dietary treatments (the same as experiment 1). This second study suggests that DDGS with low acid content and low sulfur concentration can be fed without NaOH treatment with no risk of affecting animal performance or carcass characteristics. Experiment 3 was held to evaluate the effects of the inclusion of palm kernel cake (PKC) in the supplement composition for grazing lambs on intake, digestibility, growth performance, carcass characteristics and fatty acid profile of the meat. Thirty-one non-castrated

Santa Inês-crossed male lambs, 120 ± 15 d old (initial BW = 20.0 ± 3.9 kg) were randomly allotted to 1 of 4 dietary treatments, following a completely randomized design. Treatments were 0%, 10%, 20% and 30%, related to treatments without replacement, with 10%, 20% and 30% substitution of PKC in place of ground corn and wheat bran in the supplement. Animals were placed into 4 groups: 8 animals in 0%; 8 in 10%; 6 in 20%; and 9 in 30%. The experiment consisted of 3 experimental periods of 28 days each, 84 days total. The diet consisted of soybean meal, wheat bran, ground corn, PKC, urea, mineral salt, and pasture. The level of supplementation was 1.6% BW per animal per day. The inclusion of up to 30% of palm kernel cake replacing ground corn and wheat bran in the composition of supplements for grazing sheep proved to be feasible for providing the animals with weight gain maintenance, as well as no change in carcass characteristics or the fatty acid profile of the *Longissimus dorsi* muscle of supplemented lambs. Experiment 4 aimed to evaluate intake and nutrient digestibility, weight gain and carcass characteristics of grazing lambs supplemented with levels of castor bean meal replacing soybean meal in the composition of supplements. Thirty-six Santa Inês-crossed non-castrated lambs, 120 ± 15 d old (initial BW = 21.8 ± 3.4 kg) were randomly allotted to 1 of 4 dietary treatments, following a completely randomized design, with 9 animals in each. The treatments were 0%, 33%, 67% and 100%, relative to treatment without replacement, with 33%, 67% and 100% replacement of soybean meal with castor bean meal in the supplement, respectively. The experiment consisted of three 28-d experimental periods, 84 days total. The level of supplementation was 1.6% BW per animal per day. From this experiment 4, we have concluded that despite some negative effects on nutrient intake and digestibility, the increase in castor bean meal level in the supplement did not affect the growth performance of lambs on pasture, and there was no effect on carcass characteristics of these animals.

Keywords: carcass characteristics, byproducts, diet, ruminants

INTRODUÇÃO GERAL

Na criação intensiva de ruminantes, a alimentação representa um dos principais componentes do custo de produção, podendo representar até 70% dos custos, dependendo da atividade e tipo de exploração. Assim, a busca por alimentos alternativos e de baixo custo, como os resíduos e coprodutos agrícolas, representa uma forma de diminuir os gastos com alimentação. Os custos com suplementação utilizando ingredientes convencionais como farelo de soja, milho, trigo, sorgo e outros, são elevados. Desta maneira, a viabilidade dos sistemas de produção torna-se dependente da utilização de recursos alimentares alternativos de menor custo e que mantenham índices de desempenho compatíveis com a atividade, pois a utilização de alimentos concentrados torna-se cada vez mais importante na dieta de ruminantes, seja em sistemas de confinamento ou de suplementação a pasto.

Dentre os vários fatores a serem considerados na escolha de um novo alimento a ser utilizado na alimentação de ruminantes, destacam-se os seguintes: a quantidade disponível; a proximidade entre a fonte produtora e o local de consumo; as suas características nutricionais; e os custos de transporte, condicionamento e armazenagem. A viabilidade da utilização de resíduos e coprodutos agroindustriais como alimentos para ruminantes requer trabalhos de pesquisa e desenvolvimento, visando à sua caracterização, aplicação de métodos de tratamento, determinação de seu valor nutritivo, além de sistemas de conservação, armazenagem e comercialização.

Entre as alternativas para redução dos custos com alimentação nos confinamentos e/ou suplementação de ruminantes a pasto, destaca-se a utilização de coprodutos da agricultura ou de agroindústrias, em substituição a forragens e aos grãos comumente usados (farelo de soja, farelo de algodão, farelo de trigo, milho etc.). Os resíduos da agroindústria podem assumir grande importância na alimentação de ruminantes, principalmente em situações em que a disponibilidade natural de forragens nas pastagens é baixa; quando as reservas de forragens conservadas forem insuficientes e que não venham a atender as exigências dos rebanhos; na formulação de misturas múltiplas para animais submetidos em regime de pastejo, ou ainda quando a disponibilidade, o valor nutritivo e o custo do resíduo permitirem sua inclusão na formulação de rações concentradas, substituindo os alimentos mais comumente utilizados.

Na literatura científica existem inúmeros trabalhos que relatam a utilização de coprodutos da agroindústria na alimentação de ruminantes, como por exemplo: DDGS em dietas para bovinos, farelo de mamona em dieta para bovinos e ovinos, torta de dendê em dieta para bovinos, e outros. Trabalhos científicos mostram que estes coprodutos podem ser utilizados como alimentos em dietas para ruminantes, proporcionando rentabilidade e produção de alimentos de qualidade.

No entanto, devido a algumas características intrínsecas não desejáveis, como por exemplo a presença de substâncias tóxicas, baixo pH, ou mesmo elevadas concentrações de componentes estruturais de baixa digestibilidade, o DDGS, o farelo de mamona e a torta de dendê apresentam limitações de uso na alimentação de ruminantes e, por isso, precisam ser mais estudados.

Com isso, os objetivos deste trabalho de pesquisa são avaliar a utilização de coprodutos da indústria de biocombustíveis, como o DDGS, o farelo de mamona e a torta de dendê, na composição de dietas para bovinos ou ovinos. Serão pesquisados os efeitos do uso destes coprodutos sobre a ingestão de matéria seca, digestibilidade, metabolismo ruminal, prevenção de acidose metabólica, desempenho em ganho de peso, eficiência alimentar, características de carcaça e perfil de ácidos graxos da carne desses animais.

REFERENCIAL TEÓRICO

Grãos de Destilaria (DDGS, do inglês *Dried Distillers Grains plus Solubles*)

Nos Estados Unidos, o principal ingrediente na dieta animal é o milho. Em fazendas de gado de corte, até 65% dos custos totais de produção são devidos a custos com alimentação (Ferrell, 2005). Para a produção de cada litro de etanol combustível advindo de milho, há necessidade de cerca de 2,2 kg de milho, e 0,8 kg de grãos de destilaria (DDGS) são produzidos como coproduto (Lardy, 2007; Loy, 2008). A crescente demanda por milho pela indústria de etanol, inevitavelmente, diminui o fornecimento de milho para os produtores de gado. Caso o governo norte-americano atinja seu objetivo de produzir 57 bilhões de litros de etanol por ano, 127 milhões de toneladas de milho serão desviadas das fazendas, e potencialmente 47 milhões de toneladas de DDGS serão produzidas como um coproduto. Portanto, DDGS pode se tornar o componente de alimentação mais importante na dietas de bovinos para que produtores permaneçam produzindo carne de forma economicamente viável.

Grãos de destilaria têm sido usados tradicionalmente como uma fonte de proteína para ruminantes e, segundo Waller et al. (1980), quando usado com ureia, possui valores proteicos mais elevados que o farelo de soja. Existem basicamente duas formas mais utilizadas de grãos de destilaria nos Estados Unidos, a forma úmida e a forma seca do coproduto. Ambos têm sido usados como ingrediente de rações para bovinos. Grãos de destilaria úmidos (WDG, do inglês *Wet Distillers Grains*) são usados extensivamente em fazendas de gado de leite e em confinamentos como suplemento proteico (Schingoethe, 2009). O teor médio de matéria seca do WDG é 30%, o que torna difícil o seu estoque e caro a sua comercialização para locais longínquos. Desta maneira, o uso de WDG na maioria das vezes está atrelado à proximidade da planta de etanol (Jones et al., 2007). Diferentemente, o DDGS possui teor de matéria seca entre 85 e 90%, sendo mais fácil ser armazenado e transportado. Há inúmeros estudos comparando os benefícios do WDG e DDGS Ham et al., 1994; Klopfenstein et al., 2008; Schingoethe, 2009). Apesar das importantes contribuições, esses estudos estão além do objetivo desta tese, e, por isso iremos nos referir quase que exclusivamente aos estudos voltados ao DDGS.

O processo em que o grão de cereal, principalmente milho, é fermentado e transformado em etanol foi descrito por Stock et al. (2000). Cerca de 2/3 do grão de milho é amido, que é o componente fermentado a etanol no processo industrial. Logo após, a agua é retirada dos ingredientes restantes para produzir o DDGS. Desta maneira, os teores de proteína, fibra e fósforo são aumentados 3 vezes no DDGS quando comparado ao milho. O teor de proteína aumenta de cerca de 10 para 30%; extrato etéreo, de 4% para 12%; FDN aumenta de 12 para 36%; e fósforo, de 0,3 para 0,9% da MS.

Grãos de destilaria como fonte de proteína

Devido ao mais elevado teor de proteína no DDGS quando comparado ao milho, DDGS tem sido utilizado principalmente como fonte de proteína na alimentação de bovinos (Klopfenstein et al., 1978). Em dietas para bovinos em confinamento, quando o DDGS é utilizado como fonte de energia em níveis maiores que 15 a 25%, as exigências nutricionais de proteína são atendidas e, inclusive, ultrapassadas, sugerindo reciclagem do nitrogênio (Vander Pol et al., 2005). Este excesso de proteína acaba sendo utilizado como fonte de energia através da deaminação dos aminoácidos, resultando em excreção de ureia.

Os valores de proteína bruta listados no NRC (2000) para DDGS estão entre 29,5 e 30,5%; entretanto, este valor pode variar, porque DDGS é um coproduto que varia de acordo com a planta onde é produzido (Batal & Dale, 2003). Como coproduto do milho, a maior fração da proteína no DDGS é zeína, que tem grande valor de escape da degradação ruminal, com cerca de 40% sendo degradado no rúmen (McDonald, 1954). Desta maneira, a fração proteica do DDGS não-degradável no rúmen torna-se excelente fonte de proteína by-pass (Firkins et al., 1984). Características da proteína by-pass permitem que DDGS seja uma valiosa fonte de proteínas para o intestino delgado, o que é frequentemente caro para satisfazer (Hersom, 2006).

Grãos de destilaria como fonte de energia

De acordo com o NRC (2000), os valores de NDT, ELm, e ELg são iguais aos valores para o milho (88% NDT, 2,18 Mcal/kg, e 1,5 Mcal/kg, respectivamente). No entanto, alguns estudos mostram o valor energético do DDGS de 10 a 40% maior do que o do milho, dependendo do nível de inclusão em percentual da ingestão de matéria seca (Ham et al., 1994; Buckner et al., 2008; Loy et al., 2008). Uma das teorias para o mais elevado valor energético do DDGS quando comparado ao milho pode ser a diferença dos substratos fermentescíveis e digeríveis de cada um (Klopfenstein et al., 2008). O conteúdo energético no DDGS vem da fibra digerível e do teor de lipídeos, ao invés do amido, como é no milho (Schingoethe, 2009). Devido a esta mudança de substrato, acredita-se que o aumento dos níveis de DDGS na dieta aumente o pH ruminal de maneira linear.

Leupp et al. (2009), trabalhando com novilhos alimentados com dietas contendo 30% de feno, encontrou aumento linear do pH ruminal à medida que aumentava a inclusão de DDGS de 0 a 60% na matéria seca da dieta. Segundo o NRC (2000), o milho contém apenas 9% de FDN e 4,3% de extrato etéreo, enquanto o DDGS contém 46% de FDN e 10,3% de extrato etéreo, com base na matéria seca, por causa da remoção de praticamente todo o amido do milho durante o processo de fermentação para produção do álcool. O teor de lipídeos é aproximadamente 3 vezes o do milho, o que também contribui para o seu elevado valor energético. Como os ácidos graxos não são fermentados no rúmen e são absorvidos pós-rúmen, eles não contribuem para a produção de ácidos graxos voláteis no rúmen.

Redução dos casos de acidose ruminal

Dietas contendo DDGS possivelmente reduzem casos de acidose em bovinos confinados alimentados com dietas de alto grão (Ham et al., 1994). Acidose subaguda é um problema em muitos confinamentos por causa da elevada proporção de grãos nas dietas, contendo uma quantidade significativa de amido rapidamente fermentescível. Devido ao baixo teor de amido do DDGS (2 a 5%) e elevados teores de fibra, proteína e lipídeos, o percentual de volumoso da dieta pode ser reduzido quando dietas forem compostas com mais de 20% da matéria seca ingerida de DDGS. Outra vantagem é a capacidade de utilizar forragens de baixa qualidade em dietas com mais de 20% de DDGS, por causa do seu elevado teor proteico (Klopfenstein et al., 2008). Segundo Ham et al. (1994), a substituição do milho pelo DDGS ainda pode aumentar a eficiência alimentar por reduzir a acidose ruminal, uma vez que reduz a ingestão de amido.

A fração de carboidrato mais importante no DDGS é a FDN. A maior parte do FDN no DDGS é obtido do pericarpo do grão de milho, que contém aproximadamente 69% de FDN, e caracteriza-se por elevada (87%) e rápida (6,2% por hora) taxa de digestão (DeHaan et al., 1983). Por causa desta rápida e elevada porção digerível de sua fibra, DDGS tem sido usado tanto como fonte de proteína como fonte de energia em dietas para engorda de gado em confinamento.

Efeitos do uso no desempenho e carcaça dos animais

Um dos limitantes ao fornecer DDGS para bovinos é o seu elevado teor de enxofre (S), pois altas ingestões deste mineral limitam o consumo de matéria seca (Buckner et al., 2007). Desta maneira, partindo do princípio que IMS influencia sobremaneira o ganho de peso (Ferrell, 2005), fornecer dietas ricas em DDGS poderia afetar o ganho de peso. Dados de literatura apresentam aumento do GMD e eficiência alimentar quando bovinos de corte foram alimentados com dietas contendo até 40% de DDGS em substituição ao milho (Ham et al., 1994). Quando este percentual aumentou para 60% na dieta ingerida pelos animais, Leupp et al. (2009) reportou diminuição na ingestão de matéria orgânica; no entanto, GMD não foi apresentado nesse estudo.

O nível máximo recomendável de inclusão de DDGS em dietas para bovinos em confinamento continua sendo muito discutido entre pesquisadores e entre produtores. Alguns estudos mostram que DDGS pode ser fornecido em até 40% da dieta sem apresentar efeitos negativos sobre desempenho (Ham et al., 1994; Buckner et al., 2008). Detalhes desses estudos mostram que 40% de inclusão de DDGS, ao substituir o milho, melhorariam o desempenho; mas mostram também que o máximo desempenho foi atingido com inclusão de 20% da matéria seca.

Devido às flutuações de preço no mercado de commodities, há momentos em que incluir DDGS em níveis mais elevados nas dietas trará benefícios econômicos. Desta maneira, mais pesquisas utilizando altos níveis de inclusão de DDGS devem ser conduzidas, com o intuito de avaliar os efeitos da inclusão de DDGS acima de 40% sobre o GMD e eficiência alimentar. A partir da contribuição desses estudos, é importante destacar que o nível de inclusão para obter o nível ótimo econômico pode ser diferente do nível de inclusão para o máximo desempenho ou para otimizar características de carcaça, valorizando a máxima que o ótimo econômico muitas vezes difere do ótimo biológico.

De acordo com Reinhardt et al. (2007), níveis dietéticos de inclusão de DDGS podem afetar o marmoreio, de maneira que este aumenta com até 16% de inclusão do coproduto, começando a diminuir quando o nível de inclusão ultrapassa 33%. De maneira semelhante, incluindo uma meta-análise com 21 estudos, Corah & McCully (2006) concluíram que incluir DDGS em níveis acima de 29% causa diminuição no grau de marmoreio na musculatura dos animais. No entanto, esta diminuição no marmoreio parece não afetar características sensoriais ou de aceitação pelo consumidor, uma vez que estudos têm avaliado a qualidade da carne de animais alimentados com altos níveis de DDGS na dieta e concluído não haver efeito negativo na escolha do consumidor (Erickson et al., 2005).

Grãos de destilaria para vacas de corte

Menos pesquisa tem sido conduzida sobre DDGS na alimentação de vacas de corte. No entanto, Loy et al. (2005) publicaram um resumo com resultados sobre a utilização deste coproduto para vacas. Neste estudo, eles concluíram que as melhores aplicações de uso do DDGS para vacas de corte são em situações em que: 1) suplemento proteico seja necessário (ex. quando pastejando forragens de baixa qualidade), para substituir farelo de soja ou farelo de glúten de milho; 2) quando for necessário fornecer uma fonte com baixo teor de amido e com elevado teor de fibra, para substituir casca de soja ou farelo de glúten de milho; ou 3) quando for necessário suplementar com uma fonte de lipídeos.

Loy et al. (2005) ainda desenvolveram medidas práticas para suplementação de vacas gestantes. Definiram que quando vacas gestantes em bom estado corporal estão em pastos de baixa qualidade, fornecer entre 1,4 e 2,3 kg de DDGS por dia para cada vaca durante o último terço de gestação irá suprir suas exigências de proteína e energia. Afirmaram ainda que para a fase inicial de lactação destas vacas, o ideal seria suplementar de 2,7 a 3,6 kg de DDGS para suprir as exigências de energia e proteína quando em pastagens de baixa qualidade.

Um outro estudo determinou o efeito do tipo de suplemento, concentração e frequência de fornecimento na ingestão de matéria seca e desempenho produtivo para estimar o valor energético do DDGS em uma dieta rica em forragem para novilhas em crescimento (Loy et al., 2008). Estes autores concluíram que suplementar a dieta com DDGS ou milho moído 3 vezes na semana diminuiu a ingestão de forragem e o ganho de peso quando comparado com fornecimento de suplemento todos os dias, mas o fornecimento de DDGS levou a aumento no ganho de peso e eficiência alimentar comparado com o fornecimento de milho moído. Eles ainda sugeriram que o NDT do DDGS foi 118% a 130% o valor do milho quando fornecido como suplemento a uma dieta à base de feno para novilhas em crescimento.

Morris et al. (2005) mostraram que independente da qualidade da forragem (alta ou baixa), quando novilhas foram suplementadas com 0; 0,68; 1,36; 2,04; ou 2,72 kg de DDGS por dia, o consumo de forragem diminuiu, e o GMD aumentou. Estes resultados sugerem que DDGS pode ser considerado um eficiente suplemento para animais a pasto para melhorar desempenho quando disponibilidade de forragem for limitante.

Fatores limitantes para o aumento de inclusão de DDGS nas dietas

Em grande parte dos confinamentos dos EUA, DDGS não é ofertado acima de 25% da dieta, pois algumas características intrínsecas ao coproduto poderiam prejudicar o desempenho animal em níveis de inclusão mais elevados. Entre estes fatores, podemos citar os elevados teores de lipídeos, proteína e enxofre. O aumento da ingestão destes nutrientes além dos níveis recomendáveis pode diminuir o desempenho em confinamento de bovinos alimentados com dietas de alto concentrado.

Lipídeos

O teor de lipídeos do DDGS é em média 10,3% (NRC, 2000), fazendo com que seja um ingrediente rico em energia; entretanto, este valor pode variar muito de acordo com a planta produtora. Um importante fator a ser considerado quando se fornece fontes de lipídeos na dieta de bovinos é a qualidade desses. O grau de saturação dos ácidos graxos parece determinar o quanto de lipídeos pode ser incluído na dieta sem afetar a degradabilidade da fibra (Pantoja et al., 1994; Nelson et al., 2008). Desde a década de 1940, pesquisas mostram que ácidos graxos insaturados dietéticos podem diminuir a degradabilidade da fibra no rúmen (Lucas & Loosli, 1944; Swift et al., 1947). À medida que a quantidade de gordura saturada aumenta, o efeito inibitório sobre a fermentação da fibra é diminuída (Pantoja et al., 1994). Desta maneira, é cabível a preocupação com o fornecimento de fontes de lipídeos de origem vegetal, neste caso um coproduto do milho. Como consequência da redução da função microbiana ruminal, a gordura em excesso na dieta de bovinos pode diminuir a ingestão (Palmquist & Conrad, 1977).

Proteína

Elevadas inclusões de DDGS na dieta irão aumentar a quantidade de nitrogênio disponível para os animais (Leupp et al., 2009). O excesso de N na dieta pode levar a elevados níveis de amônia ruminal e diminuir a ingestão de alimentos (Waldo, 1967). Ao consumir grandes quantidades de N, o bovino deve ser capaz de excretar o N não aproveitado, e esta excreção traz um custo metabólico embutido. O custo para metabolizar o excesso de N quando bovinos são alimentados com dieta contendo elevadas concentrações de DDGS ainda é desconhecido. Uma interessante área de estudo seria saber se esse custo metabólico limita a eficiência energética e desempenho animal em dietas contendo mais do que 50% de DDGS. Adicionalmente, o excesso de proteína também se torna uma questão ambiental, uma vez que o excesso de N no ambiente pode levar à eutrofização dos cursos de água.

Enxofre

Outro motivo que limita o elevado percentual de DDGS em dietas para bovinos em confinamento é o seu teor de enxofre (S; Lonergan et al., 2001). O teor de S é elevado devido à presença residual de ácido sulfúrico utilizado na indústria para controlar o pH do processo de fermentação para produção de álcool, assim como também é usado para limpeza dos equipamentos, o que resulta em níveis de S entre 0.6 e 1.0% no DDGS (Klopfenstein et al., 2008). O nível máximo aceitável de S em dietas de bovinos é 0,4% (NRC, 2000). Elevados níveis de S podem afetar o status de tiamina nos animais, conduzindo à polioencefalomalacia (PEM; Gooneratne et al., 1989), reduzir IMS, GMD e as reservas de cobre no fígado (Lonergan et al., 2001). O enxofre dietético se liga ao Cu para formar sulfuretos insolúveis de Cu, tornando Cu e S indisponíveis para o animal (McDowell, 2003). Adicionalmente, o baixo pH do DDGS pode ser considerado um problema, pois pode baixar o pH ruminal, reduzir a digestão da fibra com consequente diminuição da ingestão de MS, além da possibilidade de acidose metabólica dos animais.

É necessário, portanto, descobrir um melhor entendimento dos efeitos de elevados níveis dietéticos de DDGS em bovinos em crescimento e terminação de modo que possa ser incluído em dietas de bovinos como fonte primária de energia e não apenas uma fonte de proteína.

Nossa hipótese é que seja possível a inclusão de DDGS em dietas para bovinos acima de 40%, sem afetar negativamente o crescimento e desempenho dos animais se estratégias de alimentação e de gestão forem utilizadas para amenizar esses efeitos deletérios da utilização de elevados níveis de inclusão.

Torta de dendê

O clima tropical em algumas regiões do Brasil, sobretudo as regiões Norte e Nordeste, favorece o cultivo da ampla diversidade botânica de espécies palmáceas, tanto nativas quanto exóticas. Dentre as espécies palmáceas, as oleaginosas possuem grande importância econômica pela diversidade de seus produtos e subprodutos. O dendê é uma monocotiledônea, da família *Palmaceae*, de origem africana, que chegou ao Brasil no século XVII, e hoje é cultivada em vários países de clima tropical. O dendezeiro está entre as oleaginosas tropicais de maior rendimento existente, com potencial de geração anual de óleo da ordem de 3500 a 6000 kg/hectare, superior à soja, que apresenta entre 500 e 600 kg por hectare (Brasil, 2003).

Do beneficiamento do dendê obtém-se dois principais produtos: o óleo de dendê e óleo de palmiste. O óleo de dendê, produto mais importante comercialmente, é utilizado na culinária em diversos países do mundo. Extraído da polpa do mesocarpo, o óleo de dendê é conhecido no mercado internacional como *palm oil*, sendo de alta produtividade e bom valor econômico. O óleo de palmiste é extraído da amêndoa do dendê (endocarpo), sendo conhecido mundialmente como *palm kernel oil*. O coproduto deste beneficiamento consiste na torta de dendê, que vem sendo utilizado na suplementação animal substituindo principalmente fontes energéticas, com o intuito de diminuir os custos de produção (Ferreira et al., 2012).

A Malásia e a Indonésia controlam a produção de óleo de dendê, participando juntas com mais de 85% da produção mundial (USDA, 2016). O Brasil, no entanto, possui grande potencial para a produção deste óleo, tendo o Estado do Pará como responsável por mais de 80% da produção nacional, seguido da Bahia e Amapá (Cordeiro et al., 2010).

Composição Químico-bromatológica

A torta de dendê pode ser empregada na alimentação de ruminantes, porém seu uso na alimentação animal deve receber atenção pelas altas concentrações de FDN e possível baixa palatabilidade (Carvalho et al., 2006). Segundo Chin (2002), a composição da torta de dendê produzida na Malásia varia na MS de 89 a 93%; na PB, de 14,6 e 16,0%; nos teores de EE, de 0,9 a 10,6%; na matéria mineral, de 3,5 a 4,3%; e nos teores de NDT, de 67,0 a 75,0%. Autores brasileiros, ao avaliarem amostras de torta de dendê produzidas em território nacional, encontraram valores de composição bromatológica próximos aos encontrados na Malásia, porém variando de 92 a 95% de matéria seca, 12 a 16% de proteína bruta, e 7 a 12% de extrato etéreo

(Rodrigues Filho et al., 1998; Nunes et al., 2010; Bringel et al., 2011). Segundo os autores brasileiros supracitados, essa variação deve ocorrer em função de alterações nos processos industriais. Valadares Filho et al. (2016) encontraram ainda os seguintes valores na composição química da torta de dendê: 14,92% de PB; 11,59% de EE; 70,63% de CHO; 56,96% de FDN; 43,41% de FDA; 30,09% de celulose; 11,12% de lignina.

Como os teores de EE da torta de dendê são influenciados pelos métodos de extração do óleo, o método que utiliza prensagem resulta em maiores teores de gordura no subproduto (Alimon, 2004). Os efeitos marcantes dos elevados teores de EE sobre o consumo de alimentos podem estar relacionados à depressão na digestão da fibra, a fatores metabólicos ou à palatabilidade das fontes de lipídios. Apesar da mais elevada concentração energética nos lipídios que nos carboidratos e proteínas, elevadas quantidades de lipídios podem reduzir o consumo e refletir em menores quantidades de energia ingerida (NRC, 2001).

Consumo e digestibilidade dos nutrientes

Quando ruminantes são alimentados com volumosos de baixa qualidade, o consumo pode ser afetado por diferentes fatores. Os fatores físicos, quando limitam a ingestão de matéria seca, estão entre os mais importantes. Embora outros fatores possam afetar o consumo voluntário de alimentos, como o tipo de alimentação, o manejo sanitário e as condições ambientais a que os animais são submetidos, os fatores físicos devem ser primariamente encarados quando o alimento for rico em fibra (Lana, 2005).

Alguns estudos mostram que a inclusão de torta de dendê na alimentação de ruminantes é responsável por provocar redução no consumo de MS (Carvalho, 2006; Maciel et al., 2012). Esta redução tem sido atribuída a uma interação de diversos fatores inerentes à composição deste coproduto, como teor de extrato etéreo e perfil de ácidos graxos presentes no seu óleo (Bringel et al., 2011; Maciel et al., 2012), teor de FDN e aceitabilidade dos animais pelo coproduto (Ferreira et al., 2012) e principalmente teor de lignina (Maciel et al., 2012).

No entanto, Silva et al. (2005) verificaram que os consumos de MS de dietas contendo 15 e 30% de torta de dendê no concentrado não diferiram da dieta padrão à base de milho e soja. Concluíram ainda que esse alimento pode substituir o concentrado, expressos em kg/dia e % de PV, em até 9,23 e 18,81% da MS da dieta, respectivamente, sem reduzir o consumo.

Macome et al. (2008), avaliando os efeitos sobre o consumo de torta de dendê com níveis de 0; 6,5; 13,0 e 19,5% na dieta de cordeiros confinados, observaram efeito linear decrescente para o consumo de MS, MO, PB e CNF. E dessa forma consideraram que o nível de 13% de inclusão deste coproduto apresentou os melhores resultados.

Maciel et al. (2012), avaliando a inclusão de torta de dendê na dieta de novilhas leiteiras com níveis de 0, 12, 23 e 34% da matéria seca total, observaram que houve redução linear no consumo de MS, PB, FDN, CNF e NDT. Os autores atribuíram a redução no consumo de MS provavelmente ao teor de lignina presente no coproduto, que foi de 16,23%. Este teor é considerado alto quando comparado ao de alimentos tidos como de boa digestibilidade, como o milho grão e farelo de soja, por exemplo, que têm teores de lignina em torno de 1,19 e 1,62%, respectivamente (Valadares Filho et al., 2016). Segundo Maciel et al. (2012), as digestibilidades aparentes da MS e da FDN foram reduzidas com a inclusão da torta de dendê na dieta.

Silva et al. (2000), estudando níveis de substituição de 0; 25; 50 e 75% do milho pela torta de dendê no concentrado para bezerros leiteiros, não encontraram diferença no consumo de MS na fase de aleitamento. Por outro lado, na fase pós-aleitamento, os consumos decresceram linearmente com o aumento da participação da torta de dendê nos concentrados da dieta. Segundo esses autores, este decréscimo pode ter sido em consequência da palatabilidade ou pelo teor de fibra deste coproduto, igual a 70% de FDN.

Chin (2002), em experimento com bovinos, encontrou os seguintes valores de digestibilidade para os nutrientes da torta de dendê obtida a partir da extração de óleo com solventes: 65,1% de MS, 72,7% de MO e 86,7% de ENN. O mesmo autor, avaliando a digestibilidade da torta de dendê obtida por prensagem na dieta de ovinos, obteve valores de digestibilidade de 70% da MS, 52% da FDA e 53% da FDN.

Rodrigues Filho et al. (1996), avaliando a inclusão de 0%, 30%, 60% e 100% de torta de dendê em substituição ao farelo de trigo na dieta de ovinos deslanados, não observaram diferenças no coeficiente de digestibilidade da MS, MO e PB.

Silva et al. (2005), utilizando torta de dendê em níveis de 0%, 15% e 30% em substituição ao milho e à soja na alimentação de cabras a fim de avaliar o consumo e a produção leiteira, observaram que a inclusão da torta de dendê não elevou os teores de fibra no concentrado em níveis que pudessem influenciar a digestibilidade da MS, com média de 66,03%, e também não notaram diferenças nos coeficientes de digestibilidade aparente da MS, MO, PB, FDN, FDA, carboidratos totais (CHT) e carboidratos não fibrosos (CNF).

Carvalho et al. (2004) avaliaram os efeitos de diferentes níveis de torta de dendê (0, 15 e 30%) em substituição ao milho e farelo de soja no concentrado sobre o comportamento ingestivo de cabras lactantes e observaram que a inclusão em até 30% eleva os teores de FDN e MS das dietas sem afetar a digestibilidade aparente dos nutrientes. Carvalho (2006) reitera que a torta de dendê pode ser utilizada na alimentação de ovinos desde que não ultrapasse 30% da MS total da dieta.

Desempenho e perfil de ácidos graxos

Ao avaliar a torta de dendê para bezerros utilizando níveis de 0, 25, 50 e 75% em substituição ao milho no concentrado, Silva et al. (2000) observaram que os níveis de 25 e 50% de torta de dendê apresentaram o menor custo de produção por arroba, mas o nível de 25% de torta de dendê propiciou uma produção, em arrobas de carne, numericamente superior aos tratamentos contendo 50 e 75% de torta de dendê em substituição ao milho.

Ao avaliar o desempenho econômico de ovinos em terminação alimentados com torta de dendê em substituição a feno de tifton 85, Almeida et al. (2007) não observaram variação de peso corporal quando da substituição de 0 a 30% de torta de dendê. A diminuição dos custos levou os autores supracitados a concluir que a adição de até 30% deste coproduto na MS da dieta de ovinos pode ser viável em épocas de escassez de forragem.

Miranda (2000), avaliando a composição química do óleo do dendê, destacou que 98% do óleo bruto é formado pelos seguintes ácidos graxos saturados: palmítico, com 32 a 45%, e esteárico, com 2 a 7%; e insaturados: oleico, com 38 a 52 %, e linoleico, com 5 a 11%.

A maior conscientização da população em relação à influência da qualidade da dieta sobre a saúde dos humanos tem despertado o interesse de cientistas de todo o mundo. Nesta área, a pesquisa tem focado principalmente na composição dos ácidos graxos em produtos de origem animal. O conhecimento geral de que alguns tipos de ácidos graxos (a maioria dos saturados, assim como os insaturados com configuração trans) em excesso levariam a doenças crônicas, incluindo câncer, doenças cardiovasculares, diabetes tipo II e obesidade (Shingfield et al., 2013) e que outros tipos (poli-insaturados, principalmente CLA e Omega-3) trariam benefícios pra a saúde, tem motivado a pesquisa científica no sentido de buscar modificações na alimentação dos animais com o objetivo de aumentar o teor de ácidos graxos benéficos à saúde (Ponnampalam et al., 2014; Benjamin et al., 2015; Ooi et al., 2015), ou pelo menos verificar se a introdução de algum novo alimento na dieta dos animais não levaria a um perfil mais saturado no leite ou na carne, o que não seria desejável pelo consumidor (Howes et al., 2015).

Desta maneira, o estudo minucioso de um coproduto na alimentação de ruminantes torna-se cada vez mais importante e complexo, sempre tendo em mente respeitar o perfil de consumidor exigente em relação à qualidade do produto que está comprando.

Farelo de Mamona

A mamona (*Ricinus comunis* L.) é uma oleaginosa pertencente à família Euforbiaceae, que produz sementes ricas em óleo glicídico solúvel em álcool. A cultura da mamona encontra-se bastante expandida no Brasil, onde existem cerca de 115 mil hectares plantados (IBGE, 2015). Devido à implantação do projeto de produção de biodiesel no Brasil, baseado na utilização de diversas oleaginosas como fonte de matéria prima, dentre essas, a soja no Centro-Sul, o babaçu e o dendê na região Amazônica e a mamona no Semiárido Brasileiro, mais áreas deverão ser plantadas. Isto produzirá significativo impacto social para a região, com geração de empregos e movimentação da economia de pequenos municípios.

Dos produtos obtidos da mamona, o óleo é o mais importante e principal objetivo da produção comercial, cuja utilização ocorre na fabricação de tintas, vernizes, detergentes, náilon, resinas de plástico, dentre outros (Carvalho, 1997). Além disso, o óleo de mamona tem sido utilizado como matéria-prima para a produção de biodiesel, pois além de ser de origem vegetal e renovável, pode contribuir para a diminuição da importação do petróleo (Amaral, 2003).

O aproveitamento dos coprodutos é fundamental para a viabilidade financeira dos produtores e das indústrias de biodiesel. Do processamento industrial das sementes de mamona, cada tonelada de óleo extraído corresponde a 1,28 tonelada de torta (Loureiro, 1962). No Brasil, a mamona apresenta produtividade média de 727 kg/ha, podendo chegar a 2.000 kg/ha em algumas regiões. A região Nordeste, contribuindo com mais de 98% de toda a área plantada do país, possui produtividade de 728 kg/ha (IBGE, 2015). A mamona exige uma estação quente e úmida para favorecer a fase vegetativa, e uma estação pouco chuvosa ou seca para permitir condições favoráveis de maturação e colheita. Durante o ciclo de crescimento, é necessário um total de precipitação entre 500 e 1.800 mm, estando o valor ótimo entre 700 e 1.400 mm. Apesar de a mamona ser tolerante à seca, uma precipitação mínima de 600 a 750 mm é necessária durante o ano (Biodieselbr, 2006). Desta maneira, a mamoneira apresenta-se como uma alternativa de grande importância econômica e social para o semiárido nordestino.

Coprodutos da extração do óleo de mamona, torta e farelo de mamona são distintos. A torta de mamona é o coproduto do processamento mecânico de extração, ou prensagem, que possui quantidade significativa de óleo (entre 7% e 12%); ao passo que o farelo de mamona é o coproduto da extração pelo processo químico, com solvente, que possui baixo teor de óleo (cerca de 1%; Severino et al., 2006).

O farelo de mamona é um alimento concentrado rico em nitrogênio, apresentando teores entre 37 e 40% de PB na MS (Teixeira, 1997; Freitas et al., 2004). Este resíduo é considerado um alimento concentrado proteico, com cerca de 80% do teor de proteína bruta do farelo de soja e com degradabilidade ruminal efetiva da PB intermediária entre o farelo de soja e o farelo de algodão (Moreira et al., 2003). Desta maneira, vem sendo utilizado como suplemento proteico na formulação de rações para ruminantes. Assim, evidencia-se que a principal finalidade de uso do farelo de mamona em dietas para ruminantes é como suplemento proteico, em substituição a alimentos concentrados de maior custo. Segundo Naufel et al. (1962), o farelo de mamona destoxificado apresenta, em sua composição química-bromatológica, 87,8% de MS, 81,3% de MO, 29,10% de PB, e 1,97% de EE.

Entretanto, apesar do potencial de utilização do farelo de mamona na alimentação de ruminantes, este produto tem sido utilizado na maioria das vezes como fertilizante orgânico controlador de nematoides, pois contém limitações relacionadas à sua toxidez e alergenicidade (Severino, 2005). O farelo de mamona apresenta três componentes tóxicos e alergênicos, que são a ricina, a ricinina e o complexo alergênico CB-1A (Weiss, 1983). Para eliminação destes compostos, podem ser utilizadas várias técnicas de destoxificação, tanto físicas quanto químicas. Segundo Anandan et al. (2005), das três toxinas presentes na mamona, a ricina é a mais potente, e qualquer tentativa de destoxificação do farelo deveria abordar principalmente este problema. O óleo de mamona, por sua vez, não causa toxidez nem alergia, pois as substâncias causadoras destes transtornos são insolúveis no óleo, estando presente exclusivamente no resíduo de extração (torta ou farelo). Tendo efeito laxativo, o óleo pode causar efeitos desagradáveis se for ingerido por animais ou humanos (Severino et al., 2006).

Consumo e digestibilidade de nutrientes

No Brasil, há pesquisas com farelo de mamona para suplementação proteica de ruminantes desde a década de 1960. Naufel et al. (1962) avaliaram o efeito da administração do farelo de mamona destoxificado em comparação com o farelo de soja e de algodão na dieta de vacas em lactação por 84 dias experimentais e concluíram que, pelo menos para curtos períodos de utilização, o farelo de mamona destoxificado pode ser utilizado como fonte proteica em igualdade de condições aos farelos de soja e de algodão na alimentação de vacas leiteiras, não verificando efeito da fonte sobre parâmetros de desempenho. As pesquisas têm sido retomadas recentemente, principalmente após o uso desta oleaginosa para produção de óleo visando composição do biodiesel. Assim como no passado, o uso do farelo de mamona vem associado à destoxificação, embora pesquisa recente (Oliveira et al., 2007) questione a necessidade da mesma, fundamentada nos níveis séricos de alanina aminotransferase e aspartato aminotransferase, onde a inativação da ricina provavelmente se verificou por ação da microbiota ruminal.

Barros et al. (2011) apresentaram decréscimo linear das digestibilidades da MS e FDNcp ao trabalhar com novilhas a pasto suplementadas com mistura múltipla contendo níveis de farelo de mamona substituindo farelo de soja, com valores variando entre 59 e 63% para MS, e entre 64 e 68% para FDNcp. Entretanto, Oliveira et al. (2010), ao alimentar ovinos em gaiolas metabólicas, não encontraram diferenças entre os tratamentos quando substituiu farelo de soja por farelo de mamona, tratado ou não com hidróxido de cálcio (40 g/kg) e obtido por prensagem ou através de solventes, e apresentaram digestibilidade aparente total da MS entre 68 e 70%, e da FDNcp entre 47 e 55%.

Comparando farelo de mamona tratado com hidróxido de cálcio e farelo de mamona não tratado na dieta de ovinos, Oliveira et al. (2007) observaram aumento no consumo de MS quando o coproduto era tratado. Cândido et al. (2008) não obtiveram diferenças em relação ao consumo de MS entre os níveis de adição de farelo de mamona destoxificado em substituição ao farelo de soja em dietas para ovinos. De maneira semelhante, Silva et al. (2011) concluíram que a inclusão de farelo de mamona destoxificado na dieta não influencia o consumo de matéria seca e nutrientes, e possibilita atendimento às exigências nutricionais de ovinos em terminação. No entanto, as digestibilidades da MS, MO, PB e carboidratos totais decresceram linearmente com o acréscimo de farelo de mamona destoxificado na dieta, segundo estes autores.

Desempenho e características de carcaça

Barros et al. (2011), avaliando o efeito de suplementos múltiplos com diferentes níveis de farelo de mamona tratado com óxido de cálcio sobre o consumo, digestibilidade e desempenho produtivo de novilhas de corte a pasto, concluiu que apesar da diminuição no consumo de MS à medida que se aumentava o coproduto no suplemento, este não influenciou no desempenho dos animais.

Pompeu et al. (2012) observaram diminuição do GMD (197; 160; 155 e 130 g/dia) de borregos em confinamento alimentados com os mesmos níveis de substituição (0; 33; 67 e 100%) de farelo de soja por farelo de mamona destoxificado do presente experimento, respectivamente.

Ao pesquisar a adição de farelo de mamona em dietas para terminação de ovinos em confinamento, Cândido et al. (2008) concluíram que este coproduto destoxificado em substituição ao farelo de soja ao nível de 46% resulta em melhoria da conversão alimentar.

Em um estudo de 4 anos, com dados de 436 borregos de diferentes genótipos, alimentados a pasto e com acesso a piquetes de cultura de grãos, Álvarez et al. (2013) encontraram rendimento de carcaça variando entre 44,0 e 47,2%, e peso de carcaça quente entre 12,8 e 13,8 kg.

Trabalhando com borregos mais jovens e menor peso de abate (22-23 kg), Carrasco et al. (2009) obtiveram rendimento de carcaça de 51,4% quando suplementaram *ad libitum* cordeiros lactentes em sistema de *creep feeding* até o abate.

O farelo de mamona, assim como outros alimentos não convencionais para a alimentação animal, deve ser minuciosamente avaliado, uma vez que sua utilização por ruminantes traria inúmeros benefícios. Estes animais possuem importante função nos sistemas agrícolas sustentáveis, pois são capazes de converter recursos naturais renováveis, como coprodutos agrícolas, em alimentos de alta qualidade para o homem, além de possivelmente reduzir os custos da dieta.

Desta maneira, faz-se necessário um maior número de pesquisas sobre os efeitos do uso do farelo de mamona na composição de suplementos para animais a pasto, sobretudo ovinos em crescimento, sobre consumo, digestibilidade, desempenho produtivo e características de carcaça.

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CAPÍTULO 1

Effects of sodium hydroxide treatment of dried distillers grains on digestibility, ruminal metabolism, and metabolic acidosis of feedlot steers[1]

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ABSTRACT

Objectives were to determine the optimum inclusion of NaOH necessary to buffer the acidity of DDGS and its effects on digestibility, ruminal metabolism, and metabolic acidosis in feedlot steers. Rumen cannulated Angus-crossed steers were blocked by BW (small, initial BW = 555 ± 42 kg, n = 4; and large, initial BW = 703 ± 85 kg, n = 4) over four 21-d periods in a replicated 4 × 4 Latin square design. Steers were assigned to 1 of 4 dietary treatments: 1) 50% DDGS, untreated; 2) 50% DDGS, treated with 0.5% (DM basis) sodium hydroxide (**NaOH**); 3) 50% DDGS, treated with 1.0% (DM basis) NaOH; and 4) 50% DDGS, treated with 1.5% (DM basis) NaOH. The remainder of the diets, on a DM basis, were composed of 20% corn silage, 20% dry rolled corn, and 10% supplement. Ruminal pH was not affected by treatments (P = 0.56) nor by treatment × time interaction (P = 0.15). In situ NDF and ruminal DM disappearance did not differ ($P \geq 0.49$ and $P \geq 0.47$, respectively) among treatments. Similar to in situ results, apparent total tract DM and NDF digestibility were not affected ($P \geq 0.33$, $P \geq 0.21$, respectively) by increasing NaOH inclusion in the diets. Urinary pH increased (linear; $P < 0.01$) with increasing NaOH concentration in the diet. Blood pH was not affected ($P \geq 0.20$), and blood TCO_2 and PCO_2 were similar ($P \geq 0.56$ and $P \geq 0.17$, respectively) as NaOH increased in the diet. Increasing NaOH in the diet did not affect ($P \geq 0.21$) ruminal concentrations of total VFA. There were no linear (P = 0.20) or quadratic (P = 0.20) effects of treatment on ruminal acetate concentrations, nor was there a treatment × time interaction (P = 0.22) for acetate. Furthermore, there were no effects (quadratic; $P \geq 0.90$) of NaOH inclusion on ruminal propionate concentration. However, there was a quadratic response (P = 0.01) of ruminal butyrate concentrations as NaOH inclusion increased in the diet; ruminal butyrate concentrations were greatest when 0.5 and 1.0 % NaOH treatment of DDGS. In the current study, feeding DDGS treated with NaOH did not increase fiber digestibility, nor was it necessary to alleviate a possible metabolic acidosis. Alkali treatment of DDGS did not increase average ruminal pH or blood pH.

Keywords: beef cattle, DDGS treatment, metabolic acidosis, ruminal fermentation

INTRODUCTION

Dried distillers grains with solubles (**DDGS**) contain an average of 46% NDF (NRC, 2000), thus, fiber is an important source of energy for cattle consuming DDGS-based diets. However, DDGS are inherently acidic, due to the use of H_2SO_4 (pKa = 1.92) in the dry mill processing of corn for ethanol production (Schingoethe et al., 2009). Sulfuric acid in DDGS may decrease ruminal pH and may limit the maximum inclusion of DDGS in cattle diets (Klopfenstein et al., 2008). Hoover (1986) stated that ruminal pH less than 6 could decrease apparent DM and NDF digestibility in beef cattle with subsequent reductions in DMI (Mould et al., 1983) because ruminal pH below 6 reduces certain microbial populations and cellulolytic activity. Felix & Loerch (2011) found that cattle fed 60% DDGS-based diets had ruminal pH values below 5.2 between 12 and 18 h per day. Ruminal pH below 5.5 for this long could lead to metabolic acidosis (González et al., 2012). However, elevating ruminal pH above 6 can increase DMI and improve ruminal fiber digestibility (Hoover, 1986; Leventini et al., 1990). Previous research has shown ruminal pH in cattle fed DDGS-based diets can be increased by treating DDGS with NaOH before feeding, thereby reducing risk of ruminal acidosis and increasing NDF degradation in the rumen (Felix et al., 2012). However, some bases, such as CaO, may reduce DMI (Schroeder et al., 2014). Despite previous data demonstrating the benefits of neutralizing the acidity in DDGS (Felix et al., 2012), there is lack of information on optimal level of NaOH inclusion in DDGS-based diets. We hypothesize that buffering the acidity in DDGS prior to feeding will increase ruminal pH, improve fiber digestibility, and ameliorate metabolic acidosis. Therefore, our objectives were to determine the optimum inclusion of NaOH necessary to buffer the acidity of DDGS and its effects on digestibility, ruminal metabolism, and metabolic acidosis in feedlot steers.

MATERIALS AND METHODS

All animal procedures were approved by the University of Illinois Institute of Animal Care and Use Committee and followed the guidelines recommended in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010).

Animals and Management

Eight Angus-crossed steers, previously fitted with rumen cannulae, were blocked by BW into small (average initial BW = 555 ± 42 kg; n = 4) and large (average initial BW = 703 ± 85 kg; n = 4) blocks, and used in a replicated 4 × 4 Latin square design. Steers were housed at the

University of Illinois Beef Cattle and Sheep Field Laboratory in Urbana, IL, in stalls (2.3 × 1.3 m) equipped with individual feed bunks and automatic water bowls. The barn was equipped with a heating, ventilation, and air-conditioning system, providing controlled environment set at 18.3^{o}C. To initiate this study, a 14 d acclimation period took place prior to beginning the experiment to adjust steers to experimental diets. After acclimation, all 8 steers underwent partial rumen evacuations (8 L from each animal). Rumen contents from the evacuations were mixed (to make a 64 L composite) and then redistributed (8 L) to each animal to negate differences among rumen microorganisms.

After adaptation, steers were assigned to 1 of 4 dietary treatments: (1) 50% DDGS, untreated; (2) 50% DDGS, treated with 0.5% (DM basis) sodium hydroxide (**NaOH**); (3) 50% DDGS, treated with 1.0% (DM basis) NaOH; and (4) 50% DDGS, treated with 1.5% (DM basis) NaOH. The remainder of the diets were 20% corn silage, 20% dry rolled corn, and 10% supplement (DM basis; Table 1). Dietary treatment sequences were assigned according to procedures described by Patterson & Lucas (1962). The trial was divided in 21 d periods. Each period had a 14 d acclimation phase followed by a 7 d collection phase. Also, on d 1 of each period, partial rumen evacuations (8 L per animal) took place. Rumen fluid from each pair of steers on a common diet was composited, and approximately 8 L was placed back into the rumens of the pair of steers that were transitioning on to the respective diet. Steers were then transitioned for 14 d to new diets such that each steer would eventually receive all 4 diets. Steers were fed once daily at 0800 for ad-libitum intake.

A 1:2 (NaOH:H_2O) solution was mixed as 3 kg of NaOH in 6 L of distilled water and this solution buffered the DDGS as follows: no solution for the 0% treatment; 1 L for the 0.5% treatment; 2 L for the 1.0% treatment; and 3 L for the 1.5% treatment. For each treatment, 100 kg of DDGS was treated every 3 ± 1 d. The NaOH solution was added to the DDGS and mixed until it was homogeneous, approximately 15 min.

Sampling and Analysis

Dietary ingredient samples were collected at the beginning of each feeding period to adjust for DM (24 h at 105^{o}C). During the digestibility collection (d 1 through d 5 of collection phase), cattle were housed in individual pens with rubber flooring and fitted with fecal bags for total fecal collection. Feces were collected twice daily, morning and afternoon, and 5% of the total wet weight was saved at each collection. Individual feed ingredients and refusal samples were also collected for the first 5 d of the collection phase to determine total tract digestibility

Table 1. Composition of diets fed to steers on a DM basis

	%NaOH inclusion in the DDGS			
Item, % DM basis	0	0.5	1.0	1.5
Corn Silage	20.0	20.0	20.0	20.0
Dry Rolled Corn	20.0	20.0	20.0	20.0
DDGS[1]	50.0	49.75	49.50	49.25
NaOH[2]	0.0	0.25	0.50	0.75
Supplement	10.0	10.0	10.0	10.0
Ground Corn	7.197	7.197	7.197	7.197
Limestone	2.600	2.600	2.600	2.600
Dairy TM Salt[3]	0.100	0.100	0.100	0.100
Rumensin[4]	0.017	0.017	0.017	0.017
Tylosin[5]	0.011	0.011	0.011	0.011
Vegetable Oil	0.075	0.075	0.075	0.075
Analyzed composition				
NDF	31.95	32.31	31.57	31.46
ADF	15.27	15.29	15.19	15.33
CP	20.00	19.85	19.60	19.68
Fat	5.53	5.48	5.39	5.31
Ca	0.979	0.986	0.979	0.981
P	0.517	0.498	0.496	0.500
S	0.228	0.224	0.221	0.223
Na	0.133	0.271	0.400	0.537

[1]DDGS (One Earth Energy, LLC; Gibson City, IL) analyzed values: DM, 83.4%; NDF, 39.0%; CP, 31.6%; EE, 7.7%; S, 0.29%; pH, 5.5.

[2]NaOH was added to DDGS 3 ± 1 d prior to feeding.

[3]Dairy trace mineral salt (included 8.5% Ca as $CaCO_3$, 5% Mg as MgO and $MgSO_4$, 7.6% K as KCl_2, 6.7% Cl as KCl_2, 10% S as S_8, prilled, 0.5% Cu as $CuSO_4$ and Availa-4 [Zinpro Performance Minerals; Zinpro Corp, Eden Prairie, MN], 2% Fe as $FeSO_4$, 3% Mn as $MnSO_4$ and Availa-4, 3% Zn as $ZnSO_4$ and Availa-4, 278 mg/kg Co as Availa-4, 250 ppm I as $Ca(IO_3)_2$, 150 mg/kg Se as Na_2SeO_3, 2,205 KIU/kg vitamin A as retinyl acetate, 662.5 KIU/kg vitamin D as cholecalciferol, 22,047.5 IU/kg vitamin E as dl-α-tocopheryl acetate, and less than 1% CP, fat, crude fiber, salt).

[4]Rumensin 90 (200 g/kg; Elanco Animal Health, Greenfield, IN).

[5]Tylosin 40 (88 g/kg; Elanco Animal Health).

Collection of individual feed ingredients included taking a 100 g sample each morning and compositing it over the 5 d. Refusal samples were weighed once in the morning, prior to feeding, and 10% of the daily sample was composited for sub-sampling and further analysis. Then, all samples were freeze-dried (FreeZone, Labconco, Kansas City, MO) and ground through a 1 mm screen using a Wiley mill (Arthur H. Thomas; Philadelphia, PA). All freeze-dried feed ingredient and refusal samples were analyzed after the completion of the experiment for ADF and NDF (using Ankom Technology method 5 and 6, respectively; Ankom200 Fiber Analyzer, Ankom Technology, Macedon, NY), CP (Leco TruMac, LECO Corporation, St. Joseph, MI), fat (Method 2; Ankom Technology), and total ash (500° C for 12 h, HotPack Muffle Oven Model: 770750, HotPack Corp., Philadelphia, PA). Feed ingredients were also subjected to perchloric acid digestion and inductively coupled plasma atomic emission spectroscopy analysis of complete minerals (method 975.03: AOAC, 1988). Fecal samples were analyzed for DM and NDF using the same methods outlined above. The 4 DDGS samples treated with increasing levels of NaOH were analyzed for pH, using an Accumet Basic AB15 pH meter with an Accumet accuCap glass body, gel-filled electrode (Fisher Scientific, Pittsburg, PA), and titratable acidity. Fifty g of DDGS sample was mixed with 200 mL of distilled water for 30 s before the pH electrode was submersed in the mixture and pH was recorded. Then, the solution was titrated with 1 *M* NaOH to a final pH of 7.0, and the milliliters of NaOH used were recorded to calculate how much base was needed to neutralize the sample. This same procedure was made with total diet samples to calculate the NaOH needed to neutralize acidity in the diets.

Ruminal fluid samples were collected at 0, 1.5, 3, 6, 9, 12, and 18 h post-feeding during d 6 of each collection phase. Samples were strained through 2 layers of cheesecloth and pH was immediately measured using a FiveEasy FiveGo pH meter FE20/FG2 with a LE438 polyoxymethylene body gel-filled electrode with Ag/AgCl reference system and 1.2 m BNC/Cinch connection (Mettler Toledo, Columbus, OH). A subsample of fluid was saved at 0, 3, and 6 h to analyze for VFA. Seventy-five mL of strained ruminal fluid were mixed with 75 mL of 2N HCl. The mixture was then placed in a refrigerator and remixed by shaking several times per day. Three days after collection, ruminal fluid samples were removed from the refrigerator, and 40 mL of diluted rumen fluid were centrifuged at 20,000 × *g* at 4 °C for 20 min. Supernatant was filtered through a 0.45-μm filter. The filtered sample was then transferred, in 1-mL aliquots, to gas chromatography vials with 0.1 mL of 2-ethyl butyrate as an internal standard. Vials were then stored at -80°C until analyzed via gas chromatography (**GC**; model 5890A, Hewlett-Packard, Palo Alto, CA) for VFA. On d 7 of collection, dacron bags containing 15 g of soybean hulls were placed in the rumen for 24 hours to determine in-situ NDF disappearance according to the methods of Felix et al. (2012).

Blood samples were collected from a jugular vein 3 ± 1 h after feeding and immediately 2 to 3 drops were placed in an i-STAT EC8+ Cartridge and then analyzed by the VetScan i-STAT 1 Handheld Analyzer (Abbott Laboratories, Abbott Park, IL USA). The cartridge used determined blood concentrations of sodium (**Na**), potassium (**K**), chloride (**Cl**), pH, partial pressure of carbon dioxide (**PCO_2**), urea nitrogen, BUN/urea, glucose (**Glu**), hematocrit (**Hct**), total carbon dioxide (**TCO_2**), bicarbonate (**HCO_3**), base excess in the extracellular fluid compartment (**BEecf**), anion gap (**Agap**), and hemoglobin (**Hgb**).

Urine samples were collected from the steers during the digestibility phase of collection, d 1 through 5 of collection, 3 ± 1 h after feeding. Immediately after collection, pH was analyzed using the same pH meter used to measure ruminal fluid pH and recorded for the sample.

Statistical Analysis

The experimental design was a replicated 4 × 4 Latin square. Data were analyzed using the MIXED procedure of SAS (version 9.4, SAS Inst. Inc., Cary, NC). For all models, steer was considered the experimental unit and single-degree-of-freedom polynomial contrasts were used to detect linear and quadratic effects of increasing levels of NaOH concentration in the DDGS. A Kenward-Roger adjustment was used. The model for dietary pH, dietary acidity, DMI, DM and NDF apparent total tract digestibility, ruminal disappearance, blood parameters, and urine pH was:

$$Y_{ijklm} = \mu + s_i + P_j + B_k + T_l + e_{ijklm}$$

where Y_{ijklm} = the response variable, μ = the mean, s_i = the random effect of steer, P_j = the fixed effect of period, B_k = the fixed effect of Block, T_l = the fixed effect of the Treatment, and e_{ijklm} = the experimental error.

Repeated measures were used to analyze the response variables ruminal pH and VFA concentrations. The Compound Symmetry covariance structure was chosen based on the smallest Bayesian information criteria. A Kenward-Roger adjustment was used. The model for repeated measures was:

$$Y_{ijklm} = \mu + Q_i + P_j + s_{k(j)} + T_l + C_m + (TC)_{lm} + e_{ijklm},$$

where Y_{ijklm} = response variable, μ = mean, Q_i = the fixed effect of square, P_j = the fixed effect of period, $s_{k(j)}$ = the random effect of steer nested within period, T_l = the fixed effect of NaOH inclusion, C_m = the fixed effect of time of collection, $(TC)_{lm}$ = the fixed effect of the interaction of time of collection and NaOH inclusion, and e_{ijklm} = the experimental error. Differences were declared significant at $P \leq 0.05$.

RESULTS AND DISCUSSION

Despite changes in dietary pH, inherent to treatment, DMI was not affected ($P \geq 0.69$) by increasing NaOH inclusion in the diet (Table 2). In agreement with the present study, Felix et al. (2012) did not find any differences in DMI after treating DDGS with 2 % NaOH. Furhtermore, the increasing Na concentration in the diets, as NaOH treatment of DDGS increased from 0 to 1.5 % (Table 1), also had no effect on DMI. In temperate climates, requirements for Na in growing and finishing beef cattle do not exceed 0.06 to 0.08 % of the diet DM. But, cattle can consume dietary concentrations between 6.5 and 9.3 % without decreasing DMI or presenting other side effects (NRC, 2000). Therefore, DMI was not influenced by dietary Na concentrations because all treatments were more than 10 times below the 6.5% threshold (Table 1).

Table 2. Effects of increasing NaOH concentration on dietary pH and titratable acidity on DDGS-based diets

	%NaOH					*P*-value[1]	
Item	0	0.5	1.0	1.5	SEM	Linear	Quadratic
DMI, kg d^{-1}	15.1	15.7	15.3	15.7	0.67	0.69	0.85
Dietary pH[2]	4.85	5.25	5.63	6.14	0.115	<0.01	0.64
NaOH to buffer dietary acidity[2], mL/g	0.17	0.14	0.11	0.06	0.014	<0.01	0.38
NaOH to buffer DMI[3], L/d	2.63	2.19	1.67	0.91	0.209	<0.01	0.47

[1]Orthogonal polynomial contrasts for increasing NaOH inclusion in the diet.

[2]Starting pH of the total mixed ration when 20 g of diet was mixed with 80 mL of water.

[2]mL of 1 *M* NaOH needed to titrate 1 g of the diet to pH 7.00.

[3]L of 1 *M* NaOH needed to titrate daily DMI to pH 7.00.

Dietary pH increased (linear; $P < 0.01$) as NaOH addition increased (Table 2). This was by experimental design. Furthermore, titratable acidity of the daily feed consumed in the present study decreased (linear; $P < 0.01$) with increasing dietary inclusion of NaOH, which decreased (linear; $P < 0.01$) the calculated amount of 1 *M* NaOH solution that would be needed daily to buffer total dietary acidity consumed, based on DMI, to pH 7.0 (Table 2). Recent research has shown that cattle consuming diets from 40% to 60% DDGS have decreased ruminal pH values when compared to cattle fed corn-based diets (Felix et al., 2012; Morrow et al., 2013). One explanation for the reduction in observed ruminal pH has been the use of H_2SO_4 by ethanol producers to control pH during starch hydrolysis and to clean fermentation vats (Klopfenstein et al., 2008). Felix et al. (2012) ascribed observed changes in ruminal pH to be correlated with inherent pH of DDGS and noted that 2% addition of NaOH to the DDGS increased ruminal pH and alleviated ruminal acidosis. In the present trial, treating DDGS with 1.5% NaOH increased dietary pH by 1.29 units. This change in dietary pH caused a 65% decrease in 1 *M* NaOH needed to buffer dietary acidity (L/d; Table 2), similar to the 64% decrease when Felix et al. (2012) treated DDGS with 2% NaOH prior to feeding and compared the titatable acidity of that treated product to an untreated 60% DDGS diet. Average pH of DDGS used in the current experiment was 5.5. According to the titration, 7.5 g of NaOH were needed to neutralize 1 kg (as-is) of DDGS acidity. From this information, if it is assumed that all the acidity came from sulfuric acid, then each kg of DDGS (as-is) contained a calculated 9.2 g of H_2SO_4, or 11.0 g/kg on a DM basis. Felix & Loerch (2011) estimated that 1 kg of DDGS contained 25.8 g of H_2SO_4. The reduction in estimated H_2SO_4 from the papers published in 2011 and 2014 may be attributed to a greater awareness of S side-effects by the ethanol industry, leading to more judicious use of H_2SO_4. However, the authors acknowledge that they are likely over-estimating the amount of H_2SO_4 in the DDGS because: 1) sulfur content in the DDGS was only 0.29% (which means that the highest value for H_2SO_4 in the DDGS could be 8.87 g/kg), and 2) there are other sources of S in the DDGS, because corn is 0.11% S (NRC, 2000). However, these numbers are provided for discussion purposes.

We had hypothesized that increasing the dietary pH and changing the titratable acidity of the DDGS diets in the present study would increase ruminal pH. However, ruminal pH was not affected by treatments (P = 0.57) nor by the treatment × time interaction (P = 0.55; Figure 1). Mean ruminal pH values were 6.04, 6.01, 6.12, and 6.10 for the 0.0, 0.5, 1.0, and 1.5% NaOH treatments, respectively. Thus, even the control 50% DDGS diets in the present study did not have the same drop on ruminal pH reported by Felix & Loerch (2011) when a 60% DDGS diet was fed. This may be due to the variability of H_2SO_4 concentrations in the ethanol industry byproduct, DDGS. In the aforementioned study by Felix & Loerch (2011), the S content of the diet was 0.74% (DM basis) and the pH of DDGS was 3.76. In the present trial the S content of the diet was just 0.29% (DM basis), leading to a DDGS pH of 5.5. In this study, the average drop in ruminal pH from 6.57 to 6.10, that occurred from 0 to 1.5 h post feeding, may be more likely caused by enhanced post-feeding fermentation and the subsequent increase in VFA, and not H_2SO_4 from DDGS.

Figure 1

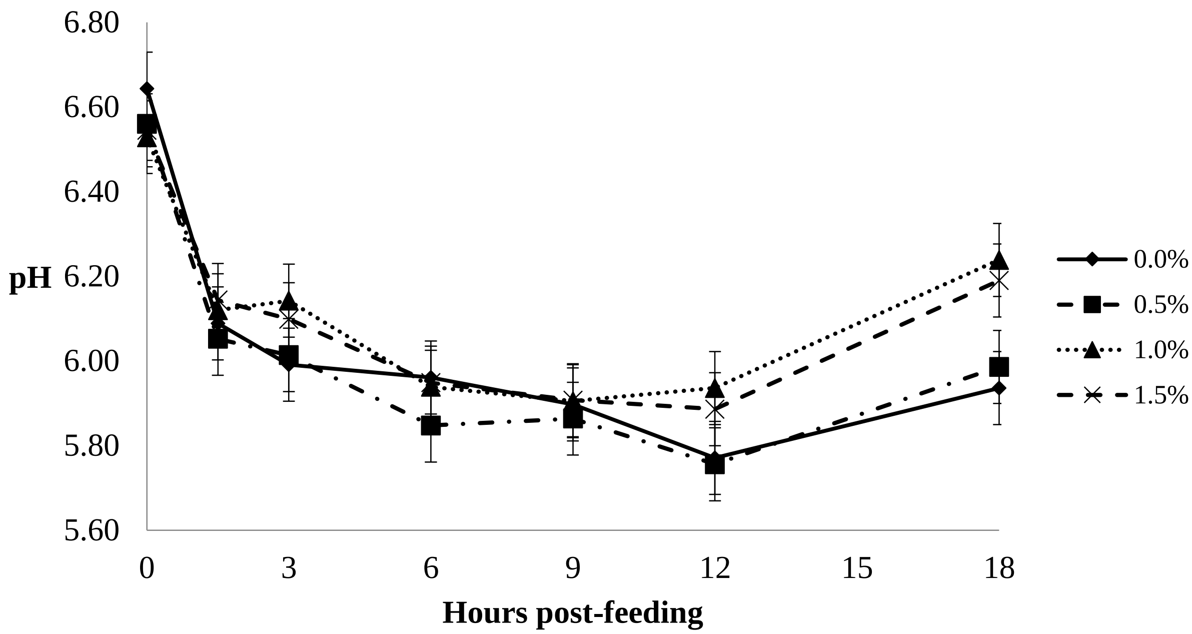

Figure 1. Effects of increasing NaOH concentration in the diet on ruminal pH of steers fed DDGS-based diets at different times post-feeding. There was no interaction (P = 0.55) of increasing NaOH × time, nor main effect of NaOH inclusion (P = 0.57). There was effect of time (P < 0.01) on ruminal pH. Error bars are associated with the interaction between diet and time (SEM = 0.0862).

Ruminal pH below 6.0 reduces fiber fermentation (Owens et al., 1998) because this acidic condition inhibits cellulolytic microorganisms (Mould et al., 1983). Our hypothesis was that mitigating acidity in DDGS would result in an increase in ruminal pH that would be effective enough to increase NDF and DM disappearance; however, in situ NDF and DM ruminal disappearance did not differ (linear; $P \geq 0.49$ and $P \geq 0.47$, respectively) among treatments (Table 3). Although all cattle in this experiment experienced ruminal pH values below 6.0 from 6 h to 12 h after feeding (Figure 1), ruminal pH remained above 6 for the majority of the day, regardless of treatment. In situ 24 h NDF disappearance fluctuated from 18.74% to 20.44%. These values are greater than the 9.0% reported by Felix et al. (2012), when cattle were fed 60% DDGS diets. However, in situ NDF and DM disappearance values in this study are comparable to values reported elsewhere. Schroeder et al. (2014) reported 22.2% and 27.0% for in situ NDF and DM disappearance, respectively, also in cattle fed 50% dried distillers grains diets.

Table 3. Effects of increasing NaOH concentration on the digestibility and disappearance of DM and NDF in steers fed DDGS-based diets

	%NaOH					*P*-value[1]	
Item	0	0.5	1.0	1.5	SEM	Linear	Quadratic
n	8	8	8	8	-	-	-
Apparent Total Tract Digestibility, % DM basis							
DM	73.99	74.60	74.17	73.41	0.69	0.48	0.33
NDF	62.16	64.49	64.16	63.21	1.27	0.62	0.21
In situ ruminal disappearance[2], % DM basis							
DM	24.19	24.29	24.90	25.89	1.74	0.47	0.80
NDF	19.10	18.74	19.89	20.44	1.66	0.49	0.79

[1]Orthogonal polynomial contrasts for increasing NaOH inclusion in the diet.

[2]Disappearance of soybean hulls incubated in the rumen for 24 h and corrected for 0 h washout of DM and NDF, respectively.

Similar to the in situ results, apparent total tract DM and NDF digestibility were not affected (quadratic; $P \geq 0.33$, $P \geq 0.21$, respectively) by increasing NaOH in the diets. Apparent total tract DM digestibility for cattle fed DDGS with no NaOH treatment in the present study was similar (74.0% vs. 72.9%) to that reported by Salim et al. (2012) when they fed a 50% DDGS, 35% dry whole corn grain and 10% alfalfa/grass haylage diet. However, total-tract apparent NDF digestibility was greater (62.16% vs. 53.9%) in the present study than that reported by Morrow et al. (2013), when lambs were fed a diet composed of 45% DDGS, which was treated with 2% NaOH. Comparison across trials is difficult, due to work with different ruminant species and due to the variability of DDGS and the historic lack of reporting on the nutrient composition of the DDGS.

Although urinary pH in ruminants is usually basic and varies from 7.4 to 8.4 (Church & Pond, 1988), feedlot cattle often suffer from mild ruminal acidosis and excrete acid in their urine (Owens et al., 1998). In the current study, urinary pH increased (linear; $P < 0.01$) with increasing NaOH concentration in the diet (Figure 2). The 1.12 pH unit increase from untreated to 1.5% NaOH diets in the present trial was lower than the 1.74 pH unit difference noted by Morrow et al. (2013) when lambs fed DDGS treated with 2% NaOH were compared to lambs fed untreated DDGS. As the NaOH in the diet increases, subsequent increases in urinary pH are expected because the animal does not have to buffer as much acid to maintain normal blood pH. Therefore, we had hypothesized there could be a slight increase in blood pH as NaOH increased in the diet, pulling animals consuming DDGS from states near metabolic acidosis to more normal ranges. However, it would appear that physiological compensatory mechanisms of the body adequately buffered the effects of dietary DDGS acidity because blood pH was not affected (*P* ≥ 0.20; Table 4) as NaOH increased in the diet. Normal blood pH in steers varies little, from 7.31 to 7.53 (Campos, 1998), because blood pH is usually kept within narrow range by the kidneys, respiratory functions, and other buffering systems. Furthermore, as discussed above, the pH decline in the present diets was not as severe as those declines noted in previous DDGS trials, thus alleviating some of the physiological stresses animals fed more acidic DDGS must endure.

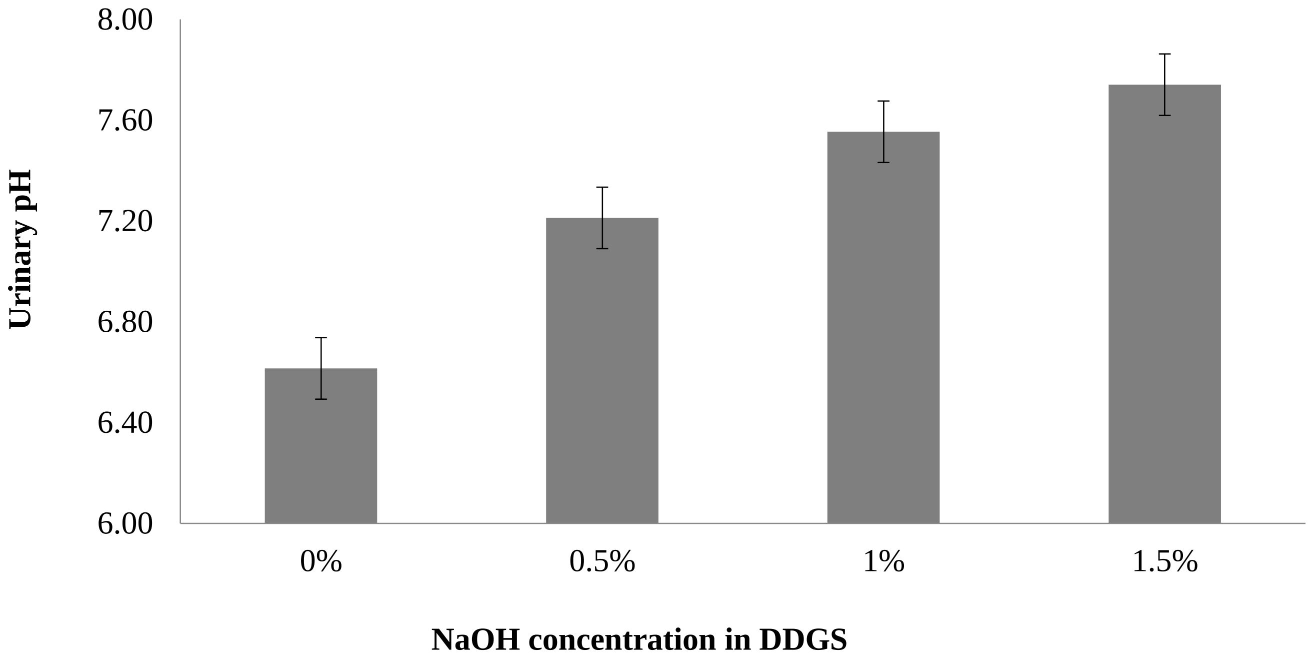

Figure 2. Effects of increasing NaOH concentration in the diet on urinary pH of steers fed DDGS-based diet at 3 h postfeeding. There was a linear effect ($P < 0.01$) of dietary NaOH inclusion on urinary pH (SEM = 0.1221).

Table 4. Effects of increasing NaOH concentration on blood chemistry concentrations in steers fed DDGS-based diets

	%NaOH					*P*-value	
Parameter[1]	0	0.5	1.0	1.5	SEM	Linear	Quadratic
n	8	8	8	8	-	-	-
pH	7.46	7.46	7.46	7.48	0.01	0.20	0.51
Na, mmol/L	138.75	138.63	139.63	138.50	0.62	0.93	0.43
K, mmol/L	4.18	4.04	4.08	4.08	0.10	0.55	0.48
Cl, mmol/L	102.00	100.88	101.63	101.25	0.53	0.53	0.48
TCO_2[2], mmol/L	31.75	31.25	31.63	31.00	0.72	0.56	0.93
PCO_2[3], mmHg	43.33	42.45	42.48	40.26	1.46	0.17	0.65
HCO_3[4], mmol/L	30.38	29.90	30.45	29.88	0.67	0.75	0.94

[1]as measured by the VetScan i-STAT 1 Handheld Analyzer (i-STAT EC8+ Cartridge); Abbott Laboratories, Abbott Park, IL.

[2]Total carbon dioxide.

[3]Partial pressure of carbon dioxide is a measure of the tension or pressure of carbon dioxide dissolved in the blood. Along with pH is used to assess acid-base balance.

[4]Bicarbonate.

Sodium (Na^+), potassium (K^+), and chloride (Cl^-) are bioavailable ions that are not metabolized and thus play a major role in determining acid-base balance in blood (Stewart, 1978). In this experiment, despite the difference in dietary Na concentrations (Table 1), there was no difference ($P \geq 0.43$; Table 4) in blood concentrations of any of these 3 ions. Similar responses were reported by Tucker et al. (1988) who showed that concentrations of these macrominerals in plasma were unaffected by dietary cation-anion difference. Acidosis can result from either excessive absorption or production of acid, or insufficient acid removal (Owens et al., 1998). In a respiratory acidosis, for instance, an animal with respiratory problems accumulates CO_2 in the blood, which depresses blood pH unless renal retention of bicarbonate compensates sufficiently (Ganong, 2010). In this experiment, blood TCO_2 and PCO_2 were similar ($P \geq 0.56$ and $P \geq 0.17$, respectively). These data would again suggest that steers in the present trial were not suffering from metabolic acidosis. Further confirming these findings, blood bicarbonate concentrations were not affected ($P \geq 0.75$; Table 4). In metabolic acidosis, blood pH could be decreased by excess acid or lack of bicarbonate (Nagaraja & Titgemeyer, 2007). Thus, it would be expected that steers suffering metabolic acidosis would have a lower bicarbonate concentration in the blood in an attempt to neutralize excess H^+ in the blood, but, again, bicarbonate concentrations did not differ among treatments. Besides blood pH, there are other clinical signs that can help diagnose metabolic acidosis in feedlot cattle such as lethargy, variable feed intake, low ruminal pH, and diarrhea (Owens et al., 1998); however, none of these signs were detected during this trial.

One of the drivers of ruminal pH is the production of volatile fatty acids which is largely impacted by substrate availability (Firkins et al., 2006). We had hypothesized that increasing dietary pH would lead to a greater ruminal pH, and an increase in fiber fermentation. However, as mentioned previously, ruminal pH in the present trial was unaffected by treatments and increasing NaOH in the diet did not affect concentrations of total VFA ($P \geq 0.21$; Table 5). Boukila et al. (1995) reported that ruminal concentrations of total VFA in sheep fed Ca and Mg hydroxides with barley-based diets were 25.7% higher than in those fed a control diet with no additional minerals. When Felix et al. (2012) treated a 60% DDGS diet with 2% NaOH, however, there was no effect on ruminal VFA concentrations. The primary end product of fiber fermentation is acetate, and in the current study, there were no linear ($P = 0.20$) or quadratic ($P = 0.20$) effects of treatment on ruminal acetate concentrations, nor was there a treatment × time interaction ($P = 0.22$) for acetate. In line with the current results, Boukila et al. (1995) reported that molar proportions of acetate were not affected when Ca and Mg hydroxides were simply added to barley-based diets and fed to sheep, as opposed to being used to treat the diets. Conversely, however, Nuñez et al. (2014) reported linear increases in acetate, butyrate, and total VFA concentrations from 0 to 12 h postfeeding with increasing dietary CaO when steers were fed 60% DDGS-based diets. This may again be explained by differences in acid concentrations of the DDGS used in the Nuñez et al. (2014) trial, which was pH = 4.29, as opposed pH = 5.5 of theDDGS in the present trial. In all aforementioned work, the goal of the oxide and hydroxide inclusions or treatments has been to decrease acidity in the rumen (i.e. increase ruminal pH). The precise method to optimize the functionality of these compounds in the rumen, treating the diet versus inclusion in the TMR for example, has not been determined.

There were no linear or quadratic effects of NaOH inclusion ($P \geq 0.90$; Table 5) on ruminal propionate concentrations. However, there was the quadratic response ($P = 0.01$) of ruminal butyrate concentrations as NaOH inclusion increased in the diet. Out of the 3 most prominent VFA in the rumen, butyrate is the one with the least variation when subjected to ruminal changes (Ham et al., 1994). Although reasons for this quadratic effect are not clear, it is important to consider that concentrations of VFA are affected by VFA production, VFA absorption, and interconversions among VFA (Firkins et al., 2006). All of these eccentricities are not apparent when one reports simply the concentration of ruminal VFA in standard practice.

Table 5. Short chain fatty acid profiles of steers fed DDGS-based diets with increasing NaOH concentration

		%NaOH[1]					*P*-value[2,3]	
Item		0	0.5	1.0	1.5	SEM	Linear	Quadratic
n		8	8	8	8	-	-	-
Acetate, m*M*						2.74	0.20	0.20
	0[4]	42.84	48.78	52.95	49.57			
	3	59.46	61.92	59.59	57.65			
	6	58.41	60.21	61.28	62.87			
Propionate, m*M*						2.06	0.94	0.90
	0	13.14	14.20	14.29	15.50			
	3	25.96	27.24	22.74	24.66			
	6	25.95	27.37	25.61	27.54			
Butyrate, m*M*						0.81	0.99	0.01
	0	6.57	8.33	8.57	6.93			
	3	12.02	13.44	13.09	10.88			
	6	11.55	13.29	13.87	12.14			
Total VFA, m*M*						4.73	0.43	0.21
	0	65.40	74.02	78.98	74.82			
	3	101.32	106.20	99.28	96.67			
	6	99.57	104.27	104.89	106.24			
A:P[5]						0.19	0.46	0.72
	0	3.44	3.64	3.72	3.52			
	3	2.33	2.33	2.63	2.52			
	6	2.39	2.24	2.45	2.45			

[1]Percentage of NaOH in the DDGS, which was 50% of the diet (DM basis).

[2]There was no interaction ($P \geq 0.22$) of NaOH inclusion × time for any of the parameters analyzed; therefore, presented orthogonal polynomial contrasts represent only the main effects of NaOH inclusion in the diet.

[3] Effect of time was significant for all parameters at $P < 0.01$.

[4]Time post-feeding, in hours.

[5]Acetate:Propionate.

Because neither acetate nor propionate was affect by treatment, there were no treatment effects ($P \geq 0.46$) on the acetate to propionate ratio (**A:P**). The A:P ratio varied from 2.24 to 3.72, and these values are higher than those reported by Felix et al. (2012) with or without 2% NaoH dietary treatment in cattle fed 60% DDGS-based diets. In the present trial, when cattle were fed

50% DDGS-based diets, VFA proportions varied from 61 to 62%, 22 to 24%, and 9 to 13%, for acetate, propionate, and butyrate, respectively, for all treatments at all time points. These VFA proportions do not match either typical VFA concentrations from forage-fed cattle or grain-fed cattle. But, rather they are between the ranges of what cattle fed forage-based diets and cattle fed a grain-based diet would normally produce (Fluharty, 2009). This is likely explained by the increased NDF and decreased starch content of the DDGS diet in the present trial when compared with a typical feedlot diet.

In the current study, DDGS treated with NaOH did not increase fiber digestibility, nor was it necessary to alleviate metabolic acidosis. The alkali treatment did not increase average ruminal pH or blood pH. Comparison with previous studies show DDGS may vary in nutrient composition; and, their pH values may directly affect DM and NDF digestibility of animals fed DDGS-based diets. Therefore, it is important to analyze the nutrient composition of DDGS, particularly pH and S content, to determine the efficacy of NaOH treatment, in addition to better predicting parameters like DMI, ruminal pH, NDF and DM digestibility, and performance of growing and finishing steers.

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CAPÍTULO 2

Effects of increasing inclusion of sodium hydroxide treatment on growth performance, carcass characteristics, and feeding behavior of steers fed 50% DDGS[1]

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ABSTRACT

The objectives of this trial were to determine the dietary inclusion of NaOH needed to optimize growth performance and carcass characteristics of feedlot steers, and to determine the effects of NaOH treatment of dried distillers grains with solubles on pattern of feed intake. One hundred and twenty Angus-cross steers were blocked into 2 BW blocks (light, initial BW = 211 ± 27 kg; and heavy, initial BW = 261 ± 27 kg) and randomly allotted within block to 20 pens (6 steers per pen). Pens within block were randomly assigned to 1 of 4 dietary treatments: 1) 50% DDGS, untreated; 2) 50% DDGS, treated with 0.5%NaOH (DM basis); 3) 50% DDGS, treated with 1.0% NaOH (DM basis); or 4) 50% DDGS, treated with 1.5% NaOH (DM basis). The remainder of the diets contained 20% dry-rolled corn, 20% corn silage, and 10% mineral and vitamin supplement, on a DM basis. There were no effects ($P \geq 0.21$) of increasing NaOH inclusion on final BW, ADG, or feed efficiency. Increasing NaOH in the diet increased (linear; $P = 0.02$) meal duration and tended (linear; $P = 0.06$) to increase meal size, but did not affect overall number of meals per day ($P = 0.21$) or overall DMI for the course of the trial. Relative to cattle fed DDGS treated with 0, 0.5 or 1% NaOH (DM basis), steers fed DDGS treated with 1.5% NaOH consumed a larger proportion of their meals in the afternoon. However, regardless of treatment, all steers consumed 78% or more of their feed in the first 12 h post-feeding. There were no effects ($P \geq 0.19$) of increasing NaOH inclusion on HCW, LM area, dressing percentage, KPH, back fat thickness, and marbling. There was a linear ($P = 0.02$) decrease on USDA Yield Grade 3 and a tendency ($P = 0.09$) for a quadratic response in carcasses grading USDA Yield Grade 4 as NaOH concentration increased in the diets. The quality grade response followed marbling score and was not different ($P \geq 0.11$) among treatments. Thus, there were no effects of feeding DDGS on growing cattle performance or carcass characteristics. However, NaOH inclusion shifted the pattern of intake slightly to the afternoon hours, and increased meal duration without increasing the total number of meals per day.

Key words: beef, dried distillers grains, feed treatment, sodium hydroxide, steers

INTRODUCTION

As market prices fluctuate, there are instances when dried distillers grains with solubles (**DDGS**) may be a cheaper energy source for beef cattle than corn; therefore, DDGS inclusion in cattle diets tends to fluctuate with changes in corn prices (USDA, 2015). However, optimal inclusion of DDGS in beef rations, to maximize growth performance, is only 20% of the diet DM (Ham et al., 1994). This is because DDGS contain sulfuric acid and can reduce DMI, ruminal pH, and fiber digestibility in beef cattle when they are fed as the majority of the dietary DM (Klopfenstein et al., 2008; Felix et al., 2012). Conversely, a slight elevation of rumen pH to 6.35 can increase DMI and improve ruminal digestibility (Leventini et al., 1990). In addition, Felix et al. (2012) found that cattle fed DDGS that were treated with 2% NaOH prior to feeding, increased in situ NDF disappearance when compared to cattle fed DDGS with no treatment. These authors postulated this was due to NaOH neutralizing the acidity from H_2SO_4 in DDGS. However, excess Na can reduce intake (Croom et al., 1982; NRC, 2000). The optimal inclusion of alkaline treatment to mitigate the inherent acidity of DDGS-based diets and improve beef cattle growth performance and carcass characteristics is not known. We hypothesize there is an optimum inclusion of NaOH that will improve growth performance and carcass characteristics in cattle fed 50% DDGS-based diets would be slightly alkaline. The objectives of this trial were to determine the dietary inclusion of NaOH needed to optimize feed efficiency, DMI, ADG, and carcass characteristics of feedlot steers.

MATERIALS AND METHODS

All animal procedures were approved by the University of Illinois Institute of Animal Care and Use Committee and followed the guidelines recommended in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010).

Animals and Diets

One hundred and twenty Angus-cross steers were used in a randomized complete block design and housed in a confinement barn at the University of Illinois Beef Cattle and Sheep Field Laboratory in Urbana, IL. Upon arrival to the feedlot, steers were placed in pens (4.88 × 4.88 m) constructed of 5.08 cm galvanized steel tubing with concrete slatted floors covered in 1.91 cm thick rubber matting. A 21-day transition period took place, prior to beginning the experiment, to adjust the steers to the 50% DDGS diet. Intake was controlled during this initial acclimation period to aid in transitions and avoid gastrointestinal issues. From day -21 to day -15, the transition diet was 20% hay, 30% corn silage, 20% dry rolled corn, 20% DDGS, and 10% supplement (DM basis); DM offered per head per day was between 3.6 and 4.5 kg. From day -14 to day -8, the transition diet was 10% hay, 25% corn silage, 20% dry rolled corn, 35% DDGS, and 10% supplement (DM basis); DM offered was between 4.5 and 5.4 kg. From day -7 to day 0, the transition diet was 0% hay, 20% corn silage, 20% dry rolled corn, 50% DDGS, and 10% supplement (DM basis); DM offered was between 5.4 and 6.7 kg.

After the 21-d acclimation, steers were weighed on 2 consecutive d to determine initial BW and were blocked into 2 BW blocks (light, initial BW = 211 ± 27 kg; and heavy, initial BW = 261 ± 27 kg). Steers within the light block were allotted to 3 pens/treatment, and steers within the heavy block were allotted to 2 pens/treatment (6 steers/pen, 20 pens total) such that pens within a block had the same average initial BW. Pens within block were randomly allotted to 1 of 4 dietary treatments: 1) 50% DDGS, untreated; 2) 50% DDGS, treated with 0.5% NaOH (DM basis); 3) 50% DDGS, treated with 1.0% NaOH (DM basis); or 4) 50% DDGS, treated with 1.5% NaOH (DM basis). The remainder of the diets, on a DM basis, were composed of 20% corn silage, 10% supplement, and 20% dry rolled corn (Table 1). A 1:2 ($NaOH$:H_2O) solution was mixed as 50 kg of NaOH in 100 L of tap water, and this solution buffered the DDGS. For each 100 kg of DDGS, we had: no added solution for the 0% treatment; 1 L for the 0.5% treatment; 2 L for the 1.0% treatment; and 3 L for the 1.5% treatment. For each DDGS treatment, 700 kg of DDGS was treated weekly by adding the NaOH solution to DDGS and mixing in a Knight Reel Auggie 2375 mixer wagon (KUHN North America, Brodhead, WI.) for 15 min.

The total mixed rations were offered once daily at 0900 h and steers were fed for ad libitum intakes and allowed free-access to water during the entire trial. Dietary ingredient samples were collected every 14 d to adjust for DM (24 h at 105°C). In addition, subsamples of each dietary ingredient were saved every 14 d and were composited for nutrient analysis at the end of the trial (described below).

On d 0, steers were implanted with Component TE-IS (80 mg trenbolone acetate and 16 mg estradiol; Elanco Animal Health; Greenfield, IN) and on d 62 they were re-implanted with Component TE-S (120 mg trenbolone acetate and 24 mg estradiol; Elanco Animal Health). Steers were weighed every 28 d during the trial and were then weighed on 2 consecutive d at the end of the trial to determine final BW before slaughter.

Table 1. Composition of diets fed to steers in feedlots, on a DM basis

	% NaOH inclusion in the DDGS			
Item	0	0.5	1.0	1.5
Ingredient, %				
Corn Silage	20.0	20.0	20.0	20.0
Dry Rolled Corn	20.0	20.0	20.0	20.0
DDGS[1]	50.0	49.75	49.50	49.25
NaOH[2]	0.0	0.25	0.50	0.75
Supplement				
Ground Corn	7.197	7.197	7.197	7.197
Limestone	2.600	2.600	2.600	2.600
Dairy TM Salt[3]	0.100	0.100	0.100	0.100
Rumensin[4]	0.017	0.017	0.017	0.017
Tylosin[5]	0.011	0.011	0.011	0.011
Vegetable Oil	0.075	0.075	0.075	0.075
Analyzed composition, %				
NDF	32.22	32.38	32.12	32.06
ADF	14.91	15.06	14.88	14.87
CP	19.26	19.20	19.23	19.14
Fat	5.95	5.79	5.80	5.75
Ca	0.836	0.838	0.837	0.837
P	0.500	0.500	0.502	0.498
S	0.213	0.214	0.215	0.214
Na	0.148	0.271	0.388	0.493

[1]DDGS (One Earth Energy, LLC; Gibson City, IL) analyzed values: DM, 85.0%; NDF, 37.7%; CP, 30.8%; EE, 8.8%; S, 0.29%; pH, 5.5.

[2]NaOH was added to DDGS approximately 7 d prior to feeding. Fifty percent of DDGS (DM basis) was in the diets.

[3]Dairy trace mineral salt (included 8.5% Ca as $CaCO_3$, 5% Mg as MgO and $MgSO_4$, 7.6% K as KCl_2, 6.7% Cl as KCl_2, 10% S as S_8, prilled, 0.5% Cu as $CuSO_4$ and Availa-4 [Zinpro Performance Minerals; Zinpro Corp, Eden Prairie, MN], 2% Fe as $FeSO_4$, 3% Mn as $MnSO_4$ and Availa-4, 3% Zn as $ZnSO_4$ and Availa-4, 278 mg/kg Co as Availa-4, 250 ppm I as $Ca(IO_3)_2$, 150 mg/kg Se as Na_2SeO_3, 2,205 KIU/kg vitamin A as retinyl acetate, 662.5 KIU/kg vitamin D as cholecalciferol, 22,047.5 IU/kg vitamin E as dl-α-tocopheryl acetate, and less than 1% CP, fat, crude fiber, salt).

[4]Rumensin 90 (200 g/kg; Elanco Animal Health, Greenfield, IN).

[5]Tylosin 40 (88 g/kg; Elanco Animal Health).

Growth Performance and Carcass Characteristics

Average daily gain, DMI, and G:F were measured from d 0 to slaughter (137 d total). Feed intake was measured on individual animals using the GrowSafe system (GrowSafe Systems Ltd., Airdrie, AB Canada). All steers were weighed off test when the average back fat thickness of the group was 1.2 cm, estimated by ultrasound scan. Steers were hauled approximately 300 km to a commercial harvest facility (Tyson Foods, Joslin, IL) and were humanely slaughtered under USDA inspection. Hot carcass weight (**HCW**) and dressing percentage (**DP**) were recorded on the day of slaughter. Carcasses were chilled for approximately 24 h at -4 ˚C and ribbed between the 12^{th} and 13^{th} ribs to determine of subcutaneous back fat thickness at the 12^{th} rib (**BF**), LM area, marbling scores KPH, and USDA Yield and Quality Grades via USDA grading cameras. Two steers from different treatments were removed from the study for health issues not related to dietary treatment.

Sampling and Analysis

Composited feed ingredient samples were freeze-dried (12 L FreeZone, Labconco, Kansas City, MO) and ground through a 1 mm Wiley mill (Thomas Scientific, Swedesboro, NJ). Feed ingredients were analyzed for ADF and NDF (using Ankom Technology method 5 and 6, respectively; $Ankom^{200}$ Fiber Analyzer, Ankom Technology, Fairport, NY), CP (Leco TruMac, LECO Corporation, St. Joseph, MI), fat (Method 2; Ankom Technology), and total ash (500° C for 12 h, HotPack Muffle Oven Model: 770750, HotPack Corp., Philadelphia, PA). Feed ingredients were also subjected to perchloric acid digestion and inductively coupled plasma atomic emission spectroscopy analysis of complete minerals (method 975.03: AOAC, 1988). The 4 DDGS samples treated with increasing levels of NaOH were analyzed for pH, using an Accumet Basic AB15 pH meter with an Accumet accuCap glass body, gel-filled electrode (Fisher Scientific, Pittsburgh, PA), and titratable acidity. Fifty g of DDGS sample was mixed with 200 mL of distilled water for 30 s before the pH electrode was submersed in the mixture and pH was recorded.

Statistical Analysis

The experimental design was a randomized complete block design. Animal performance and carcass characteristics were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Carcass yield and quality grade distributions were compared using the GLIMMIX procedure of SAS. The model used for all the aforementioned parameters was:

$$Y_{ijk} = \mu + B_i + T_j + e_{ijk}$$

where Y_{ijk} = response variable; μ = mean; B_i = the fixed effect of block; T_j = the fixed effect of NaOH inclusion; e_{ijk} = the experimental error. Pen was the experimental unit, and single-degree-of-freedom polynomial contrasts were used to detect linear and quadratic effects of increasing NaOH inclusion in the diets on dependent variables. Differences were declared significant at $P \leq 0.05$. Trends, where discussed, were declared at $0.05 < P < 0.10$.

RESULTS AND DISCUSSION

We had hypothesized that adding NaOH to DDGS prior to feeding would reduce acid load in the rumen, by neutralizing the H_2SO_4 in DDGS, and improve growth performance of steers. However, no differences ($P \geq 0.21$) were observed in final BW, ADG, DMI, or feed efficiency as the concentration of NaOH in the diets was increased (Table 2). Morrow et al. (2013) observed that when lambs were fed 2% NaOH treated DDGS on 60% DDGS-based diets, there was a significant greater than 4% increase in final BW and tendency for greater ADG and DMI for lambs fed diets containing DDGS treated with NaOH compared to lambs fed DDGS that had not been

Table 2. Growth performance of beef steers fed 50% DDGS-based diets with increasing NaOH concentration[1]

	% NaOH inclusion in the DDGS					*P*-value[2]	
Item	0	0.5	1.0	1.5	SE	Linear	Quadratic
n	30	29	30	29	-	-	-
Initial BW, kg	318	319	321	319	3.67	0.73	0.60
Final BW, kg	601	606	616	609	6.83	0.27	0.35
ADG, kg	2.07	2.10	2.15	2.12	0.036	0.21	0.36
DMI, $kg \cdot d^{-1}$	12.60	12.77	12.89	12.82	0.22	0.40	0.57
G:F[3]	0.165	0.165	0.167	0.166	0.003	0.61	0.78

[1]Days on feed was 137 for all animals.

[2]Orthogonal polynomial contrasts for increasing NaOH inclusion in the diets.

[3]G:F is calculated as ADG/DMI.

treated. However, no difference for feed efficiency in lambs was found (Morrow et al., 2013).

Similar to the results from the current trial, Schroeder et al. (2014) observed no differences in ADG or final BW when steers were fed 0% and 1.2% CaO-treated dry or modified wet DGS; however, CaO treatment reduced DMI and increased G:F regardless of DGS type. This is similar to previous research by Nuñez et al. (2014) where steers fed diets containing 60% DDGS had a linear reduction in DMI with increasing dietary CaO, up to 2.4% of the diet DM. In all of the previous reports, the authors attempt was to alleviate ruminal acid load by treating the acidic DGS with an alkaline agent.

Boukila et al. (1995) attempted to alleviate ruminal acid load by feeding sheep barley-based diets treated with alkalizing agents (1% $Ca(OH)_2$, 0.79% $Mg(OH)_2$, and 0.5% $Ca(OH)_2$ + 0.39% $Mg(OH)_2$) and reported an increase ($\geq$ 35%) in DMI, with all agents, when compared to sheep fed the control diet that had not been treated.

When DMI can be increased, ADG often increases as well because cattle are consuming more energy. In our trial, there was no effect on DMI and subsequently no effect on ADG or G:F. Nuñez et al. (2014) reported a quadratic response for ADG when cattle were fed 0, 0.8, 1.6, or 2.4% CaO, with the greatest gain in those fed the DDGS treated with 0.8% CaO. However, Nuñez et al. (2014) also pointed out that in 60% DDGS-based diets, the linear G:F increased up to 2.4% CaO inclusion on a DM basis. These authors attributed the increased G:F to the linear reduction in DMI with increasing CaO concentrations discussed above. Felix and Loerch (2011) did not treat DDGS, but fed 60% DDGS-based diets added with alfalfa haylage and found that cattle fed the added forage had increased ruminal pH and greater DMI and ADG when compared to those fed diets without additional alfalfa haylage.

Feeding DDGS as an energy source can significantly reduce ruminal pH and performance in cattle (Klopfenstein et al., 2008; Felix and Loerch, 2011; Felix et al., 2012). Initially these authors theorized these effects were caused by excessive S intake, which reduces DMI and causes polioencephalomalacia (Gould, 1998). When ruminal pH is acidic, increasing dietary S intake can increase ruminal concentrations of H_2S (Gould et al., 1997), which is also negatively correlated to DMI and feed efficiency (Uwituze et al., 2011). According to NRC (2000), the recommended dietary concentration of S for growing and finishing cattle is 0.15%, and the maximum tolerated concentration is 0.40%. The S concentrations in the current study were less than 0.215% for all diets (Table 1). These values are almost half of the maximum tolerated concentrations, and, therefore, not likely to cause any health issue, or even decrease DMI.

Table 3. Pattern of intake and meal distribution of steers fed 50% DDGS-based diets with increasing NaOH inclusion

	% NaOH inclusion in the DDGS					*P*-value[1]	
Item	0	0.5	1.0	1.5	SE	Linear	Quadratic
Meals per day	14.97	15.06	14.49	14.45	0.39	0.21	0.85
Meal size, kg	0.85	0.85	0.90	0.90	0.03	0.06	0.92
Meal Duration, min[2]	6.98	7.06	7.66	7.72	0.27	0.02	0.97
Percentage of meals consumed							
0-3h[3]	29.9	29.8	30.8	27.9	0.52	< 0.01	< 0.01
3-6h	16.6	16.7	18.1	17.0	0.32	0.06	0.05
6-9h	19.2	19.6	20.2	19.6	0.32	0.20	0.07
9-12h	15.5	14.3	12.8	13.9	0.38	< 0.01	< 0.01
12-15h	6.2	6.2	6.0	7.4	0.25	< 0.01	< 0.01
15-18h	3.5	3.8	3.1	3.8	0.18	0.69	0.21
18-21h	3.1	3.6	3.8	5.1	0.25	< 0.01	0.10
21-24h	6.1	6.1	5.2	5.3	0.30	0.02	0.90

[1]Orthogonal polynomial contrasts for increasing NaOH inclusion in the diets.

[2]Average meal event duration.

[3]Values reported as a percentage of total meals.

The lack of differences noted in the present trial may be attributed to the palatability issues associated with alkaline agents. Schroeder et al. (2014) analyzed the pattern of intake in cattle fed of dry or modified wet DGS with 0 or 1.2% CaO treatment and found that cattle fed CaO-treated DGS stood at the bunk longer but ate smaller meals more distributed throughout the day. They suggested this pattern of longer, smaller meals was indicative of reduced palatability due to the CaO treatment. In the present trial, increasing NaOH in the diet increased (linear; $P = 0.02$) meal duration and tended ($P = 0.06$) to increase meal size, but ultimately did not affect overall number of meals per day ($P = 0.21$; Table 3). Relative to cattle fed DDGS treated with 0, 0.5 or 1% NaOH (DM basis), steers fed DDGS treated with 1.5% NaOH consumed a larger proportion of their meals in the evening, 12 to 24 h post-feeding. However, regardless of treatment, all steers consumed 78% or more of their feed in the first 12 h post-feeding. Previous research has explained that acidosis is often associated with a large meal, and could be mitigated by altering animal intake in a way that smaller, more frequent meals are consumed (Britton and Stock, 1987; Pritchard and Knutsen, 1995). Felix et al. (2012) noted increased ruminal pH in cattle fed 60% DDGS-based diets treated with 2% NaOH prior to feeding and suggested that NaOH could be used as a means to mitigate acidosis in cattle fed DDGS-based diets. While differences in meal duration and distribution were strong enough to elicit statistical significance in this trial, a 1 to 2% unit change in meal distribution is not likely to be biologically relevant in the mitigation of acidosis. In addition, Freitas et al. (2015), feeding the same diets as the current experiment, did not find differences in ruminal pH or fiber disappearance/apparent digestibility among cattle fed 50% DDGS-based diets with increasing concentrations of NaOH.

We had hypothesized that treating DDGS with increasing levels of NaOH would neutralize DDGS acidity, which subsequently could enhance fiber fermentation and increase energy supply to the steers, thereby increasing HCW. However, similar to the responses observed for growth performance, feeding steers increasing dietary inclusions of NaOH did not affect ($P \geq 0.19$) HCW, LM area, dressing percentage, KPH %, fat thickness, and marbling (Table 4). Similarly, Nuñez et al. (2014) found that HCW, LM area, fat thickness, or marbling of steers fed 60% DDGS-based diets with increasing levels of CaO did not differ among treatments. On that trial, there was a linear decrease for KPH and a quadratic response for dressing percentage; however, authors did not explain those responses.

Table 4. Carcass characteristics of steers fed 50 % DDGS-based diets with increasing NaOH inclusion

	% NaOH inclusion in the DDGS					*P*-value[1]	
Item	0	0.5	1.0	1.5	SE	Linear	Quadratic
n	30	29	30	29	-	-	-
HCW, kg	371	376	381	378	4.75	0.19	0.38
LM area, cm^2	85.0	82.9	85.6	85.9	1.53	0.41	0.42
Dressing %[2]	61.58	61.89	61.79	62.00	0.295	0.38	0.87
KPH %	2.07	2.06	2.08	2.00	0.037	0.25	0.32
Back fat, cm	1.62	1.70	1.64	1.61	0.075	0.79	0.43
Marbling score[3]	455	455	436	431	15.919	0.19	0.89

[1]Orthogonal polynomial contrasts for increasing NaOH inclusion in the diets.

[2]Dressing percentage was calculated by dividing hot carcass weight by final body weight.

[3]For marbling score: 300 to 399 = slight; 400 to 499 = small; 500 to 599 = modest.

Freitas et al. (2015), feeding the same diets as this current experiment, found no difference in acetate or propionate concentrations nor difference in ruminal fiber disappearance or fiber apparent digestibility as NaOH inclusion increased in the diets. Propionate can be converted to glucose, which is a precursor for marbling (Smith and Crouse, 1984), and cattle fed increasing concentration of DDGS in the diet can have increasing molar concentrations of propionate in the rumen (Felix et al., 2012). However, increased dietary inclusion of DGS have also been associated with decreasing marbling scores in cattle (Klopfenstein, et al., 2008; Gunn et al., 2009; Schoonmaker et al., 2010; Luebbe et al., 2012). In this current study, with 50% DDGS-based diets, marbling scores among treatments were similar to studies that fed feedlot steers corn-based diets with no or low DGS (Schoonmaker et al., 2002; Koger et al., 2010; May et al., 2011). As expected, Quality Grade response followed marbling score (Table 4) and was not different (linear; $P \geq 0.11$; Table 5) among treatments. Similar to this current study, no difference in USDA Quality Grade was observed when researchers treated DDGS with CaO prior to feeding (Nuñez et al., 2014; Schroeder et al., 2014). However, there was a tendency for decreased proportion of carcasses grading USDA Select when feedlot steers were fed 60% DDGS-based diets added with alfalfa haylage (Felix and Loerch, 2011).

Yield Grade, an important estimate of carcass cutability or percentage of retail product, is calculated, or subjectively determined, based on back fat, KPH, HCW, and LM area. Because there was no difference in any of the aforementioned characteristics according to the dietary treatments, it would be reasonable not to have differences in USDA Yield Grade. However, there was an unexpected linear ($P = 0.03$) decrease in carcasses grading USDA Yield Grade 3 and a tendency ($P = 0.09$) for a quadratic response in carcasses grading USDA Yield Grade 4 as we increased NaOH concentration in the diets (Table 5). The reasons for these responses are not clear.
Similar to the carcass characteristics found in this current study, no differences in yield grade of steers have been found when trying to diminish ruminal acid load in other studies (Felix and Loerch, 2011; Nuñez et al., 2014; Schroeder et al., 2014).

We had hypothesized that increasing NaOH concentration in the DDGS prior to feeding would neutralize its inherent acidity, which subsequently could improve fiber utilization and growth performance of steers. The fact that increasing levels of NaOH up to 1.5% treating DDGS acidity did not improve growth performance or carcass characteristics in this study was likely due

Table 5. USDA Grades for carcasses from steers fed DDGS-based diets with increasing NaOH inclusion

	% NaOH inclusion in the DDGS					*P*-value[1]	
Item	0	0.5	1.0	1.5	SE	Linear	Quadratic
N	30	29	30	29	-	-	-
USDA Yield Grade[2]							
1, %	6.7	0.0	0.0	6.9	1.70	1.00	0.98
2, %	20.0	20.7	33.3	34.5	3.40	0.11	0.79
3, %	70.0	58.6	50.0	41.4	5.30	0.03	0.84
4, %	3.3	20.7	16.7	17.2	3.31	0.15	0.09
5, %	0.0	0.0	0.0	0.0	0.00	1.00	1.00
USDA Quality Grade[3]							
Prime, %	6.7	0.0	3.3	3.4	1.18	0.98	0.98
Choice, %	66.7	79.3	63.3	62.1	3.41	0.42	0.38
Select, %	16.7	13.8	26.7	31.0	3.52	0.11	0.64
Dark Cutters, %	6.7	6.9	6.7	3.4	0.73	0.59	0.65

[1]Orthogonal polynomial contrasts for increasing NaOH inclusion in the diets.

[2]Carcass Yield Grade was calculated (USDA, 1997).

[3]Treatment 0 had 1 animal that was qualified as Bloodshot, which corresponds to 3.3%.

to the lack of acidity (pH = 5.5) relative to previous trials (some citing pH as acidic as 3.2). Changes in acidity of DDGS from plant to plant production could have significant impacts on the feeding value of DDGS. Routine pH analysis, prior to use these DGS, is necessary to determine the impact alkaline agents may have in preventing ruminal acidosis and improving feedlot growth performance.

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CAPÍTULO 3

Effects of increasing palm kernel cake inclusion in supplements fed to grazing lambs on growth performance, carcass characteristics, and fatty acid profile[1]

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ABSTRACT

The aim of this study was to evaluate the effects of the inclusion of palm kernel cake (PKC) in the supplement composition for grazing lambs on intake, digestibility, growth performance, carcass characteristics and fatty acid profile of the meat. Thirty-one non-castrated Santa Inês-crossed male lambs (age =120 ± 15 d; IBW = 20 ± 3.9 kg) were divided into 4 lots, following a completely randomized design. Treatments were 0%, 10%, 20%, and 30% PKC substitution for ground corn and wheat bran in the supplement. Animals were stratified to equalize body weight and placed into 4 groups: 8 animals in treatment 0%; 8 in treatment 10%; 6 in treatment 20%; and 9 in treatment 30%. Lambs were fed for 84 d and grazed a predominantly *braquiarão* grass (*Urochloa brizantha* cv. Marandu) and Tifton 85 (*Cynodon dactylon*) grass pasture. The remainder of the supplement contained soybean meal, wheat bran, ground corn, urea, and mineral salt. The level of supplementation was 1.6% BW per animal/d. There was a linear decrease ($P < 0.01$) for total DM intake and pasture intake (linear; $P < 0.01$) as the inclusion of PKC in the supplement was increased. Feeding increasing PKC in the supplement did not affect ($P \geq 0.35$) lamb growth performance nor did it affect most carcass characteristics ($P \geq 0.16$). However, it did lower conformation ($P = 0.02$) and carcass shrink ($P = 0.03$). Palmitic fatty acid decreased (linear; $P = 0.04$) as PKC fed to lambs increased in the supplement. No other fatty acids were affected ($P \geq 0.10$). Feeding up to 30% PKC in a supplement for grazing lambs reduced DMI without altering ADG or economic measures of carcass characteristic.

Key words: digestibility, fatty acids, grazing supplementation, lambs, palm kernel cake

INTRODUCTION

The sheep industry in Brazil is characterized predominantly by grazing systems; however, forage production is intermittent throughout the year. Thus, supplementation with coproducts from the biofuel industry become a viable alternative. Among the coproducts generated is palm kernel cake (**PKC**; *Elaeis guineensis* Jacq.), the residue obtained after palm seed oil extraction. Palm kernel cake contains between 7 to 10% lipid (Chin, 2002; Macome et al, 2011; Ribeiro et al., 2011). Research has shown that the addition of excess fat in ruminant diets can negatively affect fiber digestibility and growth performance (Jenkins, 1993).

In addition to the productive aspects, there is a growing concern of the effect of saturated fatty acids in red meat on human health. Meat from ruminant animals typically contains mostly saturated fatty acids (40 to 60%) and small amounts of polyunsaturated fatty acids (around 5%; Sinclair, 2007; Wood et al., 2008; Noviandi et al., 2012). Saturated fatty acids (**SFA**) are associated with coronary heart disease (Shingfield et al., 2013) while polyunsaturated fatty acids (**PUFA**) can have benefits for consumer health (Howes et al., 2015; Ooi et al., 2015). Thus, increasing the content of PUFA, particularly the omega-3 (C18:3 *n*-3, linoleic acid; C20:5 *n*-3, eicosapentaenoic acid (**EPA**), C22:6 *n*-3 docosahexaenoic acid (**DHA**)), and conjugated linoleic acid (**CLA**), in meat products could lead to a product that is perceived as healthier (Shingfield et al., 2013; Ponnampalam et al., 2014; Howes et al., 2015). Although the profile of fatty acids in the muscle of ruminant animals are less affected by the profile of fatty acids in the diet than non-ruminant animals, the diet can influence the quality of fatty acids in the meat (Sinclair, 2007; Palmquist, 2009; Shingfield et al., 2013).

Our hypothesis was that the inclusion of PKC up to the level of 30% in the supplements for grazing lambs could influence productive parameters, carcass characteristics and profile of fatty acids in the meat.

Thus, the aim of this study was to evaluate the effects of increasing inclusions of PKC in supplement on growth performance, digestibility, carcass characteristics, and fatty acid profile in the meat of grazing lambs.

MATERIALS AND METHODS

Animals and Diets

The experiment was conducted at the Sheep and Goat Sector of the Animal and Rural Technology Department (DTRA) of the Universidade Estadual do Sudoeste da Bahia (UESB) in Itapetinga city - Bahia, from November of 2012 to February of 2013. The latitude and longitude of Itapetinga are 15° 15' South and 40° 15' West, respectively, and it is situated at 280 m altitude. The climate, according to Köppen classification, is a "Cw" mesothermal humid and warm sub-humid with dry winter. Between November and February, months of this trial, the climate is characterized as hot and rainy. The total annual rainfall is 867 mm on average. Precipitation and monthly average temperatures during the trial period, as well as during the month that preceded it, are shown in table 1 in order to better display the influence of climate variables on the pasture environment.

Table 1. Weather data recorded from October of 2012 to February of 2013 in Itapetinga - BA

	Months				
Item	Oct/12	Nov/12	Dec/12	Jan/13	Feb/2013
Temp. maximum average, °C	27.9	27.7	31.0	30.0	29.6
Temp. minimum average, °C	20.6	22.4	22.8	23.3	22.8
Temp. Absolute Maximum, °C	35.0	34.0	36.0	35.0	34.0
Temp. Absolute Minimum, °C	16.0	20.0	19.0	20.0	20.0
Relative humidity, %	69.9	73.8	62.5	68.1	65.8
Rainfall, mm	34.0	280.0	0.0	91.0	38.0

Source: INMET, National Institute of Meteorology. Website: www.inmet.gov.br.

Thirty-one Santa Inês-crossed, non-castrated lambs (120 ± 15 d old; initial BW = 20.0 ± 3.9 kg) were used in this trial. The experimental area used was 5,640 m^2 and was divided into 4 paddocks. Each paddock was provided with drinking and feed troughs with 20 cm of linear bunk space per head to allow the feeding of all animals simultaneously. Immediately before starting the experimental period, the animals underwent a 14-d adaptation period. From day -14 to day -8, they were all fed 0.8% BW per head of the 0% treatment diet (with no PKC), and from day -7 to day 0, they were fed 1.6% BW of the 0% treatment and kept on pasture. During this period, the lambs were dewormed with Cydectin® (Moxidectin 1%; Fort Dodge Animal Health, Fort Dodge, IA), vaccinated (5 mL subcutaneous, Poli-Star®; Vallée S.A., São Paulo, SP, Brazil) for clostridial diseases and identified with individual ear tags.

Table 2. Pasture characteristics during the experimental period

Item	Period			Average
	Nov/Dec	Dec/Jan	Jan/Feb	
Forage mass, kg/ha	5028	4668	6852	5516
DMpd availability, kg/ha[1]	2644	2702	3318	2888
Forage height, cm	45	37	41	41
Leaves, %[2]	31.93	24.27	20.64	25.61
Culms, %[2]	41.23	66.87	40.72	49.61
Dead matter, %[2]	26.84	8.86	38.64	24.78
Leaf : steam ratio	0.77	0.36	0.51	0.55

[1]DMpd = potentially digestible dry matter. DMpd = 0.98 * (100 - NDF) + (NDF - iNDF).

[2]Leaves, culms, and dead matter were determined via visual appraisal.

After the adaptation period, all 31 animals were randomly allotted to 1 of 4 dietary supplements. The supplements contained 4 inclusions of PKC (0%, 10%, 20%, and 30% on a DM basis) to replace ground corn and wheat bran. There were 8 replicates (lambs) on treatment 0%, 8 lambs on treatment 10%, 6 lambs on treatment 20%, and 9 lambs on treatment 30%. The remainder of the supplements were wheat bran, corn, urea, and mineral salt (Table 3). Lambs grazed on pasture that was predominantly braquiarão grass (*Urochloa brizantha* cv. Marandu) and Tifton 85 (*Cynodon dactylon*). The supplements were made according to the nutritional recommendations of NRC (2007), to target an ADG of 200 g and 20% CP. Lambs were fed at 1.6% BW per animal/d, on pasture, once daily at 1000 h.

The experiment was 84 d. The lambs changed paddocks every 7 d, at random, through all 4 paddocks, in order to reduce the effect of forage biomass from each paddock.

Sampling and Analysis

The forage mass (kg DM per ha) was estimated in 28-d intervals. Five samples were taken per paddock at soil level using a 0.25 m^2 square according to methodology described by McMeniman (1997). At the time of collection, 2 sub-samples per paddock were used to further characterize the pastures: one was weighed and taken immediately to a forced air circulation oven set at 55 °C for 72 h and subsequently ground for further determination of the chemical analysis (DM, NDF and iNDF; described below); and the other was used to determine the structural components of the pasture. Destructive sampling, where manual separation of harvested forage in to leaves (leaf blades), culms (stems + sheaths), and dead material, was used to determine the structural components of the pasture. The proportions of components in samples were calculated as the percentage of the total weight after they dried for 72 h in an oven with forced ventilation at 55 °C. The potentially digestible DM (DMpd) was estimated according to the equation:

$$DMpd = 0.98 \times (100 - NDF) + (NDF - iNDF)$$

where: NDF = neutral detergent insoluble fiber; and **iNDF** = indigestible NDF.

Forage height was also measured at the beginning of each period, at 10 random points in each paddock, using a graduated ruler measuring from the bottom to the canopy of the pasture.

Forage collection for chemical composition analysis was performed according to Sollenberger and Cherney (1995), by grazing simulation. Approximately 300 g of fresh forage per paddock was collected manually in the beginning of each period.

Forage and supplement ingredients were analyzed for DM, nitrogen (**N**), ether extract (**EE**), ash (**OM** was calculated by difference), neutral detergent fiber (**NDF**) and acid detergent fiber (**ADF**), neutral detergent insoluble nitrogen (**NDIN**), acid detergent insoluble nitrogen (**ADIN**), and lignin as methods described in AOAC (2000). The neutral detergent fiber corrected for ash and protein (**NDFap**) was estimated according to Hall (2003). Feces were analyzed for DM, N, EE, ash, and NDFap. The percentage of total carbohydrates in feed and feces were obtained from the equation: TC = 100 - (%CP + %EE + %ash) according Sniffen et al. (1992), and non-fibrous carbohydrate (**NFC**) in forage, using the equation: NFC = 100 - %NDFap - %CP - %EE - %ash, according to Hall (2000). Urea was used as a source of non-protein N. Thus, dietary levels of NFC in supplements were estimated by adjusting Hall proposition (2000): NFC = 100 - [(CP - CPu + U) + EE + ash + NDFap]; where: CPu = CP content from urea (%); and U = urea content (%).

For indigestible dry matter (**iDM**), iNDF, and indigestible acid detergent fiber (**iADF**), dietary samples were incubated for 288 hours in the rumen of two Holstein-Zebu-crossbred cows (H × Z) for later determinations of iDM content, iNDF and iADF, following procedures described by Detmann et al. (2012).

Carbohydrate fractions were estimated according to Sniffen et al. (1992) and Hall (2003), as cited above. Total digestible nutrients (**TDN**) was calculated as the sum of digestible crude protein (**DCP**), digestible neutral detergent fiber corrected for ash and protein (**DNDFap**), digestible non-fibrous carbohydrates corrected for ash and protein (**DNFCap**), and digestible ether extract (**DEE**) multiplied by 2.25, according to Weiss (1999): TDN = DCP + DNDFap + DNFCap + (DEE × 2.25).

Table 3. Composition of supplements fed to lambs and grazed forage

	PKC[1] inclusion in the supplement				Forage
Item, % DM basis	0%	10%	20%	30%	
Ground corn	41.5	38.3	39.0	26.7	
Wheat bran	36.0	27.3	17.5	20.8	
Soybean meal	17.1	19.0	18.1	17.1	
Palm kernel cake[1]	0.0	10.0	20.0	30.0	
Urea	1.8	1.8	1.8	1.8	
Mineral mixture[2]	3.6	3.6	3.6	3.6	
Analyzed composition, %					
Organic matter[3]	91.88	91.93	93.06	91.38	90.66
Crude protein	20.50	21.50	21.20	21.90	11.31
NDIP, % CP[4]	21.93	24.92	27.87	29.09	33.24
ADIP, % CP[5]	11.85	16.69	19.01	22.74	25.85
Ether Extract	4.07	4.73	5.19	6.05	3.06
Total Carbohydrates[6]	67.31	65.70	66.67	63.43	76.29
Non-fiber carbohydrates[7]	39.34	34.65	32.35	23.82	9.92
NDF	34.17	37.41	40.81	46.83	74.42
NDFap[8]	30.69	33.77	37.04	42.33	66.37
ADF	9.90	15.39	20.09	27.86	39.56
Lignin	2.55	3.79	5.48	7.68	6.05
iNDF[9]	8.05	11.00	13.29	18.17	34.25

[1]PKC: palm kernel cake. Chemical composition: DM, 94.85%; CP, 14.70%; NDIP, 51.53%; ADIP, 45.67%; EE, 10.26%; NDF, 81.06%; NDFap, 75.51%; iNDF, 44.04%; ADF, 62.40%; Lignin, 18.84%; Ash, 2.92%.
[2]Mineral mixture per kg of DM contained: 150 g Ca as $CaCO_3$, 65 g P as $CaHPO_4$, 107 g Na as NaCl, 12 g S as S_8, 6 g Mg as MgO and $MgSO_4$, 175 mg Co as $CoSO_4$, 100 mg Cu as $CuSO_4$, 175 mg I as $Ca(IO_3)_2$, 1,440 mg Mn as $MnSO_4$, 27 mg Se as Na_2SeO_3, 6 g Zn as $ZnSO_4$.
[3]OM = 100 – Ash.
[4]NDIP = neutral detergent insoluble protein, as percentage of CP.
[5]ADIP = acid detergent insoluble protein, as percentage of CP.
[6]TC = 100 - (%CP + %EE + %ash).
[7]For supplement: NFC = 100 - [(CP - CPu + U) + EE + ash + NDFap]; where: CPu = CP content from urea (%); and U = urea content (%);
For forage: NFC = 100 - %NDFap - %CP - %EE - %ash.
[8]NDFap = neutral detergent fiber corrected for ash and protein.
[9]iNDF = indigestible neutral detergent fiber. Samples were incubated for 288 hours.

Feed intake

Estimation of feed intake for grazing animals is a challenge under experimental conditions. However, researchers have validated the estimation of herbage and supplement intake with the aid of external and internal markers (Smit et al., 2005; Undi et al., 2008; Hellwing et al., 2015; Saliba et al., 2015).

Fecal production estimation

To estimate fecal production, Enriched and Purified Isolated Lignin from *Eucalyptus grandis* (LIPE®; UFMG, Minas Gerais, Brazil) was used as external marker (Saliba et al., 2015). A 250 mg capsule containing LIPE® was orally administered for each animal for 6 consecutive days (d 7 to d 12 of period 2); the first 2 d were to stabilize the fecal excretion of the marker. Fecal samples were collected directly from the rectum twice a day at 0800 h and 1500 h for 5 consecutive days (from d 9 to d 13 of period 2) and stored in a cold chamber at -10 °C. After that, the fecal samples were dried, ground and composed. Approximately 10 g of each composed sample of feces was sent to the Federal University of Minas Gerais (UFMG) to estimate the total daily fecal output (Saliba et al., 2015).

Supplement intake

To determine the DM intake (**DMI**) of the supplement (SI), titanium dioxide was used as an external marker, according to the equation:

$$SI = (FP * CTF) / CTS$$

where SI is the DMI of the supplement (g/d); FP is the daily fecal production (g/d); CTF is the concentration of titanium dioxide (TiO_2) in feces (g/g DM) and CTS is the concentration of titanium dioxide in the supplement (g/g DM).

Five grams of TiO_2 for each 495 g of supplement (1% concentration) were mixed. This mixture was offered to the animals for 12 d (a 7-d adaptation period to obtain a more homogeneous excretion plateau, and for 5 days of fecal collection). The adaptation period was from d 2 to d 8 of period 2. The 5 days of fecal collection were the same for fecal production estimation (from d 9 to d 13 of period 2). The fecal TiO_2 content was determined according to Myers et al. (2004).

DM intake estimation

Total apparent digestibility and DMI was estimated from fecal production, verified with the aid of LIPE as external marker and iNDF as internal marker.

Dry matter intake was obtained by the following equation:

$$DMI = \{[(FP * IMF) - IMS] / IMF\} + SI$$

where DMI = dry matter intake (kg/d); FP = fecal production (kg/d); IMF = concentration of the internal marker (iNDF) in feces (kg/kg); IMS = iNDF intake from supplement (kg/d); IMF = concentration of iNDF present in forage (kg/kg); and SI is the supplement intake (DM basis; kg/d).

Growth Performance and Feed Efficiency

Animals were weighed once at the beginning and once at the end of the trial, after fasting for about 16 to determine initial BW (**IBW**), final BW (**FBW**), ADG, and feed efficiency (**G:F**). Intermediate weight measurements were taken every 28 d to adjust the supplement supply. Feed efficiency was determined by dividing the weight gain (kg) by the amount of feed intake (kg) during the experimental period.

Carcass characteristics

At the end of the experiment, the animals were slaughtered in the slaughterhouse of the Goats and Sheep Experimental Unit (**UECO**) of the university (UESB). After evisceration, carcasses were weighed to obtain the hot carcass weight (**HCW**) and, soon after, were sent to cold storage at 4 °C, where they remained for a period of 24 h, hanging by the metatarsal joint. After cooling, carcasses were weighed to obtain cold carcass weight (**CCW**), back fat, carcass length, and conformation were measured. The carcass length was measured from the front edge of the pubic bone to the cranial edge of the first rib; the back fat was taken on the external surface of the Longissimus dorsi muscle between the 12th and 13th ribs, using a caliper. Dressing percentage and carcass shrink were calculated as HCW/FBW × 100 and (HCW – CCW) ×100 / HCW, respectively. Evaluation of carcass conformation was set as follows: Concave = 1; Sub rectilinear = 2; Rectilinear = 3; Sub convex = 4; and Convex = 5. This subjective evaluation was adapted from the EUROP system assessment lamb carcasses (European Community, 1992).

Between the 9th and 11th ribs, a portion of the Longissimus dorsi was removed to determine the fatty acid profile.

Table 4. Fatty acid profile in the PKC, supplements, and forage

	PKC[1]	PKC inclusion in the supplement				Forage
Item		0%	10%	20%	30%	
C 6:0	0.10	0.45	0.40	0.35	0.28	0.32
C 8:0	0.71	0.17	0.23	0.28	0.38	0.12
C 10:0	0.08	0.31	0.29	0.30	0.29	0.09
C 12:0	37.75	1.07	3.86	7.21	13.30	0.93
C 13:0	0.14	0.09	0.09	0.14	0.16	0.16
C 14:0	19.51	1.88	4.34	6.80	9.13	0.32
C 14:1 *n*-5	0.04	0.04	0.01	0.04	0.07	2.39
C 15:0	0.03	0.36	0.30	0.22	0.22	0.46
C 16:0	11.76	17.74	16.35	16.70	16.62	21.84
C 16:1 *n*-7	0.06	0.18	0.15	0.10	0.07	0.67
C 17:0	0.09	0.15	0.15	0.14	0.08	1.12
C 17:1 *n*-7	0.08	0.29	0.30	0.79	0.65	1.08
C 18:0	4.22	1.01	1.25	1.99	2.71	4.90
C 18:1 *n*-9	19.70	31.12	29.79	25.88	26.34	19.46
C 18:2 *n*-6	3.28	36.86	34.90	31.07	24.23	20.40
C 18:3 *n*-6	0.17	0.66	0.54	0.49	0.42	1.20
C 20:0	0.00	1.85	1.78	1.46	1.33	0.24
C 18:3 *n*-3	0.00	1.16	1.22	1.27	1.22	1.86
C 20:1	0.15	0.90	0.76	0.71	0.60	0.91
C 20:2	0.00	0.44	0.39	0.35	0.34	9.83
C 21:0	0.02	0.26	0.22	0.25	0.23	0.35
C 20:3 *n*-6	0.01	0.02	0.05	0.05	0.06	0.18
C 22:0	0.11	0.39	0.39	0.31	0.28	1.68
C 20:3 *n*-3	0.07	0.16	0.12	0.11	0.10	0.24
C 23:0	0.15	0.50	0.36	0.66	0.56	0.79
C 20:4 *n*-6	0.08	0.13	0.10	0.13	0.10	1.23
C 24:0	0.15	0.48	0.34	0.43	0.21	3.34
C 20:5 *n*-3	0.01	0.29	0.24	0.17	0.19	0.64
C 22:5 *n*-3	0.39	1.05	0.94	0.80	0.52	3.25
SFA[2]	75.72	26.72	30.31	36.97	45.00	36.66
MUFA[3]	20.27	32.53	31.02	27.52	27.91	24.51
PUFA[4]	4.01	40.76	38.66	35.51	27.08	38.82
n-6[5]	3.54	37.66	35.78	32.78	24.70	23.01
n-3[6]	0.46	2.66	2.51	2.35	2.04	5.98
n-6/*n*-3	7.63	14.16	14.25	13.98	12.12	3.85
PUFA/SFA	0.05	1.53	1.28	0.95	0.60	1.06

[1]PKC: palm kernel cake.

[2]SFA: saturated fatty acid = sum of C 6:0, C 8:0, C 10:0, C 12:0, C 13:0, C 14:0, C 15:0, C 16:0, C 17:0, C 18:0, C 20:0, C 21:0, C 22:0, C 23:0, and C 24:0.

[3]MUFA: monounsaturated fatty acid = sum of C 14:1 *n*-5, C 16:1 *n*-7, C 17:1 *n*-7, C 18:1 *n*-9, and C 20:1.

[4]PUFA: polyunsaturated fatty acid = sum of C 18:2 *n*-6, C 18:3 *n*-3, C 18:3 *n*-6, C 20:2, C 20:3 *n*-3, C 20:3 *n*-6, C 20:4 *n*-6, C 20:5 *n*-3, and C 22:5 *n*-3.
[5]Omega 6 = sum of C 18:2 *n*-6, C 18:3 *n*-6, C 20:3 *n*-6, C 20:4 *n*-6.

[6]Omega 3 = sum of C 18:3 *n*-3, C 20:3 *n*-3, C 20:5 *n*-3, and C 22:5 *n*-3.

Total lipid extraction

To obtain the sample fatty acid profile, extraction was made with a mixture of chloroform, methanol and water (2:2:1.8 v/v/v), respectively, according to Bligh and Dyer (1959). Approximately 10 g of a Longissimus dorsi sample was placed into a 250 mL beaker, in which 15 mL of chloroform and 30 mL of methanol were added, and stirred for 5 minutes. Next, another 15 mL of chloroform was added, stirring the mixture again for 5 minutes. After, 15 mL of distilled water was added to the solution, maintaining it stirring for 5 more minutes. The obtained solution was vacuum filtered through a Büchner funnel with a quantitative filter paper, which was further added to the residue 15 mL of chloroform, keeping it stirring for 5 min. The residue was filtered by using the same filter paper and the beaker wash washed/rinsed with 10 mL of chloroform.

The filtrate was collected in a separation funnel and added 10 mL of sodium chloride solution. After separation of the phases, the lower one, chloroform- and grease-containing matter, was collected in a round bottom flask, and rotary evaporated (bath at 33 - 34 °C). The solvent residue was removed with nitrogen flow. The remaining material in the flask was weighed and the lipid content determined by gravimetry.

Transesterification of triacylglycerol

The transesterification of triacylglycerol was performed according to the ISO 5509 method (1978). Approximately 200 mg of extracted lipid matter was transferred to 10-mL screw-cap tubes, in which 1 mL of n-heptane was added and stirred until complete dissolution. Then, 2 mL of 2 M KOH in methanol was added. The flask was tightly closed and the mixture underwent vigorous stirring to obtain a slightly cloudy solution. After the occurrence of the separation of phases, the upper (heptane and methyl esters of fatty acids) was transferred to 2.5 mL Ependorf capacity, hermetically sealed and stored in a freezer (-18 °C) for further chromatographic analysis. Fatty acid esters were quantified by gas chromatography (Shimadzu 14 A®) equipped with a flame ionization detector and silica-capillary column (100 m long, 0.25 mm internal diameter, and 0.20 μm Carbowax 20 M) with a flow of 1.2 mL/min of H_2 (carrier gas), 30 mL/min of N_2 (auxiliary gas), 30 mL/min, and 300 mL/min for the H_2 and synthetic air, respectively, to the flame detector. The fatty acid profile was expressed as percentage of total fatty acid.

Statistical Analysis

The design was completely randomized with 4 treatments in the model:

$$Y_{ij} = \mu + T_i + e_{ij}$$

where Y_{ij} = observed value for the characteristic analyzed; μ = mean; T_i = effect of diet; e_{ij} = experimental error.

Data were evaluated by analysis of variance and polynomial regression using the MIXED procedure of SAS statistical software (SAS Inst. Inc., Cary, NC; 2005). For all variables, the animal was considered the experimental unit and orthogonal contrasts were used to detect the linear and quadratic effects of the increase in levels of castor bean meal replacing soybean meal in supplements. The level of probability of 0.05 was adopted for the type I error.

RESULTS AND DISCUSSION

Intake and nutrient digestibility

There was a decrease (linear; $P < 0.01$) in total DMI (g/d) among treatments as PKC was increased in the supplement (Table 5). Intake was reduced 19.5% from treatment 0% to treatment 30%. The decrease in DMI can be explained by the increase of NDF and lignin concentrations in the supplement (Table 3) PKC inclusion increased. Forage intake also decreased (linear; $P < 0.01$) as PKC inclusion increased in the supplement. This response influenced the overall DMI because the supplement intake was kept at 1.6% BW for all treatments, and there was no leftovers in the troughs. Despite the increase in the NDFap concentration in supplements as PKC inclusion increased (Table 3), NDFap (g/d) intake decreased (linear; $P = 0.02$) as PKC was increased in the supplement. Again, the reduction in NDFap intake follows the general reduction in overall intake. There was no difference ($P \geq 0.26$) in CP intake, however, with a mean of 97.3 g/d among all treatments. In lambs grazing pasture and consuming supplements in the current trial, at least 80% of their CP intake was provided by the supplement, which did not vary among group due to the feeding for percent of BW, thus, all group were fed similar protein and the lack of effect on CP intake would be expected. The EE content of PKC in this experiment was 10.26%. Thus, with increasing levels of PKC, supplements increased EE concentration, from 4.07% to 6.05%; and, EE concentration in the supplements were greater than the values presented in forage (3.06%). Thus, even with the decrease in forage intake, maintenance of supplement consumption explains the linear effect (*P* = 0.03) of EE intake (g/d) as PKC increased in the supplement. There was also a negative effect (*P* < 0.01) of treatment on NFC and TDN intake as PKC was increased in the diet because these components were reduced in the supplement as PKC replace corn and wheat bran.

Table 5. Growth performance, daily nutrient intake, and nutrient apparent total tract digestibility in grazing lambs supplemented with increasing levels of PKC

	PKC inclusion in the supplement					*P*-value	
Item	0%	10%	20%	30%	SEM	Linear	Quadratic
n[1]	8	8	6	9	-	-	-
Initial BW, kg	19.95	20.27	20.86	19.03	0.69	0.73	0.47
Final BW, kg	31.20	31.48	32.95	29.49	2.10	0.70	0.39
ADG, g/d	133.9	133.5	143.9	124.6	6.34	0.76	0.48
Feed efficiency[2]	0.260	0.248	0.276	0.289	0.014	0.35	0.65
Dry matter intake, g/d	544.7	540.4	511.0	438.5	13.76	< 0.01	0.16
Forage intake, g/d	143.0	134.0	88.5	57.4	8.85	< 0.01	0.39
Supplement intake, g/d	401.7	406.4	422.5	381.0	15.94	0.75	0.50
PKC intake, g/d	0.0	40.6	84.5	114.3	8.69	< 0.01	0.33
NDFap intake, g/d[3]	218.2	226.2	215.2	199.4	3.56	0.02	0.08
CP intake, g/d	98.5	102.5	99.6	89.9	2.93	0.27	0.26
EE intake, g/d	20.7	23.3	24.6	24.8	0.71	0.03	0.39
NFC intake, g/d[4]	172.2	154.1	145.5	96.5	7.17	< 0.01	0.14
TDN intake, g/d[5]	337.1	332.8	312.4	238.3	13.86	< 0.01	0.17
Digestibility, %							
Dry matter	57.13	56.71	55.00	47.09	1.34	< 0.01	0.12
NDFap	36.86	36.54	35.74	30.49	1.49	0.13	0.42

[1]Number of lambs.

[2]Feed efficiency = ADG /DMI.

[3]NDFap = neutral detergent fiber corrected for ash and protein.

[4]NFC = non-fiber carbohydrate.

[5]TDN = total digestible nutrients. TDN intake (g) = DCP (g) + DNDFap (g) + DNFCap (g) + DEE (g) × 2.25.

There was a negative effect (linear; *P* < 0.01) of treatment on DM digestibility as PKC was increased in the diet (Table 5). The lower digestibility can be explained by the increase in indigestible fractions as PKC increased in the supplement: approximately 90% increase in ADIP concentration, from 11.85 to 22.47%; increase in the NDF and iNDF fractions; and increase in the lignin concentrations from 2.55 to 7.68% (Table 3). Dry matter digestibility for grazing animals is usually negatively associated to NDF content in feed (Van Soest, 1994), characterized by reduced passage rate and limited DMI when diet digestibility is below 66% (Conrad et al., 1964); suggesting that DMI may have been determined by gut fill. While elevated dietary fat concentration (measured as EE) have also been shown to reduce DM digestibility (NRC, 2001), effects are generally not realized until fat concentrations in the diet exceed 6 to 7% (DM basis; Palmquist and Jenkins, 1980; Jenkins, 1993; Doreau et al., 1997). Even with the elevated fat concentration in PKC, 10.26%, the dietary fat levels were 3.8%, 4.3%, 4.8%, and 5.7% for 0, 10, 20 and 30% treatments, respectively. Further supporting the lack of effect of fat concentration on digestibilities in the current research, there were no effects ($P \geq 0.13$) of treatment on NDFap digestibility, 35.81% on average. Jenkins (1993) concluded that *type* of fat would affect ruminal fermentation rate, more specifically that fiber fermentation would be negatively affected by the presence of unsaturated fatty acids, as these would be more toxic to ruminal microorganisms. The PKC has a highly saturated fatty acid profile, 37.8% lauric acid (C12:0), 19.5% myristic (C14:0), and 11.8% palmitic acid (C16:0), totaling almost 70% only with these 3 fatty acids (Table 4). Following Jenkin's theory, the use of PKC should be less harmful to ruminal fermentation than other coproducts with the same lipid content due to the lower concentrations of unsaturated fatty acids (Wanapat et al., 2011).

Growth performance and carcass characteristics

Despite the negative correlation between dietary levels of PKC with pasture intake and apparent digestibility, there was no effect ($P \geq 0.35$) of treatments on FBW, ADG, and G:F. In agreement, Macome et al. (2011) found no difference in weight gain of 4 to 6 mo old lambs with increasing PKC in the diet, despite decreased DMI when feedlot sheep were fed diets containing 19.5% PKC (DM basis). Lambs in that trial had an ADG of 170 g/d. The ADG of the animals in the current experiment was 133 g/d.

There was no effect ($P \geq 0.19$) of treatment on HCW, cold carcass weight (CCW), and dressing %, with averages of 13.49 kg, 12.97 kg, and 43.16%, respectively (Table 6). Because weight gain and FBW were similar among treatments (Table 5), the findings on carcass weights were expected. Unexpectedly, there was a decrease (linear; $P = 0.03$) in carcass shrink as PKC was increased in the supplements. Carcass shrink is an index that suggests the degree of carcass fat cover, greater fat cover prevents the carcass from losing water during the cooling process.

Table 6. Carcass characteristics of grazing lambs supplemented with increasing levels of castor bean meal

	PKC inclusion in the supplement					P-value[1]	
Item	0%	10%	20%	30%	SEM	Linear	Quadratic
n[2]	8	8	6	9	-	-	-
HCW, kg[3]	13.74	13.74	14.26	12.52	0.520	0.50	0.43
CCW, kg[4]	13.16	13.22	13.72	12.08	0.506	0.55	0.43
Dressing %[5]	43.84	43.54	43.05	42.31	0.428	0.19	0.81
Carcass shrink, %[6]	4.27	3.90	3.78	3.55	0.122	0.03	0.78
Conformation[7]	3.3	3.3	2.8	2.7	0.118	0.02	0.75
Back fat, mm[8]	1.49	1.17	1.14	1.42	0.156	0.86	0.37
Carcass length, cm[9]	53.7	54.5	54.2	51.4	0.593	0.16	0.15

[1]Orthogonal polynomial contrasts for increasing castor bean meal inclusion in the diets.

[2]n = number of animals.

[3]Hot carcass weight.

[4]Cold carcass weight.

[5]Dressing percentage was calculated by dividing HCW by FBW.

[6]Calculated as (HCW – CCW) ×100 / HCW.

[7]Conformation was estimated as follows: Concave = 1; Sub rectilinear = 2; Rectilinear = 3; Sub convex = 4; and Convex = 5.

[8]Back fat was measured between the 12^{th} and 13^{th} ribs.

[9]Carcass length was measured from the front edge of the pubic bone to the cranial edge of the first rib.

Despite the lower energy intake as PKC was increased in the supplement (Table 5), no difference ($P \geq 0.37$) was observed among treatments on back fat. The difference on carcass shrink may be explained by the carcasses becoming more concave (P = 0.02) as PKC increased in the supplement. Our hypothesis is that carcasses with more convex conformation have a larger surface area and exposure to cold than carcasses with more concave conformation, and this may explain, partially, the higher levels of carcass shrink as conformation level shifts from more convex to more concave.

Fatty acid profile

Current research papers should not only show productive aspects of new feed and/or new forms of feeding, but also certify the population that the feed in test is not going to compromise the health of humans who will consume it. Thus, in the current study, it was concluded that there was no effect (P > 0.05) of PKC levels up to the level of 30% in the composition of supplements on the profile of fatty acids evaluated in the flesh of the lambs; the only exception was palmitic acid (C16:0), which was reduced (linear; P = 0.04) as PKC inclusion increased (Table 7).

Table 7. Fatty acid profile (%) in the *Longissimus dorsi* muscle of lambs fed increasing levels of PKC in the supplement

	PKC[1] inclusion in the supplement					*P*-value[1]	
Item	0%	10%	20%	30%	SEM	Linear	Quadratic
C 6:0	0.25	0.21	0.20	0.14	0.0407	0.37	0.89
C 8:0	0.15	0.15	0.10	0.10	0.0239	0.32	0.94
C 10:0	0.10	0.13	0.09	0.04	0.0180	0.19	0.26
C 12:0	0.21	0.10	0.10	0.16	0.0333	0.62	0.22
C 13:0	0.26	0.10	0.10	0.13	0.0498	0.41	0.46
C 14:0	1.68	1.91	1.35	1.76	0.2245	0.88	0.85
C 14:1	0.29	0.30	0.26	0.30	0.0197	0.96	0.71
C 15:0	0.73	0.70	0.84	0.96	0.0917	0.32	0.69
C 16:0	31.37	29.59	23.65	15.66	2.9098	0.04	0.60
C 16:1	1.94	1.80	2.43	3.59	0.4485	0.16	0.48
C 17:0	2.30	2.08	3.15	3.28	0.3872	0.25	0.83
C 17:1	0.90	0.83	0.96	0.73	0.0798	0.57	0.66
C 18:0	16.75	18.42	28.89	25.82	2.6844	0.12	0.66
C 18:1 *n*-9	34.87	37.28	28.16	37.70	1.8012	0.97	0.34
C 18:2 *n*-6	3.27	3.10	3.41	3.53	0.2189	0.16	0.60
C 18:3 *n*-6	0.70	0.57	1.13	0.98	0.1383	0.24	0.97
C 20:0	0.39	0.30	0.54	0.61	0.0775	0.19	0.62
C 18:3 *n*-3	0.86	0.71	1.82	1.72	0.2505	0.10	0.96
C 20:1	0.48	0.23	0.82	0.77	0.1191	0.16	0.69
C 20:2	0.19	0.08	0.09	0.13	0.0241	0.36	0.13
C 21:0	0.32	0.12	0.21	0.17	0.0382	0.30	0.31
C 20:3 *n*-6	0.29	0.18	0.47	0.50	0.0890	0.26	0.70
C 22:0	0.15	0.07	0.15	0.19	0.0230	0.35	0.23
C 20:3 *n*-3	0.71	0.54	0.32	0.49	0.0825	0.26	0.33
C 23:0	0.48	0.23	0.21	0.08	0.0659	0.06	0.63
C 20:4 *n*-6	0.11	0.05	0.15	0.17	0.0251	0.21	0.47
C 24:0	0.20	0.09	0.18	0.05	0.0429	0.38	0.94
C 20:5 *n*-3	0.17	0.10	0.21	0.22	0.0371	0.47	0.61
C 22:5 *n*-3	0.14	0.14	0.13	0.14	0.0210	0.91	0.97
SFA[2]	55.09	53.97	59.44	48.85	2.4287	0.19	0.48
MUFA[3]	38.48	40.44	32.62	43.09	1.9121	0.97	0.34
PUFA[4]	6.43	5.47	7.73	7.88	0.6513	0.20	0.70
n-6[5]	4.36	3.91	5.17	5.18	0.3110	0.17	0.42
n-3[6]	1.88	1.48	2.48	2.57	0.3185	0.30	0.90
n-6/*n*-3	2.32	2.64	2.08	2.02	0.2156	0.94	0.89
PUFA/SFA	0.12	0.10	0.13	0.16	0.0192	0.05	0.20

[1]PKC: palm kernel cake.

[2]SFA: saturated fatty acid = sum of C 6:0, C 8:0, C 10:0, C 12:0, C 13:0, C 14:0, C 15:0, C 16:0, C 17:0, C 18:0, C 20:0, C 21:0, C 22:0, C 23:0, and C 24:0.

[3]MUFA: monounsaturated fatty acid = sum of C 14:1 *n*-5, C 16:1 *n*-7, C 17:1 *n*-7, C 18:1 *n*-9, and C 20:1.
[4]PUFA: polyunsaturated fatty acid = sum of C 18:2 *n*-6, C 18:3 *n*-3, C 18:3 *n*-6, C 20:2, C 20:3 *n*-3, C 20:3 *n*-6, C 20:4 *n*-6, C 20:5 *n*-3, and C 22:5 *n*-3.
[5]Omega 6 = sum of C 18:2 *n*-6, C 18:3 *n*-6, C 20:3 *n*-6, C 20:4 *n*-6.

[6]Omega 3 = sum of C 18:3 *n*-3, C 20:3 *n*-3, C 20:5 *n*-3, and C 22:5 *n*-3.

Although the fatty acid C16:0 was kept relatively stable as PKC was added in the supplement (Table 4), this linear decrease can be explained by the decrease in forage intake, which had a C16:0 content equal to 21.84%.

The highly saturated fatty acid profile of PKC found in this study confirms the data found by Gervajio (2005) for palm kernel oil. Ribeiro et al. (2011), working with the addition of PKC up to the level of 19.5% in the diets of confined lambs, noted increased levels of C12:0 and C14:0 in the meat, and attributed this effect to the increase of these fatty acids in the 19.5% PKC diet relative to those that did not include PKC. The fact that there was no increase in the levels of these fatty acids in the flesh of sheep in this experiment can be considered beneficial. Excessive consumption of saturated fatty acids such as C12:0, C14:0, and C16:0 increase blood concentration of low-density cholesterol (LDL) in humans (Noakes et al., 1996; Denke, 2006), thereby increasing the risk of cardiovascular disease (Mihaylova et al., 2012).

In agreement with Khan et al. (2015), the current study shows that tropical forages fatty acid profile is characterized by high levels of PUFA (38.82% of total; Table 4). In addition, the forage in the current trial had greater concentrations of beneficial fatty acids for human health, such as linolenic (C18:3 *n*-3), arachidonic (C20:4), eicosapentaenoic (C20:5 *n*-3, EPA), and docosapentaenoic (C22:5 *n*-3, DPA), than the supplement. Ruminants fed forage-based diets have increased the concentrations of PUFA in meat, especially PUFA omega series 3 (*n*-3), beneficial to human health, when compared to those fed concentrate-based diets (Realini et al., 2004; Noviandi et al., 2012).

CONCLUSION

Despite the reduction in forage and total DM intakes, and reduction in apparent DM digestibility, with increasing PKC in the supplement, lamb performance was not affected. The inclusion of up to 30% of coproduct replacing ground corn and wheat bran in the composition of supplements for grazing lambs afforded similar weight gain and did not modify carcass characteristics or fatty acid profile of the Longissimus muscle of lambs when compared to a control group fed no PKC. This way, palm kernel cake can be added to supplements to lambs up to the level of 30%, and humans can eat the flesh of these animals without concern of increased levels of saturated fat in the diet and its health consequences.

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CAPÍTULO 4

Replacement of soybean meal with treated castor bean meal in supplements for grazing lambs[1]

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ABSTRACT

The objectives of this trial were to evaluate intake and nutrient digestibility, weight gain, and carcass characteristics of grazing lambs supplemented with increasing dietary inclusion of castor bean meal. Thirty-six Santa Inês-crossed, non-castrated, 120 ± 15 d old lambs (initial BW = 21.8 ± 3.4 kg) were randomly allotted to 1 of 4 dietary treatments. The treatments consisted of 4 levels of soybean meal substitution (SM) with lime treated castor bean meal (0, 33, 67, and 100%) on the DM basis. The experimental design was a completely randomized design with 4 treatments and 9 replicates (lambs) for each treatment. The experiment duration was 84 d. Supplementation level was 1.6% BW per animal/d. There was a linear decrease ($P < 0.01$) for total DM intake (g/d) and a quadratic effect (negative; $P = 0.05$) for pasture intake (g/d) as castor bean meal was increased in the supplement. There was a negative quadratic effect of castor bean meal inclusion on NDFap intake, both in g/d ($P = 0.01$) and as in BW % ($P = 0.05$). There was a decreasing linear effect of the castor bean meal dietary inclusion on CP intake ($P = 0.01$), EE intake ($P < 0.01$), and TDN intake ($P < 0.01$). There was a linear effect (negative; $P < 0.01$) on DM and NDFap digestibility coefficients. There were no effects ($P \geq 0.48$) of treatments on HCW, dressing percentage, carcass conformation, back fat or carcass length. Despite some negative effects on intake and nutrient digestibility, increasing castor bean meal inclusion in the supplement, up to the substitution of all the soybean meal in the supplement, did not affect weight gain of grazing lambs or carcass characteristics.

Keywords: carcass characteristics, growth performance, Ricinus communis, sheep, supplementation

INTRODUCTION

Sheep production in Brazil is predominantly pasture-based and is characterized by seasonality of forage production throughout the year. During the dry season, forage availability and nutritional quality decreases. As expected, animal growth follows the seasonal availability of forage, weight gain is reduced during the dry season, and, often, carcass quality of sheep grazing in the dry season is also reduced (Abouheif et al., 2013). Therefore, during the dry season in Brazil, it becomes necessary to supplement animals on pasture to improve growth performance. The aim of supplementation programs during the dry season is to provide nutrients, in quantity and quality, necessary to match the productive indexes of modern and competitive sheep industry in the tropics.

The replacement of "traditional" ingredients, such as corn and soybeans, with lower-cost ingredients that do not harm animal performance is one alternative to enhance profitability and production on these poor quality pastures. One such alternative feed source are byproducts of the biodiesel agribusiness. Among these products is castor bean meal (CBM; *Ricinus communis*). As a feed source, CBM contains 5 to 2% moisture, 21 to 40% CP, 0.1 to 1.7% EE, 38 to 47% NDF, and 30 to 35% ADF, depending on variables such as previous treatment, level of dehulling and deoiling (Diniz et al., 2010; Akande et al., 2015).

Production of castor beans is greatly increasing in Brazil. In 2014, approximately 128,000 ha of castor plants were planted (IBGE, 2015). Castor bean meal may be an economically viable alternative in ruminant feeding systems; however, the use of CBM has been limited as supplement, due to its toxicity. That is why most CBM is currently used as organic fertilizer. There are 3 anti-nutritional factors present in castor bean: ricin, ricinine, and a castor allergen. Ricin is the most important factor limiting the use of coproducts of the castor bean in animal feeding (Anandan et al., 2005). In recent studies, however, research showed that it is possible to detoxify CBM with calcium hydroxide, making the product safe for animal feeding (Oliveira et al., 2010).

The current literature related to CBM for ruminants has mainly targeted nutritional value and production performance for feedlot cattle and sheep (Diniz et al., 2010; Pompeu et al., 2012; Menezes et al., 2016), and there is little information about the effects of its use in supplements for grazing ruminants, especially growing sheep. Thus, it is necessary to establish of the optimum inclusion of CBM in supplements for grazing lambs.

Our hypothesis was that CBM in the supplement would effectively replace soybean meal without affecting intake, digestibility, weight gain, and carcass characteristics of grazing lambs.

The objectives were to evaluate the intake and nutrient digestibility, weight gain, and carcass characteristics of grazing lambs supplemented levels of increasing dietary inclusion of CBM.

MATERIALS AND METHODS

Animals and Diets

The experiment was conducted at the Sheep and Goat Sector of the Animal and Rural Technology Department (DTRA) of the Universidade Estadual do Sudoeste da Bahia (UESB) in Itapetinga city - Bahia, from June to September of 2013. The latitude and longitude of Itapetinga are 15° 15' South and 40° 15' West, respectively, and it is situated at 280 m altitude. The climate, according to Köppen classification, is a "Cw" mesothermal humid and warm sub-humid with dry winter. The total annual rainfall is 867 mm on average. Precipitation and monthly average temperatures during the trial period, as well as during the month that preceded it, are shown in table 1 in order to better display the influence of climate variables on the pasture environment.

Table 1. Weather data recorded from May to September 2013 in Itapetinga - BA

	Months				
Item	May/13	Jun/13	Jul/13	Aug/13	Sep/13
Temp. maximum average, °C	28.3	26.4	26.5	26.2	27.2
Temp. minimum average, °C	19.6	19.2	17.9	17.6	18.8
Temp. Absolute Maximum, °C	31.0	29.0	29.0	30.0	31.0
Temp. Absolute Minimum, °C	16.0	15.0	15.0	12.0	17.0
Relative humidity, %	75.0	82.8	77.8	74.8	73.2
Rainfall, mm	26.0	76.0	21.0	69.0	31.0

[1]INMET, National Institute of Meteorology. Website: www.inmet.gov.br.

Thirty-six Santa Inês-crossed, non-castrated, 120 ± 15 d old lambs (initial BW = 21.8 ± 3.4 kg) were used in this trial. The experimental area used was 5,640 m^2 and was divided into 4 paddocks, all provided with drinking and feed troughs with 20 cm of linear bunk space per head to allow the feeding of all animals simultaneously. Prior to the initiation of the trial, animals had a 14-d adaptation period to incrementally transition intakes of the supplements. From day 14 to day 8, they were all fed 0.8% BW per head of the 0% treatment diet (with no CBM), and from day

7 to day 0, they were fed 1.6% BW of the 0% treatment and kept on pasture. During this period, the lambs were dewormed with Cydectin® (Moxidectin 1%; Fort Dodge Animal Health, Fort Dodge, IA), vaccinated (5 mL subcutaneous, Poli-Star®; Vallée S.A., São Paulo, SP, Brazil) for clostridial diseases and identified with individual ear tags.

Table 2. Pasture characteristics during the experimental periods

	Period			Average
Item	Jun/Jul	Jul/Aug	Aug/Sep	
Forage mass, kg/ha	1680	1250	1114	1348
DMpd[1] availability, kg/ha	1074	673	550	765
Forage availability, kg DM/ 100 kg BW d^{-1}	4.0	2.7	2.3	3.0
Forage height, cm	22.0	18.0	16.0	18.7
Leaves, %	22.3	20.0	16.7	19.7
Culms, %	46.0	40.3	45.6	44.0
Dead matter, %	31.7	39.7	37.6	36.3
Leaf : steam ratio	0.49	0.50	0.37	0.45

[1]DMpd = potentially digestible dry matter. DMpd = 0.98 * (100 - NDF) + (NDF - iNDF).

After the adaptation period, all 36 animals were randomly allotted to 1 of 4 dietary treatments. The treatments consisted of 4 levels of soybean meal (SBM) substitution with lime treated CBM (0, 33, 67, and 100%) on the DM basis. The experimental design was a complete random design with 4 treatments and 9 replicates (lambs) for each treatment. The remainder of the supplements were wheat bran, corn, urea, and mineral salt (Table 3). Lambs grazed on pasture that was predominantly braquiarão grass (*Urochloa brizantha* cv. Marandu) and Tifton 85 (*Cynodon dactylon*). Pasture characteristics during the experimental period are shown in table 2. The supplements were made according to the nutritional recommendations of NRC (2007), to target an ADG of 200 g, with 20% CP. The level of supplementation was 1.6% BW per animal/d, coming from the supplement in the trough, which was provided daily at 1000 h. The experiment duration was 84 d. The lambs rotated paddocks every 7 days, at random, through all 4 paddocks, in order to reduce the effect of forage biomass from each paddock.

In order to detoxify the CBM, a calcium hydroxide (lime; $Ca(OH)_2$) solution was applied. Each kg of the alkaline agent was diluted in 10 liters of water and homogenized to make a solution. Then, the solution was applied to CBM in accordance to a ratio of 60 grams of lime per kg of CBM, as is, as recommended by Oliveira et al. (2007). After mixing CBM with lime solution, the

Table 3. Composition of supplements fed to lambs and grazed forage, on a dry matter basis

	Substitution Level[1]				Forage
Item	0%	33%	67%	100%	
Ground corn	46.8	50.6	58.0	65.6	
Wheat bran	28.0	24.0	16.0	8.0	
Soybean meal	20.0	13.4	6.6	0.0	
Castor bean meal[2]	0.0	6.6	13.4	20.0	
Urea	1.2	1.4	2.0	2.4	
Mineral mixture[3]	4.0	4.0	4.0	4.0	
Analyzed composition, %					
Organic matter[4]	91.20	90.59	90.07	88.85	90.12
Crude protein	18.89	18.25	18.33	17.96	11.70
NDIP, %CP[5]	30.98	33.08	36.55	39.56	40.18
ADIP, %CP[6]	23.99	26.63	31.06	35.02	35.96
Ether Extract	3.32	3.02	2.44	1.69	1.67
Total Carbohydrates[7]	68.99	69.32	69.30	69.20	76.75
Non-fiber carbohydrates[8]	39.18	40.37	40.59	39.60	17.54
NDF	38.75	38.21	39.43	41.83	72.31
NDFap[9]	31.98	31.48	32.33	33.94	59.21
ADF	16.53	18.60	19.16	23.94	30.27
Lignin	3.37	5.36	6.84	10.23	5.90
iNDF[10]	8.07	10.39	12.25	14.75	24.20

[1]Percent replacement castor bean meal by soybean meal in the supplement composition.

[2]Castor bean meal was treated with $Ca(OH)_2$ at a rate of 60 g $Ca(OH)_2$/kg of CBM (as-is). Chemical composition: DM, 87.72%; CP, 25.69%; NDIP, 42.50%; ADIP, 39.48%; EE, 0.04%; NDF, 64.39%; NDFap, 42.19%; ADF, 51.06%; Lignin, 26.11%; Ash, 22.47%, iNDF, 36.08%.

[3]Mineral mixture per kilogram of product contained: 150 g Ca as $CaCO_3$, 65 g P as $CaHPO_4$, 107 g Na as NaCl, 12 g S as S_8, 6,000 mg Mg as MgO and $MgSO_4$, 175 mg Co as $CoSO_4$, 100 mg Cu as $CuSO_4$, 175 mg I as $Ca(IO_3)_2$, 1,440 mg Mn as $MnSO_4$, 27 mg Se as Na_2SeO_3, 6,000 mg Zn as $ZnSO_4$.

[4]OM = 100 - Ash

[5]NDIP = neutral detergent insoluble protein, as percentage of CP;

[6]ADIP = acid detergent insoluble protein, as percentage of CP

[7]TC = 100 - (%CP + %EE + %ash)

[8]For supplement: NFC = 100 - [(CP - CPu + U) + EE + ash + NDFap]; where: CPu = CP content from urea (%); and U = urea content (%);
For forage: NFC = 100 - %NDFap - %CP - %EE - %ash.

[9]NDFap = neutral detergent fiber corrected for ash and protein.

[10]iNDF = indigestible neutral detergent fiber. Samples were incubated for 288 hours.

material was allowed to stand for 12 h, and then dry at room temperature for a period between 48 and 72 h, depending on climate conditions.

Sampling and Analysis

The forage mass (kg of DM per ha) estimate was performed on 28-d intervals. Five samples were taken per paddock at soil level with a square of 0.25 m^2 according to methodology described by McMeniman (1997). At the time of collection, sample division was carried out in 2 sub-samples per paddock: one was weighed and taken immediately to the oven with forced air circulation at 55 °C for 72 hours for further determination of the chemical analysis (DM, NDF and iNDF); and the other was used to determine the structural components of the pasture. Destructive sampling, where manual separation of harvested forage in to leaves (leaf blades), culms (stems + sheaths), and dead material, was used to determine the structural components of the pasture. The proportions of components in samples were calculated as the percentage of the total weight after they dried for 72 h in an oven with forced ventilation at 55 °C. The potentially digestible dry matter (DMpd) was estimated according to the equation:

$$DMpd = 0.98 \times (100 - NDF) + (NDF - iNDF)$$

where: NDF = neutral detergent insoluble fiber; and iNDF = indigestible NDF.

Forage height was also measured at the beginning of each period, at 10 random points in each paddock, using a graduated ruler measuring from the bottom to the canopy of the pasture.

Forage collection for chemical composition analysis was performed according to Sollenberger and Cherney (1995), by grazing simulation. Approximately 300 g of fresh forage per paddock was collected manually in the beginning of each period.

Forage and supplement ingredients were analyzed for DM, total nitrogen (TN), ether extract (EE), ash (OM was calculated by difference), neutral detergent fiber (NDF) and acid detergent fiber (ADF), neutral detergent insoluble nitrogen (NDIN), acid detergent insoluble nitrogen (ADIN), and lignin as methods described in AOAC (2000). The neutral detergent fiber corrected for ash and protein (NDFap) was estimated according to Hall (2003). Feces were analyzed for DM, TN, EE, ash, and NDFap. The percentage of total carbohydrates in feed and feces were obtained from the equation: TC = 100 - (%CP + %EE + %ash) according Sniffen et al. (1992), and non-fibrous carbohydrate (NFC) in forage, using the equation: NFC = 100 - %NDFap - %CP - %EE - %ash, according to Hall (2000). Urea was used as a source of non-protein nitrogen compound. Thus, dietary levels of NFC in supplements were estimated by adjusting Hall proposition (2000): NFC = 100 - [(CP - CPu + U) + EE + ash + NDFap]; where: CPu = CP content from urea (%); and U = urea content (%).

For indigestible dry matter (iDM), indigestible neutral detergent fiber (iNDF) and indigestible acid detergent fiber (iADF), dietary samples were incubated for 288 hours in the rumen of 2 Holstein-Zebu-crossbred cows (H × Z) for later determinations of iDM content, iNDF and iADF, following procedures described by Detmann et al. (2012).

Carbohydrate fractions were estimated according to Sniffen et al. (1992) and Hall (2003), as cited above. Total digestible nutrients (TDN) was calculated as the sum of digestible crude protein (DCP), digestible neutral detergent fiber corrected for ash and protein (DNDFap), digestible non-fibrous carbohydrates corrected for ash and protein (DNFCap), and digestible ether extract (DEE) multiplied by 2.25, according to Weiss (1999): TDN = DCP + DNDFap + DNFCap + DEE × 2.25.

Feed intake

Estimation of feed intake for grazing animals is a challenge under experimental conditions. However, research has showed results that validate the estimation of herbage and supplement intake with the aid of external and internal markers (Smit et al., 2005; Undi et al., 2008; Hellwing et al., 2015; Saliba et al., 2015).

Fecal production estimation

To estimate fecal production, Enriched and Purified Isolated Lignin from *Eucalyptus grandis* (LIPE®; UFMG, Minas Gerais, Brazil) was used as external marker (Saliba et al., 2015). A 250 mg capsule containing LIPE® was orally administered for each animal for 6 consecutive days (d 7 to d 12 of period 2); the first 2 d were to stabilize the fecal excretion of the marker. Fecal samples were collected directly from the rectum twice a day at 0800 h and 1500 h for 5 consecutive days (from d 9 to d 13 of period 2) and stored in a cold chamber at -10 °C. After that, the fecal samples were dried, ground and composed. Approximately 10 g of each composed sample of feces was sent to the Federal University of Minas Gerais (UFMG) to estimate the total daily fecal output (Saliba et al., 2015).

Supplement intake

To determine the dry matter intake of the supplement (SI), titanium dioxide has been used as an external marker, according to the equation:

$$SI = (FP * CTF) / CTS$$

where SI is the dry matter intake of the supplement (g/d); FP is the daily fecal production (g/d); CTF is the concentration of titanium dioxide (TiO_2) in feces (g/g DM) and CTS is the concentration of titanium dioxide in the supplement (g/g DM).

Five grams of TiO_2 for each 495 g of supplement (1% concentration) were mixed. This mixture was offered to the animals for 12 d (a 7-d adaptation period to obtain a more homogeneous excretion plateau, and for 5 days of fecal collection). The adaptation period was from d 2 to d 8 of period 2. The 5 days of fecal collection were the same for fecal production estimation (from d 9 to d 13 of period 2). The fecal TiO_2 content was determined according to Myers et al. (2004).

DM intake estimation

Total apparent digestibility and dry matter intake (DMI) was estimated from fecal production, verified with the aid of LIPE as external marker and iNDF as internal marker.

Dry matter intake was obtained by the following equation:

$$DMI = \{[(FP * IMF) - IMS] / IMF\} + SI$$

where DMI = dry matter intake (kg/d); FP = fecal production (kg/d); IMF = concentration of the internal marker (iNDF) in feces (kg/kg); IMS = iNDF intake from supplement (kg/d); IMF = concentration of iNDF present in forage (kg/kg); and SI is the supplement intake (DM basis; kg/d).

Growth Performance and Feed Efficiency

Animals were weighed at the beginning and end of the trial, after fasting for about 16 hours to determine initial BW (IBW), final BW (FBW), ADG, and feed efficiency (G:F). Intermediate weight measurements were taken every 28 days to assess the ADG to adjust the supplement supply. Feed efficiency was determined by dividing the weight gain (kg) by the amount of feed intake (kg) during the experimental period. Before slaughter, body condition score (BCS) was estimated while the animals were standing on flat surface, by palpation of the transverse processes of the lumbar and dorsal vertebrae and sternum of animals. Scores were assigned to be within a range of 1 to 5, with intermediate values of 0.5. Score 1 was for lean animals and score 5 for obese animals (Russell et al., 1969).

Carcass characteristics

At the end of the experiment, the animals were slaughtered at the Goats and Sheep Experimental Unit (UECO) slaughterhouse at the university (UESB). After evisceration, carcasses were weighed to obtain the hot carcass weight (HCW) and, soon after, were sent to cold storage at 4 °C, where they remained for a period of 24 h, hanging by the metatarsal joint. After cooling, back fat, carcass length, and conformation were measured. The carcass length was measured from the front edge of the pubic bone to the cranial edge of the first rib; the back fat (BF) was taken on the external surface of the Longissimus dorsi muscle between the 12th and 13th ribs, using a caliper. To evaluate the conformation of the carcass, the scores were set as follows: Concave = 1; Sub rectilinear = 2; Rectilinear = 3; Sub convex = 4; and Convex = 5. The subjective evaluation was adapted from the EUROP system assessment lamb carcasses (European Community, 1992). The calculation of the dressing percentage was made as follows: Dressing % = HCW/FBW × 100.

Statistical Analysis

The design was completely randomized with 4 treatments in the model:

$$Y_{ij} = \mu + Tr_i + e_{ij}$$

where Y_{ij} = observed value for the characteristic analyzed; μ = general average; Tr_i = effect of diet; e_{ij} = experimental error. Data were evaluated by analysis of variance and polynomial regression using the MIXED procedure of SAS statistical software (version 9.2, SAS Inst. Inc., Cary, NC). For all variables, the animal was considered the experimental unit, and orthogonal contrasts were used to detect the linear and quadratic effects of the increase in levels of CBM replacing soybean meal in supplements. The level of probability of 0.05 was adopted for the type I error. Trends are discussed at $0.05 < P < 0.10$.

RESULTS AND DISCUSSION

Intake and nutrient digestibility

In the current trial, there was a decrease (linear; $P < 0.01$) in DMI (g/day) by lambs from different treatments as the proportion of the CBM in the supplement was increased. For each percentage point of substitution of soybean meal by CBM in the supplement, there was a DMI decrease of 1.22 g/d, which resulted in a 19.2% decrease when compared treatment 100% CBM substitution to 0% CBM substitution. This decrease in consumption (g/d) can be explained by the lignin and NDF rise in supplement (Table 3) as CBM is increased. Pasture intake (g/d) was responsible for the difference in DMI (g/d), because the supplement intake was kept at the 1.6% BW level for all treatments. There was a negative effect (quadratic; $P = 0.05$) of CBM inclusion in the supplement on pasture intake (g/d). There was a decrease trend ($P = 0.07$) in pasture intake (BW %) among treatments, which means a 28.6% decrease when CBM was increased from treatment 0% to 100%. This numerical difference can become important as it would allow more

Table 4. Daily nutrient intake, and DM and NDFap apparent total tract digestibility in grazing lambs supplemented with increasing levels of castor bean meal

	Substitution Level[1]					*P*-value	
Item	0%	33%	67%	100%	SEM	Linear	Quadratic
Dry matter intake, g/d	687.9	595.6	567.9	555.9	15.47	< 0.01	0.14
Dry matter intake, BW %	2.73	2.31	2.40	2.32	0.078	0.10	0.27
Pasture intake, g/d	281.7	198.2	178.0	194.5	13.60	0.01	0.05
Pasture intake, BW %	1.12	0.75	0.77	0.80	0.059	0.07	0.07
NDFap intake, g/d[2]	296.7	235.9	231.4	229.8	6.99	< 0.01	0.01
NDFap intake, BW %	1.18	0.91	0.98	0.95	0.034	0.03	0.05
Crude protein intake, g/d	109.7	97.2	92.3	89.6	2.98	0.01	0.39
Ether Extract intake, g/d	18.2	15.6	12.5	9.4	0.69	< 0.01	0.76
NFC intake, g/d[3]	207.1	198.7	187.1	181.3	6.59	0.15	0.92
TDN intake, g/d[4]	437.5	351.3	335.8	310.0	14.80	< 0.01	0.25
Digestibility, %							
Dry matter	63.10	57.26	57.53	54.26	1.02	< 0.01	0.48
NDFap[2]	53.46	44.49	40.54	39.71	1.50	< 0.01	0.11

[1]Percentage of soybean meal replaced by castor bean meal in supplements.

[2]NDFap = neutral detergent fiber corrected for ash and protein.

[3]NFC = non-fiber carbohydrate.

[4]TDN = total digestible nutrients.

animals on the same area, and it could be used as a strategy for increasing gain per area. There was no effect ($P \geq 0.10$) of treatment on DMI (BW %), which was 2.44% on average. As there was no daily supplement remains in the bunks in any of the treatments, the response on the DMI (BW %) followed a similar behavior to that presented in pasture intake (BW %). In a study of confined lambs, Pompeu et al. (2012) observed DMI values of 969.2, 880.0, 866.5, and 829.4 g/d to levels of 0, 33, 67 and 100% when CBM replaced soybean meal in the diet, respectively. Although these intakes are greater than those of the present trial, it should be considered that confined animals usually have less environmental challenges, such as endo and ecto parasites infestation, exposure to great temperature variations, or need to walk for food, what would inherently favor the increase in DMI by confined animals (psychogenic regulation of consumption). There was a negative linear effect of the inclusion of castor meal in the diets on CP ($P = 0.01$), EE ($P < 0.01$), and TDN ($P < 0.01$) intake. There was a decrease in CP, EE, and TDN concentrations in the supplement as CBM increased in the diet (Table 3). Despite the decrease in CP intake, the content of this nutritional component in the diet remained constant, very close to 16% for all treatments, demonstrating that animals, despite differences in total DMI (g/d) among treatments, selected forage in a similar manner, with the same quality. Non-fiber carbohydrates intake did not differ ($P = 0.15$) among treatments, averaging 193.5 g/d, which can be explained by the maintenance of supplement intake at similar levels among treatments, since NFC in supplements was twice as much as the NFC in forage. Thus, forage intake (g/d) decrease was not sufficient to elicit a NFC intake decrease.

There was a negative effect (linear; $P < 0.01$) of treatment on DM and NDFap digestibility (Table 4). This was expected because there was a gradual increase in iNDF and lignin concentrations in supplements as CBM was increased (Table 3). In agreement, Diniz et al. (2010) found a reduction in ruminal degradation of DM when beef cattle were fed increasing calcium oxide treated CBM in the supplement. In grazing production systems, NDF digestibility is a very important parameter for overall efficiency. Any negative effect on NDF digestibility can also compromise DM digestibility, animal performance, and efficiency of the entire production system. Another factor that may have contributed to a lower DM digestibility is the greater ADIP fraction content in CBM (approximately 40% of CP; Table 4). Thus, as CBM concentration was increased in the diet, CP digestibility was decreased because CP content in diets was kept very close. Similar to this work, Barros et al. (2011) observed a linear decrease in DM and NDFap digestibility when grazing heifers were supplemented with CBM levels replacing soybean meal, 59 to 63% for DM, and 64 to 68% for NDFap digestibility.

Growth performance

There was no effect ($P \geq 0.15$) of replacing soybean meal by CBM in supplements for grazing lambs on final BW, ADG, or BCS (Table 5). Final BW was not influenced ($P \geq 0.64$) by treatments, averaging 29.2 kg, due to the similarity of ADG ($P \geq 0.41$), which averaged 85.9 g/d for all treatments. In contrast to these results, Pompeu et al. (2012) observed an ADG decrease (197, 160, 155, and 130 g/d) in feedlot lambs fed the same levels (0, 33, 67 and 100%) of CBM replacing soybean meal, respectively.

There was no effect ($P \geq 0.15$) of treatment on final BCS or BCS change, 3.26 and 0.29 on average, respectively. This response can be explained by the ADG similarity among lambs throughout the trial period, in addition to genetic, age and body structure similarity of the animals.

There was a positive trend (linear; $P \geq 0.09$) in feed efficiency among treatments as CBM was increased in the supplement. Menezes et al. (2016) observed no difference in feed efficiency when lams were fed increasing CBM dietary concentrations. However, Pompeu et al. (2012)

observed a decrease in feed efficiency as CBM was increased in the lambs' diets. The response on the current study is largely driven by the lower DMI at a similar ADG when CBM was increased in supplement, thus improving feed efficiency as CBM increased in grazing lambs' diets.

Table 5. Growth performance of grazing lambs supplemented with increasing levels of castor bean meal

	Substitution Level[1]					*P*-value	
Item	0%	33%	67%	100%	SEM	Linear	Quadratic
n[2]	9	9	8	8	-	-	-
Initial BW, kg	22.19	22.39	21.50	21.55	-	-	-
Final BW, kg	28.59	30.22	28.84	29.06	0.722	0.99	0.64
ADG, g/d	76.12	93.27	87.34	87.04	5.057	0.57	0.41
Feed efficiency[3]	0.110	0.158	0.154	0.158	0.009	0.09	0.21
Initial BCS[4]	3.00	2.94	2.94	3.00	0.051	0.99	0.59
Final BCS[4]	3.33	3.38	3.16	3.16	0.064	0.20	0.83
BCS change	0.33	0.44	0.22	0.16	0.058	0.15	0.46

[1]Percentage of soybean meal replaced by castor bean meal in supplements.

[2]n = number of animals (1 animal from 67% and 1 animal from 100% treatments were removed for non-treatment related reasons).

[3]Feed efficiency = ADG /DMI

[4]BCS = body condition score. It varied from 1 to 5. Score 1 was for lean animals and score 5 for obese animals.

Carcass characteristics

There was no difference ($P \geq 0.48$) among treatments for hot carcass weight (HCW), dressing percentage (DP), conformation, back fat (BF), or carcass length (Table 6). We had hypothesized that increasing CBM in the supplement to replace SBM would negatively impact carcass characteristics; however, this was not the case.

Growth rate and final BW, which did not differ in our trial, influence HCW. Therefore, it was not surprising to find that there was also no effect ($P \geq 0.77$) of treatments on HCW, with an average of 13.04 kg. There was no effect ($P \geq 0.52$) of treatments on dressing %. Lambs averaged 46.2% dress. In a 4-year study, with data from 436 lambs of different genotypes fed on pasture and access to grain crop paddocks, Álvarez et al. (2013) found dressing % ranged between 44.0 and 47.2% and HCW between 12.8 and 13.8 kg, thus, the lambs in this trial were comparable to Brazil industry averages.

Table 6. Carcass characteristics of grazing lambs supplemented with increasing levels of castor bean meal

	Substitution Level[1]					P-value[2]	
Item	0%	33%	67%	100%	SEM	Linear	Quadratic
n[3]	7	8	7	7	-	-	-
HCW, kg	13.08	13.33	12.91	12.83	0.406	0.77	0.85
Dressing %[4]	45.4	44.9	49.9	44.9	1.681	0.82	0.52
Conformation[5]	2.7	2.4	2.4	2.5	0.096	0.50	0.48
Degree of Fat Cover[6]	1.9	2.1	1.8	1.7	0.121	0.50	0.50
Back fat, mm[7]	0.39	0.40	0.32	0.37	0.035	0.68	0.80
Carcass length, cm[8]	50.4	51.5	50.0	49.7	0.543	0.48	0.55

[1]Percentage of soybean meal replaced by castor bean meal in supplements.

[2]Orthogonal polynomial contrasts for increasing castor bean meal inclusion in the diets.

[3]n = number of animals (some animals were removed for non-treatment related reasons).

[4] Dressing percentage was calculated by dividing hot carcass weight by final body weight.

[5]Conformation was estimated as follows: Concave = 1; Sub rectilinear = 2; Rectilinear = 3; Sub convex = 4; and Convex = 5

[6]For degree of fat cover: 1 = lean, absence of fat up to 1 mm fat thickness; 2 = little fat, 1 to 3 mm thickness; 3 = mid fat, 3 to 6 mm thickness; 4 = fat uniform, 6 to 10 mm thickness; and 5 = excessive fat, above 10 mm thickness.

[7]Back fat was measured between the 12th and 13th ribs.

[8]Carcass length was measured from the front edge of the pubic bone to the cranial edge of the first rib.

It would be reasonable to expect BF to decrease with increasing CBM inclusion in the supplement because TDN intake decreased as CBM increased; however, this was not the case. There was no effect ($P \geq 0.68$) of treatment on BF. This may be explained by the low BF in lamb carcasses in the current trial, 0.37 mm on average. There was no effect of treatments ($P \geq 0.48$) on carcass conformation, which was 2.5 on average, in the current trial. Carcass length was not affected ($P \geq 0.48$) by treatments, averaging 50.4 cm. These results can be explained as a result of similar animal growth, given the absence of difference in ADG and FBW.

CONCLUSION

The replacement of soybean meal by calcium hydroxide-treated CBM in the supplement for grazing lambs reduced DMI (g/d) as a consequence of decreased forage intake. Thus, there was a decrease in energy and protein intake. The replacement of SBM with CBM also decreased total DM and NDFap apparent digestibility. Despite some negative effects on intake and nutrient digestibility, increasing CBM in the supplement, up to the entire substitution of soybean meal, did not affect weight gain or carcass characteristics of grazing lambs.

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CONSIDERAÇÕES FINAIS

A crescente preocupação mundial com o meio ambiente, juntamente com a necessidade de diminuir custos de produção, tem levado pesquisadores e técnicos a utilizar coprodutos da indústria do biocombustível (álcool e biodiesel) na alimentação de animais ruminantes. Diversos países, dentre eles o Brasil e os Estados Unidos, dois dos maiores produtores de biocombustível do mundo, tem aumentado a produção desses coprodutos.

Assim como o etanol está se firmando nos Estados Unidos cada vez mais como uma alternativa à utilização de derivados do petróleo, o biodiesel no Brasil é uma importante alternativa energética. A produção de biocombustíveis gera coprodutos que podem ser utilizados na alimentação animal. Assim, propomos estudos da utilização desses coprodutos na alimentação animal visando aumentar a produtividade e diminuir custos de produção.

A partir da transformação de milho para a produção de etanol, são gerados grãos de destilaria (DDGS). A crescente demanda por milho pela indústria de etanol, inevitavelmente, diminui o fornecimento de milho para os produtores de gado. Desta maneira, a elevada oferta de DDGS e a baixa oferta de milho podem transformar o DDGS em um importante componente de alimentação na dieta de bovinos.

Considerando as limitações de uso de DDGS na dieta de bovinos, desenvolvemos o experimento 1 com o objetivo de utilizar elevados níveis de DDGS na dieta (50% da MS) e determinar o nível ótimo de NaOH necessário para tamponar a acidez do DDGS e seus efeitos sobre a digestibilidade, metabolismo ruminal e acidose metabólica em novilhos em confinamento. Concluímos que DDGS tratado com NaOH não aumentou a degradabilidade da fibra, nem foi necessário para aliviar possíveis sintomas de acidose metabólica. O tratamento também não elevou o pH ruminal ou o pH sanguíneo. Aprendemos, em comparação com outros trabalhos de pesquisa, que a composição bromatológica do DDGS varia entre plantas de produção, e que seus valores de pH podem afetar diretamente a digestibilidade da MS e da fibra em animais alimentados com dietas à base de DDGS. Desta maneira, é importante analisar a composição bromatológica do DDGS, especialmente os teores de pH e enxofre, para determinar a eficácia do tratamento com NaOH. Com isso, será possível uma melhor predição de parâmetros como ingestão de MS, pH ruminal, digestibilidade da fibra e da MS, assim como desempenho de bovinos em confinamento.

O experimento 2 teve como objetivo determinar qual inclusão de NaOH (usadas no experimento 1) resultaria na melhor eficiência alimentar, ingestão de MS, ganho médio diário, e características de carcaça em novilhos em confinamento. Nossa hipótese era que aumentando a concentração de NaOH no DDGS antes de fornecê-lo aos animais, iria neutralizar a acidez inerente do coproduto, e consequentemente poderia melhorar a utilização da fibra pelos animais e desempenho dos novilhos em confinamento. O fato de que o aumento de NaOH até 1,5% da MS no tratamento do DDGS não ter melhorado o desempenho ou características de carcaça neste estudo representa uma importante resposta ao uso do DDGS pela indústria de produção de carne bovina. Isto nos mostrou que a indústria do etanol está se tornando cada vez mais consciente das limitações do DDGS como alimento para bovinos e tem ajustado suas práticas de produção para diminuir esses problemas. Essas mudanças nas plantas de produção irão provavelmente impactar as características nutricionais do DDGS. Desta maneira, torna-se importante avaliar rotineiramente a qualidade deste coproduto através de análises de laboratórios antes de usá-lo para alimentar os animais. Foi também uma descoberta importante porque concluímos que não será necessário que a planta de produção de etanol acrescente mais uma etapa para a produção de DDGS, o que provavelmente aumentaria os custos do coproduto para a indústria e para o produtor. Desta maneira, sugerimos que DDGS com baixos níveis de ácido e com baixa concentração de enxofre podem ser fornecidos em dietas para os animais sem o risco de prejudicar o desempenho ou características de carcaça.

Na produção do biodiesel são gerados resíduos e coprodutos que devem ser aproveitados, de forma que toda a cadeia de produção do biodiesel seja sustentável e economicamente viável. Entre esses principais resíduos sólidos estão a torta de dendê e o farelo de mamona. É importante atentar aos níveis ideais da utilização desses coprodutos na alimentação animal, destacando principalmente o teor residual de lipídeos no caso da torta de dendê, e a presença de fatores antinutricionais que podem prejudicar a saúde e o desempenho animal.

O experimento 3 teve como objetivo avaliar os efeitos da inclusão de níveis de torta de dendê na composição de suplementos para borregos a pasto sobre o consumo, digestibilidade, desempenho, características da carcaça e perfil de ácidos graxos na carne destes animais. Concluímos que a inclusão de até 30% da torta de dendê em substituição ao milho moído e farelo de trigo na composição de suplementos para ovinos a pasto mostrou-se viável por proporcionar manutenção de ganho de peso dos animais, assim como não modificar características de carcaça ou perfil de ácidos graxos do musculo *Longissimus dorsi* dos borregos suplementados. Desta maneira, o humano pode ingerir a carne desses animais sem sofrer com aumento dos níveis de gordura saturada em sua dieta e suas consequências para a saúde.

O experimento 4 teve como objetivo avaliar o consumo e a digestibilidade de nutrientes, ganho de peso e características de carcaça de borregos alimentados a pasto e suplementados com níveis de farelo de mamona em substituição ao farelo de soja na composição dos suplementos. Deste experimento, concluímos que apesar de alguns efeitos negativos sobre consumo e digestibilidade de nutrientes, o aumento no nível de farelo de mamona no suplemento não afetou o desempenho dos borregos a pasto, assim como não houve efeito sobre as características de carcaça destes animais.