UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
FACULDADE DE AGRONOMIA
PROGRAMA DE PÓS-GRADUAÇÃO EM ZOOTECNIA

O EFEITO DA SUPLEMENTAÇÃO DIETÉTICA DE HIDROXI-SELENOMETIONINA NA PRODUÇÃO DE CARNE DE FRANGO

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Tese apresentada como um dos requisitos à obtenção do grau de
Doutor em Zootecnia
Área de Concentração: Produção Animal

Porto Alegre (RS), Brasil
Abril de 2021

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Orientador: Sergio Luiz Vieira
Coorientadora: Liris Kindlein

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Vinicius de Queiroz Teixeira
Médico Veterinário

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para obtenção do Grau de

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O EFEITO DA SUPLEMENTAÇÃO DIETÉTICA DE HIDROXI-SELENOMETIONINA NA PRODUÇÃO DE CARNE DE FRANGO[1]

Autor: Vinicius de Queiroz Teixeira
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RESUMO

O Brasil segue se destacando entre os grandes produtores e exportadores de proteína animal no mundo. Dentre as proteínas animais produzidas em nosso país, a de aves ocupa mundialmente a terceira posição em produção e primeira em exportação. Com uma produção altamente tecnológica, buscamos aperfeiçoamentos em diversos campos da produção, onde a nutrição se destaca. Com a maior eficiência produtiva nas linhagens modernas, o consumo relativo de nutrientes tem sido reduzido frente ao ganho de peso das aves. Sabemos que algumas regiões do mundo são escassas em selênio (Se), assim como o território brasileiro e com isso as lavouras produzidas aqui são podres neste mineral, havendo assim a necessidade de suplementação exógena deste elemento. Esta tese foi conduzida para avaliar os efeitos da suplementação de Se, exclusivamente de uma fonte de hidroxi-selenometionina (OH-SeMet), sobre o desempenho de frangos de corte. O objetivo deste estudo foi avaliar os efeitos de níveis crescentes de OH-SeMet sobre o desempenho zootécnico e rendimento de carcaça e cortes comerciais, além da influência na severidade de lesões de peito amadeirado, oxidação lipídica e atividade da glutationa peroxidase em órgão e tecidos de frangos de corte aos 35 e 42 dias de idade. De acordo com as respostas obtidas, foram estimadas ainda as exigências de OH-SeMet, como única fonte de selênio para frangos de corte, para ganho de peso e rendimentos de carcaça e carne de peito. Um total de 1.500 pintos machos de um dia Cobb 500 foram alimentados com cinco tratamentos, com 12 repetições de 25 aves cada uma em um programa alimentar de três fases (inicial, crescimento e final). Dietas a base de milho e soja foram suplementadas com 0,0; 0,15; 0,30; 0,45 e 0,60 ppm de Se proveniente de OH-SeMet (as rações não suplementadas com Se tinham 0,03; 0,03 e 0,02 ppm de Se analisado). Além da avaliação semanal dos parâmetros produtivos, ganho de peso, consumo de ração, conversão alimentar e mortalidade, aos 35 e 42 dias de idade, cinco aves de cada box, selecionadas de forma randômica, foram processadas para avaliação de rendimento de carcaça e de cortes comerciais e classificadas quanto aos escores de peito amadeirado (WB). Adicionalmente, aos 42 dias de idade, as carnes de peito destas aves foram analisadas para perda por cozimento (CL) e capacidade de retenção de água (WHC), bem como para oxidação lipídica (TBARS) e atividade de glutationa peroxidase (GSH-Px). Essas duas últimas análises foram também realizadas em outros tecidos e órgãos como eritrócitos, jejuno, íleo e fígado. As análises estatísticas foram realizadas utilizando modelos de regressão polinomial quadrático (QP) e exponencial assimptótico (EA). Os níveis crescentes de OH-SeMet resultaram em aumentos quadráticos e exponenciais ($P < 0,05$) no ganho de peso (GP) de 1 a 21 dias, com níveis ótimos de 0,48 e 0,50 ppm de Se, respectivamente. No período total acumulado, de 1 a 42 dias, os maiores GP foram obtidos com 0,43 e 0,40 ppm nos modelos QP e EA respectivamente. O nível de Se que maximizou o

rendimento de peito e de carcaça aos 42 dias foi de 0,35 e 0,44 ppm usando o modelo QP e de 0,47 e 0,38 ppm de Se usando o modelo EA. Estimou-se que a atividade da GSH-Px nos eritrócitos, aos 42 dias de idade, foi elevada com a suplementação de 0,27 ppm de OH-SeMet na dieta, usando-se o modelo QP ($P < 0,05$). Nenhum efeito ($P > 0,05$) foi observado em escores de WB, CL e WHC assim como em TBARS de amostras de íleo, jejuno, fígado e músculo peitoral. Os resultados deste experimento mostraram que a dietas brasileiras e base de milho e soja, quando suplementadas com Se proveniente de OH-SeMet melhorou o desempenho dos frangos de corte e o rendimento de carcaça e peito. Quanto a recomendação média deste oligoelemento, fornecido por uma fonte de OH-SeMet, para otimizar a performance produtiva foi encontrado 0,46 ppm para o GP, 0,44 ppm para a melhora do rendimento de carcaça e 0,38 ppm para aumentar o rendimento de peito.

Palavras-chave: frango, crescimento, exigência, micromineral, peito amadeirado.

[1] Tese de doutorado em Zootecnia – Produção Animal, Faculdade de Agronomia, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brasil. (85p.) Abril, 2021.

BROILER MEAT PRODUCTION AS AFFECTED BY DIETARY SUPPLEMENTAL HYDROXY-SELENOMETHIONINE[1]

Author: Vinicius de Queiroz Teixeira
Advisor: Sergio Luiz Vieira

ABSTRACT

Brazil continues to stand out among the major producers and exporters of animal protein in the world. Among the animal proteins produced in our country, poultry is the third position in production and the first in export. With a highly technological production, we seek improvements in many fields of production, where nutrition stands out. With the highest productive efficiency in modern genetic lines, the relative consumption of nutrients has been reduced when compared to body weight gain of birds. We know that some regions of the world are scarce in selenium (Se), as well as the Brazilian territory and with this the crops produced here are scare in this mineral, thus there is a need for exogenous supplementation of this element. This thesis was conducted to evaluate the effects of Se supplementation, exclusively from a hydroxy-selenomethionine (OH-SeMet) source, on broiler performance. The objective of this study was to evaluate the effects of increasing levels of OH-SeMet on broiler performance and carcass and commercial cuts yield, in addition to the influence on the severity of wooded breast lesions, lipid oxidation and glutathione peroxidase activity in organs and tissues of broilers at 35 and 42 days of age. According to the results obtained, OH-SeMet requirements were also estimated as the only source of selenium for broilers, for weight gain and carcass and breast meat yields. A total of 1,500 cobb 500 one-day male chicks were fed five treatments, with 12 replicates of 25 birds each in a three-phase food program (initial, growth and final). Corn and soybean based diets were supplemented with 0.00; 0.15; 0.30; 0.45 and 0.60 ppm of Se, from OH-SeMet, (analysis of diets not supplemented with Se showed a content of 0.03; 0.03 and 0.02 ppm of Se). In addition to the weekly evaluation of the productive parameters, body weight gain (BWG), feed intake (FI), feed conversion ratio (FCR) and mortality at 35 and 42 days of age, five birds of each box, randomly selected, were processed to evaluate carcass and commercial cuts yield and classified according to the scores of wooden breast (WB). Additionally, at 42 days of age, the breast meats of these birds were analyzed for cooking loss (CL) and water holding capacity (WHC), as well as for lipid oxidation (TBARS) and glutathione peroxidase (GSH-Px) activity. These last two analyses were also performed in other tissues and organs such as erythrocytes, jejunum, ileum and liver. Statistical analyses were performed using quadratic polynomial regression (QP) and asymptotic exponential regression (AS) models. Increasing levels of OH-SeMet resulted in quadratic and exponential increases ($P < 0.05$) in BWG from 1 to 21 days, with optimal levels of 0.48 and 0.50 ppm of Se respectively. From 1 to 42 days, the highest rates of BWG were obtained with 0.43 and 0.40 ppm in the QP and EA models respectively. It was estimated that at 42 days of age, using the QP model ($P < 0.05$), the activity of GSH-Px increased in erythrocytes of broilers with supplementation of 0.27 ppm of OH-SeMet in the diet. No effect ($P > 0.05$) was observed in WB, CL and WHC scores as well as in TBARS from ileum,

jejunum, liver and pectoral muscle samples. The results of this experiment showed that corn and soybean base Brazilian diets, when supplemented with Se from OH-SeMet, improved the performance of broilers and carcass and breast meat yield. On average, the recommendation of this trace element provided by an OH-SeMet source, to optimize productive performance, was 0.46 ppm for BWG, 0.44 ppm for the improvement of carcass yield and 0.38 ppm to increase breast yield.

Keywords: broiler, growth performance, micromineral, requirement, wooden breast.

[1] Doctoral thesis in Animal Science, College of Agronomy, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil. (85 p.) April, 2021.

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LISTA DE ABREVIATURAS

°C: graus Celsius
ABPA: Associação Brasileira de Proteína Animal
BWG: body weight gain
CA: conversão alimentar
CAT: atividade da catalase
CL: cooking loss (perda por cozimento)
CNPq: Conselho Nacional de Pesquisa
EA: exponential asymptotic
EFSA: European Food Safety Authority
FCR: feed conversion ration
FDA: Food and Drug Administration
FI: feed intake
GP: ganho de peso
GSH: glutationa
GSH-PX: glutationa peroxidase
H_2O: água
H_2O_2: peróxido de hidrogênio
HMSeBA: ácido 2-hidroxi-4-metil-selênio-butanóico (selenometionina hidroxianáloga)
L: linear
MDA: malonaldeído
Met: metionina
MSR: metionina sulfóxido redutase
NRC: National Research Council
O_2: oxigênio
OH-SeMet: hidroxi-selenometionina
QP: polinomial quadrático
SAS: Statistical Analyses System
Se: selênio
Se^{-2}: selenido
Se^{+4}: selenito
Se^{+6}: selenato
SeCys: selenocisteína
SeMet: selenometionina
SOD: superóxido dismutase
SS: selenito de sódio
T-AOC: total antioxidant capacity (capacidade antioxidante total)
T-SOD: superóxido dismutase total
TBARS: Thiobarbituric Acid Reactive Substances (substâncias reativas ao ácido tiobarbitúrico)
TrxR: tioredoxina redutase
u: massa atômica relativa
WB: wooden breast (peito madeira)
WHC: water-holding capacity (capacidade de retenção de água)
Zn-L-SeMet: zinc-L-selenomethionine

CAPÍTULO I

1. INTRODUÇÃO

O Brasil possui o talento natural para a produção de alimentos. A farta oferta de grãos e o clima favorável em quase todo o país são fatores que geram ganhos antes mesmo do emprego de alta tecnologia. Com essas vantagens produtivas o Brasil se mantém como maior exportador de carne de frango e terceiro maior produtor, ficando atrás dos Estados Unidos e China (ABPA, 2021).

O nível de tecnologia aplicada na indústria de aves do país é um dos mais elevados do mundo, principalmente no que diz respeito a indústria de rações (Rostagno *et al*., 2017). No entanto, as recomendações nutricionais devem sofrer atualizações constantes uma vez que o frango moderno tem seu potencial genético atualizado constantemente fazendo com que os animais consumam cada vez menos nutrientes, proporcionalmente ao seu ganho de peso. Desta forma, temos a necessidade de avaliarmos constantemente as exigências de nutrientes como os minerais que atualmente dispõem de fontes suplementares na forma inorgânica e orgânica.

O Selênio (Se) é um micromineral essencial para os animais de produção e possui uma linha tênue entre sua essencialidade e sua toxicidade entre as diferentes espécies (Alian *et al*., 2020). Esse mineral constitui parte integral de um sistema antioxidante de vários tecidos e de todo o organismo, (Surai, 2018). Os cultivos que geralmente compõem as dietas dos animais, por outro lado, não possuem níveis de exigência para o Se (Mikkelsen *et al*., 1989), embora baixos níveis de Se tenham relatado poucos efeitos benéficos para algumas plantas (Hasanuzzaman *et al*., 2011; Saidi *et al*., 2014). As preocupações relacionadas a toxicidade por Se, são majoritariamente relacionadas a uma minoria de espécies de vegetais que podem atingir concentrações muito altas de Se, as então chamadas acumuladoras de Se ou seleníferas (Terry *et al*., 2000; Tinggi, 2003; Gupta and Gupta, 2017). Estas espécies dependem do conteúdo de Se no solo, que varia dependendo nas rochas que o originam, bem como do Se proveniente de fontes antropogênicas, como irrigação e mineração (Mikkelsen *et al*., 1989).

A essencialidade do Se para animais foi primeiramente relatada em 1957 por Schwarz e Foltz (1957), depois de demonstrarem o papel do Se na distrofia muscular, bem como na prevenção da necrose hepática em ratos. Desde então grandes esforços foram feitos para elucidar a função do Se e o impacto de sua deficiência na

alimentação animal. Sabe-se que um ótimo status de Se no organismo fornece uma adequada síntese de selenoproteínas, responsáveis pela proteção contra o estresse oxidativo causado por diversos fatores estressantes da produção comercial de aves (Surai, 2018). Até o presente, cerca de 30 selenoproteínas foram identificadas, principalmente com funções antioxidantes, síntese de DNA, hormônio da tireoide e reprodução (Ducros e Favier, 2004; Kawai *et al*., 2018).

Frente a essas descobertas tem se buscado respostas aos níveis adequados de suplementação deste mineral par aos animais de produção. Em 1974 o Food and Drug Administration (FDA), Agência Americana para Alimentos e Medicamentos, concedeu a aprovação de 0,10 ppm de Se como suplemento alimentar para aves e suínos e de 0,20 ppm para perus (FDA, 1974). A maioria das espécies de animais domésticos teve exigências de Se publicadas dentro de uma variação de 0,05 ppm e 0,30 ppm (NRC, 1983). Esse número foi aumentado posteriormente quando a suplementação de 0,30 ppm de Se foi aprovada pela FDA (1987), valor que é recomendado até hoje pela instituição (FDA, 2020).

Na literatura encontramos diversas recomendações quanto a suplementação de Se, algumas recomendações tradicionais para rações de frangos de corte são de 0,15 ppm, como no NRC (1994), indicações de faixas de suplementação, dependendo da fonte, como o case de Rostagno *et* al. (2017) que recomenda 0,18 a 0,35 ppm para fontes inorgânicas e 0,08 a 0,015 ppm para fontes orgânicas. O FEDNA (2018) recomenda 0,34 ppm como suplementação máxima. O EFSA (2012), Autoridade Europeia para a Segurança dos Alimentos, por sua vez, determina um conteúdo máximo de selênio nas dietas de aves, valor este que não pode ultrapassar 0,20 ppm entre o Se suplementado e o já existente nos ingredientes da dieta.

Recentemente foi demonstrado que a otimização da produção de carne de frango requer níveis mais altos de Se dietético quando comparado com as referências citadas acima (Cemin *et al*., 2018). O desempenho produtivo do frango de corte moderno tem melhorado com o passar do tempo (Havenstein *et al*., 2003), o que pode ter sido impactado por uma redução contínua da ingestão de alimentos por unidade de massa viva. Portanto, a ingestão de Se tem sido reduzida em paralelo ao aumento das taxas metabólicas necessárias para sustentar uma maior síntese muscular. Isto levou a especulação sobre a necessidade de uma maior ingestão de Se dietético do que normalmente recomendado ou feito comercialmente.

Tradicionalmente a suplementação de Se é feita com sais de selenito. No entanto possui algumas limitações que são bem conhecidas, que incluem, toxicidade, interação com outros minerais e vitaminas, baixa eficiência em transferência para a carne e ovos, além da falta de habilidade de constituir reservas e se manter armazenado no organismo animal. Em resumo, uma expressiva parte do que os animais consomem na forma inorgânica é excretada (Surai, 2018).

Entretanto, inovadoras formas orgânicas de Se, nas quais este elemento substitui o enxofre na molécula de metionina (Met), estão disponíveis para uso na alimentação animal (Prakash *et al*., 2018; Bakhsalinejad *et al*., 2019; Shabani *et al*., 2019). Como a importância do Se na nutrição animal tem sido cada vez mais notada, o estudo de seu papel em outras vias metabólicas além do crescimento animal pode apresentar informações importantes. A hidroxi-selenometionina (OH-SeMet) é uma nova fonte de Se, que foi desenvolvida utilizando-se o hidroxi análogo do Met 2-hidroxi, ácido 4-metiltiobutírico, uma popular fonte suplementar de Met em dietas de frangos de corte. Nesta estrutura molecular, o Se está ligado por meio de duas ligações covalentes simples (EFSA, 2013).

O Se suplementar do OH-SeMet não foi totalmente investigado para atender o desempenho *in vivo*, assim como outras possíveis respostas afetadas por esse elemento. Portanto o objetivo do presente estudo foi avaliar o desempenho de crescimento, o rendimento de carcaça e de peito e a severidade das lesões de peito amadeirado (WB), bem como a oxidação lipídica e a atividade enzimática de frangos de corte alimentados com dietas suplementadas com níveis crescentes de Se provenientes de OH-SeMet. As necessidades de Se para as respostas avaliadas também foram estimadas usando-se o OH-SeMet como única fonte suplementar de Se.

2. REVISÃO BIBLIOGRÁFICA

2.1. Selênio

O Selênio foi descoberto por Jöns Jacob Berzelius em Estocolmo, Suécia, e, 1817. Além de sua utilização na área de nutrição, outros ramos da indústria tinham interesse neste mineral, como a indústria de vidro, cerâmica, borracha, aço e eletrônica (Muth *et al*., 1958).

É um elemento químico com o número atômico 34, peso atômico de 78,971u (massa atômica relativa), ponto de fusão de 221°C e ponto de ebulição de 685°C. Ele pertence aos Calcogênios, Grupo 16 (não metais), Família VIA da tabela periódica, onde também encontramos o oxigênio, enxofre, telúrio, polônio e livermório (Lopes, 2019).

Dentre os diversos minerais, o Se tem um lugar especial, sendo o mais controverso oligoelemento. A pesquisa deste elemento na nutrição animal tem sido alimentada por haver de um lado uma estreita lacuna entre essencialidade, toxicidade e questões ambientais e por outro lado uma deficiência global de Se (Surai, 2018).

Houveram inúmeros avanços na pesquisa do Se. O primeiro foi quando a importância nutricional do Se ficou evidente na década de 1950 quando foi demostrado que a maioria das miopatias em bovinos e ovelhas, e a diátese oxidativa em frangos puderam ser prevenidas pela suplementação dietética deste elemento e da vitamina E (McDonald *et al*., 2002). O segundo foi a descoberta, em 1973, que a glutationa peroxidase (GHS-Px) é uma seleno proteína. O terceiro avanço veio quase 30 anos após, com a caracterização das principais selenoproteínas nos organismos humano e animal e um maior entendimento do papel do Se na nutrição e saúde. De fato, estas últimas descobertas levaram a uma revolução do Se, com a criação de inúmeras novas hipóteses, estímulo a novas pesquisas e fornecimento de aplicações práticas na área da medicina e agropecuária (Surai, 2018).

O selênio em conjunto com a vitamina E são responsáveis pela proteção das membranas celulares da ação dos radicais livres, que são resultados bioquímicos do metabolismo endógeno normal da célula (Mc Donald *et al*., 2002 e Watanabe, 2010). A GHS-Px possui quatro átomos de Se, sendo uma enzima com a capacidade de catalisar a remoção do peróxido de hidrogênio (H_2O_2), transformando-o em oxigênio (O_2) e água (H_2O), protegendo assim as membranas celulares de danos oxidativos. Esta enzima é a segunda linha de defesa do organismo após a vitamina E, desde que

alguns peróxidos permanecem mesmo que os níveis de vitamina E estejam adequados (McDonald, 2002). O Se tem um efeito de economia na vitamina E, garantindo a normal absorção desta vitamina, desta forma o Se reduz a quantidade requerida de vitamina E para a manutenção da integridade das membranas lipídicas e ajuda na retenção da vitamina E no plasma, segundo McDonald (2002). O autor ainda afirma que a vitamina E também tem uma ação em poupar o Se, uma vez que o mantém em sua forma ativa, prevenindo sua perda. Isso reduz a produção de hidroperóxidos e com isso a necessidade de GHS-Px para proteger as células.

2.2. Selênio na natureza

Na natureza encontraremos o Se em duas formas químicas, orgânica e inorgânica. O Se elementar pode estar reduzido a Se^{-2} no estado de oxidação (selenido) ou oxidado a Se^{+4} (SeO_3^{-2}, selenito) ou Se^{+6} (SeO_4^{-2}, selenato). Portanto, a forma inorgânica do Se pode ser encontrada em diferentes minerais na forma de selenito, selenato ou selenido, bem como na forma cristalina, Se^0 (metálica) (Surai, 2018). Ao contrário das formas inorgânicas, o Se encontrado em ingredientes de rações (forragens, grãos, oleaginosas e etc.) é parte integrante da gama de Se-aminoácidos, incluindo selenometionina (SeMet) e selenocisteína (SeCys), além do estado de oxidação Se^{-2}. Como resultado, as aves receberão o Se principalmente na forma de SeMet (Combs e Combs, 1986; Surai, 2006), que é considerada a forma nutricionalmente natural do Se para as aves (Surai, 2018).

O ciclo do Se na cadeia produtiva de proteína de aves se inicia no solo, que é a maior fonte deste mineral para as lavouras cultivadas sobre ele, passam pela aves que consomem esses vegetais, com capacidade de assimilação de acordo com a forma química presente, e fontes suplementares de Se na forma inorgânica ou orgânica e pelos humanos, com o consumo de certos vegetais e proteína de origem animal. Esse ciclo pode ser muito variado uma vez que as concentrações de Se no solo variam muito entre regiões (Reilly, 2006).

2.3. Selenometionina (SeMet) e Hidroxi-selenometionina (OH-SeMet)

Selenometionina começou a ser estudada como uma possível causa da toxicidade do trigo selenífero na década de 1950. Posteriormente foi provado que a SeMet pode ser sintetizada a partir de fontes de Se inorgânico por diversas plantas,

leveduras, algas marinhas, *Candida albicans*, *Escherichia coli* e bactérias ruminais (Schrauzer, 2000, 2003; Schrauzes e Surai, 2009).

O Se na sua forma orgânica ocorre naturalmente como selenoaminoácidos nas dietas dos animais e do homem. Desta forma o sistema digestivo se adaptou a esta forma durante a evolução, explicando assim porque existem diferenças na assimilação e metabolismo entre as formas orgânicas e inorgânicas de Se (Surai, 2002, 2006). O Se orgânico ocorre na forma de diversos selenoaminoácidos mas a SeMet representa mais de 50% do Se na maioria dos ingredientes, incluindo grãos e oleaginosas (Surai, 2018).

A SeMet pura é uma forma de se aumentar o Se biodisponível para aves e animais de produção (Achrauzer, 2000, 2001, 2003; Achrauzer e Surai , 2009). Podemos encontrar diversas publicações que mostram os efeitos benéficos do Se na forma orgânica de SeMet em dietas de aves (Wang e Xu, 2008; Wang *et al*., 2011a; Yuan *et al*., 2011, 2013) como a melhora do crescimento, maior concentração muscular de Se e atividade antioxidante em frangos, além de melhorar a qualidade da carne de frango (Wang *et al*., 2021).

Na década de 2010, uma nova forma orgânica de Se foi desenvolvida e introduzida no mercado, a selenometionina hidroxianáloga, ácido 2-hidroxi-4-metil-selênio-butanóico (HMSeBA) (Briens *et al*., 2013, 2014; EFSA, 2013). Esta nova fonte foi comparada a outras fontes usuais de Se para aves, o selenito de sódio (SS) e o selênio leveduras, quanto a deposição de Se total, SeMet e SeCys no músculo das aves (*Pectoralis major*) e a digestibilidade total aparente do Se. Briens *et al*. (2014) chegaram a resultados que comprovaram a maior biodisponibilidade das fontes de selênio orgânico em relação a fonte mineral e puderam demonstrar ainda uma significativa eficiência do HMSeBA, quando comparado com o selênio levedura, para o enriquecimento muscular por Se.

Surai (2018) pontuou as maiores diferenças entre as fontes orgânicas, SeMet e OH-SeMet, quando comparadas com o selenito. As fontes orgânicas de Se possuem uma absorção similar à metionina, com um transporte ativo no intestino, o selenito por sua vez á absorvido por transporte passivo como os outros minerais. As formas orgânicas conseguem formar reservas no organismo com uma incorporação não específica de SeMet nas proteínas, já a forma inorgânica não se acumula nos tecidos animais. Como vantagens a forma orgânica possui ainda uma maior biodisponibilidade para os animais, apresenta propriedades antioxidantes *per se*. A lista de propriedades

da SeMet e OH-SeMet vai além, estimulando a produção de enzimas reparadoras de DNA, é transferida em maiores concentrações para ovos e tecido muscular, são neutras em relação a outros elementos, como vitaminas e minerais, e a presença do ácido ascórbico favorece sua assimilação da dieta. Em situações de estresse as reservas do organismo podem ser mobilizadas, provendo assim uma proteção adicional. Por sua maior absorção, possui um menor impacto ambiental, uma vez que é menos excretado junto as fezes e urina. Todas essas características fazem com que a forma orgânica apresente maior eficiência que o selenito. De Marco *et al*. (2021) demostraram que uma fonte se Se orgânico tem maior bioeficácia quanto maior for a sua proporção de SeMet em seu conteúdo.

2.4. Selênio na nutrição de frangos

O Se na nutrição de aves é relacionado ao uso em matrizes, incluindo fêmeas e machos, para melhorar as defesas antioxidantes dos reprodutores, dos espermatozoides dos galos e dos embriões em desenvolvimento (Surai, 2018). O Se também é importante para os frangos de corte, por possuir propriedades imunomoduladoras e ajudar a proteger as células imunes do estresse oxidativo. Possui ainda uma ação protetora no intestino mantendo o balanço antioxidante-prooxidante nos eritrócitos e tem um efeito positivo na qualidade da carne, reduzindo a oxidação proteica e prevenindo a perda por gotejamento. Portanto, a ótima suplementação com Se para frangos de corte é associada com a melhora da imunidade, conversão alimentar (CA) e qualidade de carne (Surai, 2018).

Os avanços na bioquímica do Se proporcionou um melhor entendimento nas principais diferenças entre o metabolismo das duas apresentações do Se, Se inorgânico (selenito ou selenato de sódio) e Se orgânico (essencialmente SeMet). O Se orgânico, que pode ser encontrado nos ingredientes vegetais das rações está principalmente sob a forma de SeMet e é metabolizado da mesma forma que a metionina (Wolfram, 1999). A SeMet é transportada de forma ativa através das membranas intestinais, durante a absorção e ativamente acumulada em alguns tecidos como fígado e músculos. É sabido que a metionina não é sintetizada pelas aves e outros animais e por isso é um aminoácido essencial. O mesmo é verdade para a SeMet, que não é sintetizada pelas aves e outros animais e deve ser entregue aos animais via ração (Schrauzer, 2000, 2003; Schrauzer e Surai, 2009). Em contrapartida, o Se inorgânico é absorvido como um mineral, sendo pouco retido nas

reservas teciduais. Por essa razão uma grande parte do Se inorgânico é excretada com a urina ou uratos dos monogástricos, sendo uma pequena parte armazenada nos tecidos (Wolfram, 1999).

Parece provável que o Se ingerido seja firmemente ligado à albumina, que irá transportá-lo ao fígado onde o Se é liberado e servirá como componente para a síntese da selenoproteína P. Essa proteína é liberada na corrente sanguínea e servirá como transportadora do Se do fígado para outros tecidos (Suzuki *et al*. 2009). De fato o fígado e os rins são considerados como os principais órgãos sintetizadores de selenoproteínas, incluindo a selenoproteína P, GSH-Px celular (fígado) e GSH-Px extracelular (rins) (Suzuki *et al*., 2009).

A SeMet é uma forma não específica de Se que é metabolizada como constituinte do *pool* de metionina do organismo, sendo aleatoriamente distribuída, desta forma não é afetada pelos processos metabólicos usuais do Se. Assim sendo a SeMet pode ser considerada uma forma de armazenamento do Se no organismo das aves e outros animais (Burk *et al*., 2001). Essas reservas podem ser utilizadas em condições de estresse, onde a exigência de Se aumenta, mas o consumo deste oligoelemento normalmente decresce uma vez que os animais têm um menor consumo de alimentos quando estão sob estresse. Nesta condição o catabolismo proteico, realizado por proteassomos, podem liberar SeMet, que podem servir de fonte de Se para as novas selenoproteínas que estão sendo formadas como a GSH-Px, tioredoxina redutase (TrxR), metionina sulfóxido redutase, entre outras. Essas enzimas tem a capacidade de processar o excesso de radicais livres presentes nas situações de estresse e prevenir a queda da performance produtiva e reprodutiva dos animais (Deagen *et al*., 1987).

2.5. Selênio: biodisponibilidade, absorção e metabolismo

A biodisponibilidade do Se é influenciada por diversos fatores. Como os animais não podem sintetizar SeMet ou distingui-la da metionina, como resultado a SeMet é incorporada em uma gama de proteínas de uma forma não específica (Daniels, 1996). O Se, quando presente na forma de SeMet, consegue ser retido em maior proporção na proteína dos tecidos do que quando se apresenta na forma de selenocisteína (SeCys) ou nas formas inorgânicas. Além da forma química que o Se se apresenta, outros fatores podem também influenciar a biodisponibilidade e distribuição do Se no organismo. Segundo Thomson (1998) componentes da dieta,

status fisiológico e de Se do animal, além da espécie, são cruciais no aproveitamento deste mineral. Daniels (1996) constatou que o Se foi melhor absorvido em dietas de alta proteína. Quando a dieta é limitada em metionina, há a possibilidade de que a SeMet seja preferencialmente incorporada às proteínas do animal, conforme sugere Tian *et al*. (2001). Surai (2006) verificou que a biodisponibilidade do Se depende de outros nutrientes da ração, incluindo o teor de cobre, zinco e manganês, além de vitaminas como B2 e B6.

Algumas interações entre ingredientes são bastante relevantes e devem ser consideradas nas dietas dos animais de produção. O selenito pode ser dissolvido em dietas com alta atividade de água. Uma vez dissolvido, pode formar o ácido selenioso, que ao se volatilizar faz com que o Se da dieta seja perdido e não cumpra sua função nutricional (Eisenberg, 2007). Em premix vitamínico e mineral, quando há a presença de selenito de sódio e ácido ascórbico e esses compostos se encontram, há uma reação química entre eles que leva a redução do selenito à Se elementar, que nesta forma não é absorvido pelo trato gastrointestinal dos animais, de forma semelhante o ácido ascórbico também é oxidado perdendo sua função biológica. Essa reação pode ocorrer tanto na embalagem de premix quanto dentro do trato gastrointestinal dos animais (Gosetti *et al*., 2007). Ip (1986) constatou que o ácido ascórbico é compatível com o Se em sua forma orgânica dentro do premix e que o mesmo não poderia ser afirmado para o selenito ou o selenito. Isso é um ponto de atenção principalmente para o uso de ácido ascórbico em doses crescentes, como usual nos premixes que tem por objetivo reduzir o estresse dos animais, em especial o térmico.

Frente a incompatibilidades como essas, o uso do selenito de sódio nas dietas animais tem sido questionado pela comunidade científica (Fisinin *et al*., 2008; Mahan e Peters, 2004; Ortman e Pehrson, 1997, 1998; Surai, 2002, 2006; Surai e Fisinin, 2014, 2015, 2016a, 2016b). O selenito com sua ação prooxidante e interações com outros nutrientes fez com que a indústria de nutrição animal buscasse outras fontes de Se que fossem mais estáveis e efetivas para serem usadas como suplementação deste mineral. Então, a forma mais simples foi a utilização do Se na mesma forma que ele se apresenta nas plantas, principalmente como SeMet (Surai, 2018).

2.6. A ação do selênio na performance de crescimento de frangos

Muitos estudos confirmam que a suplementação de Se para as aves está relacionada com o aumento do crescimento, desenvolvimento e com a saúde. Surai

(2018) apontou a ação antioxidante do Se, via as diversas selenoproteínas, a ativação dos hormônios da tireoide e a manutenção da saúde intestinal como fatores que influenciam positivamente o crescimento e desenvolvimento das aves. As propriedades imunomoduladoras do Se podem ajudar a manter o sistema imunológico sem o gasto desnecessário de outros nutrientes, uma vez que esse sistema, quando ativado, demanda um gasto metabólico grande para mantê-lo ativo, redirecionando nutrientes que seriam utilizados para o crescimento e desenvolvimento (Song *et al*., 2006; Surai, 2006). Segundo Valcić *et al*. (2011), quando os animais são suplementados com Se orgânico, em comparação com o selenito de sódio, há uma conversão mais eficiente do pró-hormônio T4 em T3 (forma ativa).

O desenvolvimento de aves nas duas primeiras semanas após a eclosão e suplementadas com Se orgânico em selenito foi estudado por Papazyan e Surai (2007). Foi observado que tanto a fonte de Se quanto a dose utilizada (0,2 ou 0,4 mg/kg) podem influenciar na morfologia intestinal das aves. Os pesquisadores constataram que tanto o consumo de ração quanto a conversão alimentar (CA) foram melhoradas nas aves suplementadas com 0,2 mg/kg de Se orgânico e da mesma forma a massa relativa do duodeno também foi superior. O autor Skřivan *et al*. (2008a) observaram que a suplementação de SeMet na dieta das aves fez com que as aves ganhassem mais peso em comparação com as aves suplementadas com selenito de sódio ou não suplementadas.

A suplementação com Se se traduz em uma maior eficiência no ganho de peso das aves. Dietas contendo doses de 0,1 e 0,25 mg/kg de Se orgânico e inorgânico se traduziram em melhora da CA com o aumento da dose, independente da fonte utilizada. O escore de empenamento das aves foi melhorado com a adição de Se, sendo a fonte orgânica superior ao selenito, da mesma forma a fonte orgânica foi significativamente superior para aumentar o peso da carcaça eviscerada e rendimento de peito (Naylor *et al*. 2000). A ausência de Se suplementar se mostrou prejudicial reduzindo o desempenho das aves e até mesmo aumentando a mortalidade ao passo que o Se orgânico se mostrou superior para aumentar o desempenho das aves quando comparado com selenito de sódio ou aos tratamentos não suplementados (Stolic *et al*., 2002). Observamos ainda relatos de frangos consumindo dietas suplementadas com Se orgânico apresentando melhores performances que os animais suplementados com selenito onde o ganho de peso foi superior em 4,2% e a CA 9,8% mais eficiente. Em relação ao grupo suplementado

com selenito, que apresentou uma mortalidade de 6,7%, o grupo suplementado com a fonte orgânica obteve uma menor mortalidade, apresentando apenas 0,84% (Vlahovic *et al*., 1998).

Em avaliações onde duas fontes de Se são utilizadas nos mesmos tratamentos, foi observado um melhor desempenho das aves quando se utilizou uma fonte suplementar de Se em comparação ao uso do selenito. Arruda *et al*.(2004) avaliaram parâmetros produtivos de frangos de 1 a 42 dias de idade. Observaram que a adição de 0,1 mg/kg de Se levedura em combinação com 0,2 mg/kg de selenito proporcionou uma melhora no ganho de peso e CA quando comparado a 0,3 mg/kg de selenito. Outra avaliação semelhante utilizou a associação de 0,2 mg/kg de Se levedura com 0,1 mg/kg de selenito e também foi obtido uma melhora no ganho de peso das aves. Em relação à CA, os autores observaram que ao se utilizar o Se orgânico (0,1; 0,2 ou 0,3 mg/kg) sempre se tinha uma maior eficiência alimentar quando comparado ao grupo suplementado apenas com selenito.

2.7. O papel do selênio na ação antioxidante em frangos

Alguns trabalhos recentes têm focado na ação antioxidante do Se, em especial na comparação entre diferentes fontes (Guo e Yuan, 1998; Wang e Xu, 2008; Jiang *et al*., 2009; Wang *et al*., 2011; Chen *et al*., 2014). Chen *et al*. (2014) mostraram que a atividade da GSH-Px do soro, superóxido dismutase (SOD) total, a habilidade de inibição do radical hidroxil e a capacidade antioxidante total (T-AOC) de aves suplementadas com Se levedura eram significantemente superiores as de aves que consumiram selenito de sódio. Da mesma forma, a oxidação lipídica, expressa em conteúdo de malonaldeído (MDA), foi significativamente menor nas aves que receberam na dieta Se levedura do que nas que consumiram selenito de sódio. Da mesma forma, a atividade de GSH-Px, em amostra de sangue total, foi significativamente maior, com a adição de 0,35 mg/kg de Se de fonte orgânica do que de fonte inorgânica (Guo e Yuan, 1998). Wang e Xu (2008) demonstraram que a maior atividade da GSH-Px em tecidos foi obtida quando Se orgânico foi suplementado na dieta das aves. O uso de 0,225 mg/kg de SeMet foi capaz de aumentar no soro T-AOC, GSH-Px, superóxido dismutase total (T-SOD), atividade da catalase (CAT), concentração de glutationa (GSH) e baixar a produção de MDA, quando comparado com o tratamento não suplementado com Se ou suplementado com selenito de sódio (Jiang *et al*., 2009). No músculo peitoral, Jiang *et al*.(2009), conseguiram observar

ainda que a adição de SeMet significativamente elevou T-AOC, GSH-Px, T-SOD, atividade da CAT, conteúdo de metalotioneína e GSH, e reduziu o conteúdo de proteína carbonílica. De forma similar, foi observado melhora substancial no status antioxidante de frangos suplementados com L-SeMet em comparação com as aves tratadas com selenito de sódio, essa comprovação se deu pelo aumento significativo da concentração da GSH no soro, fígado e músculo peitoral, atividade de SOD no fígado, além da capacidade antioxidante total (T-AOC) nos rins, pâncreas e músculo peitoral e decréscimo da concentração de MDA nos rins, e músculo peitoral dos frangos (Wang *et al*., 2011b).

A forma orgânica do Se tem a capacidade de ser armazenada em grandes quantidades na musculatura de aves, principalmente no músculo peitoral e nos músculos das coxas e sobrecoxas. Bierla *et al*. (2008) observaram que a SeMet compunha 66% e 56,1% do selênio total dos músculos do peito e pernas, respectivamente. No entanto quando SeMet era suplementado para as aves a proporção de SeMet nestes tecidos passou a 99% do total de Se, mostrando uma incorporação não específica da SeMet nas proteínas musculares. Com essa alta concentração de Se nos músculos, devido a suplementação com fontes orgânicas, podemos considerar que há nos organismos uma reserva preciosa de Se principalmente quando os animais são expostos a condições de estresse, quando há um incremento da necessidade de Se e o consumo de ração e consequentemente de Se diminuem (Surai e Fisinin, 2016b). O Se acumulado por fontes orgânicas e armazenado na musculatura de aves é utilizado para sustentar a expressão de selenoproteínas como a GSH-Px, principalmente nos casos de baixa disponibilidade de Se, quando a suplementação é cessada por falta de ingestão de ração (Payne e Southern, 2005).

A GSH-Px foi a primeira selenoproteína descrita e é considerada como o mais importante elemento do sistema de defesa antioxidante das células e do organismo em geral (Surai, 2018). A família da GSH-Px possui pelo menos oito membros, sendo cinco deles enzimas dependentes de Se. Nas espécies de aves ocorrem quatro espécies de GSH-Px (Surai, 2006). A GSH-Px foi descoberta por Mills em 1957 e entre suas funções foi descrito a proteção dos eritrócitos contra o peróxido de hidrogênio (H_2O_2), ela é caracterizada pela alta especificidade da GSH como uma doadora de redutor equivalente (substrato) e catalizadora de redução de uma variedade de hidroperóxidos (Surai, 2018). Takebe *et al*. (2002) sugere que em diferentes condições

celulares e extracelulares uma combinação de selenoproteínas podem ser eficientes na desintoxicação por H_2O_2 e hidroperóxidos lipídicos. Segundo o autor a família da GSH-Px é uma parte importante da defesa antioxidante do organismo animal e essas enzimas apresentam ainda outras importantes funções no metabolismo que exigem investigações mais profundas.

2.8. A relação do selênio com a qualidade da carne de frango

A SeMet é a forma complexada do Se que efetivamente consegue ser depositada no tecido muscular (Surai, 2006). Desta forma, o Se na sua forma orgânica, quando suplementado para as aves, consegue ser depositado nos músculos melhorando a qualidade da carne, reduzindo a perda por gotejamento e peroxidação lipídica durante o armazenamento. Resultados obtidos por Naylor *et al*. (2000) mostraram que as aves que receberam suplementação de Se orgânico em suas dietas tiveram uma menor perda por gotejamento. O efeito dos diferentes níveis e fontes de Se suplementar para aves e seu efeito sobre a qualidade da carne tem sido estudado e os resultados apresentados por Periae *et al* (2007) não mostraram efeito das suplementações com Se sobre alterações no pH da carne mas a suplementação significativamente reduziu a perda pro gotejamento após 24 e 48 horas de armazenamento.

Independente da fonte e dose de Se utilizado e dias de armazenagem, características sensoriais como odor, sabor e aceitação pelo consumidor não foram alteradas para a carne de peito. No entanto a percepção do consumidor quanto a coloração e suculência aos 12 dias foram favoráveis para os tratamentos suplementados com Se (Ahmad *et al*., 2012).

Pesut *et al*. (2005) conduziram um experimento onde frangos foram suplementados com diferentes níveis de Se orgânico (0,05; 0,1 ou 0,3 mg/kg) com ou sem a adição de 100 UI de vitamina E. Conseguiram demonstrar que todos os níveis de suplementação com Se ou vitamina E reduziram significativamente TBARS no plasma aos 28 dias de idade. A atividade da GSH-Px no plasma também foi aumentada em todos os tratamentos com Se. Desta forma concluiu-se que Se levedura teria um efeito semelhante à vitamina E na concentração de MDA no plasma e que a associação de Se com a vitamina E tem um efeito sinérgico. É provável que a SeMet eleve o conteúdo de vitamina E na carne de frango (Skřivan *et al*., 2008a,b). Provavelmente a suplementação de Se orgânico não somente afete a expressão das

seleno proteínas mas também possa potencializar o efeito de outras enzimas antioxidantes e antioxidantes não enzimáticos, aprimorando a efetividade dos mecanismos antioxidantes de defesa do organismo. No entanto a efetividade do Se orgânico na prevenção da peroxidação lipídica na carne de aves dependerá de diferentes fatores, o que inclui o conteúdo basal de SeMet contido na ração não suplementada e na qualidade e quantidade de Se suplementado (Surai, 2018).

Estes dados se assemelham aos obtidos por Perez *et al*. (2010) onde a peroxidação lipídica, em carne de frango congelada por seis meses, foi inibida por suplementação dietética de 0,3 mg/kg de SeMet. Da mesma forma, carne de peito de frangos tiveram uma menor concentração de MDA quando as aves foram suplementadas com fontes orgânicas de Se quando comparadas com as amostras provenientes de aves que consumiram 0,15 mg/kg de Se na forma de selenito (Ahmad, 2012; Wang *et al*., 2010).

A substituição de selenito de sódio por uma fonte orgânica de Se, nas dietas de frangos de corte, pode ser associado com a redução da peroxidação lipídica em amostras de carne de peito ao abate e aos três e cindo dias de armazenagem à quatro a seis graus Celsius (Chekani-Azar *et al*., 2010). Wang *et al*. (2011a) observaram, da mesma forma, um efeito protetivo da suplementação de SeMet em comparação com o selenito de sódio, ambos a 0,15 mg/kg, em termos de redução da peroxidação lipídica, com medidas de concentração de MDA de 0,44 e 0,78 nM/mg de proteína, respectivamente, nas amostras de carne de peito frescas. Dlouhá *et al*. (2008) reportaram que o valor de MDA era inferior na carne de peito de aves, após cinco dias de armazenagem (três a cinco graus Celsius), suplementadas com microalgas (*Chlorella*) enriquecidas com Se em comparação com a suplementação com selenito de sódio. Aparentemente é provável que haja um efeito estabilizador do Se associado à integridade da membrada celular dos músculos (Surai, 2018).

O uso do Se orgânico tem se mostrado mais efetivo que o selenito para aumentar a atividade da GSH-Px no sangue. Esse dado sugere que a qualidade da carne pode ser melhorada pela inclusão de Se orgânico na dieta das aves (Acamovic e Bertin, 2007). A função da oxidação proteica na perda por gotejamento merece mais atenção. A ativação da enzima metionina sulfóxido redutase (MSR), selenoproteína responsável pela prevenção da oxidação proteica, pelo Se dietético pode ser um dos mecanismos que reduz a perda por gotejamento ao longo do armazenamento (Surai, 2006).

2.9. Conclusões

O Se é um oligoelemento essencial na nutrição de aves e dos animais de produção e a sua suplementação ideal é fundamental para a saúde e desenvolvimento destas espécies. Pudemos observar que inúmeros estudos apontam as fontes orgânicas de Se, principalmente a SeMet, como sendo mais biodisponíveis e seguras que as fontes inorgânicas, como o tradicional selenito de sódio.

O SeMet é a forma que o organismo tem de armazenar Se mas como as aves, assim como os outros animais, não são capazes de sintetizar SeMet, o fornecimento via dieta deste elemento é essencial para que o organismo se desenvolva de forma adequada e combata situações de estresse. Sob condições estressantes, há o aumento da expressão de selenoproteínas, requerendo mais Se para sua formação. No entanto, sob estresse os animais reduzem o consumo de ração e consequentemente a ingestão de Se, assim as reservas de Se do organismo, principalmente nos músculos, são mobilizadas para atender a manutenção das defesas antioxidantes.

Podemos considerar a HMSeBA a terceira geração de Se para a suplementação dietética de aves (Surai, 2018). A primeira geração inclui as formas inorgânicas como o selenito e selenato. A segunda geração inclui as formas orgânicas como a seleno levedura, SeMet e Zn-SeMet. Essa nova forma de Se, o HMSeBA, parece ser uma forma que combina vantagens das formas comerciais hoje disponíveis de SeMet. Ela possui a estabilidade da SeMet das seleno leveduras e possui alta concentração de SeMet que observamos na SeMet pura.

Ainda há espaço para pesquisarmos os efeitos da SeMet no organismo das aves como única fonte de Se suplementar e determinar qual a exigência para esse oligoelemento proporciona o melhor desenvolvimento dos animais.

3. HIPÓTESES E OBJETIVOS

Hipóteses

A suplementação com hidroxi-selenometionina pode atender as exigências de selênio para aves e melhorar o desempenho zootécnico dos frangos de corte.

O rendimento de carcaça de frangos de corte, bem como seus cortes podem ser melhorados quando os animais são alimentados com níveis crescentes de hidroxi-selenometionina.

A suplementação das dietas de frangos de corte com hidroxi-selenometionina altera os níveis de oxidação lipídica e a atividade enzimática da GHS-Px em eritrócitos e tecidos do jejuno, íleo, fígado e peito.

Objetivos

Avaliar os efeitos de níveis crescentes de hidroxi-selenometionina sobre o desempenho zootécnico e rendimento de carcaça e cortes comerciais de frangos de corte.

Avaliar os efeitos de níveis crescentes de hidroxi-selenometionina sobre a severidade de lesões de peito amadeirado, bem como a oxidação lipídica e a atividade de glutationa peroxidase no sangue, órgãos e tecidos de frangos de corte aos 35 e aos 42 dias de idade.

Estimar a exigência de hidroxi-selenometionina, como única fonte de selênio, para frangos de corte de acordo com os parâmetros avaliados e as respostas obtidas.

CAPÍTULO II[1]

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METABOLISM AND NUTRITION

HYDROXY-SELENOMETHIONINE FOR BROILERS

Broiler meat production as affected by dietary supplemental hydroxy-selenomethionine

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ABSTRACT Selenium is essential and usually deficient in corn-soy diets for broilers. Hydroxy-selenomethionine (OH-SeMet) is a commercial organic source scarcely evaluated as a single supplemental source of Se. The objective of this study was to evaluate the increasing Se supplementation from OH-SeMet on broiler live performance, carcass yield and oxidation responses. A total of 1,500 Cobb 500 one-day-old male chicks were fed five treatments with 12 replicates of 25 birds each in a 3-phase feeding program from 1 to 42 d. Corn-soy feeds had no added OH-SeMet (with 0.0, 0.03, 0.03 and 0.02 ppm analyzed Se) or supplemented with 0.15, 0.30, 0.45 and 0.60 ppm of Se from OH-SeMet. At 35 and 42 d, five birds were randomly selected from each pen, processed for carcass evaluation and scored for WB. At 42 d, breasts were analyzed for cooking loss (CL) and water-holding capacity (WHC) as well as lipid oxidation (TBARS) and glutathione peroxidase (GSH-Px) activity. Analyses were conducted using quadratic polynomial (QP) and exponential asymptotic (EA) regression models. Increasing OH-SeMet led to quadratic and exponential increases ($P < 0.05$) on BWG from 1 to 21 d, 1 to 35 d and 1 to 42 d with optimum responses at 0.48 and 0.50 ppm, 0.44 and 0.49 ppm and 0.40 ppm dietary Se for QP and EA models, respectively. Dietary Se that maximized breast and carcass yields at 42 d were 0.35 and 0.44 ppm using QP and 0.47 and 0.38 ppm Se using EA model. Dietary Se increased GSH-Px activity in erythrocytes of broilers at 42 d was 0.27 ppm using QP model ($P < 0.05$). No effects of Se levels were observed on WB scores at 35 and 42 d, CL and WHC as well as on TBARS in intestine, liver and breast muscle samples ($P > 0.05$). Supplementation of Se from OH-SeMet in corn-soy feeds improved broiler performance and carcass and breast yields. Average Se that optimized BWG was 0.46 whereas 0.44 ppm was needed for carcass and 0.38 ppm for breast yield.

Key words*:* broiler, growth performance, micromineral, requirement, wooden breast.

INTRODUCTION

Selenium (**Se**) is an essential micromineral for animal growth that, however, presents a narrow line between essentiality and toxicity among different species (Alian *et al*., 2020). Growing crops that are usually fed to animals, on the other hand, do not have a requirement for Se (Mikkelsen *et al*., 1989), even though low levels of Se have reported few beneficial effects for some plants (Hasanuzzaman *et al*., 2011; Saidi *et al*., 2014). Existing concerns related to Se toxicity, therefore, in practical feeding is mainly related to a minority of plant species that can reach very high Se concentrations, the so-called Se accumulators (Gupta and Gupta, 2017; Tinggi, 2003; Terry *et al*., 2000). These are dependent on soil Se content, which varies depending on the rocks that originate it as well as Se carrying anthropogenic activities such as irrigation and mining (Mikkelsen *et al*., 1989).

The essentiality of Se for animals was firstly reported in 1957 by Schwarz and Foltz (1957), after demonstrating the role of Se in muscular dystrophy as well as in the prevention of liver necrosis in rats. Since then, major efforts have been made to elucidate Se function and the impact of its deficiency in animal feeds. To the present, about 30 selenoproteins have been identified, mainly carrying roles as antioxidants, synthesis of DNA, thyroid hormones and reproduction (Ducros and Favier, 2004; Kawai *et al*., 2018).

In 1974, the Food and Drug Administration (**FDA**) granted the approval for 0.10 ppm supplemental dietary Se for swine and chickens, and 0.20 ppm for turkeys (FDA, 1974). The majority of domestic animal species have had Se requirements published in a range between 0.05 ppm to 0.30 ppm in the past (NRC, 1983). However, this figure was later increased when supplemental Se at 0.30 ppm was approved by the FDA (FDA, 1987). Traditional recommendations for Se supplementation in broiler feeds

appeared as 0.15 ppm in the NRC (1994), whereas a range from 0.08 to 0.15 ppm Se, when supplemented from organic sources were presented by Rostagno *et al*. (2017). However, it has been recently demonstrated that optimization of broiler meat requires higher dietary Se when compared to all the above cited references (Cemin *et al*., 2018). Modern broiler chicken performance has been considerably improved with time (Havenstein *et al*., 2003), which may have been impacted by a continuous reduced feed intake per unit of growing live mass. Therefore, Se intake has been reduced in parallel with increased metabolic rates needed to sustain greater muscle synthesis. This has led to the speculation on the need of higher dietary Se than usually done commercially.

Traditionally, Se supplementation is done with selenite salts. However, novelty organic forms of Se, in which this element replaces sulphur in the methionine (**Met**) molecule, are available for in-feed use (Prakash *et al*., 2018; Bakhsalinejad *et al*., 2019; Shabani *et al*., 2019). Since Se involvement in nutrition has been increasingly noted, the study of its role in metabolic pathways other than growth may present important information. Hydroxy-selenomethionine (**OH-SeMet**) is a novel source of Se, which has been developed using the hydroxy analogue of Met 2-hydroxy, 4-methylthiobutyric acid, a popular supplemental source of Met in broiler feeds. In its structure, OH-SeMet has Se linked via two single covalent bonds (EFSA, 2013).

The supplemental Se from OH-SeMet has not been fully investigated to attend live performance as well as other potential responses affected by this element. The objectives of the present study were to evaluate growth performance, carcass and breast yields and the severity of wooden breast (**WB**) as well as lipid oxidation and enzyme activity of broiler chickens fed diets supplemented with increasing levels of Se.

Selenium requirements for the evaluated responses were also estimated using OH-SeMet as the sole supplemental source of Se.

MATERIALS AND METHODS

All procedures used in the present study were approved by the Ethics and Research Committee of the Federal University of Rio Grande do Sul, Porto Alegre, Brazil.

Bird Husbandry

A total of 1,500 slow-feathering, Cobb × Cobb 500 one-day-old male chicks (BRF, Lajeado, RS, Brazil), vaccinated for Marek's disease at the hatchery were randomly placed into 60 floor pens (1.65 m × 1.65 m; 9.19 birds/m^2) in a tunnel ventilated house. Broilers were fed 5 experimental diets, with 12 replicates of 25 birds each, distributed in a completely randomized design. Bedding material was new rice hulls and pens were equipped with a 15 kg capacity tube feeder and 3 nipple drinkers. Birds had *ad libitum* access to water and mash feeds. Average temperature was 32ºC at placement, being reduced 1ºC every 2 days. Attempts to maintain thermal comfort were conducted throughout the use of heaters, fans with evaporative coolers and foggers. Lighting was continuous until 14 d of age, with a 16L:8D cycle used afterwards.

Experimental Feeds

The dietary treatments consisted of corn-soy all vegetable feeds having increased supplemental Se from OH-SeMet as follow: 0.0, 0.15, 0.30, 0.45 and 0.60 ppm (Table 1). The commercially available OH-SeMet (Selisseo, Adisseo Brasil Ltda, São Paulo, SP, Brazil) contains 2% Se and 5% 2-hydroxy, 4-methylthiobutyric acid. A three-phase feeding program with starter (1 to 21 d), grower (21 to 35 d), and finisher (35 to 42 d) feeds was used. Feeds were formulated as usual in the Brazilian broiler

industry. The non-supplemented starter, grower and finisher feeds had formulated Se contents of 0.03, 0.03 and 0.02 ppm, respectively.

Experimental Procedures and Chemical Analysis

For each feeding phase a non-supplemented Se feed was prepared, which was further added with OH-SeMet (previously mixed with finely ground soybean meal). Feeds with 0 and 0.60 ppm supplemental Se were manufactured in 400 kg batches and then proportionally blended to achieve the intermediate Se supplementation in the different treatments. After preparation, the final diets were sampled and analyzed in duplicate to determine Se concentration (method 999.10; AOAC International, 2000). The ingredient composition of experimental diets (crude protein, calcium and phosphorus) and expected Se from formulation are presented in Table 1.

Growth performance was evaluated by measuring body weight gain (**BWG**), feed intake (**FI**) and FCR (corrected for the weight of dead birds) at 1, 7, 14, 21, 35 and 42 d. At 35 and 42 d, 5 birds were randomly selected from each pen and processed for carcass and yield of commercial cuts. Prior to processing, broilers were fasted for 8 h and then individually weighed. Birds were rendered insensible by electrical stunning (45 V for 3 s), bled through a jugular vein cut for 3 min, scalded at 60ºC for 45 s, and lastly defeathered. Evisceration was manually performed with carcasses being statically chilled in ice for approximately 3 h. Carcasses (without feet and neck) were hung for 3 min to remove the excess of water prior to weighing. Commercial cuts were performed by a crew of industry-trained personnel into bone-in drumsticks, thighs, and wings, as well as deboned breast fillets and tenders. Abdominal fat was weighed separately. Carcass yield was expressed as a percentage of live weight, while

commercial cuts and abdominal fat were expressed as percentage of the eviscerated carcass.

Deboned fillets were separated into groups by the presence or absence of WB at 35 and 42 d. Breast fillets were then submitted to a four-subject panel evaluation to provide scores of WB as previously described by Simões *et al*. (2020). Scores included the absence of WB (normal breast-score 0); mild hardening in the upper (score 1); moderate hardening in the upper and/or lower part of the fillet (score 2); severe hardening (score 3); and severe hardening with haemorrhagic lesions, increased volume and presence of yellow fluid (score 4).

Samples of tissues and breast fillets were taken after 0, 3, 6 and 9 d of storage at 4ºC for lipid oxidation assessment. The oxidative stability was measured by using thiobarbituric acid reactive substances (**TBARS**) according to the guidelines of Botsoglou *et al*., (1994) and Liu *et al*. (2010). The TBARS was expressed as nmol of malondialdehyde (**MDA**) per mg of sample. Water-holding capacity (**WHC**) and cooking loss (**CL**) of breast samples were determined as described by Wierbicki and Deatherage (1958). Glutathione peroxidase (**GSH-Px**) activity was determined according to Paglia and Valentine (1967), being expressed in units per gram of sample (Punchard and Kelly, 1996).

Statistical Analysis

The study was designed with a gradient treatment structure distributed in a completely randomized design. Data were tested for homoscedasticity and normality prior to statistical analyses. Data that were not normally distributed were square root transformed for analyses, but the real means are the ones presented in tables of results. Data were submitted to an ANOVA using the MIXED procedure of SAS (SAS,

2009). Occurrence and grading of myopathies were analyzed by descriptive statistics. Mean differences in the occurrence of WB and performance data were also separated using Tukey's HSD test. Significance was accepted at $P \leq 0.05$.

Estimations of maximum responses to total dietary Se were done using linear (**L**), quadratic polynomial (**QP**) and exponential asymptotic (**EA**) regression models. The L model ($Y = \beta1 + \beta2 \times X$) had Y as the dependent variable, X as the dietary level of Se, β1 as the intercept, and β2 as the linear coefficient. The QP model ($Y = \beta1 + \beta2 \times Se + \beta3 \times (Se)^2$) had Y as the dependent variable as a function of dietary level of Se; β1 as the intercept; β2 as the linear coefficient and β3 as the quadratic coefficient. The maximum response for Se was defined as $Se = – \beta2 \div (2 \times \beta3)$. The EA model was expressed as $Y = \beta0 + \beta1 \times (1 – EXP(– \beta2 \times (Se – \beta3)$, where Y is the dependent variable, β0 is the response for the dependent variable estimated for the feed with the lower Se, β1 is the difference estimated between the minimum and maximum response obtained by the increasing Se, β2 is the slope of the exponential curve, β3 is the Se at the lower level. Maximum response at 95% of the plateau was obtained by $\ln (0.05) \div – \beta2 + \beta3$.

RESULTS

Analyzed Se in the experimental feeds were within acceptable ranges when compared to formulated values (Table 1). There were no effects of treatments on mortality (Grand mean = 1.57%) and feed intake was not affected by the treatments throughout the study ($P > 0.05$).

Effects of the increasing dietary supplementation of OH-SeMet on BWG and FCR of broiler chickens are shown in Table 2. Mean comparisons between treatments for live performance showed no effects of dietary Se from 1 to 14 d; however, from 1 to

21 d, 1 to 35 d and 1 to 42 d the BWG increased when Se was supplemented at 0.15, 0.45 and 0.30 ppm compared to the non-supplemented feeds ($P < 0.05$). Reductions in FCR were observed when broilers were fed 0.45 ppm Se compared to non-supplemented broilers from 1 to 21 d ($P < 0.05$); however, no differences were observed in the other periods ($P > 0.05$). Mean comparisons of carcass and commercial cuts of broilers fed increasing dietary Se from OH-SeMet are shown in Table 3; no differences were observed by the Tukey test for carcass and commercial cuts responses.

Estimations of optimized responses of performance and carcass yield by regression analyses are presented in Table 4. No effects were observed using the linear regression model ($P > 0.05$); however, increases in supplemental Se allowed QP and EA adjustments ($P < 0.001$) for most live performance and meat responses. Dietary Se that maximized BWG were 0.48 ppm ($R^2 = 0.40$), 0.44 ppm ($R^2 = 0.23$) and 0.43 ppm ($R^2 = 0.25$) from 1 to 21 d, 1 to 35 d and 1 to 42 d, respectively, using the QP model. Through the EA model, dietary Se that maximized BWG from 1 to 21 d, 1 to 35 d and 1 to 42 d were 0.50 ppm ($R^2 = 0.32$), 0.49 ppm Se ($R^2 = 0.11$) and 0.40 ppm Se ($R^2 = 0.17$), respectively. Estimations of dietary Se that optimized FCR were only obtained when the QP model was used and values that optimized this response were 0.35 ppm and 0.32 ppm from 1 to 21 d and 1 to 35 d, respectively.

Significant regressions ($P < 0.05$) allowed for the estimation of dietary Se that optimized carcass responses as follow: 42 d carcass weight and yield at 0.48 ppm ($R^2 = 0.25$) and 0.44 ($R^2 = 0.27$) using the QP model as well as at 0.47 ppm ($R^2 = 0.20$) and 0.38 ($R^2 = 0.16$) using the EA model; 42 d breast weight at 0.39 ppm ($R^2 = 0.24$) and 0.30 ppm ($R^2 = 0.10$), respectively using QP and EA models; 42 d breast yields at 0.35 ppm ($R^2 = 0.24$) and 0.47 ($R^2 = 0.20$) using QP and EA models, respectively.

No differences ($P > 0.05$) between treatments were observed on WB scores, WHC and CL (Table 5) as well as on GSH-Px and TBARS in jejunum, ileum, liver and breast muscle (Table 6). Increasing Se levels from OH-SeMet also did not affect WB occurrence, WHC, CL and TBARS ($P > 0.05$); however, estimations of total dietary Se that increased GSH-Px activity in erythrocytes were 0.27 ppm ($R^2 = 0.16$) using the QP model.

DISCUSSION

Basal feeds used in this experiment were formulated with corn and soybean meal containing nutrient and energy contents as usual in broiler commercial feeds, except for Se. The majority of dietary Se in the current study was provided by OH-SeMet. Traditionally, Se supplementation in broiler feeds varies between organic and inorganic sources (most commonly from sodium selenite, f.i.). Increasing levels of supplemented Se from OH-SeMet have not been fully investigated such that live performance and carcass yield can be considered altogether.

Results observed in the present experiment indicated that Se supplementation for broilers led to increases in BWG from 1 to 42 d. Moreover, broilers fed diets without supplemented Se presented lower BWG and higher FCR compared to broilers fed increasing dietary Se from OH-SeMet, demonstrating that their Se contents are below requirements for optimum bird performance. Choct *et al*. (2004) observed higher BW at 38 d and no effects on FI of broilers fed 0.25 ppm Se from Se yeast when compared to sodium selenite at 0.10 or 0.25 ppm. On the other hand, Oliveira *et al*. (2014) observed that Se yeast supplementation at 0.19 ppm of analyzed Se was enough to obtain adequate bird performance until 42 d. Studies with Se resulting from fermentation sources usually do not provide analyses of the molecule that binds Se.

In the current study, increasing dietary Se from OH-SeMet resulted in quadratic and exponential responses on broiler growth performance. Contents of Se that maximized BWG from 1 to 42 d were 0.43 and 0.40 ppm, using EA and QP models, respectively. Cemin *et al*. (2018) evaluated the supplementation of zinc-L-selenomethionine (Zn-L-SeMet) from 1 to 42 d and observed that optimal dietary Se for BWG and FCR were 0.67 and 0.63 ppm, respectively, using the QP model.

Optimal dietary Se supplementation observed in the current study were 0.44 and 0.38 ppm for carcass yield using EA and QP models, respectively. For breast yield at 42 d, the observed requirement was 0.35 and 0.47 ppm using EA and QP models, respectively. Cemin *et al*. (2018) also verified quadratic increases on carcass and breast yields at 42 d as well as higher dietary Se contents to optimize responses at 0.85 and 0.86 ppm, respectively. Previous studies from Downs *et al*. (2000) and Deniz *et al*. (2005) did not show differences in BWG and carcass yields when broilers were fed 0.30 ppm from Se yeast compared to non-supplemented diets. Research on Se requirements with dietary Se levels higher than 0.30 ppm are scarce, presumably due to FDA regulations (FDA, 1987).

In the current study, increasing Se levels had no effects on WB occurrence at 35 or 42 d ($P > 0.05$). The WB is commonly related to high growth rates (Kuttappan *et al*., 2012; Petracci and Cavani, 2012; Zimermann *et al*., 2012; Livingston *et al*., 2018; Petracci *et al*., 2019; Aguirre *et al*., 2020; Simões *et al*., 2020). The possibility that Se supplementation can reduce the severity of myopathies through the amelioration of antioxidant status in broilers may have been shadowed by the positive impact in the growth rate produced by the increased Se in feeds.

Customer preferences for fresh meat that do not present water loss during handling and cooking are important (Surai, 2015). These aspects of meat quality are

related to the capability of muscle proteins to hold water efficiently within the cells (Saleh *et al*., 2014). Once Se is involved in intra and in extracellular antioxidant systems, it could be possible that the supplementation of Se can increase meat quality, reducing water loss (Mahan and Parrett, 1996). Notwithstanding, in this study, no differences among Se levels were observed on CL and WHC. Similarly, Boiago *et al*. (2014) observed no effects on CL and WHC when evaluating meat from birds at 42 d when fed diets with SeMet supplementation ranging from 0.0 to 0.5 ppm. In corroboration with that, Göçmen *et al*. (2016) did not verify any effect of Se yeast in broilers fed on CL and WHC when tested at 0, 0.15, 0.30, 0.45 and 0.60 ppm Se. Oliveira *et al*. (2014) observed higher breast CL ($P < 0.05$) from broilers fed 0.15 ppm of Se from a yeast source when compared to those fed diets with 0.30, 0.45 and 0.60 ppm Se. These authors also observed a significant reduction in CL when using 0.60 ppm Se (15.87%).

The present study was not designed to compare effects of Se sources. Muscle Se deposition, bioavailability of organic and inorganic Se sources as well as the impact of Se on lipid oxidation and GSH-Px activity have been previously described (Schrauzer, 2000; Briens *et al*., 2014; Markovic *et al*., 2018). Briens *et al*. (2014) reported that OH-SeMet is a precursor of selenomethionine (**SeMet**), which is easily converted and metabolized from dietary consumed OH-SeMet, including building Se reserves in muscles.

Relationships between dietary Se supply and GSH-Px activity was demonstrated to be dependent on Se source as well as in the investigated tissue (Bermingham *et al*., 2014). In the current study, it was observed a quadratic increase on GSH-Px concentration in erythrocytes with a maximum activity at 0.27 ppm Se. However, no differences were observed in the GSH-Px concentration in muscle, liver and intestinal

samples. Nonetheless, increasing Se levels in broiler feeds did not influence GSH-Px activity in erythrocytes (Choct *et al*., 2004), plasma and breast muscle (Payne and Southern, 2005; Leeson *et al*., 2008), thighs (Cichoski *et al*., 2012), or liver (Heindl *et al*., 2010). Ingested Se is used to produce several selenoproteins besides GSH-Px (Cichoski *et al*., 2012), which can be a supportive explanation for the findings in the present study.

Increasing levels of Se supplementation improved GSH-Px activities in broiler plasma (Wang *et al*., 2011; Rama Rao *et al*., 2013; Göçmen *et al*., 2016). Göçmen *et al*. (2016) reported that the highest plasma and liver GSH-Px activity were observed when broilers were fed 0.60 ppm Se from yeast compared to 0, 0.15 and 0.30 ppm. Yoon *et al*. (2007) reported that the GSH-Px activity linearly increased when broilers were fed from 0.1 to 0.3 ppm from Se yeast. Perhaps because Se is involved in several protein synthesis, the effect of dietary Se supplementation can have inconsistent effects on GSH-Px activity in broilers. Furthermore, Hu *et al*. (2012) observed that GSH-Px produced the greatest response when 0.15 ppm from nano elemental Se was fed to broilers, plasma GSH-Px activity reached a plateau, and did not increase further with higher Se concentrations in the diet.

Lipid oxidation causes loss of nutritional value and produce potentially toxic compounds that compromise meat quality and reduce its shelf life (Cortinas *et al*., 2005). Metabolic antioxidant activities reduce muscle lipid oxidation by preventing free radical production (Fellenberg and Speisky, 2006). However, in this experiment, there were no differences on lipid oxidation when increasing levels of Se from OH-SeMet. Boiago *et al*. (2014) also did not observe differences in lipid oxidation when evaluating 0, 0.3 and 0.5 ppm Se from selenomethionine in broiler feeds.

In conclusion, presently determined Se requirements for broiler chickens fed corn-soy diets were higher than presented to date in popular tables of recommendations. Increasing Se levels resulted in improved broiler performance as well as carcass and breast meat yields. Optimizing body weight with increased dietary Se did not led to changes in the severity or occurrence of wooden breast; therefore, the wooden breast myopathy do not seem to be associated with dietary Se content. Maximum responses of Se from OH-SeMet for the cumulative BWG from 1 to 42 d were estimated at 0.43 ppm and 0.40 ppm using QP and EA models, respectively. Breast fillets responses to dietary Se were estimated at 0.35 and 0.47 ppm of Se using the QP and EA models, respectively. The average Se that optimized BWG was 0.46 whereas 0.44 ppm was needed for carcass and 0.38 ppm for breast meat yields.

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References

Aguirre, M.A., H. Leyva-Jimenez, R. Travis, J.T. Lee, G. Athrey, and C.Z. Alvarado. 2020. Evaluation of growth production factors as predictors of the incidence and severity of white striping and woody breast in broiler chickens. Poult. Sci. 99:3723–3732. doi:10.1016/j.psj.2020.03.026.

AOAC International. Official Methods of Analysis. 17th ed. Arlington, VA: AOAC Int. (2000).

Alian, H. A., H. M. Samy, M. T. Ibrahim, and M. M. A. Mahmoud. 2020. Nanoselenium effect on growth performance, carcass traits, antioxidant activity, and immune

status of broilers. Environ. Sci. Pollut. Res. 38607–38616. doi:10.1007/s11356-020-09952-1

Bakhshalinejad, R., A. Hassanabadi, and R. A. Swick. 2019. Dietary sources and levels of selenium supplements affect growth performance, carcass yield, meat quality and tissue selenium deposition in broilers. Anim. Nutr. 5:256–263. doi:10.1016/j.aninu.2019.03.003

Bermingham, E. N., J. E. Hesketh, B. R. Sinclair, J. P. Koolaard, and N. C. Roy. 2014. Selenium-enriched foods are more effective at increasing glutathione peroxidase (GPx) activity compared with selenomethionine: a meta-analysis. Nutrients. 6:4002–4031.

Boiago, M. M., H. Borba, F. R. Leonel, A. Giampietro-Ganeco, F. B. Ferrari, L. M. Stefani, and P. A. Souza. 2014. Sources and levels of selenium on breast meat quality of broilers. Ciênc. Rural. 44:1692–1698. doi:10.1590/0103-8478cr20131256

Botsoglou, N. A., D. J. Fletouris, G. E. Papageorgiou, V. N. Vassilopoulos, A. J. Mantis, and A. G. Trakatellis. 1994. Rapid, sensitive, and specific thiobarbituric acid method for measuring lipid peroxidation in animal tissue, food, and feedstuff samples. J. Agric. Food Chem. 42:1931–1937. doi:10.1021/jf00045a019

Briens, M., Y. Mercier, F. Rouffineau, F. Mercerand, and P. A. Geraert. 2014. 2-hydroxy-4-methylselenobutanoic acid induces additional tissue selenium enrichment in broiler chickens compared with other selenium sources. Poult. Sci. 93: 85–93. doi:10.3382/ps.2013-03182

Cemin, H. S., S. L. Vieira, C. Stefanello, L. Kindlein, T. Z. Ferreira, and A. K. Fireman. 2018. Broiler responses to increasing selenium supplementation using Zn-L-selenomethionine with special attention to breast myopathies. Poult. Sci. 97:1832–1840. doi:10.3382/ps/pey001

Choct, M., A.J. Naylor, and N. Reinke. 2004. Selenium supplementation affects broiler growth performance, meat yield and feather coverage. Br. Poult. Sci. 45:677–683. doi:10.1080/00071660400006495

Cichoski, A. J., R. Bezerra Rotta, G. Scheuermann, A. C. Junior, and J. S. Barin. 2012. Investigation of glutathione peroxidase activity in chicken meat under different experimental conditions Investigação da atividade de glutationa peroxidase em carne de frango submetida a diferentes condições experimentais. Ciência e Tecnol. Aliment. 32:661–667. doi:0.1590/S0101-20612012005000107

Cortinas, L., A. Barroeta, C. Villaverde, J. Galobart, F. Guardiola, and M. D. Baucells. 2005. Influence of the dietary polyunsaturation level on chicken meat quality: Lipid oxidation. Poult. Sci. 84:48–55. doi:10.1093/ps/84.1.48

Deniz, G., S. S. Gezen, and I. I. Turkmen. 2005. Effects of two supplemental dietary selenium sources (mineral and organic) on broiler performance and drip-loss. Rev. Med. Vet. 156:423–426.

Dlouhá, G., S. Ševčíková, A. Dokoupilová, L. Zita, J. Heindl, and M. Skřivan. 2008. Effect of dietary selenium sources on growth performance, breast muscle selenium, glutathione peroxidase activity and oxidative stability in broilers. Czech J. Anim. Sci. 67:1350–1359. doi:10.17221/361-CJAS

Downs, K. M., J. B. Hess, and S. F. Bilgili. 2000. Selenium source effect on broiler carcass characteristics, meat quality and drip loss. J. Appl. Anim. Res. 18:61–72. doi:10.1080/09712119.2000.9706324

Ducros, V., and A. Favier. 2004. Métabolisme du sélénium Selenium metabolism 1:19–28. https://doi.org/10.1016/S1762-5653(03)00002-9

EFSA, European Food Safety Authority. 2013. Scientific opinion on safety and efficacy of hydroxy-analogue of selenomethionine as feed additive for all species. EFSA J.

11:3046. doi:10.2903/j.efsa.2013.3046

FDA, Food and Drug Administration. 1974. Food additives: Selenium in animal feed. Federal Register., 39 (1974), p. 1355.

FDA, Food and Drug Administration. 1987. Food additives permitted in feed and drinking water of animals: selenium. Federal Register, 52 (1987), p. 1087.

Fellenberg, M. A., and H. Speisky. 2006. Antioxidants: their effects on broiler oxidative stress and its meat oxidative stability. Worlds. Poult. Sci. J. 62:53–70. doi: 10.1079/wps200584

Göçmen, R., O. Yazgan, and Y. Cufadar. 2016. Effect of different organic and inorganic selenium levels on performance, selenium concentrations of some tissues, glutathione peroxidase enzyme activity and meat quality in broilers. J. Anim. Plant. Sci. 26:916–923.

Gupta, M., and S. Gupta. 2017. An overview of selenium uptake, metabolism, and toxicity in plants. Front. Plant Sci. 7:1–14. doi:10.3389/fpls.2016.02074

Hasanuzzaman, M., Hossain, M. A and M. Fujita. 2011. Selenium-induced up-regulation of the antioxidant defense and methylglyoxal detoxification system reduces salinity-induced damage in rapeseed seedlings. Biol. Trace Elem. Res. 143: 1704-1721. doi: 10.1007/s12011-011-8958-4

Havenstein, G. B., P. R. Ferket, and M. A. Qureshi. 2003. Growth, livability , and feed conversion of 1957 versus 2001 broilers when fed representative 1957 and 2001 broiler diets. Poult. Sci. 1:1500–1508. doi: 10.1093/ps/82.10.1500

Heindl, J., Z. Ledvinka, M. Englmaierova, L. Zita, and E. Tumova. 2010. The effect of dietary selenium sources and levels on performance, selenium content in muscle and glutathione peroxidase activity in broiler chickens. Czech J. Anim. Sci. 55: 572–578.

Hu, C. H., Y. L. Li, L. Xiong, H. M. Zhang, J. Song, and M. S. Xia. 2012. Comparative effects of nano elemental selenium and sodium selenite on selenium retention in broiler chickens. Anim. Feed Sci. Technol. 177:204–210. doi:10.1016/j.anifeedsci.2012.08.010

Kawai, M., Y. Shoji, S. Onuma, Y. Etani, and S. Ida. 2018. Thyroid hormone status in patients with severe selenium deficiency. Clin. Pediatr. Endocrinol. 27:67–74. doi:10.1297/cpe.27.67

Kuttappan, V. A., V. B. Brewer, J. K. Apple, P. W. Waldroup, and C. M. Owens. 2012. Influence of growth rate on the occurrence of white striping in broiler breast fillets. Poult. Sci. 91:2677–2685. doi:10.3382/ps.2012-02259

Leeson, S., H. Namkung, L. Caston, S. Durosoy, and P. Schlegel. 2008. Comparison of selenium levels and sources and dietary fat quality in diets for broiler breeders and layer hens. Poult. Sci. 87:2605–2612. doi:10.3382/ps.2008-00174

Liu, F., R. Dai, J. Zhu, and X. Li. 2010. Optimizing color and lipid stability of beef patties with a mixture design incorporating with tea catechins, carnosine, and α-tocopherol. J. Food Eng. 98:170–177. doi:10.1016/j.jfoodeng.2009.12.023

Livingston, M. L., C. Landon, H. J. Barnes, and J. Brake. 2018. White striping and wooden breast myopathies of broiler breast muscle is affected by time-limited feeding, genetic background, and egg storage. Poult. Sci. 98:217–226. doi:10.3382/ps/pey333

Mahan, D. C., and N. A. Parrett. 1996. Evaluating the efficacy of selenium-enriched yeast and sodium selenite on tissue selenium retention and serum glutathione peroxidase activity in grower and finisher swine. J. Anim. Sci. 74:2967–2974. doi:10.2527/1996.74122967x

Markovic, R., J. Ciric, M. Starcevic, D. Sefer, and M. Z. Baltic. 2018. Effects of selenium

source and level in diet on glutathione peroxidase activity, tissue selenium distribution, and growth performance in poultry. Anim. Heal. Res. Rev. 19:166–176. doi:10.1017/S1466252318000105

Mikkelsen, R. L., A. L. Page, and F. T. Bingham. 1989. Factors affecting selenium accumulation by agricultural crops 1. Selenium in Agriculture and the Environment, SSSA.

National Research Council. 1983. Selenium in Nutrition. National Academy Press, Washington, DC.

National Research Council. 1994. Nutrient Requirements of Poultry. 9th rev. ed. Natl. Acad. Press, Washington, DC.

Oliveira, T. F. B., D. F. R. Rivera, F. R. Mesquita, H. Braga, E. M. Ramos, and A. G. Bertechini. 2014. Effect of different sources and levels of selenium on performance, meat quality, and tissue characteristics of broilers. J. Appl. Poult. Res. 23:15–22. doi:10.3382/japr.2013-00761

Paglia, D. E., and W. N. Valentine. 1967. Studies on the quantitative and qualitative characterization of erythrocyte glutathione peroxidase. J. Lab. Clin. Med. 70:158–169.

Payne, R. L., and L. L. Southern. 2005. Comparison of inorganic and organic selenium sources for broilers. Poult. Sci. 1:2 898–902. doi:10.1093/ps/84.6.898

Perić, L., N. Milošević, D. Žikić, Z. Knački, N. Džinić, L. Nollet, and P. Springs. 2009. Effect of selenium sources on performance and meat characteristics of broiler chickens. J. Appl. Poult. Res. 18:403–409. doi:10.3382/japr.2008-00017

Petracci, M., and C. Cavani. 2012. Muscle growth and poultry meat quality issues. Nutrients. 4:1–12. doi:10.3390/nu4010001

Petracci, M., F. Soglia, M. Madruga, L. Carvalho, E. Ida, and M. Estévez. 2019.

Wooden breast, white striping, and spaghetti meat: causes, consequences and consumer perception of emerging broiler meat abnormalities. Compr. Rev. Food Sci. Food Saf. 18:565–583. doi:10.1111/1541-4337.12431

Prakash, B., S.V. Rama Rao, M.V.L.N Raju, and C.S. Reddy. 2018. Effect of supplementing selenized yeast on performance and anti-oxidant responses in Vanaraja and commercial broiler chickens. Indian J. Anim. Res. 53:500–504. doi:10.18805/ijar.b-3520

Punchard, N. A., and F. J. Kelly. 1996. Glutathione peroxidase: activity and steady-state level of mRNA. In: Daret, K. *et al*. Free radicals: a pratical approach. London: Oxford University Press, p.227–240.

Rama Rao, S. V., B. Prakash, M. V. L. N Raju, A. K. Panda, S. Poonam, and O. K. Murthy. 2013. Effect of supplementing organic selenium on performance, carcass traits, oxidative parameters and immune responses in commercial broiler chickens. Asian-Australasian J. Anim. Sci. 26:247–252. doi:10.5713/ajas.2012.12299

Rostagno, H. S., L. F. T. Albino, M. I. Hannas, J. L. Donzele, N. K. Sakomura, F. G. Perazzo, A. Saraiva, M. V. Teixeira, P. B. Rodrigues, R. F. Oliveira, S. L. T. Barreto, and C. O. Brito. 2017. Tabelas brasileiras para aves e suínos. Composição de alimentos e exigências nutricionais. 4rd ed. UFV, Viçosa, MG, Brazil.

Saidi, I., Y. Chtourou, and W. Djebali. 2014. Selenium alleviates cadmium toxicity by preventing oxidative stress in sunflower (*Helianthus annuus*) seedlings. J. Plant Physiol. 171:85-91. doi:10.1016/j.jplph.2013.09.024

Saleh, A. A., D. Ijiri, and A. Ohtsuka. 2014. Effects of summer shield supplementation on growth performance, nutrient utilisation, and plasma lipid profiles in broiler chickens. Vet. Med. 59:536–542. doi:10.17221/7818-VETMED

SAS Institute. 2012. User's Guide: Statistics Version 9.4.edition. Cary, NC: SAS Institute.

Schrauzer, G. N. 2000. Selenomethionine: a review of its nutritional significance, metabolism and toxicity. J. Nutr. 130:1653–1656. doi:10.1093/jn/130.7.1653

Schwarz, K., and C. M. Foltz. 1957. Selenium as an integral part of Factor 3 against dietary necrotic liver degeneration. J. Am. Chem. Soc. 79:3292–3293. doi:10.1021/ja01569a087

Shabani, R., J. Fakhraei, H. M. Yarahmadi, and A. Seidavi. 2019. Effect of different sources of selenium on performance and characteristics of immune system of broiler chickens. Rev. Bras. Zootec. 48:e20180256. doi:10.1590/RBZ4820180256

Simões, C. T., S. L. Vieira, C. Stefanello, L. Kindlein, T. Z. Ferreira, A. Favero, and B. Xavier. 2020. An in vivo evaluation of the effects of feed restriction regimens on wooden breast using ultrasound images as a predictive tool. Br. Poult. Sci. 61(5):1–7. doi:10.1080/00071668.2020.1764909

Surai, P. 2015. Organic selenium: benefits to animals and humans, a biochemist's view, in: Lyons, T.P., and K.A. Jacques (Eds.), Biotechnology in the Feed Industry. Nottingham University Press, Nottinghan, p. 205–260.

Terry, N., A. Zayed, M.Company, and A. Tarun. 2000. Selenium in higher plants. Annu. Rev. Plant Physiol. 51:401-432. doi:10.1146/annurev.arplant.51.1.401

Tinggi, U. 2003. Essentiality and toxicity of selenium and its status in Australia: A review. Toxicol. Lett. 137:103–110. doi:10.1016/S0378-4274(02)00384-3

Wang, Y.X., X.A. Zhan, D. Yuan, X.W. Zhang, and R.J. XW. 2011. Effects of selenomethionine and sodium selenite supplementation on meat quality, selenium distribution and antioxidant status in broilers. Czech J. Anim. Sci. 56:305–313.

Wierbicki, E., and F. E. Deatherage. 1958. Water content of meats, determination of water-holding capacity of fresh meats. J. Agric. Food Chem. 6: 387–392.

Yoon, I., T. M. Werner, and J. M. Butler. 2007. Effect of source and concentration of

selenium on growth performance and selenium retention in broiler chickens. Poult. Sci. 86:727–730. doi:10.1093/ps/86.4.727

Zimermann, F. C., L. C. B. Fallavena, C. T. P. Salle, H. L. S. Moraes, R. A. Soncini, M. H. Barreta, and V. P. Nascimento. 2012. Downgrading of heavy broiler chicken carcasses due to myodegeneration of the anterior *Latissimus dorsi*: pathologic and epidemiologic studies. Avian Dis. 56:418–421. doi:0.1637/9860-072111-case.1

Table 1. Ingredient and nutrient composition of feeds supplemented with increased levels of hydroxy-selenomethionine.

Item	1 to 21 d	21 to 35 d	35 to 42 d
Ingredients, %			
Corn	48.62	53.67	58.26
Soybean meal	42.67	37.13	33.24
Soybean oil	4.20	5.40	5.21
Limestone	1.20	0.92	0.72
Dicalcium phosphate	2.04	1.68	1.41
Salt	0.51	0.46	0.43
Min. and Vit. Premix[1]	0.15	0.15	0.15
DL-Methionine, 99%	0.38	0.34	0.31
L-Lysine HCl, 78%	0.14	0.16	0.17
L-Threonine, 98.5%	0.04	0.04	0.04
Choline chloride, 60%	0.04	0.04	0.05
Energy and nutrients, % or as noted[2]			
AME, kcal/kg	3,000	3,150	3,200
CP	23.5 (23.8)	21.4 (22.2)	20.0 (20.5)
Ca	1.05 (1.01)	0.85 (0.80)	0.70 (0.67)
Total P	0.74 (0.75)	0.65 (0.66)	0.59 (0.58)
Av. P	0.50	0.43	0.37
Se	0.03	0.03	0.02
Choline, mg/kg	1,600	1,500	1,500
Dig. Lys	1.30	1.18	1.10
Dig. Met+Cys	1.00	0.91	0.85
Dig. Thr	0.84	0.77	0.71
Dig. Val	1.00	0.91	0.87
Dig. Arg	1.52	1.36	1.25
Dig Trp	0.27	0.24	0.22
Dig. Ile	0.94	0.84	0.78
Dig. Leu	1.80	1.67	1.58

[1]Composition per kg of feed: vitamin A, 8,000 UI; vitamin D_3, 2,000 UI; vitamin E, 30 UI; vitamin K_3, 2 mg; thiamine, 2 mg; riboflavin, 6 mg; pyridoxine, 2.5 mg; cyanocobalamin, 0.012 mg, pantothenic acid, 15 mg; niacin, 35 mg; folic acid, 1 mg; biotin, 0.08 mg; iron, 40 mg; zinc, 80 mg; manganese, 80 mg; copper, 10 mg; iodine, 0.7 mg, and 1,000 fungal phytase units (Novozymes A/S, Bagsvaerd, Denmark).
[2]Values in parenthesis were analyzed.

Table 2. Cumulative growth performance of broilers fed increasing dietary Se from hydroxy-selenomethionine.

Supplemental OH-SeMet[1], ppm	1 to 14 d			1 to 21 d			1 to 35 d			1 to 42 d		
	BWG[2], g	FCR	FI[3], g	BWG, g	FCR	FI, g	BWG, g	FCR	FI, g	BWG, g	FCR	FI, g
0.00	365	1.391	507	815[b]	1.396[a]	1,138	2,084[b]	1.516	3,165	2,792[b]	1.549	4,329
0.15	368	1.358	499	851[a]	1.347[ab]	1,147	2,132[ab]	1.472	3,141	2,881[ab]	1.517	4,391
0.30	365	1.330	485	862[a]	1.335[ab]	1,150	2,167[ab]	1.458	3,140	2,917[a]	1.521	4,441
0.45	379	1.334	505	883[a]	1.315[b]	1,162	2,203[a]	1.455	3,187	2,938[a]	1.510	4,442
0.60	367	1.388	509	872[a]	1.366[ab]	1,193	2,165[ab]	1.508	3,232	2,914[a]	1.546	4,509
SEM	0.004	0.010	0.005	0.005	0.010	0.010	0.010	0.011	0.030	0.014	0.011	0.041
P-value	0.321	0.129	0.253	0.001	0.050	0.315	0.001	0.436	0.534	0.002	0.183	0.140

[a-b]Means within the same column with different superscripts differ by Tukey test ($P \leq 0.05$).

[1]Analyzed Se from hydroxy-selenomethionine were 0.03, 0.15, 0.33, 0.47, 0.62 ppm (starter), 0.03, 0.17, 0.35, 0.42, 0.57 ppm (grower), and 0.02, 0.15, 0.29, 0.43, 0.58 ppm (finisher).

[2]BWG = body weight gain.

[3]FI = feed intake.

Table 3. Carcass and commercial cuts of broilers fed increasing dietary Se from hydroxy-selenomethionine at 35 and 42 d, %.

Supplemental OH-SeMet[1], ppm	Carcass[2]		Abdominal fat		Breast fillets[3]		Breast tenders		Thighs		Drumsticks		Wings	
	35 d	42 d	35 d	42 d	35 d	42 d	35 d	42 d	35 d	42 d	35 d	42 d	35 d	42 d
0.00	79.6	78.9	1.29	1.34	22.5	24.6	5.32	5.80	16.8	17.8	12.1	11.9	10.2	10.1
0.15	79.8	79.0	1.30	1.43	22.1	24.5	5.24	5.79	17.2	17.7	12.2	11.8	10.3	10.1
0.30	80.4	79.7	1.25	1.30	22.4	25.1	5.20	5.45	17.1	17.7	11.8	11.8	10.2	10.0
0.45	80.5	80.0	1.30	1.25	23.0	25.7	5.26	5.55	16.8	17.4	11.9	11.6	10.2	10.1
0.60	80.3	79.5	1.20	1.47	22.8	24.8	5.35	5.52	17.0	17.8	11.9	11.8	10.4	10.1
SEM	0.26	0.16	0.02	0.03	0.02	0.16	0.05	0.06	0.08	0.09	0.06	0.06	0.05	0.04
P-value	0.301	0.117	0.654	0.090	0.888	0.146	0.230	0.260	0.501	0.368	0.148	0.605	0.763	0.724

[1]Analyzed Se from hydroxy-selenomethionine were 0.03, 0.15, 0.33, 0.47, 0.62 ppm (starter), 0.03, 0.17, 0.35, 0.42, 0.57 ppm (grower), and 0.02, 0.15, 0.29, 0.43, 0.58 ppm (finisher).

[2]Eviscerated carcass as a percentage of body weight, whereas cuts were proportions of the eviscerated carcass (total = 600 birds).

[3]Skinless boneless *Pectoralis major.*

Table 4. Regression equations of broilers fed increasing dietary Se from hydroxy-selenomethionine[1]

Item	Regression equations[2]	Effect[3]	R^2	*P*-value	Se requirement, ppm
BWG 1 to 21 d, g	$Y= -297x^2 + 286x + 816$	QP	0.4020	0.013	0.48
	$Y= 811 + 68.1x (1-exp (-5.95x (Se-0.03))$	EA	0.3210	0.002	0.50
BWG 1 to 35 d, g	$Y= -540x^2 + 479x + 2,079$	QP	0.2296	0.040	0.44
	$Y= 2,069 + 118x (1-exp (-6.11x (Se-0.03))$	EA	0.1129	0.002	0.49
BWG 1 to 42 d, g	$Y= -876x^2 + 754x + 2,794$	QP	0.2456	0.019	0.43
	$Y= 2,782 +146x (1-exp (-7.62x (Se-0.03))$	EA	0.1676	0.006	0.40
FCR 1 to 21 d	$Y= 708x^2 - 501x + 1.411$	QP	0.1236	0.019	0.35
FCR 1 to 35 d	$Y= 758x^2 - 490x + 1.532$	QP	0.1064	0.018	0.32
Carcass[4] 42 d, g	$Y= -461.09x^2 + 445.33x + 2,253$	QP	0.2488	0.028	0.48
	$Y= 2,242 + 118x (1-exp (6.32x (Se – 0.03))$	EA	0.1984	0.035	0.47
Carcass 42 d, %	$Y= -8.17x^2 + 7.24x + 78.30$	QP	0.2682	0.053	0.44
	$Y= 78.45 + 1.55x (1-exp (7.79x (Se-0.03))$	EA	0.1642	0.054	0.38
Breast fillets[5] 42 d, g	$Y= -290.23x^2 + 226.8x + 554.65$	QP	0.2406	0.016	0.39
	$Y= 541 + 52.0x (1-exp (10.54x (Se – 0.03))$	EA	0.1008	0.023	0.30
Breast fillets 42 d, %	$Y= -8.87x^2 + 6.26x + 23.75$	QP	0.2368	0.041	0.35
	$Y= 23.56 + 2.04x (1-exp (6.31x (Se-0.03))$	EA	0.2010	0.018	0.47

[1]Regression equations considering analyzed Se levels: 0.03, 0.15, 0.33, 0.47, 0.62 ppm (starter), 0.03, 0.17, 0.35, 0.42, 0.57 ppm (grower), and 0.02, 0.15, 0.29, 0.43, 0.58 ppm (finisher) from hydroxy-selenomethionine (OH-SeMet).

[2]Quadratic polynomial (QP): $Y = \beta1 + \beta2 \times X + \beta3 \times X^2$; where Y is the dependent variable, X is the dietary level of Se, β1 is the intercept, β2 and β3 are the linear and quadratic coefficients, respectively; maximum response were obtained by calculating: $- \beta2 \div (2 \times \beta3)$. Exponential asymptotic (EA): $Y = \beta0 + \beta1 \times (1 – EXP (– \beta2 \times (X – \beta3)$, where Y is the dependent variable. X is the dietary Se supplementation, β0 is the response for the dependent variable estimated for the feed with the lower Se, β1 is the difference estimated between the minimum and maximum response obtained by the increasing Se, β2 is the slope of the exponential curve, β3 is the Se at the lower level; requirement were estimated by calculating $(\ln(0.05)/– \beta2) + \beta3$ for 95% of the requirement.

[3]Quadratic (QP) or exponential asymptotic (EA) effects ($P \leq 0.05$).

[4]Eviscerated carcass as a percentage of body weight, whereas cuts are proportions of the carcass.

[5]Skinless boneless *Pectoralis major*.

Table 5. Average score and occurrence of wooden breast of broilers fed increasing dietary Se from hydroxy-selenomethionine.

Supplemental OH-SeMet[1], ppm	WB score[2]	WB score	WB occurrence[3] 35 d, %				WB occurrence 42 d, %				CL[4], %		WHC[5], %	
	35 d	42 d	1	2	3	4	1	2	3	4	35 d	42 d	35 d	42 d
0.00	2.11	2.94	38.8	18.7	37.5	5.4	4.2	20.8	62.5	12.5	3.5	5.8	88.1	86.8
0.15	2.06	3.01	31.9	22.9	41.7	5.0	0.0	20.8	62.5	17.0	3.3	6.5	84.9	87.2
0.30	2.25	2.94	32.8	25.5	42.6	2.1	4.4	30.4	43.5	21.7	3.3	6.1	87.9	86.6
0.45	2.19	2.75	29.2	22.9	45.9	4.1	16.7	33.3	41.7	8.3	3.5	5.1	88.3	85.6
0.60	2.08	2.81	28.7	24.5	43.7	3.1	4.2	41.7	45.8	8.3	3.5	5.2	88.6	85.1
SEM	0.091	0.053	2.92	2.10	4.32	0.98	2.17	4.20	4.60	3.14	0.13	0.21	0.73	0.73
P-value	0.968	0.430	0.723	0.231	0.984	0.234	0.143	0.469	0.395	0.617	0.979	0.593	0.520	0.802

[1]Analyzed Se from hydroxy-selenomethionine in dietary treatments: 0.03, 0.15, 0.33, 0.47, 0.62 ppm (starter), 0.03, 0.17, 0.35, 0.42, 0.57 ppm (grower), and 0.02, 0.15, 0.29, 0.43, 0.58 ppm (finisher).

[2]Average of wooden breast scores of broilers according to the dietary selenium supplementation. Scores ranged the absence of WB (normal breast-score 0); mild hardening in the upper (score 1); moderate hardening in the upper and/or lower part of the fillet (score 2); severe hardening (score 3); and severe hardening with haemorrhagic lesions, increased volume and presence of yellow fluid (score 4) (Simões *et al*., 2020). Wooden breast score values were square root transformed but data presented in the table are their actual means.

[3]Wooden breast occurrence is the percentage of scores from 1 to 4. Score 0 was not observed at 35 and 42 d.

[4]CL = cooking loss of breast muscle.

[5]WHC = water-holding capacity of breast muscle.

Table 6. Glutathione peroxidase content and lipid oxidation samples collected from broilers fed increasing dietary Se from hydroxy-selenomethionine.

Supplemental OH-SeMet[1], ppm	Glutathione peroxidase[2], U/g					Lipid oxidation (TBARS)[3], nmol MDA/mg				
	Erythrocytes[4]	Jejunum	Ileum	Liver	Breast muscle	Erythrocytes	Jejunum	Ileum	Liver	Breast muscle
0.00	14.5[b]	12.2	15.6	11.4	5.72	116	0.125	0.168	0.289	0.016
0.15	22.3[a]	10.1	17.2	14.5	6.26	101	0.136	0.137	0.113	0.013
0.30	18.7[ab]	7.4	11.6	12.6	6.12	110	0.102	0.095	0.199	0.014
0.45	15.3[b]	8.0	19.8	16.6	5.51	111	0.130	0.129	0.106	0.010
0.60	16.0[b]	9.0	14.1	12.5	6.36	102	0.138	0.120	0.108	0.011
SEM	0.81	0.70	1.73	0.85	0.251	4.72	0.010	0.012	0.035	0.001
P-value	0.007	0.201	0.661	0.260	0.815	0.856	0.816	0.408	0.471	0.346

[a-b] Means within the same column with different superscripts differ by Tukey test ($P \leq 0.05$).

[1]Analyzed Se from hydroxy-selenomethionine in dietary treatments: 0.03, 0.15, 0.33, 0.47, 0.62 ppm (starter), 0.03, 0.17, 0.35, 0.42, 0.57 ppm (grower), and 0.02, 0.15, 0.29, 0.43, 0.58 ppm (finisher).

[2]Glutathione peroxidase analyses were performed using homogenate samples of each tissue at 42 d.

[3]Thiobarbituric acid reactive substances performed in homogenate samples of tissues at 42 d.

[4]Regressions for erythrocytes were estimated considering analyzed Se levels: $Y = -44.608x^2 + 24.142x + 16.126$; $R^2 = 0.1624$; $P = 0.039$; Se requirement = 0.27 ppm using quadratic polynomial model.

4. CONSIDERAÇÕES FINAIS

A suplementação de doses crescentes de hidroxi-selenometionina para frangos de corte, conforme realizado neste estudo, demonstrou a capacidade desta fonte orgânica de selênio em prover esse oligoelemento às aves, se refletindo em uma resposta de desempenho com aumento significativo ($P < 0,05$) de ganho de peso e rendimento de carne de peito e de carcaça.

Quanto à ação antioxidante do selênio, se observou que a suplementação de OH-SeMet elevou significativamente ($P < 0,05$) os níveis e atividade de glutationa peroxidase nos eritrócitos das aves. No entanto o mesmo não pode ser observado em outros tecidos como jejuno, íleo, fígado e musculatura peitoral, onde os níveis crescentes de selênio não influenciaram na atividade da GSH-PX no valor de TBARS.

Os ensaios realizados para avaliar o aumento da qualidade da carne das aves demonstraram que, neste estudo, não foi possível observar redução das lesões de peito amadeirado. Da mesma forma, não foi possível reduzir a perda por cocção ou aumentar a capacidade de retenção de água da musculatura peitoral das aves.

Devemos ressaltar que com a avaliação para a determinação da exigência de selênio a partir de uma fonte única de OH-SeMet, para aves, pudemos confirmar que os animais responderam a suplementação de forma positiva, aumentando sua performance e rendimentos de carcaça e carne de peito, onde obtivemos valores superiores aos da literatura para a suplementação deste oligoelemento para esta espécie. Com as novas fontes de selênio que estão surgindo no mercado ainda teremos uma grande necessidade de investigarmos o requerimento deste mineral para as diversas espécies, principalmente com as linhagens de alto desempenho que a cada ano se tornam mais eficientes e reduzem o consumo relativo de nutrientes para produzir mais carne.

5. REFERÊNCIAS

ABPA – ASSOCIAÇÃO BRASILEIRA DE PROTEÍNA ANIMAL. **Relatório anual 2021**. São Paulo: ABPA, 2021. 148 p.

ACAMOVIC, T.; BERTIN, G. The effects of selenium supplementation as sodium selenite or Sel-Plex, in maize-based diets for turkey. *In*: ALLTECH'S ANNUAL SYMPOSIUM, 23., 2007, Lexington. **Proceedings** […]. Nottingham: Nottingham University Press, 2007. supl. 1, p. 19.

AHMAD, H. *et al*. Effects of dietary sodium selenite and selenium yeast on antioxidant enzyme activities and oxidative stability of chicken breast meat. **Journal of Agricultural and Food Chemistry**, Washington, DC, v. 60, p. 7111-7120, 2012.

ALAIN, H. A. *et al*. Manoselenium effect on growth performance, carcass traits, antioxidant activity, and immune status of broilers. **Environmental Science and Pollution Research**, Berlin, v. 27, n. 31, p. 38607-38616, 2020.

ANCIUTI, M. A. *et al*. Effect of replacement of dietary inorganic by organic selenium (Sel-Plex) on performance of broilers. *In*: ANNUAL SYMPOSIUM: NUTRITIONAL BIOTECHNOLOGY IN THE FEED AND FOOD INDUSTRY, 20., 2004, Lexington. **Proceedings** […]. Nottingham: Nottingham University Press, 2004. supl. 1, p. 14.

ARRUDA, J. S.; RUTZ, F.; PAN, E. A. Influence of replacing dietary inorganic with organic selenium (Sel-Plex) on performance of broilers. *In*: ANNUAL SYMPOSIUM: NUTRITIONAL BIOTECHNOLOGY IN THE FEED AND FOOD INDUSTRY, 20., 2004, Lexington. **Proceedings** […]. Nottingham: Nottingham University Press, 2004. supl. 1, p. 13.

BAKHSHALINEJAD, R.; HASSANABADI, A.; SWICK, R. A. Dietary sources and levels of selenium supplements affects growth performance, carcass yield, meat quality and tissue selenium deposition in broilers. **Animal Nutrition**, Beijing, v. 5, p. 256-263, 2019.

BIERLA, K. *et al*. Determination of selenocysteine and selenomethionine in edible animal tissues by 2D size-exclusion reversed-phase HPLC-ICP MS following carbamidomethylation and proteolytic extraction. **Analytical and Bioanalytical Chemistry**, Heidelberg, v. 390, p. 1789-1798, 2008.

BRIENS, M. *et al*. 2-Hydroxy-4-methylselenobutanoic acid induces additional tissue selenium enrichment in broiler chicken compared to other selenium sources. **Poultry Science**, Oxford, v. 93, p. 85-93, 2014.

BRIENS, M. *et al*. Comparative study of a new organic selenium source v. seleno-yeast and mineral selenium sources on muscle selenium enrichment and selenium digestibility in broiler chickens. **British Journal of Nutrition**, Wallingford, v. 110, p. 617-624, 2013.

BURK, R. F.; HILL, K. E.; MOTEY, A. K. Plasma selenium in specific and non-specific forms. **Biofactors**, Amsterdam, v. 14, p. 107-114, 2001.

CEMIN, H. S. *et al*. Broiler responses to increasing selenium supplementation using Zn-L-selenomethionine with special attention to breast myopathies. **Poultry Science**, Oxford, v. 97, p. 1832-1840, 2018.

CHEKANI-AZAR, S. *et al*. Effect of replacing inorganic by organic selenium sources in diet of male broilers on selenium and vitamin E contents and oxidative stability of meat. **Journal of Animal and Veterinary Advances**, Faisalabad, v. 9, p. 1501-1505, 2010.

CHEN, G.; WU, J.; LI, C. Effect of different selenium sources on production performance and biochemical parameters of broilers. **Journal of Animal Physiology and Animal Nutrition**, Berlin, v. 98, p. 747-754, 2014.

COMBS, G. F. Jr.; COMBS, S. B. **The role of selenium in nutrition**. New York: Academic Press, 1986.

DANIELS, L. A. Selenium metabolism and bioavailability. **Biological Trace Element Research**, London, v. 54, p. 185-199, 1996.

DE MARCO, M. *et al*. Bio-efficacy of organic selenium compounds in broiler chickens. **Italian Journal of Animal Science**, Bologna, v. 20, p. 514-525, 2021.

DEAGEN, J. T. *et al*. Effects of dietary selenite, selenocystine and selenomethionine on selenocysteine lyase and glutathione peroxidase activities and on selenium levels in rat tissues. **Journal of Nutrition**, Rockville, v. 117, n. 1, p. 91-98, 1987.

DLOUHÁ, G. *et al*. Effect of dietary selenium sources on growth performance, breast muscle selenium, glutathione peroxidase activity and oxidative stability in broilers. **Czech Journal of Animal Science**, Praha, v. 53, p. 265-269, 2008.

DUCROS, V.; FAVIER, A. Métabolisme du sélénium. **EMC - Endocrinologie**, Paris, v. 1, n. 1, p. 19-28, 2004.

EFSA – EUROPEAN FOOD SAFETY AUTHORITY. Scientific opinion on safety and efficacy of hydroxy-analogue of selenomethionine as feed additive for all species. **EFSA Journal**, Parma, p. 1-30, 2013.

EISENBERG, S. Relative stability of selenites and selenates in feed premixes as a function of water activity. **Journal of AOAC International**, Arlington, v. 90, p. 349-353, 2007.

FDA – FOOD AND DRUG ADMINISTRATION. Food additives: selenium in animal feed. **Federal Register**, [Silver Spring], v. 39, p. 1355, 1974.

FDA – FOOD AND DRUG ADMINISTRATION. Food additives permitted in feed and drinking water of animals: selenium. **Federal Register**, [Silver Spring], v. 52, p. 1087, 1987.

FDA – FOOD AND DRUG ADMINISTRATION. Part 573 - Food additives permitted in feed and drinking water of animals: subpart B - Food additive listing: selenium. *In*: FDA. **Code of Federal Regulations**. [Silver Spring]: FDA, 2020. Title 21, cap. 1, v. 6, sec. 573.920.

FISININ, V. I.; PAPAZYAN, T. T.; SURAI, P. F. Selenium in poultry nutrition. *In*: SURAI, P. F.; TAYLOR-PICKARD, J. (ed.). **Current advances in Se research and applications**. Wageningen: Wageningen Academic, 2008. v. 1, p. 221-261.

GOSETTI, F. *et al*. Speciation of selenium in diet supplements by HPLC-MS/MS methods. **Food Chemistry**, London, v. 105, p. 1738-1747, 2007.

GUO, Y. M.; YUAN, J. M. Effects of different dietary vitamin E, organic or inorganic selenium levels on laying breeders. **Chinese Journal of Animal Science**, Beijing, v. 34, p. 10-12, 1998.

GUPTA, M.; GUPTA, S. An overview of selenium uptake, metabolism, and toxicity in plants. **Frontiers in Plant Science**, Lausanne, v. 7, [art.] 2074, 2017.

HASANUZZAMAN, M.; HOSSAIN, M. A.; FUJITA, M. Selenium-induced up-regulation of the antioxidant defense and methylglyoxal detoxification system reduces salinity-induced damage in rapeseed seedlings. **Biological Trace Element Research**, London, v. 143, n. 3, p. 1704-1721, 2011.

HAVENSTEIN, G. B.; FERKET, P. R.; QURESHI, M. A. Growth, livability, and feed conversion of 1957 versus 2001 broilers when fed representative 1957 and 2001 broiler diets. **Poultry Science**, Champaign, v. 1, p. 1500-1508, 2003.

IP, C. Interaction of vitamin C and selenium supplementation in modification of mammary carcinogenesis in rats. **Journal of the National Cancer Institute**, Bethesda, v. 77, n. 1, p. 299-303, 1986.

JIANG, Z. *et al*. Effects of dietary selenomethionine supplementation on growth performance, meat quality and antioxidant property in yellow broilers. **Journal of Agricultural and Food Chemistry**, Washington, DC, v. 57, p. 9769-9772, 2009.

KAWAI, M. *et al*. Thyroid hormone status in patients with severe selenium deficiency. **Clinical Pediatric Endocrinology**, Tokyo, v. 27, n. 2, p. 67-74, 2018.

LOPES, R. J.; BRUDNA, L. **Um mergulho na tabela periódica**. São Paulo: C6 Bank, 2019. 84 p.

MAHAN, D. C.; PETERS, J. C. Long-term effects of dietary organic and inorganic selenium sources and levels on reproducing sows and their progeny. **Journal of Animal Science**, Champaign, v. 82, p. 1343-1358, 2004.

MCDONALD, P. *et al*. **Animal Nutrition**, 6th ed. [New York]: Longman Group United Kingdom, 2002. 708 p.

MIKKELSEN, R. L.; PAGE, A. L.; BINGHAM, F. T. Factors affecting selenium accumulation by agricultural crops. *In*: JACOBS, L. W. (ed.). **Selenium in agriculture and the environment**. Madison: American Society of Agronomy, 1989. (SSSA Special Publications, v. 23). cap. 4, p. 65-94.

MUTH, O. H. *et al*. Effects of selenium and vitamin E on white muscle disease. **Science**, New York, v. 128, n. 3331, p. 1090, 1958.

NAYLOR, A. J.; CHOCT, M.; JACQUES, K. A. Effects of selenium source and level on performance and meat quality in male broilers. **Poultry Science**, Champaign, v. 79, p. 117-225, 2000.

NRC - NATIONAL RESEARCH COUNCIL. **Nutrient requirements of poultry**. 9th rev. ed. Washington, DC: National Academy Press, 1994.

NRC - NATIONAL RESEARCH COUNCIL. **Selenium in nutrition**. Washington, DC: National Academy Press, 1983.

ORTMAN, K.; PEHRSON, B. Selenite and selenium yeast as feed supplements for dairy cows. **Zentralblatt fur Veterinarmedizin. Reihe A**, Berlin, v. 44, p. 373-380, 1997.

ORTMAN, K.; PEHRSON, B. Selenite and selenium yeast as feed supplements to growing fattening pigs. **Zentralblatt fur Veterinarmedizin. Reihe A**, Berlin, v. 45, p. 551-557, 1998.

PAYNE, R. L.; SOUTHERN, L. L. Changes in glutathione peroxidase and tissue selenium concentrations of broilers after consuming a diet adequate in selenium. **Poultry Science**, Champaign, v. 84, p. 1268-1276, 2005.

PEREZ, T. I. *et al*. Effects of vitamin E and organic selenium on oxidative stability of omega-3 enriched dark chicken meat during cooking. **Journal of Food Science**, v. 75, p. 25-34, 2010.

PERIAE, L. *et al*. The influence of selenium source on the breast meat moisture loss. *In*: ALLTECH'S ANNUAL SYMPOSIUM, 23., 2007, Lexington. **Proceedings** […]. Nottingham: Nottingham University Press, 2007. supl. 1, p. 16.

PESUT, O. *et al*. Effect of organic selenium (Sel-Plex) in combination with alpha-tocopherol on GSH-Px activity and TBARS in plasma broilers. *In*: ALLTECH'S ANNUAL SYMPOSIUM, 21., 2005, Lexington. **Proceedings** […]. Nottingham: Nottingham University Press, 2005. supl. 1, p. 83.

PRAKASH, B. *et al*. Effect of supplementing selenized yeast on performance and anti-oxidant responses in Vanaraja and commercial broiler chickens. **Indian Journal of Animal Research**, Karnal, v. 53, p. 500-504, 2018.

REILLY, C. **Selenium in food and health**. New York: Springer, 2006.

ROSTAGNO, H. S. *et al*. **Tabelas brasileiras para aves e suínos:** composição de alimentos e exigências nutricionais. 4. ed. Viçosa, MG: UFV. Departamento de Zootecnia, 2017. 488 p.

RSC - ROYAL SOCIETY OF CHEMISTRY. **Selenium**. [London], 2021. Disponível em: https://www.rsc.org/periodic-table/element/34/selenium. Acesso em: 27 mar. 2021.

SAIDI, I.; CHTOUROU, Y.; DJEBALI, W. Selenium alleviates cadmium toxicity by preventing oxidative stress in sunflower (*Helianthus annuus*) seedlings. **Journal of Plant Physiology**, Stuttgart, v. 171, p. 85-91, 2014.

SCHRAUZER, G. N. Nutritional selenium supplements: product types, quality, and safety. **Journal of the American College of Nutrition**, New York, v. 20, p. 1-4, 2001.

SCHRAUZER, G. N. Selenomethionine: a review of its nutritional significance, metabolism and toxicity. **Journal of Nutrition**, Rockville, v. 130, p. 1653-1656, 2000.

SCHRAUZER, G. N. The nutritional significance, metabolism and toxicology of selenomethionine. **Advances in Food and Nutrition Research**, San Diego, v. 47, p. 73-112, 2003.

SCHRAUZER, G. N.; SURAI, P. F. Selenium in human and animal nutrition: resolved and unresolved issues. A partly historical treatise in commemoration of the fiftieth anniversary of the discovery of the biological essentiality of selenium, dedicated to the memory of Klaus Schwarz (1914-1978) on the occasion of the thirtieth anniversary of his death. **Critical Reviews in Biotechnology**, London, v. 29, n. 1, p. 2-9, 2009.

SCHWARZ, K.; FOLTZ, C. M. Selenium as an integral part of Factor 3 against dietary necrotic liver degeneration. **Journal of the American Chemical Society**, Washington, DC, v. 79, p. 3292-3293, 1957.

SHABANI, R. *et al*. Effect of different sources of selenium on performance and characteristics of immune system of broiler chickens. **Revista Brasileira de Zootecnia**, Viçosa, MG, v. 48, [art.] e20180256, 2019.

SKŘIVAN, M. *et al*. Dietary selenium increases vitamin E contents of egg yolk and chicken meat. **British Poultry Science**, Abingdon, v. 49, p. 482-486, 2008a.

SKŘIVAN, M. *et al*. Effect of dietary selenium on lipid oxidation, selenium and vitamin E content in broiler chickens. **Czech Journal of Animal Science**, Praha, v. 53, p. 306-311, 2008b.

SONG, Z.; GUO, Y.; YUAN, J. Effect of dietary iodine and selenium on the activities of blood lymphocytes in laying hens. **Asian-Australasian Journal of Animal Sciences**, Seoul, v. 19, n. 5, p. 713-719, 2006.

SPALLHOLZ, J. E. Free radical generation by selenium compounds and their prooxidant toxicity. **Biomedical and Environmental Sciences**, Beijing, v. 10, n. 2/3, p. 260-270, 1997.

STOLIC, N. *et al*. Study of the improvements of the fattering chick feeding quality using organic selenium. **Biotechnology in Animal Husbandry**, Beograd-Zemun, v. 18, p. 239-246, 2002.

SURAI, P. F. **Natural antioxidants in avian nutrition and reproduction**. Nottingham: Nottingham University Press, 2002.

SURAI, P. F. **Selenium in nutrition and health**. Nottingham: Nottingham University Press, 2006.

SURAI, P. F. **Selenium in poultry nutrition and health**. Wageningen: Wageningen Academic, 2018. 430 p.

SURAI, P. F.; FISININ, V. I. Selenium in livestock and other domestic animals. *In*: HATFIELD, D. L. *et al*. **Selenium:** its molecular biology and role in human health. New York: Springer International, 2016b. p. 595-606.

SURAI, P. F.; FISININ, V. I. Selenium in pig nutrition and reproduction: boars and semen quality – a review. **Asian-Australasian Journal of Animal Sciences**, Seoul, v. 28, p. 730-746, 2015.

SURAI, P. F.; FISININ, V. I. Selenium in poultry breeder nutrition: an update. **Animal Feed Science and Technology**, Amsterdam, v. 191, p. 1-15, 2014.

SURAI, P. F.; FISININ, V. I. Selenium in sow nutrition. **Animal Feed Science and Technology**, Amsterdam, v. 211, p. 18-30, 2016a.

SUZUKI, Y. *et al*. Dynamic pathways of selenium metabolism and excretion in mice under different selenium nutritional stresses. **Metallomics: Integrated Biometal Science**, Cambridge, v. 2, n. 2, p. 126-132, 2009.

TAKEBE, G. *et al*. A comparative study on the hydroperoxide and thiol specificity of the glutathione peroxidase family and selenoprotein P. **Journal of Biological Chemistry**, Baltimore, v. 277, p. 41254-41258, 2002.

TERRY, N. *et al*. Selenium in higher plants. **Annual Review of Plant Physiology**, Palo Alto, v. 51, p. 401-432, 2000.

THOMSON, C. D. Selenium speciation in human body fluids. **Analyst**, Cambridge, v. 123, p. 827-831, 1998.

TIAN, Y. *et al*. Effect of methionine supplementation on the selenium bioavailability in rats fed on grains from Keshan disease endemic area. **Wei Sheng Yan Jiu**, Beijing Shi, v. 30, n. 1, p. 55-57, 2001.

TINGGI, U. Essentiality and toxicity of selenium and its status in Australia: a review. **Toxicology Letters**, Amsterdam, v. 137, p. 103-110, 2003.

VALCIĆ, O.; JOVANOVIĆ, I. B.; MILANOVIĆ, S. Selenium, thiobarbituric acid reactive substances, and thyroid hormone activation in broilers supplemented with selenium as selenized yeast or sodium selenite. **Japanese Journal of Veterinary Research**, Sapporo, v. 59, p. 69-77, 2011.

VLAHOVIC, M. *et al*. Influence of different selenium sources on broiler performance. **Yugoslav Poultry Science**, Belgrade, v. 3, p. 3-4, 1998.

WANG, Y. *et al*. Comparison of different forms of dietary selenium supplementation on growth performance, meat quality, selenium deposition, and antioxidant property in broilers. **Biological Trace Element Research**, London, v. 143, p. 261-273, 2011b.

WANG, Y.-B.; XU, B.-H. Effect of different selenium source (sodium selenite and selenium yeast) on broiler chickens. **Animal Feed Science and Technology**, Amsterdam, v. 144, p. 306-314, 2008.

WANG, Y. X. *et al*. Comparison of different forms of dietary selenium supplementation on growth performance, meat quality, selenium deposition, and antioxidant property in broilers. **Biological Trace Element Research**, London, v. 143, p. 261-273, 2010.

WANG, Y. X. *et al*. Influence of dietary selenomethionine supplementation on performance and selenium status of broiler breeders and their subsequent progeny. **Biological Trace Element Research**, London, v. 143, p. 1497-1507, 2011a.

WANG, C.-L. *et al*. Effects of selenium source and level on growth performance, antioxidative ability and meat quality of broilers. **Journal of Integrative Agriculture**, Beijing, v. 20, p. 227-235, 2021.

WATANABE, T. T. N. **Oligoelementos no metabolismo**. Porto Alegre, 2010. 10 p. Seminário apresentado na disciplina de Bioquímica do tecido animal. Programa de Pós-Graduação em Ciências Veterinárias da Universidade Federal do Rio Grande do Sul.

WHANGER, P. *et al*. Metabolism of subtoxic levels of selenium in animals and humans. **Annals of Clinical Laboratory Science**, Philadelphia, v. 26, p. 99-113, 1996.

WOLFFRAM, S. Absorption and metabolism of selenium: difference between inorganic and organic sources. *In*: LYONS, T. P.; JACQUES, K. A. (ed.). **Biotechnology in the feed industry**. Nottingham: Nottingham University Press, 1999. p. 547-566.

WOLFFRAM, S. *et al*. Transport of selenoamino acids and their sulfur analogues across the intestinal brush border membrane of pigs. **Journal of Nutrition**, Rockville, v. 119, p. 706-712, 1989.

YUAN, D. *et al*. Regulation of selenoprotein P concentration and expression by different sources of selenium in broiler breeders and their offspring. **Poultry Science**, Champaign, v. 92, p. 2375-2380, 2013.

YUAN, D.; ZHAN, X.; WANG, Y. Effects of selenium sources and levels on reproductive performance and selenium retention in broiler breeder, egg, developing embryo, and 1-day-old chick. **Biological Trace Element Research**, London, v. 144, p. 705-714, 2011.

APÊNDICE

APÊNDICE 1 – Normas utilizadas para preparação do Capítulo II

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GUIDE FOR AUTHORS

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Vitamin A

1 IU = 0.3 µg of all-trans retinol 1 IU = 0.344 µg of retinyl acetate

1 IU = 0.552 µg of retinyl palmitate

1 IU = 0.60 µg of ß-carotene

Vitamin E

1 IU = 1 mg of dl-α-tocopheryl acetate 1 IU = 0.91 mg of dl-α-tocopherol

1 IU = 0.67 mg of d-α-tocopherol

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Bagley, L. G., and V. L. Christensen. 1991. Hatchability and physiology of turkey embryos incubated at sea level with increased eggshell permeability. Poult. Sci. 70:1412-1418.

Bagley, L. G., V. L. Christensen, and R. P. Gildersleeve. 1990. Hematological indices of turkey embryos incubated at high altitude as affected by oxygen and shell permeability. Poult. Sci. 69:2035- 2039.

Witter, R. L., and I. M. Gimeno. 2006. Susceptibility of adult chickens, with and without prior vaccination, to challenge with Marek's disease virus. Avian Dis. 50:354-365. doi:10.1637/7498-010306R.1

Book:

Metcalfe, J., M. K. Stock, and R. L. Ingermann. 1984. The effects of oxygen on growth and development of the chick embryo. Pages 205- 219 in Respiration and Metabolism of Embryonic Vertebrates. R. S. Seymour, ed. Dr. W. Junk, Dordrecht, the Netherlands.

National Research Council. 1994. Nutrient Requirements of Poultry. 9th rev. ed. Natl. Acad. Press, Washington, DC.

Federal Register:

Department of Agriculture, Plant and Animal Health Inspection Service. 2004. Blood and tissue collection at slaughtering and rendering establishments, final rule. 9CFR part 71. Fed. Regis. 69:10137-10151.

Other:

Choct, M., and R. J. Hughes. 1996. Long-chain hydrocarbons as a marker for digestibility studies in poultry. Proc. Aust. Poult. Sci. Symp. 8:186. (Abstr.)

Dyro, F. M. 2005. Arsenic. WebMD. Accessed Feb. 2006. http:// www.emedicine.com/neuro/topic20.htm.

El Halawani, M. E., and I. Rosenboim. 2004. Method to enhance reproductive performance in poultry. Univ. Minnesota, as- signee. US Pat. No. 6,766,767.

Hruby, M., J. C. Remus, and E. E. M. Pierson. 2004. Nutritional strategies to meet the challenge of feeding poultry without antibiotic growth promotants. Proc. 2nd Mid-Atlantic Nutr. Conf., Timonium, MD. Univ. Maryland, College Park.

Luzuriaga, D. A. 1999. Application of computer vision and electronic nose technologies for quality assessment of color and odor of shrimp and salmon. PhD Diss. Univ. Florida, Gainesville.

Peak, S. D., and J. Brake. 2000. The influence of feeding program on broiler breeder male mortality. Poult. Sci. 79(Suppl. 1):2. (Abstr.)

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• The following abbreviations may be used without definition in *Poultry Science*:
A adenine
ADG average daily gain

ADFI average daily feed
AME apparent metabolizable energy
AMEn nitrogen-corrected apparent metabolizable energy
ANOVA analysis of variance
B cell bursal-derived, bursal-equivalent derived cell bp base pairs
BSA bovine serum albumin
BW body weight
C cytosine
cDNA complementary DNA
cfu colony-forming units
CI confidence interval
CP crude protein
cpm counts per minute
CV coefficient of variation
d day
df degrees of freedom
DM dry matter
DNA deoxyribonucleic acid
EDTA ethylenediaminetetraacetate
ELISA enzyme-linked immunosorbent antibody assay
EST expressed sequence tag
g gram
g gravity
G guanine
GAT glutamic acid-alanine-tyrosine
GLM general linear model
h hour
HEPES N-2-hydroxyethyl piperazine-N'-ethane-sulfonic acid
HPLC high-performance (high-pressure) liquid chromatography
i.m. intramuscular
i.p. intraperitoneal
i.v. intravenous
ICU international chick units
Ig immunoglobulin
IL interleukin
IU international units
kb kilobase pairs
kDa kilodalton
L liter*
L:D hours light:hours darkness in a photoperiod (e.g., 23L:1D)
m meter
µ micro M molar
MAS marker-assisted selection
ME metabolizable energy
MEn nitrogen-corrected metabolizable energy
MHC major histocompatibility complex
mRNA messenger ribonucleic acid min minute
mo month
MS mean square
n number of observations

N normal
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NRC National Research Council
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PBS phosphate-buffered saline
PCR polymerase chain reaction
pfu plaque-forming units
ppm parts per million
QTL quantitative trait loci
r correlation coefficient
r2 coefficient of determination, simple
R2 coefficient of determination, multiple
RH relative humidity
RIA radioimmunoassay
RNA ribonucleic acid
rpm revolutions per minute
s second
s.c. subcutaneous
SD standard deviation
SDS sodium dodecyl sulphate
SE standard error
SEM standard error of the mean
SRBC sheep red blood cells
SNP single nucleotide polymorphism
T thymine
TBA thiobarbituric acid
T cell thymic-derived cell
TME true metabolizable energy
TMEn nitrogen-corrected true metabolizable energy
Tris tris(hydroxymethyl)aminomethane
TSAA total sulfur amino acids
U uridine
USDA United States Department of Agriculture
UV ultraviolet
vol/vol volume to volume
vs. versus
wt/vol weight to volume
wt/wt weight to weight
wk week
yr year
*Also capitalized with any combination, e.g., mL.

International words and phrases

Non-English words in common usage (defined in recent editions of standard dictionaries) will not appear in italics (e.g., in vitro, in vivo, in situ, a priori). However, genus and species of plants, animals, or bacteria and viruses should be italicized. Authors must indicate accent marks and other diacriticals on international names and institutions. German nouns shall begin with capital letters.

Capitalization
Breed and variety names are to be capitalized (e.g., Single Comb White Leghorn).

Number style
Numbers less than 1 shall be written with preceding zeros (e.g., 0.75). All numbers shall be written as digits. Measures must be in the metric system; however, US equivalents may be given in parentheses. *Poultry Science* requires that measures of energy be given in calories rather than joules, but the equivalent in joules may be shown in parentheses or in a footnote to tables. Units of measure not preceded by numbers must be written out rather than abbreviated (e.g., lysine content was measured in milligrams per kilogram of diet) unless used parenthetically. Measures of variation must be defined in the Abstract and in the body of the paper at first use. Units of measure for feed conversion or feed efficiency shall be provided (i.e., g:g).

Nucleotide sequences
Nucleotide sequence data must relate to poultry or poultry pathogens and must complement biological data published in the same or a companion paper. If sequences are excessively long, it is suggested that the most relevant sections of the data be published in *Poultry Science* and the remaining sequences be submitted to one of the sequence databases. Acceptance for publication is contingent on the submission of sequence data to one of the databases. The following statement should appear as a footnote to the title on the title page of the manuscript. "The nucleotide sequence data reported in this paper have been submitted to Embank Submission (Mail Stop K710, Los Alamos National Laboratories, Los Alamos, NM 87545) nucleotide sequence database and have been assigned the accession number XNNNNN." Publication of the description of molecular clones is assumed by the
editors to place them in the public sector. Therefore, they shall be made available to other scientists for research purposes.
Nucleotide sequences must be submitted as camera- ready figures no larger than 21.6 x 27.9 cm in standard (portrait) orientation. Abbreviations should follow *Poultry Science* guidelines.

Gene and protein nomenclature
Authors are required to use only approved gene and protein names and symbols. For poultry, full gene names should not be italicized. Gene symbols should be in uppercase letters and should be in italics. A protein symbol should be in the same format as its gene except the protein symbol should not be in italics.
General usage
• Note that "and/or" is not permitted; choose the more appropriate meaning or use "x or y or both."
• Use the slant line only when it means "per" with numbered units of measure or "divided by" in
equations. Use only one slant line in a given expression (e.g., g/d per chick). The slant line may not be used to indicate ratios or mixtures.
• Use "to" instead of a hyphen to indicate a range. Insert spaces around all signs (except slant lines) of operation (=, -, +, x, >, or <, etc.) when these signs occur between two items.
• Items in a series should be separated by commas (e.g., a, b, and c).
• Restrict the use of "while" and "since" to meanings related to time.

• Appropriate substitutes include "and," "but," or "whereas" for "while" and "because" or "although" for "since."
• Leading (initial) zeros should be used with numbers less than 1 (e.g., 0.01).
• Commas should be used in numbers greater than 999.
•Registered (®) and trademark (©) symbols should not be used, unless as part of an article title in the References section. Trademarked product names should be capitalized.

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SUPPLEMENTARY DATA
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6. VITA

Vinicius de Queiroz Teixeira, filho de Roberto de Almeida Teixeira e Edilma de Queiroz Teixeira, nasceu no dia 15 de maio de 1982 no município do Rio de Janeiro, Rio de Janeiro. Cursou o ensino fundamental no Colégio Pedro II e ensino médio no Colégio Santo Ignácio, ambos no município do Rio de Janeiro, Rio de Janeiro. Em 2000 ingressou no curso de Medicina Veterinária da Universidade Federal Fluminense, Niterói, Rio de Janeiro, obtendo o Grau de Médico Veterinário em agosto de 2006. Em 2001 ingressou no curso de Ciências Aeronáuticas na Universidade Estácio de Sá, Rio de Janeiro, Rio de Janeiro, obtendo o Grau de Bacharel em Ciências Aeronáuticas em 2004. Iniciou em abril de 2007, o Mestrado em Medicina Veterinária, área de concentração de Higiene Veterinária e Processamento Tecnológico de Produtos de Origem Animal, na Universidade Federal Fluminense, Niterói, Rio de Janeiro, realizando estudos na área de anatomopatologia e bacteriologia de frangos de corte. Obteve o título de mestre em Medicina Veterinária em outubro de 2008. Em outubro de 2008 ingressou na Agrogen S.A. Agroindustrial no município de Montenegro, Rio Grande do Sul, como Médico Veterinário Trainee, onde atuou na produção de reprodutoras pesadas, avós e matrizes, manejo de frangos de corte e fábrica de rações. Em outubro de 2010 assumiu a Coordenação de Fomento da Agrogen no município de Sete Lagoas, Minas Gerais, onde era responsável pela produção avícola, equipe técnica de extensionistas e fábrica de rações. Em janeiro de 2012, ainda na Agrogen, regressou para Montenegro, Rio Grande do Sul, e assumiu a área de Nutrição Animal como Nutricionista, sendo responsável pelas cinco fábricas de rações da empresa e onde atuou até maio de 2019. No ano de 2017, no mês de abril, ingressou no curso de Doutorado em Zootecnia, área de Produção de Animal pelo Programa de Pós-Graduação em Zootecnia na Universidade Federal do Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, desenvolvendo o trabalho de tese sobre a suplementação de hidroxi-selenometionina na dieta de frangos de corte. Em julho de 2019 ingressou na Evonik na linha de negócio de Animal Nutrition, no município de São Paulo, São Paulo, onde assumiu a função de Gerente Técnico na área de Saúde Intestinal, sendo responsável pela linha de probióticos e soluções para a saúde intestinal, onde atua até o momento. Submeteu-se à banca de defesa de Tese em abril de 2021 pela Universidade Federal do Rio Grande do Sul em Porto Alegre, Rio Grande do Sul.