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

SUPLEMENTAÇÃO DE MICROMINERAIS COMPLEXADOS COM LISINA NO DESEMPENHO DE MATRIZES PESADAS E QUALIDADE DA PROGÊNIE

RAQUEL MEDEIROS HORN

Zootecnista - UFRGS

Dissertação apresentada como um dos requisitos à obtenção do Grau de Mestre em Zootecnia

Área de Concentração: Nutrição Animal

Porto Alegre (RS), Brasil

Novembro de 2023.

CIP - Catalogação na Publicação

Medeiros Horn, Raquel
SUPLEMENTAÇÃO DE MICROMINERAIS COMPLEXADOS COM LISINA NO DESEMPENHO DE MATRIZES PESADAS E QUALIDADE DA PROGÊNIE / Raquel Medeiros Horn. -- 2023.
78 f.
Orientador: Sergio Luiz Vieira.

Dissertação (Mestrado) -- Universidade Federal do Rio Grande do Sul, Faculdade de Agronomia, Programa de Pós-Graduação em Zootecnia, Porto Alegre, BR-RS, 2023.

1. Matriz Pesada. 2. Progênie. 3. Microminerais Complexados. 4. Desempenho. I. Luiz Vieira, Sergio, orient. II. Título.

Elaborada pelo Sistema de Geração Automática de Ficha Catalográfica da UFRGS com os dados fornecidos pelo(a) autor(a).

Raquel Medeiros Horn
Zootecnista

DISSERTAÇÃO
Submetida como parte dos requisitos
para obtenção do Grau de
MESTRE EM ZOOTECNIA
Programa de Pós-Graduação em Zootecnia
Faculdade de Agronomia
Universidade Federal do Rio Grande do Sul
Porto Alegre (RS), Brasil

Aprovada em: 27.11.2023
Pela Banca Examinadora

Sergio Luiz Vieira
Assinado de forma digital por Sergio Luiz Vieira
Dados: 2023.11.30 16:33:20 -03'00'

Sergio Luiz Vieira
PPG Zootecnia/UFRGS
ORIENTADOR

gov.br
Documento assinado digitalmente
ALEXANDRE DE MELLO KESSLER
Data: 30/11/2023 11:24:37-0300
Verifique em https://validar.iti.gov.br

Alexandre de Mello Kessler
UFRGS

gov.br
Documento assinado digitalmente
ANDRE FAVERO
Data: 29/11/2023 09:37:10-0300
Verifique em https://validar.iti.gov.br

André Favero
Consultor Independente

gov.br
Documento assinado digitalmente
MARCO ANTONIO EBBING
Data: 28/11/2023 14:18:53-0300
Verifique em https://validar.iti.gov.br

Marco Antônio Ebbing
Auburn University

Homologado em: 01/12/2023
Por

Sergio Luiz Vieira
Assinado de forma digital por Sergio Luiz Vieira
Dados: 2023.12.01 16:43:09 -03'00'

SERGIO LUIZ VIEIRA
Coordenador do Programa de
Pós-Graduação em Zootecnia

gov.br
Documento assinado digitalmente
CARLOS ALBERTO BISSANI
Data: 01/12/2023 17:11:57-0300
Verifique em https://validar.iti.gov.br

CARLOS ALBERTO BISSANI
Diretor da Faculdade de Agronomia

“Mentes incansáveis movem o mundo para frente; são elas que, por meio de seus esforços incessantes, iluminam o caminho para o progresso e a inovação."

- Thomas Edison

AGRADECIMENTOS

Gostaria de expressar meus sinceros agradecimentos às pessoas que foram fundamentais na minha jornada acadêmica e pessoal durante a elaboração desta dissertação. Primeiramente, dedico este trabalho aos meus queridos pais, Neide e Marcelo, cujo amor, apoio incondicional e valores foram a base sólida que me permitiu alcançar este marco acadêmico. Agradeço também aos meus amados avós, Mercedes Medeiros e João Carlos Medeiros, cuja sabedoria, histórias de vida e encorajamento foram fontes de inspiração constantes ao longo desta jornada. À minha avó Neila Rêgo Ferreira Horn, que mesmo não estando mais aqui, deixou o seu legado que me incentivou a sempre continuar evoluindo. Ao meu companheiro e parceiro, Douglas Drebes, agradeço pela paciência, compreensão e apoio emocional durante os desafios enfrentados durante este processo. Sua presença tornou esta jornada mais significativa.

Não poderia deixar de expressar minha gratidão ao meu orientador, Professor Sergio Luiz Vieira, pela orientação, insights valiosos e dedicação incansável ao longo deste projeto. Sua orientação foi fundamental para o desenvolvimento desta dissertação. Aos colegas que compartilharam comigo as vivências do Aviário de Ensino e Pesquisa ao longo desses 6 anos, quero agradecer a troca de saberes e pelas amizades que permanecerão.

À Universidade Federal do Rio Grande do Sul, aos professores e funcionários do Programa de Pós-Graduação em Zootecnia e à Estação Experimental Agronômica da UFRGS, meu profundo agradecimento pelo apoio constante e pela infraestrutura que tornaram possível minha pesquisa e estudos. Ao CNPq, por conceder a bolsa de Mestrado que viabilizou minha educação. À empresa Phytobiotics pelo auxílio na realização do projeto de dissertação, em especial ao Dimitri Freitas.

A todos, meu muito obrigado. Cada um de vocês contribuiu de maneira única para o sucesso desta pesquisa e para o meu crescimento pessoal e acadêmico.

SUPLEMENTAÇÃO DE MICROMINERAIS COMPLEXADOS COM LISINA NO DESEMPENHO DE MATRIZES PESADAS E QUALIDADE DA PROGÊNIE[1]

Autor: Raquel Medeiros Horn

Orientador: Sergio Luiz Vieira

Resumo - Microminerais são essenciais para aves de corte. O objetivo do presente estudo foi avaliar o impacto da substituição parcial de microminerais inorgânicos (MI) por microminerais complexados com aminoácidos (MC) no desempenho de reprodutoras pesadas e sua progênie. Um total de 682 matrizes pesadas Cobb 500 e 62 machos, com 24 semanas de idade, foram distribuídos em três tratamentos dietéticos: T1 - contendo MI, Zn, Mn e Cu a 70, 70 e 10 ppm, respectivamente; T2 - substituição parcial (50%) da forma inorgânica de Zn, Mn e Cu por fontes de MC; T3 - substituição parcial (70%) da forma inorgânica de Zn, Mn e Cu por fontes de MC. Cada tratamento foi replicado 10, 10 e 11 vezes, respectivamente. A produção de ovos foi avaliada das semanas 25 a 40, enquanto a qualidade dos ovos foi avaliada nas semanas 27, 31, 35 e 39 para aferir o peso do ovo, porcentagem de gema, albúmen e casca, a espessura da casca do ovo também foi mensurada. Nas semanas 32, 36 e 40, os ovos foram incubados e avaliados quanto aos parâmetros de eclodibilidade e qualidade da progênie. Os pintos nascidos oriundos de matrizes de 40 semanas, tiveram seu conteúdo mineral das tíbias e fêmures analisados. A análise estatística foi realizada utilizando os procedimentos do software SAS, PROC MIXED e GLM, ANOVA a 5% de significância. A produção total, a produção de ovos incubáveis e os parâmetros de incubação não foram influenciados pelos tratamentos ($P > 0,05$). A espessura da casca do ovo apresentou um aumento significativo ($P < 0,05$) com a substituição de 50% por MC em comparação com o MI. O peso dos pintos eclodidos melhorou com a substituição de 50% por MC ($P < 0,05$). A inclusão de microminerais complexados pode aprimorar a qualidade da casca do ovo e o peso dos pintinhos, sugerindo melhorias potenciais na eficiência produtiva da progênie em sistemas avícolas.

Palavras-chave: matriz pesada, microminerais, complexados, desempenho, progênie.

---

[1] Dissertação de Mestrado em Zootecnia – Produção Animal, Faculdade de Agronomia, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brasil (78 p.), novembro, 2023.

BROILER BREEDER HEN PERFORMANCE FED WITH COMPLEXED LYSINE TRACE MINERALS AND CHICK QUALITY[1]

Author: Raquel Medeiros Horn

Advisor: Sergio Luiz Vieira

Abstract – Trace minerals are essential for poultry. The objective of the current study was to assess the impact of partially substituting inorganic trace minerals (ITM) with amino organic trace minerals (OTM) on the performance of broiler breeder hens and their offspring. A total of 682 Cobb 500 broiler breeder hens and 62 males, aged 24 weeks, were assigned to three dietary treatments: T1 - containing ITM forms of Zn, Mn, and Cu at 70, 70, and 10 ppm, respectively; T2 - partial replacement (50%) of the inorganic form of Zn, Mn, and Cu with OTM sources; T3 - partial replacement (70%) of the inorganic form of Zn, Mn, and Cu with OTM sources. Each treatment was replicated 10, 10, and 11 times, respectively. Laying production was assessed from weeks 25 to 40, while egg quality was evaluated periodically, including measurements of egg weight, yolk, albumen, shell percentage, and eggshell thickness. In weeks 32, 36, and 40, eggs were incubated and assessed for hatchability parameters and chick quality. At 40 weeks of age, the mineral content of the tibiae and femurs of hatching chicks was analyzed. The statistical analysis was performed using the procedures of the SAS software, PROC MIXED, and GLM, with ANOVA at a 5% significance level. Total and settable egg production and incubation parameters were not influenced by the supplementation treatments ($P > 0.05$). Eggshell thickness exhibited a significant increase ($P < 0.05$) with 50% OTM substitution compared to ITM. The weight of hatching chicks showed improvement with 70% OTM replacement ($P < 0.05$). The inclusion of OTM may enhance eggshell quality and chick weight, suggesting potential improvements in productivity efficiency and the health of progeny in poultry systems.

Keywords: broilers breeders, trace minerals, complexed, performance, offspring.

---

[1] Master of Science Dissertation in Animal Science – Faculdade de Agronomia, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil. (78 p.), November 2023.

SUMÁRIO

LISTA DE TABELAS

RELAÇÃO DE APÊNDICES

LISTA DE ABREVIATURAS

Cu	Cobre
Fe	Ferro
I	Iodo
Se	Selênio
MC	Micromineral complexado
MI	Micromineral inorgânico
Mn	Manganês
Zn	Zinco

CAPÍTULO I

INTRODUÇÃO

A avicultura desempenha um papel vital na economia brasileira, consolidando-se como uma das indústrias agrícolas mais significativas do país. Além de gerar empregos e movimentar a economia, destaca-se como um pilar fundamental da segurança alimentar nacional. Com uma produção expressiva de carne de frango (14,5 milhões ton) e ovos (52 bilhões de unidades), o Brasil assume uma posição de destaque no mercado global (ABPA, 2023). As reprodutoras pesadas desempenham um papel crucial na rentabilidade da indústria avícola, influenciando tanto a produção de ovos quanto o preço dos pintos de um dia, e contribuem significativamente para atender às crescentes demandas globais por proteína animal.

A oferta de uma dieta balanceada com nutrientes essenciais para as aves é de grande importância para otimizar a produção máxima de ovos e o desenvolvimento saudável dos frangos de corte. Os nutrientes, como proteínas, carboidratos, gorduras e vitaminas, desempenham papéis fundamentais no crescimento, sobrevivência, produção de carne e ovos, bem como na reprodução das aves de corte. As matrizes necessitam de, no mínimo, 14 minerais, abrangendo macrominerais (cálcio, cloro, magnésio, fósforo, potássio, sódio e enxofre) e microminerias (cobre (Cu), ferro (Fe), manganês (Mn), selênio (Se), zinco (Zn) e iodo (I)) (GONZÁLEZ; SILVA, 2019).

A deficiência desses minerais pode resultar em ossos e casca de ovos mais frágeis, anemia, deficiência reprodutiva, entre outros. Embora a alimentação forneça minerais, esses recursos, muitas vezes, não atendem totalmente às demandas das aves de alto desempenho, destacando a necessidade de suplementação mineral nas dietas avícolas para otimizar o rendimento máximo com níveis adequados de minerais (BLAIR, 2008). Estudos recentes revelaram a exigência dos microminerais para reprodutoras pesadas (TASCHETTO et al., 2017; BERWANGER et al., 2018; MAYER et al., 2019; NOETZOLD et al., 2020), e para frangos de corte com a adição da enzima fitase (FEIJÓ et al., 2023; SOSTER et al., 2023). Esses estudos demonstram a importância de uma correta suplementação de microminerais para aves visto o vasto número de funções que desempenham.

Os microminerais Zn, Mn e Cu estão presentes nos ovos e são essenciais para o correto desenvolvimento do embrião. Exercem uma função multifuncional em processos bioquímicos essenciais. A conexão entre a nutrição durante o período embrionário e a saúde locomotora posterior destaca a importância crucial de uma atenção cuidadosa à dieta das reprodutoras de frangos de corte. É evidente que a qualidade nutricional fornecida durante essa fase crítica tem implicações significativas não apenas no desenvolvimento do embrião, mas também no desempenho subsequente das aves (DIBNER et al., 2007).

Os microminerais podem ser suplementados na forma de sais inorgânicos (MI), como sulfatos e óxidos, mas também podem ser suplementadas na forma orgânica, complexados (MC) com aminoácidos, carboidratos ou proteínas. A adição dos MC na dieta das aves pode melhorar o seu desempenho, ademais podem minimizar a excreção de metais pesados por parte das aves. Isso resulta em uma redução significativa da poluição ambiental. Essa característica torna os MC um componente altamente benéfico das dietas dessas aves reprodutoras (LEESON; SUMMERS, 2009). Com isso, o objetivo do estudo foi investigar a interação entre a fonte de microminerais, Cu, Mn e Zn, inorgânicos ou complexados, no desempenho de reprodutoras pesadas em relação à taxa de eclosão, fertilidade, qualidade dos pintinhos, conteúdo mineral, espessura da casca do ovo e percentuais de gema, albúmen e casca.

REVISÃO BIBLIOGRÁFICA

Uso de microminerais na avicultura

Os minerais desempenham papéis cruciais em diversas vias metabólicas. Macrominerais, são expressos em percentagem nos alimentos ou tecidos, estão principalmente envolvidos em funções estruturais, enquanto microminerais, tem uma difícil avaliação devido a suas baixas concentrações nos tecidos animais. Os minerais estão frequentemente associados a proteínas, formando metaloenzimas. A absorção de minerais depende do alimento ingerido, onde podem ser encontrados em diversas formas químicas, como moléculas orgânicas ou parte de sais com diferentes solubilidades. O interesse em formas orgânicas inclui diferenças na disponibilidade, mas também está relacionado a possíveis melhorias em suas ações específicas no nível celular (VIEIRA, 2008).

Microminerais inorgânicos geralmente são suplementados nas dietas das aves nas formas de sulfatos e óxidos. No intestino, íons são absorvidos através de difusão passiva ou transporte ativo. Para ingressarem na corrente sanguínea, órgãos e tecidos, esses íons necessitam se associar a um agente transportador que facilite sua travessia pela parede intestinal. Caso não encontrem esse agente, podem ser eliminados, levando a perdas. Em certas circunstâncias, as perdas podem ocorrer devido a reações com compostos insolúveis ou devido à competição por locais de absorção entre diferentes elementos minerais, resultando em interações antagônicas que prejudicam a absorção (HERRICK, 1993).

Quelatos são minerais estáveis que são encontrados com um tipo de carregador ou ligante, podendo ser aminoácidos, carboidratos ou proteínas de cadeia curta. Reduzem a excreção de metais pesados pelas aves, minimizando assim a poluição ambiental (LEESON, 2003; LEESON; SUMMERS, 2009). Esses minerais utilizam as mesmas vias de absorção das moléculas às quais estão ligados, evitando assim problemas de interação com outros minerais. Uma maior biodisponibilidade prolonga a vida das aves, já que os minerais orgânicos desempenham diversas funções essenciais no organismo. Isso inclui contribuir para a formação do tecido conjuntivo, manter a homeostase dos fluidos corporais, equilibrar as membranas celulares e ativar reações bioquímicas por meio da estimulação de sistemas enzimáticos, entre outras funções vitais (GUZ et al., 2022).

Embora a utilização de microminerais ser importante para as aves, é de grande valia levar em consideração que um uso exacerbado desses minerais pode gerar antagonismos entre eles. O antagonismo mais relevante na nutrição mineral de aves ocorre entre minerais divalentes, como Zn, Mn, Cu, e o fitato, que forma quelatos estáveis e insolúveis (LEESON; SUMMERS, 2001). Antagonismos também ocorrem entre minerais, como níveis elevados de Zn que podem reduzir a disponibilidade de Cu (EVANS et al., 1975). A competição por transportadores semelhantes é uma fonte significativa de interferência na transferência de metais do lúmen para o enterócito. Esses transportadores, pequenas proteínas com alta capacidade de quelar cátions livres na solução intestinal, podem envolver micro ou macrominerais devido à competição físico-química entre cátions (STARCHER, 1969).

Vários estudos vêm sendo conduzidos com o intuito de averiguar os benefícios dos microminerais orgânicos. Ao testar diferentes combinações de MI e MC (Zn, Mn, Cu, Se, and Fe), Noetzold et al., (2022), verificou melhorias na qualidade da casca do ovo, assim como uma melhora no ganho de peso da progênie resultante de matrizes suplementadas com uma substituição parcial de MC. Ademias, Yaqoob et al., (2020), constatou que a utilização de uma substituição parcial de Cu, Zn, Fe e Mn pode auxiliar o status antioxidante do fígado durante o pico de postura e resultar em um perfil sanguíneo melhor, porém, para se obter um melhor desempenho reprodutivo, a combinação de 50% de MC e 50% de MI é a opção mais eficaz.

Cobre

O Cu é vital para a dieta das aves. Está envolvido em muitos processos fisiológicos e bioquímicos nos organismos. De acordo com as suas observações, Suttle e Underwood (2010), o Cu desempenha um papel crucial nas funções reprodutivas e no desenvolvimento ósseo, estando intrinsecamente ligado às operações de diversas enzimas, como a citocromo C oxidase, hefaestina, ceruloplasmina e lisil oxidase. Suas contribuições estendem-se ainda aos cofatores, notadamente a superóxido dismutase, e às proteínas reativas. As funções vitais do cobre abrangem metaloenzimas associadas à respiração celular, transporte de ferro, formação de tecido conjuntivo, síntese de melanina, desenvolvimento ósseo e produção de hemoglobina (AL-UBAIDI; SULLIVAN, 1963; WHO, 1996; NITTIS; GITLIN, 2004). No contexto específico dos ovos, destaca-se o papel do Cu na estrutura da casca, principalmente na síntese e manutenção do colágeno da matriz (VIEIRA, 2007).

Além disso, o cobre possui propriedades antimicrobianas e desempenha um papel específico no metabolismo do ferro, no metabolismo do colesterol, na produção de energia, na absorção e na eficiência de outros minerais em aves e outros organismos (KIM et al., 1992; LUO et al., 1992; LEESON; SUMMERS, 2009; SCOTT et al., 2018). A distribuição e concentração de Cu variam entre espécies, idade e dieta de animais. Nas aves, as maiores concentrações de Cu se encontram nos músculos, ossos, fígado, pele, penas e sangue, enquanto nos ovos esse micromineral pode ser encontrado na gema, casca do ovo e membranas (GEORGIEVSKIĬ; ANNENKOV; SAMOKHIN, 1981; VIEIRA, 2007). Estudos indicam diferentes níveis de Cu em órgãos avícolas, com variações de 0,53 a 4,10 ppm em ovos (KIRKPATRICK; COFFIN, 1975). A deficiência de Cu manifesta-se em deformidades ósseas, anemia e problemas na reprodução. Contudo, efeitos de intoxicação não são comumente observados, embora doses acima de 500 ppm possam impactar o ganho de peso e consumo de ração em frangos de corte, além de lesões na mucosa da moela (NRC, 1980; SCHMIDT et al., 2005; BERTECHINI, 2007).

Manganês

O Mn desempenha uma função crucial em várias operações vitais para os organismos, atuando como um cofator enzimático em processos relacionados à síntese de ATP, ciclo de Krebs, fosforilação oxidativa, além de participar em reações da fosfatase alcalina e piruvato oxidase (GONZÁLEZ; SILVA, 2019). Este micromineral está associado a metaloenzimas ativadas por ele, como glicosiltransferases, arginase, tiaminase, piruvato carboxilase, Mn-superóxido dismutase e dipeptidases intestinais (SUTTLE; UNDERWOOD, 2010). Sua importância estende-se ao desenvolvimento da matriz orgânica óssea e é essencial para a reprodução e o adequado funcionamento do sistema nervoso central (BERTECHINI, 2007).

É indispensável para o desenvolvimento embrionário, o crescimento adequado do corpo e o metabolismo de carboidratos e lipídios. Além disso, desempenha uma função crucial na manutenção da qualidade da casca do ovo (OLGUN, 2016). Segundo Xie et al. (2014), o Mn dietético pode influenciar a expressão gênica do hormônio liberador de gonadotrofina no cérebro, o hormônio folículo estimulante na hipófise, e exerce impacto na qualidade da casca do ovo.

De acordo com Leeson e Summers (2001), a maior parte do Mn no corpo animal concentra-se nos ossos, seguido pelo fígado. Em aves jovens, as maiores concentrações de Mn são encontradas no fígado, rim e ossos (SUTTLE; UNDERWOOD, 2010). Em ovos, estudos de Yair e Uni (2011) indicam que o Mn é o quinto micromineral com maior concentração na casca de ovos. A deficiência de Mn pode resultar em malformações esqueléticas, crescimento retardado, ataxia em recém-nascidos, infertilidade e anormalidades no metabolismo lipídico e de carboidratos (OBERLEAS; HARLAND; BOBILYA, 1999).

A perose, caracterizada por deformidades articulares em aves jovens, é uma síndrome significativa associada à deficiência de Mn (LEESON; SUMMERS, 2001). A ausência desse micromineral na dieta pode levar à condrodistrofia em embriões, resultando em pernas e asas encurtadas. A deficiência também pode causar morte embrionária tardia e afetar o sistema reprodutivo de machos e fêmeas (LEESON; SUMMERS, 2009; OBERLEAS; HARLAND; BOBILYA, 1999). A ingestão oral de Mn é pouco tóxica, mas a inalação de poeira contendo esse elemento pode resultar em uma doença debilitante que afeta o sistema nervoso (OBERLEAS; HARLAND; BOBILYA, 1999).

Zinco

O Zn desempenha um papel crucial como cofator e ativador de diversas enzimas, incluindo DNA e RNA polimerases, influenciando diretamente processos de proliferação celular e síntese de proteínas, com efeitos notórios sobre funções reprodutivas (BERTECHINI, 2007). Participa de mais de 300 enzimas com diversas funções, atuando como componente essencial em metaloenzimas como enzima conversora de angiotensina, fosfolipase A2, fosfatase alcalina, anidrase carbônica, carboxipeptidase A, álcool desidrogenase, entre outras (COLEMAN, 1992; VALLEE; FALCHUK, 1993; AULD, 2021). Além de seu papel no metabolismo lipídico, o Zn é fundamental para a formação adequada da casca do ovo em galinhas, influenciando a produção estável de ovos incubáveis (GUIMARÃES et al., 2013; ROBERTS, 2004; VIEIRA, 2007). Tem sido associado como um melhorador da qualidade interna e externa dos ovos. Está envolvido na formação da casca do ovo através de seu efeito na deposição de carbonato de cálcio.

A suplementação de Zn pode variar a concentração em diferentes órgãos, como fígado, mucosa e tecidos moles, sendo influenciada pelo estado nutricional ou fisiológico dos animais (MOHANNA; NYS, 1999; SKŘIVAN, SKŘIVANOVÁ E MAROUNEK, 2005). A deficiência desse micromineral está diretamente associada ao crescimento retardado, cicatrização, atraso da puberdade, fertilidade e na competência imunológica, enquanto a toxicidade é rara, ocorrendo principalmente em dietas com níveis acima de 1.000 ppm (GONZÁLEZ; SILVA, 2019). A detecção de deficiência de Zn em animais pode ser realizada por meio da análise da concentração de eritrócitos e valores baixos indicam o início de uma deficiência. A concentração de Zn no plasma sanguíneo é considerada um indicador confiável, e parâmetros como Zn na membrana plasmática, deficiência de ALP e alterações no conteúdo de proteínas e lipídios também são avaliados para determinar a deficiência desse micromineral (SUTTLE; UNDERWOOD, 2010).

A utilização de Zn complexado com aminoácidos pode auxiliar em uma maior gravidade específica e maior conteúdo desse mineral nos ovos, além disso, está envolvido com menores taxas de ovos trincados e redução na mortalidade embrionária precoce (HUDSON et al. 2004). Além disso, a porcentagem de fertilidade, eclosão e taxa de produção de pintos qualificados pode ser maior em animais que receberam Zn complexado (ZHANG et al. 2017).

Minerais e desenvolvimento embrionário

Os minerais presentes na matriz estão relacionados aos minerais fornecidos via dieta, consequentemente afetando o conteúdo dos ovos e o desenvolvimento embrionário. Os minerais estão relacionados a um grande número de atividades metabólicas que garantem o correto crescimento de desenvolvimento embrionário. Os microminerais Mn e Zn podem ser depositados no ovo de forma homogênea no ovo, porém sua maior fração pode ser encontrada na fração granular da gema. Todavia, o Cu pode ser encontrado no albúmen, casca e membranas internas casca (RICHARDS, 1997).

A deficiência de Mn pode gerar alguns quadros de desfavoráveis ao embrião, como a incidência de perose, má formação da cartilagem da placa de crescimento tibial e pode levar a morte embrionária tardia (18 a 21 dias) (LIU; HEINRICHS; LEACH, 1994; LEESON; SUMMERS, 2001; LEESON; SUMMERS, 2009). A deficiência de zinco está relacionada com a formação inadequada dos ossos durante o período embrionário, assim como com o desenvolvimento deficiente de penas, crescimento retardado, perose e descamação da pele após a eclosão (LEESON; SUMMERS, 2001). O Cu está envolvido no funcionamento de várias enzimas, em decorrência disso, na sua ausência podem ser vistos casos de anemia, hemorragias, desenvolvimento ósseo retardado, má formação no tecido conjuntivo e deficiência na respiração celular (AL-UBAIDI; SULLIVAN, 1963; WHO, 1996; NITTIS; GITLIN, 2004).

De acordo com Avila et al. (2023), a utilização de Mn, Zn e Cu orgânicos pode aumentar a densidade mineral óssea em pintos nascidos de galinhas jovens e velhas, porém nenhuma diferença foi encontrada nas cinzas da tíbia e no percentual mineral. Araújo et al. (2019), ao testar as fontes dos microminerais Fe, Mn, Zn, Cu e Se, encontrou uma melhor taxa de conversão alimentar da progênie de reprodutoras alimentadas com MC. Segundo Saber et al. (2019) o uso de MC nas proporções de 50% ou 100% na dieta de reprodutoras pesadas pode melhorar a massa corporal e o rendimento de carcaça da progênie.

HIPÓTESES E OBJETIVOS

HIPÓTESES

Matrizes pesadas suplementadas com microminerais complexados com lisina podem melhorar o desempenho zootécnico.

A suplementação de microminerais complexados com lisina melhora a qualidade da progênie.

OBJETIVO GERAL

Avaliar os efeitos da suplementação de Zn, Mn e Cu complexados a lisina ou não em dietas de matrizes pesadas

OBJETIVO ESPECÍFICO

Mensurar os efeitos dos microminerais na produção de ovos, ovos incubáveis e qualidade da casca do ovo.

Avaliar a eclodibilidade, fertilidade e a qualidade dos pintos.

Verificar os impactos dos tratamentos na composição mineral das gemas e dos ossos da progênie.

CAPÍTULO II

Broiler Breeder Hen performance fed with complexed lysine trace minerals and chick quality

R. M. Horn, [a] S. L. Vieira,[a]* D. D. B. Maria,[a] J. C. Feijó,[a] Y. J. Olabarriaga,[a] S. M. J. Silveira[a]

*Department of Animal Science, Federal University of Rio Grande do Sul, Av. Bento Gonçalves, 7712, Porto Alegre, RS, Brazil, 91540-000.

* Corresponding author: Tel.: +55 51 3308 6048

E-mail address: slvieira@ufrgs.br (S.L. Vieira)

SUMMARY

The present study aimed to evaluate the effects of partial substitution of inorganic trace minerals (ITM) by amino organic trace minerals (OTM) on broiler breeder hens' performance and offspring. A total of 682 Cobb 500 broiler breeder hens and 62 males, 24 wk of age, were allocated to 3 dietary treatments: T1- contained ITM forms of Zn, Mn, and Cu, at 70, 70, and 10 ppm, respectively; T2- partial replacement (50%) of inorganic form of Zn, Mn and Cu by OTM sources; T3- partial replacement (70%) of inorganic form of Zn, Mn and Cu by OTM sources. Each treatment had 10, 10 and 11 replicates. Laying production was evaluated from 25 to 40 wk, whereas egg quality was evaluated once a period to access egg weight, yolk, albumen, shell percentage and eggshell thickness. In the weeks 32, 36, and 40, eggs were incubated and evaluated for hatchability parameters and chick quality. At 40 wk of age, the tibiae and femurs of hatching chicks were collected for the mineral content. Total and settable egg production and incubation parameters were not affected by supplementation treatments ($P > 0.05$). Eggshell thickness significantly increased ($P < 0.05$) in the 50% OTM substitution compared to the ITM. The hatching chick weight has improved with 70% OTM replacement ($P < 0.05$).

Key words: broiler breeder, trace mineral, egg quality, chick quality.

DESCRIPTION OF PROBLEM

Trace minerals play a crucial role in the health of broiler breeder hens as they are related to better performance, egg quality, embryonic and offspring development (Favero et al., 2013a; Noetzold et al., 2020; Noetzold et al., 2022a; Virden et al., 2003). Zn, Mn, and Cu are associated with the activity of enzymes and proteins, besides, the deficiency of these trace minerals in the breeder's diet can result in a shortage of these minerals in the eggs, affecting the embryo (Richards, 1997).

Zn, Mn and Cu are involved in a series of metalloenzymes such as alkaline phosphatase, superoxide dismutase, carbonic anhydrase, lysyl oxidase and others (Surai, 2015; Mayer et al., 2019; Laczko and Csiszar., 2020). In poultry, these enzymes are essential since they play a significant role in the formation of extracellular matrix proteins, such as collagen and elastin, precursors of eggshell membrane (Lucero and Kagan, 2006; Smith-Mungo and Kagan., 1998). Specifically, their main function in the shell gland is to catalyze the conversion of carbon dioxide and water into bicarbonate, a key process in eggshell synthesis (Roberts, 2004; Zhang et al., 2017). The quality of eggshell is crucial for guaranteeing an acceptable production of hatchable eggs, as it offers mechanical protection while serving as a source of calcium and other essential minerals for the developing embryo (Hunton, 1995; Vieira, 2007).

The supplementation of trace minerals in poultry diets can have several sources. Generally, these sources can be in the inorganic form, such as sulfate, oxide, and carbonate (Bao et al., 2007), or in the form of chelated minerals, bound to amino acids, proteins, carbohydrate, or organic acids (Vieira, 2008; Yaqoob et al., 2020). Inorganic trace minerals (ITM) exhibit instability and swift dissociation within the gastrointestinal tract, interacting with other compounds, resulting in their loss before absorption occurs (Aksu et al., 2011). Given the limited digestibility of ITM, higher dietary levels of ITM are necessary to provide the requirements of breeders (Sirri et al., 2016), oversupplying ITM can result in increased diet production costs and environmental concerns. These issues can be mitigated by replacing ITM with organic trace minerals (OTM). Trace minerals bound to organic ligands can improve digestion and absorption within the intestine, thus, OTM is absorbed as part of a specific organic compound's pathways until it is fully utilized. (Vieira, 2008; Favero et al., 2013b; Wang et al., 2019).

Different studies have shown that the utilization of OTM can improve hatchability, eggshell thickness, eggshell conductance, yolk mineral content, feed conversion of the offspring (Favero et al., 2013b; Zhang et al., 2017; Araújo et al., 2019; Brand et al., 2023). Virden et al (2003) has found that offspring originated from broiler breeders fed with OTM sources of Zn and Mn can improve chicks' livability from 1 to 18 d and 1 to 34 d. The use of ITM in combination with OTM is able to increase the mineral yolk content also improve hatching chicks (Favero et al, 2013a). The aim of the present trial was to investigate the interaction between trace minerals source, Cu, Mn and Zn, inorganic or complexed on broiler breeder hens' performance as hatchability, fertility, chicks' quality, eggshell thickness, yolk, albumen and shell percentage.

MATERIALS AND METHODS

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

Birds and Husbandry

A total of 682 Cobb 500 broiler breeder hens and 62 males were used at 24 weeks provided from commercial farm (Vibra Agroindustrial S. A, Montenegro, RS, Brazil). The birds were divided randomly into 31 floor pens (2.0 x 2.5 m) after being weighted so their variation coefficient (CV) could be accessed. The experimental units were composed of 22 hens and two males per pen, reared during 24 to 40 weeks of age in a conventional house, following Cobb-Vantress (2020b) breeder recommendation for light program and environmental temperature and relative humidity (RU). A total of 32 males were maintained in separate pens to replace sexually inactive or dead males to maintain fertility. The photostimulation occurred at the day of placement (24 wk of age; 13L:11D) with 1 hour light increased per week until 16L:8D was achieved and maintained until the end of the trial. The birds were raised on non-reused rice hull litter, with water provided ad libitum, through 3 nipple waterers per pen and 6 nests. Feed was supplied in restricted daily amount using a separated feeding arrangement for males and females, which denied males to access female's feed and vice-versa. Hens were individually weight (25% of the flock weekly, and 100% once a month). Feed allocation was adjusted weekly to achieve target standard grow curve suggested from the breeder genetic line (Cobb-Vantress, 2020a).

Dietary Treatments

All ingredients utilized during the trial were taken from the same batch and remained under appropriate storage conditions until experimental diets were mixed. Hens were fed the experimental feeds from 25 to 40 wk (Table 1). The experimental diets were composed of 3 treatments as follow: T1- containing only inorganic sources of trace minerals (Zn – 70 ppm, Mn – 70 ppm and Cu – 10 ppm); T2- Partial replacement (50%) of inorganic form of Zn, Mn and Cu by OTM sources; T3- Partial replacement (70%) of inorganic form of Zn, Mn and Cu by OTM sources. The trial was conducted using inorganic sources from sulfates of Zn (ZnSO47H20, 22%), Mn (MnSO4, 31%), Cu (CuSO45H20, 25%). All OTM sources used in the research were products of Phytobiotics Futterzusatzstoffe GmbH, Eltville, Germany: Zn OTM (Plexomin® L-Zn, L: 45%, Zn: 20%), Mn OTM (Plexomin® L-Mn, L: 44%, Mn: 16%), and Cu OTM (Plexomin® L-Cu, L: 45%, Cu: 19%). Dietary treatments were replicated 10, 10, and 11 times, respectively. Trace mineral results were obtained using inductive coupled plasma atomic emission spectroscopy as described by Ashoka et al. (2009). The supplemented and analyzed levels of Zn, Mn, and Cu are listed in Table 3.

Hen Performance Measurements

Hen performance was evaluated in 4 periods of 4 wk each from 25 to 40 wk of age. Eggs were collected 4 times daily, and then classified as settable, cracked, shell-less or deformed. All hatchable eggs laid in the last week of 32, 36 and 40 wk were weighed and and set into a single-stage incubator (Avicomave, Iracemápolis, SP, Brazil). The incubator was set at 37.5ºC and 65% relative humidity (RH). On d 18, eggs were then transferred to the hatcher compartment set at 36.6ºC and 80% RH. Total hatchability was expressed as percentage of hatching chicks of total eggs set, and hatchability of fertile eggs was expressed as the number of hatching chicks per fertile eggs set. At hatch, chicks were weighed and had their length measured in the distance from the tip of the beak to the end of the middle toe as described by Molenaar et al. (2008). The evaluation of chick bones (tibiae and femurs) was conducted using samples collected from 30 euthanized hatching chicks per pen.

Parameters of egg production and quality (egg weight, percentage of yolk, albumen and eggshell, eggshell breaking strength, thickness) were accessed in thirty eggs per treatment gathered in 3 consecutive days at 27, 31, 35 and 39 weeks of age. Albumen weight was obtained by subtracting the yolk and shell weight from the egg weight. Eggshell weight was obtained after washing and drying shells at 105°C overnight, whereas eggshell thickness was measured using a micrometer in the basal, equatorial, and apical regions, with these values being averaged for statistical analysis. Twenty eggs per group were used to determine eggshell breaking strength, using a texture analyzer (Model TA.XT. plus; Texture Technologies Corp., Hamilton, AL) with a 75-mm (P/75) breaking probe as described by Molino et al., (2015). For the analysis of yolk trace minerals, a pooling of the yolks from weeks 36 and 40 was conducted. The results were obtained through atomic absorption spectroscopy (Shang and Hong, 1996).

Statistical Analysis

Data were submitted to the normality of variance test to check for normal distribution and homogeneity of variance test (Levene, 1960; Shapiro and Wilk, 1965). A variance analysis was performed using the PROC MIXED model procedure of SAS with effect of diets and periods and their interactions using the repeated statement of SAS 9.4 (2013). The best covariance structure was based on the Akaike information criteria (Littell et al., 1998). Furthermore, the total egg production, settable eggs production per hen at 40 wk and yolk and chick bones analyses were also analyzed using PROC GLM. The Tukey-Kramer test was used for means comparison with differences being considered significant at $P < 0.05$ (Tukey, 1991). The periods of evaluations were 25-28, 29-32, 33-36, 37-40 weeks of age. Nonetheless, the weeks of evaluations for incubation analyses were only 32, 36 and 40 wk of age.

RESULTS AND DISCUSSION

The formulations and analyses of CP, Ca, P, and trace minerals were consistent across treatments (n=12, with CP at 14.2% ± 0.31, Ca at 3.2% ± 0.024, and P at 0.58% ± 0.014). These levels were considered adequate as they fell within the expected formulated range. Trace mineral analyses for the dietary treatments were based on samples from four sets of two mixed batches throughout the study and are detailed in Table 2. The trace mineral content in the experimental diets corresponded to the supplementation levels indicated in Table 2."

Egg Production and Incubation

The egg production and incubation outcomes are summarized in Tables 3 and 4, respectively. There were no significant differences in both total and settable egg production among the dietary treatments ($P > 0.05$). Egg production started at 25 weeks and peaked (84.5%) at 30 weeks of age. Therefore, egg production was lower in the first period and then decreased as age advanced. These findings are in accordance with the results of Favero et al. (2013b), where no disparities were observed in egg production and settable eggs when comparing the use of Cu, Zn, and Mn between inorganic and inorganic plus organic trace minerals. In laying hens, Lim and Paik (2003) demonstrated that the incorporation of organic Zn, Mn, and Cu had no impact on egg production. A similar study, investigated the impact of low inclusion levels of OTM (Fe, Cu, Mn, and Zn) on the performance of laying hens, identified that egg production did not significantly differ between the use of ITM at commercial levels and a diet supplemented with OTM at 1/3 of commercial levels of Fe, Cu, Mn, and Zn. However, the egg production from OTM 1/3 was higher than that from the ITM 1/3 ($P < 0.05$) (Qiu et al., 2020).

On the other hand, Avila et al. (2023), using three diets with Zn, Mn, and Cu, tested an ITM at commercial levels, OTM, and a combination of 33% OTM and 67% ITM. They found that hens receiving a combination of trace minerals had higher egg production than the other treatments (P < 0.001). An increase in egg production in broiler breeder hens fed with organic trace minerals (Zn, Mn, Cu, Se, and Fe) at 34, 46, and 56 weeks of age, compared to those receiving the inorganic treatment, was demonstrated by Araújo et al. (2019). It seems that there is inconsistency in egg production across studies, potentially attributed to variations in the types of trace minerals employed, the utilization of organic sources, and disparities in experimental methodologies.

Parameters of fertility and hatchability were not affected by treatments of trace minerals in the present study (P > 0.05), nevertheless, fertility and fertile eggs hatchability were significantly affected by period. Similar results were found by Araújo et al., (2019) and Avila et al. (2023), where fertility and hatchability had no difference between the organic and ITM. On the contrary, Saber et al. (2020) showed that broiler breeder hens, when provided with a diet consisting of a 50% OTM and 50% ITM sources of Mn, Fe, Zn, Cu, Se, Co, and I, demonstrated a higher fertility rate compared to groups receiving only inorganic or organic supplementation.

Furthermore, Wang et al., 2019 exhibited that birds supplemented with ITM (Fe, Zn, Mn, Cu and Se) commercial levels showed better reproductive performance, where the fertility was higher than the other treatments (levels of ITM and OTM). Additionally, it demonstrated a lower hatchability in the treatment with a 37.5% reduction of commercial levels of OTM (P < 0.05). Moreover, Favero et al. (2013b) showcased a higher hatchability of fertile eggs in the substitution group, outperforming both the IMT and On Top supplementation groups. In the context of this study, the absence of any significant effects on the parameters of production and incubation may suggest that all treatment combinations provided sufficient mineral content for satisfactory performance.

Egg quality

Results from egg quality are described in Table 5. Parameters of egg weight, eggshell breaking strength, specific gravity, yolk, albumen, and shell percentage were not affected by treatments ($P > 0.05$), but were significantly influenced by the period ($P < 0.05$) as expected. Corresponding outcomes were found by Noetzold et al. (2022a) when studying the influence of partial substitutions of organic trace minerals (Zn, Mn, Cu, Fe, and Se); they did not find any differences between the replacements in the inner egg quality. However, breaking strength had significantly increased with On Top supplementation ($P < 0.05$).

The eggshell thickness presented a significant difference among the dietary treatments, where a 50% replacement of OTM showed a higher thickness ($P < 0.05$). In agreement to this study, eggshell thickness improvements have been reported in similar studies (Stefanello et al., 2014; Araújo et al., 2019; Akhtar et al., 2020; Yaqoob et al., 2020; Noetzold et al., 2022a). Nevertheless, some researchers have found no differences on eggshell thickness between ITM and OTM source of trace minerals (Zn, Fe, Cu, Mn, or Se) (Zhang et al., 2017; Wang et al., 2019; Qiu et al., 2020; Brand et al., 2023).

Noetzold et al. (2022a) detected an improvement in eggshell thickness as hens aged, particularly when the shells are expected to be thinner (at 65 weeks). In this study, similar outcomes were observed, where eggshell thickness at weeks 35 and 39 was higher than at 27 and 31 weeks. This finding might suggest that the trace minerals maintained higher eggshell thickness during periods when the shell is expected to begin thinning.

Chick Quality and Mineral Content

Results from chick weight and mineral content of yolk and bones are illustrated in Table 4 and 6, respectively. Chick length was not affected by treatments of trace minerals ($P > 0.05$), still, was significantly affected by period. The replacement of 50% organic trace elements of Zn, Mn and Cu has demonstrated a higher body weight of hatched chicks ($P < 0.05$).

In their investigation involving various substitutions of organic trace minerals (Zn, Mn, Cu, Fe, Se, and I), Noetzold et al. (2022b) observed enhancements in both chick weight and length within treatments that incorporated OTM. These outcomes align with the discoveries made by Favero et al. (2013b), who reported that on top supplementation can improve the length of hatching chicks. On the other hand, some studies have found no differences between the sources of trace minerals (Zn, Mn, Fe, and Cu) in hatching weight but observed effects depending on hens age (Favero et al., 2013b; Araújo et al., 2019; Saber et al., 2020; Guz et al., 2022). It has been reported that chick weight can be related to the body weight of broilers at 7 and 42 days, improving slaughter performance (Willemsen et al., 2008; Petek et al., 2010).

The substitution of 50% of OTM resulted in a higher Zn content in the yolk ($P < 0.05$), while Mn and Cu remained unaffected. Regarding the mineral content in the tibiae plus femurs of hatching chicks, the 70% replacement exhibited elevated levels of Zn ($P < 0.05$), while Mn and Cu showed no significant response to the treatments. Previous studies indicate that the yolk mineral content can be affected by dietary trace minerals (Nys et al., 2018; Ghasemi et al., 2022; Santos et al., 2022). Favero et al. (2013a), when analyzing a pool of yolk and albumen, found higher differences only in Zn concentrations for the organic treatments; Mn and Cu were not affected. Contrary to the results of these studies, Avila et al. (2023) did not find any differences in yolk mineral content between ITM and OTM source.

The mineral composition of bones may be influenced by the presence of those same minerals in the yolk. As the primary reservoir for trace minerals, the yolk plays a crucial role in providing essential nutrients to hatchlings from the fertilized egg (Richards, 1997; Vieira, 2007; Uni et al., 2012).

CONCLUSIONS AND APPLICATIONS

1. Broiler breeder hens fed with OTM lysine source had increased eggshell thickness compared to the inorganic control group. Despite that, no effect was found on hatchability and fertility.
2. Yolk zinc was higher with OTM at 50%, and the hatched chicks' weight was also higher compared to ITM or OTM at 70%.
3. Tibiae and femurs of hatched chicks had similar Mn and Cu values; however, the Zn values in OTM at 70% demonstrated higher levels.

Acknowledgements

The authors acknowledge the partial funding from Conselho Nacional de Pesquisa (CNPq – Brasilia, DF, Brazil), Coordenacão de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and Zinpro for their integrated supported in this project.

References

Akhtar, K., N. Chand, S. Khan, S. Dai, and R. U. Khan. 2020. Supplementation of organic minerals and its effect on production performance and egg quality of laying hens. J. Anim. Physiol. Nutr. Sci. 1:12-16.

Aksu, T., B. Özsoy, D. S. Aksu, M. A. Yörük, and M. Gül. 2011. The effects of lower levels of organically complexed zinc, copper, and manganese in broiler diets on performance, mineral concentration of tibia and mineral excretion. Kafkas Univ. Vet. Fak. Derg. 17:141–146.

Araújo C.S.S., R.G. Hermes, L.C. Bittencourt, C.C. Silva, L.F. Araújo, C.A. Granghelli, P.H. Pelissari, F.A. Roque, and B.G.S. Leite. 2019. Different dietary trace mineral sources for broiler breeders and their progenies. Poult Sci. 98:4716-4721.

Ashoka, S., B. M. Peake, G. Bremner, K. J. Hageman, and M. R. Reid. 2009. Comparison of digestion methods for ICP-MS de-termination of trace elements in fish tissues. Anal. Chim. Acta. 653:191–199.

Avila, L. P., K. M. Sweeney, M. Roux, R. E. Buresh, D. L. White, W. K. Kim, and J. L. Wilson. 2023. Evaluation of industry strategies to supply dietary chelated trace minerals (Zn, Mn, and Cu) and their impact on broiler breeder hen reproductive performance, egg quality, and early offspring performance. J. Appl. Poult. Res. 32:100354.

Bao, Y. M., M. Choct, P. A. Iji, and K. Bruerton. 2007. Effect of Organically Complexed Copper, Iron, Manganese, and Zinc on Broiler Performance, Mineral Excretion, and Accumulation in Tissues. J. Appl. Poult. Res.16:448-455.

Berwanger, E., S. L. Vieira, C. R. Angel, L. Kindlein, A. N. Mayer, M. A. Ebbing, and M. Lopes. 2018. Copper requirements of broiler breeder hens. Poult. Sci. 97:2785–2797.

Brand, H., T. Hubers, I. Ankar, C. A. Torres, E. Frehen, M. Ooms, J. Arts, B. F. A. Laurenssen, M. J. W. Heetkamp, B. Kemp, and R. Molenaar. 2023. Effects of trace minerals source in the broiler breeder diet and eggshell translucency on embryonic development of the offspring. Poult Sci. 102:102455.

Cobb-Vantress 2020b. Cobb 500 SF Breeder Management Supplement. Cobb-Vantress Inc., Siloam Springs, AR.

Cobb-Vantress, 2020. Cobb Breeder Management Guide. Cobb Vantress Inc., Siloam Springs, AR.

Favero, A., S. L. Vieira, C. R. Angel, A. Bos-Mikich, N. Lothhammer, D. Taschetto, R. F. A. Cruz, and T. L. Ward. 2013a. Development of bone in chick embryos from Cobb 500 breeder hens fed diets supplemented with zinc, manganese, and copper from inorganic and amino acid-complexed sources. Poult. Sci. 92:402–411.

Favero, A., S. L. Vieira, C. R. Angel, F. Bess, H. S. Cemin, and T. L. Ward. 2013b. Reproductive performance of Cobb 500 breeder hens fed diets supplemented with zinc, manganese, and copper from inorganic and amino acid-complexed sources. J. Appl. Poult. Res. 22: 80-91.

Ghasemi, H. A., I. Hajkhodadadi, M. Hafizi, S. Fakharzadeh, M. Abbasi, S. Kalanaky, M. H. Nazara. 2022. Effect of advanced chelate compounds-based mineral supplement in laying hen diet on the performance, egg quality, yolk mineral content, fatty acid composition, and oxidative status. Food Chem. 366:130636.

Guz, B. C., I. C. Jong, U. E. Bol, B. Kemp, M. van Krimpen, R. Molenaar, H. van den Brand. 2022. Effects of organic macro and trace minerals in fast and slower growing broiler breeders' diet on offspring growth performance and tibia characteristics. Poult. Sci. 101:101-647.

Hunton, P. 1995. Understanding the architecture of the eggshell. Worlds Poult. Sci. J. 51:141–147.

Laczko, R., and K. Csiszar. 2020. Lysyl Oxidase (LOX): Functional Contributions to Signaling Pathways. Biomolecules. 10-1093.

Levene, H. 1960. Robust tests for the equality of variance. Pages 278–292 in Contributions to Probability and Statistics. I. Olkin, ed. Stanford University Press, Palo Alto, CA.

Lim H.S., I.K. Paik. 2003. Effects of Supplementary Mineral Methionine Chelates (Zn, Cu, Mn) on the Performance and Eggshell Quality of Laying Hens. Asian-Aust. J. Anim. Sci.16:1804-1808.

Littell, R. C., P. R. Henry, and C. B. Ammerman. 1998. Statistical analysis of repeated measures data using SAS procedures. J. Anim. Sci. 76:1216-1231.

Lucero, H. A.; H. M. Kagan. 2006. Lysyl oxidase: An oxidative enzyme and effector of cell function. Cell. Mol. Life Sci. 63: 2304-2316.

Mayer, A. N., S. L. Vieira, E. Berwanger, C. R. Angel, L. Kindlein, I. França, and T. L. Noetzold. 2019. Zinc requirements of broiler breeder hens. Poult. Sci. 98:1288– 1301.

Molenaar, R., I. A. M. Reijrink, R. Meijerho, and H. Van Den Brand. 2008. Relationship between hatchling length and weight on later productive performance in broilers. World's Poult. Sci. J. 64: 599–604.

Molino, A. B., E. A. Garcia, G. C. Santos, J. A. Vieira Filho, G. A.A. Baldo, and I. C. L. Almeida Paz. 2015. Photostimulation of Japanese quail. Poult. Sci. 94:156–161.

Noetzold, T. L., S. L. Vieira, A. Favero, R. M. Horn, C. M. Silva, and G. B. Martins. 2020. Manganese requirements of broiler breeder hens. Poult. Sci. 99:5814–5826.

Noetzold, T. L., S. L. Vieira, A., R. M. Horn, C. R. de Freitas, and A. Fireman. 2022a. Improved offspring performance of broiler breeder hens fed amino acid complexed trace minerals. Appl. Poult. Res. 31:100284.

Noetzold, T. L., S. L. Vieira, A., B. B. Xavier, Y. J. de Olabarriaga, and A. Fireman. 2022b. Supplemental effects of amino acid-complexed trace minerals on broiler breeder hen performance. Anim. Feed Sci. Technol. 290:115371.

Nys, Y., P. Schlegel, S. Durosoy, C. Jondreville, and A. Narcy. 2018. Adapting trace mineral nutrition of birds for optimising the environment and poultry product quality. World's Poult. Sci. J. 74:225-238.

Petek, M., A. Orman, S. Dikmen, and F. Alpay. 2010. Physical chick parameters and effects on growth performance in broiler. Arch. Tierz. 53:108-115.

Qiu, J. L., Q. Zhou, J. M. Zhu, X. T. Lu, B. Liu, D. Y. Yu, G. Lin, T. Ao, e J. M. Xu. 2020. Organic trace minerals improve eggshell quality by improving the eggshell ultrastructure of laying hens during the late laying period. Poult. Sci. 99:1483–1490.

Richards, M. P. 1997. Trace mineral metabolism in the avian embryo. Poult. Sci. 76:152–164.

Roberts, J. R. 2004. Factors affecting egg internal quality and eggshell quality in laying hens. J. Poult. Sci. 41:161–177.

Saber, S., H. R. Kutlu, Y. Uzun, L. Celik, O. Yucelt, e M. Baylan. 2020. Effects of form of dietary trace mineral premix on fertility and hatchability of broiler breeder hens and post-hatch performance and carcass parameters of their progenies. Kafkas Univ Vet. Fak. Derg. 26:171–180.

Santos, J. S., I. C. S. Araújo, P. C. Martins, A. F. B. Royer, M. B. Café, M. A. Andrade, Z. Uni, and J. H. Stringhini. 2022. The transfer of amino acids and minerals to the egg yolk and to the yolk sac of their progeny is affected by breeder age. J. Anim. Physiol. Anim. Nutr. 10:139-146.

SAS. 2013. SAS/STAT 9.4 User's Guide SAS Institute Inc., Cary, NC.

Shang, S., and W. Hong. 1996. Flame atomic absorption spectrometric determination of copper, zinc, calcium, magnesium and iron in fresh eggs using microvolume injection. Talanta. 44: 269-274.

Shapiro, S. S., and M. B. Wilk. 1965. An analysis of variance test for normality (complete samples). Biometrika. 52:591-611.

Sirri, F., G. Maiorano, S. Tavaniello, J. Chen, M. Petracci, and A. Meluzzi. 2016. Effect of different levels of dietary zinc, manganese, and copper from organic or inorganic sources on performance, bacterial chondronecrosis, intramuscular collagen characteristics, and occurrence of meat quality defects of broiler chickens. Poult. Sci. 95:1813-1824.

Smith-Mungo, L. I.; H. M. Kagan. 1998. Lysyl oxidase: properties, regulation and multiple functions in biology. Matrix Biol. 16: 387–398.

Stefanello, C., T. C. Santos, A. E. Murakami, E. N. Martins, and T. C. Carneiro. 2014. Productive performance, eggshell quality, and eggshell ultrastructure of laying hens fed diets supplemented with organic trace minerals. Poult. Sci. 93:104–113.

Surai, P. F. 2015. Antioxidant systems in poultry biology: superoxide dismutase. J. Anim. Res. Nutr. 1 – 1:8.

Tukey, J. W. 1991. The philosophy of multiple comparisons. Stat. Sci. 6:100-116.

Uni, Z., L. Yadgary, and R. Yair. 2012. Nutritional limitations during poultry embryonic development. J. Appl. Poult. Res. 21:175–184.

Vieira, S. L. 2007. Chicken embryo utilization of egg micronutrients. Rev. Bras. Cienc. Avic. 9:1–8.

Vieira, S. L. 2008. Chelated Minerals for Poultry. Rev. Bras. Cienc. Avic. 10:73–79.

Virden, W. S., J. B. Yeatman, S. J. Barber, C. D. Zumwalt, T. L. Ward, A. B. Johnson, and M. T. Kidd. 2003. Hen mineral nutrition impacts progeny livability. Appl. Poult. Res. 12:411-416.

Wang, G., L. J. Liu, W. J. Tao, Z. P Xiao, X. Pei, B. J. Liu, M. Q. Wang, G. Lin, and T. Y. Ao. 2019. Effects of replacing inorganic trace minerals with organic trace minerals on the production performance, blood profiles, and antioxidant status of broiler breeders. Poult. Sci. 98:2888-2895.

Willemsen, H., N. Everaert, A. Witters, L. De Smit, M. Debonne, F. Verschuere, P. Garain, D. Berckmans, E. Decuypere, and V. Bruggeman. 2008. Critical assessment of chick quality measurements as an indicator of posthatch performance. Poult. Sci. 87:2358–2366.

Yaqoob, M. U., G. Wang, W. Sun, X. Pei, L. Liu, W. Tao, Z. Xiao, M. Wang, M. Huai, L. Li, and W. Pelletier. 2020. Effects of inorganic trace minerals replaced by complexed glycinates on reproductive performance, blood profiles, and antioxidant status in broiler breeders. Poult. Sci. 99:2718-2726.

Zhang, Y. N., H. J. Zhang, J. Wang, H. Y. Yue, X. L. Qi, S. G. Wu, and G. H. Qi1. 2017. Effect of dietary supplementation of organic or inorganic zinc on carbonic anhydrase activity in eggshell formation and quality of aged laying hens. Poult. Sci. 96: 2176–2183.

Table 1. Composition of basal diet supplied to broiler breeder hens from 25 to 40 wk of age.

Ingredients, % as-is	Laying 1	Males
Corn	61.07	55.13
Soybean Meal, 46%	18.04	9.55
Wheat Meal	6.75	31.46
Soybean Oil	2.36	0.50
Dicalcium Phosphate	0.92	0.34
Limestone	9.73	1.92
Sodium bicarbonate	0.21	0.28
Salt	0.33	0.23
Methionine hydroxy analogue[1]	0.14	0.09
L-Lysine HCL	0.02	-
L-Threonine	0.03	0.04
Vitamin premix[2]	0.15	0.15
Mineral premix[3]	0.10	0.10
Choline Chloride 60%	0.14	0.19
BHT	0.01	0.01
HiPhos 20.000[4]	0.01	0.005
Total	100.00	100.00
AME, kcal/kg	2,800	2,700
Crude Protein	14.10	13.92
Ca	3.40	0.95
Av. P	0.42	0.42
Na	0.20	0.18
d Lys	0.63	0.50
d Met	0.33	0.27
d TSAA	0.55	0.49
d Thr	0.47	0.43
d Trp	0.14	0.13
d Val	0.60	0.53
Choline, mg/kg	1,500	1,500

[1] Novus (DL-2-hydroxy-(4-methylthio) butanoic acid).

[2] Composition per kg of product: vitamin A, 9,000.000 UI; vitamin D3, 2,500.000 UI; vitamin E, 20,000 UI; vitamin K3, 2,500 mg; vitamin B1, 2,000 mg; vitamin B2, 6,000 mg; vitamin B6 3,000.38 mg; pantothenic acid, 12 g; vitamin B12, 15,000 mcg; nicotinic acid, 35 g; folic acid, 1,500 mg; biotin, 100 mg; selenium, 250 mg.

[3] Experimental treatments resulted from feed additions with Sulfates: $CuSO_4$, $ZnSO_4$, $MnSO_4$. OTM: PlexominZn, Plexomin Mn and Plexomin Cu.

[4] Ronozyme HiPhos 20,000 FYT/g, Novozymes A/S, Bagsvaerd, Denmark.

Table 2. Description of treatments composed by varying strategies of trace mineral supplementation[1].

Mineral	Zn, ppm	Mn, ppm	Cu, ppm
Treatments[2]	Sulfate / OTM	Sulfate / OTM	Sulfate / OTM
ITM	70/0 (82±14)	70/0 (129±17)	10/0 (18±4)
50% ITM, 50% OTM	35/35 (109±13)	35/35 (134±20)	5/5 (18±3)
30% ITM, 70% OTM	20/50 (104±7)	20/50 (144±37)	3/7 (16±3)

[1] Values within parenthesis are analyzed ± SD (n=3). Data were obtained using inductive coupled plasma atomic emission spectroscopy as described by Ashoka et al. (2009).

[2] T1- Control ITM with Zn, Mn, and Cu at 70, 35, and 20 ppm, respectively; T2- same total mineral content as in T1 in a combination of 50% ITM and 50% OTM; T3- same total mineral content as in T1 in a combination of 30% ITM and 70% OTM.

Table 3. Broiler breeder hen productive performance as affected by supplemental trace mineral sources.

Treatments[1]	Total egg production	Settable eggs	Total egg[2]	Settable eggs[2]
ITM	70.0	43.1	77.7	77.2
50% ITM, 50% OTM	72.9	43.7	79.1	78.6
30% ITM, 70% OTM	71.9	47.5	76.7	76.2
Periods				
25-28	46.1^{c}	25.1^{c}	-	-
29-32	82.0^{a}	52.9^{a}	-	-
33-36	81.2^{a}	52.8^{a}	-	-
37-40	76.9^{b}	48.4^{b}	-	-
SEM	1.399	1.184	0.648	0.654
P-value				
Treatment	0.2252	0.1568	0.3296	0.3370
Period	<.0001	<.0001	-	-
Treatment *vs*. period	0.1081	0.0530	-	-

a>b>c Means with different letters in the same column indicate significant differences ($P \leq 0.05$).

[1] T1- Control ITM with Zn, Mn, and Cu at 70, 35, and 20 ppm, respectively; T2- same total mineral content as in T1 in a combination of 50% ITM and 50% OTM; T3- same total mineral content as in T1 in a combination of 30% ITM and 70% OTM.

[2] Total eggs from 25 to 40 weeks per hen housed.

Table 4. Broiler breeder hen reproductive performance as affected by trace mineral sources.

Treatments[1]	Fertility[2], %	Hatchability, %		Body weight, g	Body Length, cm
		Total eggs[3]	Fertile eggs[4]		
ITM	97.3	87.2	90.6	46.2^{b}	18.8
50% ITM, 50% OTM	97.1	85.7	89.1	48.0^{a}	19.2
30% ITM, 70% OTM	94.5	86.6	89.7	46.8^{b}	18.9
Periods					
32	97.3^{a}	86.5	88.3^{b}	45.7^{c}	19.0^{b}
36	94.5^{b}	87.2	91.4^{a}	46.8^{b}	18.6^{c}
40	97.2^{a}	85.8	89.7^{ab}	48.4^{a}	19.5^{a}
SEM	0.483	0.582	0.448	0.704	0.067
P-value					
Treatment	0.1613	0.7217	0.4034	0.0420	0.4670
Period	<.0001	0.4414	0.0205	<.0001	<.0001
Treatment *vs*. period	0.5875	0.5047	0.3643	0.6770	0.5370

[1] T1- Control ITM with Zn, Mn, and Cu at 70, 35, and 20 ppm, respectively; T2- same total mineral content as in T1 in a combination of 50% ITM and 50% OTM; T3- same total mineral content as in T1 in a combination of 30% ITM and 70% OTM.

[2] Fertility, % = (number of fertile eggs/numbers of total egg set) × 100.

[3] Hatchability total eggs set, % = (number of chicks hatched/number of eggs set) × 100.

[4] Hatchability of fertile eggs set, % = (number of chicks hatched/number of fertile eggs set) × 100.

Table 5. Broiler breeder hen egg characteristics as affected by trace mineral sources.

Treatment[1]	Egg weight, g	%			Thickness, μm
		Yolk	Albumen	Shell	
ITM	62.6	27.5	63.6	8.8	373.0^{c}
50% ITM, 50% OTM	63.1	27.7	63.5	8.9	394.7^{a}
30% ITM, 70% OTM	63.5	27.4	63.8	8.9	381.0^{b}
Periods					
27	55.9^{d}	25.9^{d}	64.9^{a}	9.1^{a}	373.8^{b}
31	61.9^{c}	26.9^{c}	64.3^{a}	8.8^{ab}	370.8^{b}
35	65.8^{b}	28.2^{b}	62.9^{b}	8.9^{ab}	399.5^{a}
39	68.7^{a}	29.1^{a}	62.4^{b}	8.7^{b}	389.9^{a}
SEM	0.335	0.111	0.112	0.045	1.768
P-value					
Treatment	0.6320	0.3660	0.7160	0.9725	0.0001
Period	<.0001	<.0001	<.0001	0.0147	<.0001
Treatment *vs*. period	0.8980	0.2210	0.1680	0.4340	<.0001

$^{a>b>c>d}$ Means with different letters in the same column indicate significant differences ($P \le 0.05$).

[1] T1- Control ITM with Zn, Mn, and Cu at 70, 35, and 20 ppm, respectively; T2- same total mineral content as in T1 in a combination of 50% ITM and 50% OTM; T3- same total mineral content as in T1 in a combination of 30% ITM and 70% OTM.

Table 6. Mineral composition of yolks and hatched chicks bones[1], ppm.

Treatments[2]	Cu	Mn	Zn
Yolks, pool 36 - 40 weeks			
	2.41	3.89	65.14^{b}
50% ITM, 50% OTM	2.15	3.97	77.32^{a}
30% ITM, 70% OTM	2.20	4.24	71.32^{ab}
Mean	2.25	4.04	70.85
SEM	0.059	0.070	1.478
P-value	0.1608	0.1003	0.0023
Bones, 40 weeks			
Inorganic Sulfate	14.33	13.38	606.80^{ab}
50% Inorganic Sulfate, 50% Plexomin	14.06	12.10	537.59^{b}
30% Inorganic Sulfate, 70% Plexomin	12.11	13.14	685.76^{a}
Mean	13.45	12.88	614.99
SEM	0.611	0.451	23.170
P-value	0.2674	0.4953	0.0270

$^{a>b}$ Means with different letters in the same column indicate significant differences ($P \leq 0.05$).

[1] Tibiae (n=20) and femurs (n=20).

[2] T1- Control ITM with Zn, Mn, and Cu at 70, 35, and 20 ppm, respectively; T2- same total mineral content as in T1 in a combination of 50% ITM and 50% OTM; T3- same total mineral content as in T1 in a combination of 30% ITM and 70% OTM.

CAPÍTULO III

CONSIDERAÇÕES FINAIS

Com base nos resultados obtidos neste estudo, podemos concluir que a inclusão de microminerais complexados com lisina, combinados com microminerais inorgânicos nas dietas de reprodutoras pesadas, apresentou benefícios significativos nos resultados de progênie e na qualidade da casca dos ovos. A abordagem de utilizar uma combinação equilibrada de 50% de microminerais inorgânicos e 50% de microminerais complexados demonstrou ser uma alternativa promissora em comparação com a utilização exclusiva de microminerais inorgânicos.

Observou-se que as gemas provenientes de ovos de matrizes pesadas submetidas a 50% de substituição por lisinatos apresentaram um aumento no teor de Zn. Além disso, a progênie proveniente de matrizes que receberam a suplementação de 70% de microminerais complexados exibiu uma maior quantidade de Zn nos ossos. Quanto ao parâmetro de espessura da casca dos ovos, o nível de substituição mais eficaz foi de 50% de microminerais complexados.

Considerando os resultados alcançados nesta pesquisa, a combinação de microminerais inorgânicos e complexados indicam uma eficiência notável na transmissão desses elementos para os ovos e, consequentemente, para a progênie subsequente. Essa abordagem pode desempenhar um papel relevante na melhoria da performance de frangos de corte. Os dados sugerem que a escolha criteriosa de microminerais na dieta das reprodutoras pesadas pode ter impactos positivos na qualidade dos ovos e também no correto desenvolvimento da progênie.

REFERÊNCIAS

ABPA - ASSOCIAÇÃO BRASILEIRA DE PROTEÍNA ANIMAL. **Relatório anual 2023**. São Paulo: ABPA, 2023.

AL-UBAIDI, Y. Y.; SULLIVAN, T. W. Studies on the requirements and interaction of copper and iron in broad breasted bronze turkeys to 4 weeks of age. **Poultry Science**, Champaign, v. 42, n. 3, p. 718-725, 1963.

ARAÚJO, C. S. S. *et al*. Different dietary trace mineral sources for broiler breeders and their progenies. **Poultry Science,** Champaign, v. 98, p. 4716-4721, 2019.

AVILA, L. P. *et al*. Evaluation of industry strategies to supply dietary chelated trace minerals (Zn, Mn, and Cu) and their impact on broiler breeder hen reproductive performance, egg quality, and early offspring performance. **Journal of Applied Poultry Research**, Oxford, v. 32, n. 3, [art.] 100354, 2023.

BERTECHINI, A. G. **Nutrição de monogástricos**. Lavras: UFLA, 2007.

BERWANGER, E. *et al*. Copper requirements of broiler breeder hens. **Poultry Science**, Champaign, v. 98, p. 2785-2797, 2018.

BLAIR, R. **Nutrition and feeding of organic poultry**. 2nd ed. Wallingford: CABI North American, 2008. 314 p.

COLEMAN, J. E. Zinc proteins: enzymes, storage proteins, transcription factors, and replication proteins. **Annual Review of Biochemistry**, Palo Alto, v. 61, p. 897-946, 1992.

DÍAZ, T. G. *et al.* Metabolismo do cobre na nutrição animal: revisão. **PubVet**, Maringá, v. 9, n. 6, p. 279-286, 2015.

DIBNER, J. J. *et al*. Metabolic challenges and early bone development. **Journal of Applied Poultry Research**, Oxford, v. 16, p. 126-137, 2007.

EVANS, G.; GRACE, C.; VOTAVA, H. Proposed mechanism of zinc absorption in the rat. **American Journal of Physiology**, Bethesda, v. 228, p. 501-505, 1975.

FAVERO, A. *et al*. Development of bone in chick embryos from Cobb 500 breeder hens fed diets supplemented with zinc, manganese, and copper from inorganic and amino acid-complexed sources. **Poultry Science**, Champaign, v. 92, p. 402–411, 2013a.

FAVERO, A. *et al.* Reproductive performance of Cobb 500 breeder hens fed diets supplemented with zinc, manganese, and copper from inorganic and amino acid-complexed sources. **Journal of Applied Poultry Research**, Oxford, v. 22, n. 1, p. 80-91, 2013b.

FEIJÓ, J. C. *et al*. Iron requirements of broiler chickens as affected by supplemental phytase. **Journal of Animal Science**, Champaign, v. 101, [art.] skad265, [p. 1 -12], 2023.

GEORGIEVSKIĬ, V. I.; ANNENKOV, B. N.; SAMOKHIN, V. T. **Mineral nutrition of animals**. London: Butterworths, 1981.

GONZÁLEZ, F. H. D.; SILVA, S. C. **Minerais e vitaminas no metabolismo animal**. Porto Alegre: UFRGS, 2019.

GUIMARÃES, A. C. T. *et al*. Microminerais complexados a aminoácidos no desempenho reprodutivo de matrizes pesadas e resposta da progênie. **Ciência Rural**, Santa Maria, v. 43, n. 6, p. 1044-1049, 2013.

GUZ, B. C. *et al*. Effects of organic macro and trace minerals in fast and slower growing broiler breeders' diet on offspring growth performance and tibia characteristics. **Poultry Science**, Champaign. v. 101, p. 101-647, 2022.

HERRICK, J. B. Mineral in animal health. *In*: ASHMEAD, H. D. (ed.). **The roles of amino acid chelates in animal nutrition**. New Jersey: Noyes, 1993. p. 3-9.

KIM, J. W.; CHAO, P. Y.; ALLEN, A. Inhibition of hepatic glutathione abolishes copper defciency cholesterolemia. **FASEB Journal**, Bethesda, v. 6, p. 2467-2471, 1992.

KIRKPATRICK, D. C.; COFFIN, D. E. Trace metal content of chicken eggs. **Journal of the Science of Food and Agriculture**, London, v. 26, n. 1, p. 99-103, 1975.

LEESON, S. A new look at trace mineral nutrition of poultry: can we reduce environmental burden of poultry manure? *In*: LYONS, T. P.; K. A. JACQUES, K. A. (ed.). **Nutritional biotechnology in the feed and food industrie:** proceedings of Alltech's 19th annual symposium. Nottingham: Nottingham University Press, 2003. p. 125–131.

LEESON, S. Copper metabolism and dietary needs. **World's Poultry Science**, Ithaca, v. 65, p. 353-366, 2009.

LEESON, S.; SUMMERS, J. D. **Scott's nutrition of the chicken**. 4th ed. Guelph: University Books, 2001.

LEESON, S.; SUMMERS, J. D. **Commercial poultry nutrition**. 3rd ed. Nottingham: Nottingham University Press, 2009.

LIU, A. C.; HEINRICHS, B. S.; LEACH JUNIOR, R. M. Influence of manganese deficiency on the characteristics of proteoglycans of avian epiphyseal growth plate cartilage. **Poultry Science**, Champaign, v. 73, n. 5, p. 663-669, 1994.

LUO, X. G. *et al*. Efects of manganese (Mn) defciency on tissue Mn-containing superoxide dismutase (MnSOD) activity and its mitochondrial ultrastructures of broiler chicks fed a practical diet. **Chinese Journal of Animal Science**, Beijing, v. 23, p. 97-101, 1992.

MAYER, A. N. *et al*. Zinc requirements of broiler breeder hens. **Poultry Science**, Champaign, v. 98, p. 1288-1301, 2019.

MOHANNA, G.; NYS, Y. Effect of dietary zinc content and sources on the growth, body zinc deposition and retention, zinc excretion and immune response in chickens. **British Poultry Science**, Abingdon, v. 40, n. 1, p. 108-114, 1999.

NITTIS, T.; GITLIN, J. D. Role of copper in the proteosome-mediated degradation of the multicopper oxidase hephaestin. **Journal of Biological Chemistry**, Baltimore, v. 279, n. 24, p. 25696-25702, 2004.

NOETZOLD, T. L. *et al*. Improved offspring performance of broiler breeder hens fed amino acid complexed trace minerals. **Journal of Applied Poultry Research**, Oxford, v. 31, [art.] 100284, 2022.

NOETZOLD, T. L. *et al*. Manganese requirements of broiler breeder hens. **Poultry Science**, Champaign, v. 99, p. 5814-5826, 2020.

NRC – NATIONAL RESEARCH COUNCIL. **Mineral tolerance of domestic animals**. Washington, DC: The National Academies Press, 1980.

OBERLEAS, D.; HARLAND, B.; BOBILYA, D. J. Manganese (Mn). *In*: OBERLEAS, D.; HARLAND, B.; BOBILYA, D. J. **Minerals**: nutrition and metabolism. New York: Vantage Press, 1999. p. 141-148.

OLGUN, O. Manganese in poultry nutrition and its effect on performance and eggshell quality. **World's Poultry Science Journal**, Ithaca, v. 73, n. 1, p. 45-56, 2016.

RICHARDS, M. P. Trace mineral metabolism in the avian embryo. **Poultry Science**, Champaign, v. 76, p. 152–164, 1997.

ROBERTS, J. R. Factors affecting egg internal quality and eggshell quality in laying hens. **The Journal of Poultry Science**, Tsukuba, v. 41, n. 3, p. 161-177, 2004.

SABER, S. *et al*. Effects of form of dietary trace mineral premix on fertility and hatchability of broiler breeder hens and post-hatch performance and carcass parameters of their progenies. **Kafkas Universitesi Veteriner Fakultesi Dergisi**, Kars, v. 26, p. 171–180, 2020.

SCHMIDT, M. *et al.* Níveis nutricionais de cobre para frangos de corte machos e fêmeas na fase inicial. **Revista Brasileira de Zootecnia**, Viçosa, MG, v. 34, n. 5, p. 1599-1605, 2005.

SCOTT, A. *et al*. Copper nanoparticles as an alternative feed additive in poultry diet: a review. **Nanotechnology**, Bristol, v. 7, p. 69-93, 2018.

SKŘIVAN, M.; SKŘIVANOVÁ, V.; MAROUNEK, M. Effects of dietary zinc, iron, and copper in layer feed on distribution of these elements in eggs, liver, excreta, soil, and herbage. **Poultry Science**, Champaign, v. 84, n. 10, p. 1570-1575, 2005.

SOSTER, P. *et al*. Dietary phytase effects on copper requirements of broilers. **Frontiers in Veterinary Science**, Lausanne, v. 10, [art.] 1170488, 2023.

STARCHER, B. C. Studies on the mechanism of copper absorption in the chick. **Journal of Nutrition**, Rockville, v. 97, p. 321-326, 1969.

SUTTLE, N. F.; UNDERWOOD, E. J. **The mineral nutrition of livestock**. 4th ed. Wallingford: CABI Publishing, 2010.

TASCHETTO, D. *et al*. Iron requirements of broiler breeder hens. **Poultry Science**, Champaign, v. 96, p. 3920-3927, 2017.

VALLEE, B. L.; FALCHUK, K. H. The biochemical basis of zinc physiology. **Physiological Reviews**, Bethesda, v. 73, n. 1, p. 79-118, 1993.

VALLEE, B. L.; AULD, D. S. Cocatalytic zinc motifs in enzyme catalysis. **Proceedings of the National Academy of Sciences of the United States of America**, Washington, DC, v. 90, n. 7, p. 2715–2718, 2021.

VIEIRA, S. L. Chelated minerals for poultry. **Brazilian Journal of Poultry Science**, Campinas, v. 10, p. 73-79, 2008.

VIEIRA, S. L. Chicken embryo utilization of egg micronutrients. **Revista Brasileira de Ciência Avícola**, Campinas, v. 9, n. 1, p. 1-8, 2007.

WHO – WORLD HEALTH ORGANIZATION. **Trace elements in human nutrition and health**. Brussels: WHO, 1996.

XIE, J. *et al*. Effects of inorganic and organic manganese supplementation on gonadotropin-releasing hormone-I and follicle-stimulating hormone expression and reproductive performance of broiler breeder hens. **Poultry Science**, Champaign, v. 93, n. 4, p. 959-969, 2014.

YAIR, R.; UNI, Z. Content and uptake of minerals in the yolk of broiler embryos during incubation and effect of nutrient enrichment. **Poultry Science**, Champaign, v. 90, n. 7, p. 1523-1531, 2011.

YAQOOB, M. U. *et al*. Effects of inorganic trace minerals replaced by complexed glycinates on reproductive performance, blood profiles, and antioxidant status in broiler breeders. **Poultry Science,** Champaign, v. 99, n. 9, p. 2718-2726, 2020.

ZHANG, Y. N. *et al*. Effect of dietary supplementation of organic or inorganic zinc on carbonic anhydrase activity in eggshell formation and quality of aged laying hens. **Poultry Science**, Champaign, v. 96, n. 7, p. 2176-2183, 2017.

APÊNDICES

Apêndice 1: Normas para publicação de artigos no periódico Journal of Applied Poultry Research

Journal Applied Poultry Research Guide to Authors[1]

SCOPE AND GENERAL INFORMATION

Aims and scope.

The Journal of Applied Poultry Research (JAPR) publishes original research reports, field reports, and reviews on breeding, hatching, health and disease, layer management, meat bird processing and products, meat bird management, microbiology, food safety, nutrition, environment, sanitation, welfare, and economics. JAPR is an Open Access journal with no subscription charges, meaning authors who publish here can make their research immediately, permanently, and freely accessible worldwide while retaining copyright to their work.

The readers of JAPR are in education, extension, industry, and government, including research, teaching, administration, veterinary medicine, management, production, quality assurance, product development, and technical services. Nutritionists, breeder flock supervisors, production managers, microbiologists, laboratory personnel, food safety and sanitation managers, poultry processing managers, feed manufacturers, and egg producers use JAPR to keep up with current applied poultry research.

SUBMISSION

All manuscripts are submitted and reviewed via the journal's Editorial Manager manuscripts submission site at https://www.editorialmanager.com/japr/default.aspx. New authors should create an account prior to submitting a manuscript for consideration. The submission system guides you stepwise through the process of entering your article details and uploading your files. The system converts your article files to a single PDF file used in the peer review process. Editable files (e.g., Word) are required to typeset your article for final publication. All correspondence, including notification of the Editor's decision and requests for revision, is sent by e-mail.

Submission Checklist

You can use this list to carry out a final check of your submission before you send it to the journal for review. Please check the relevant section in this Guide for Authors for more details. Ensure that the following items are present: One author has been designated as the corresponding author with contact details (please note that co-corresponding authors are not allowed):

- E-mail address
- Full postal address All necessary files have been uploaded: Manuscript:
- Include keywords
- All tables (including titles, description, footnotes)
- Figure legends
- Ensure all figure and table citations in the text match the files provided
- Ethical treatment of animals statement

Figure files (figures must be uploaded as separate files, not embedded in the manuscript) Supplemental files (where applicable)

Conflict of Interest statement

Further considerations

- Manuscript has been 'spell checked' and 'grammar checked'
- All references mentioned in the Reference List are cited in the text, and vice versa
- Permission has been obtained for use of copyrighted material from other sources (including the Internet)
- A competing interests statement is provided, even if the authors have no competing interests to declare
- Journal policies detailed in this guide have been reviewed
- Referee suggestions and contact details provided, based on journal requirements

For further information, visit our Support Center.

Submission declaration and verification

Submission of an article implies that the work described has not been published previously (except in the form of an abstract, a published lecture or academic thesis, see 'Multiple, redundant or concurrent publication' for more information), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright holder.

To verify originality, your article may be checked by the originality detection service Crossref Similarity Check.

CONTACT INFORMATION

For information on the scientific content of the journal, contact the editor-in-chief, Dr. Brian

Fairchild, University of Georgia, Department of Poultry Science; e-mail: brian.fairchild@uga.edu.

For assistance with Editorial Manager manuscripts and manuscript submission, contact David Busboom at david.busboom@poultryscience.org.

For all other inquiries, visit the Elsevier Support Center. Here you will find everything from Frequently Asked Questions to ways to get in touch.

You can also check the status of your submitted article or find out when your accepted article will be published.

TYPES OF ARTICLES

Research reports

Most papers published in JAPR are research reports. The journal emphasizes the importance of good scientific writing and clarity in presentation of the concepts, apparatus, and sufficient background information that would be required for thorough understanding by scientists in other disciplines. The results of experiments published in JAPR must be replicated, either by replicating treatments within experiments or by repeating experiments.

Field reports

Field reports will be published when adequate background is available and conclusions can be supported by quantifiable laboratory or diagnostic results. The manuscript should follow the format outlined in the Style and Form section of this document. It should include a section titled Field Report in which the observations are explained and discussed under subheadings of Materials and Methods and Results and Discussion. Authors are encouraged to include subheadings for all major areas in this section.

Applied research notes

Applied Research Notes report the results of complete experiments but are less comprehensive than full-length articles. These short papers may convey case reports, preliminary, or final data fulfilling one or more of the following criteria: a single experiment, low sample numbers, or limited replication. Manuscripts should be prepared according to the guidelines for full-length articles. The title of an Applied Research Note must begin with the words "Applied Research Note:". The running head shall be "APPLIED RESEARCH NOTE." Results and Discussion should be a unified section with concise data interpretation. A conclusions heading is not permitted. Supplementary data are not permitted. These papers are limited to: 1) 3,000 words or approximately nine typed, double-spaced pages; 2) two tables or figures or one of each; and 3) maximum ten (10) references. Authors must also indicate the section under which the manuscript is to be reviewed on the manuscript title page and on the Manuscript Submission Form. Editors may request that submitted full-length papers be revised for publication as Applied Research Notes.

Review articles

Articles submitted to this section may cover new developments in a field, describe the evolution of a currently accepted management practice, propose changes in management based on current research, or describe procedures. Clear distinctions should be made between firmly established practices and unresolved questions. Articles should begin with a concise description of the topic, followed by a critical evaluation of the important references. Review articles, whether solicited or unsolicited, will be subject to a stringent review process. Review articles should follow the general format outlined in the Style and Form, when appropriate, and include brief subheadings to separate main ideas. A Conclusions and Applications section should be included in most cases.

Symposium and workshop articles

Manuscripts presented at the annual meeting as part of a symposium or workshop may be submitted with prior agreement by the editor-in-chief. These submissions will be subject to peer review and may be accepted or rejected in the same manner as other submissions. The format may be similar to reviews, research reports, or field reports, as outlined in the Style and Form. Please see the full guidelines here.

Letters and commentaries

The journal accepts letters, book reviews, and other free-form communications (used to correct errors, provide clarification, or offer other points of view on pertinent issues). Submissions may be edited in consultation with the author.

JOURNAL POLICIES

PEER REVIEW PROCESS

This journal operates a single blind review process. All contributions will be initially assessed by the editor for suitability for the journal. Papers deemed suitable are then sent to a minimum of two independent expert reviewers to assess the scientific quality of the paper, frequently under the direction of a section editor with expertise in the manuscript topic. The Editor is responsible for the final decision regarding acceptance or rejection of articles. The Editor's decision is final. For more information on the types of peer review, please visit: https://www.elsevier.com/reviewers/peerreview.

All submissions to the journal are initially reviewed by the editorial office. At this stage, manuscripts may be rejected without peer review if it is felt that they are not relevant to the journal's scope or do not conform to manuscript formatting requirements. This fast rejection process means that authors are given a quick decision and do not need to wait for the review process.

Manuscripts that pass initial screening will be forwarded to the appropriate section editor. The section editor may suggest rejection based on fatal design flaw, inappropriate replications, lack of novelty, or other major concerns. If appropriate, the paper will be sent out for peer review, usually to 2 independent reviewers who will provide comments. The section editor may recommend rejection or acceptance at this point, after which the manuscript and reviewer comments are made available to the editor-in-chief for a final decision to the authors. The manuscript will be sent back to the corresponding author for revision according to the guidelines of the reviewers. Authors have 30 days to complete the revision, which shall be returned to the section editor. Failure to return the manuscript within 30 days will lock the author out of re- submitting the revision.

Rejected manuscripts can be resubmitted only with an invitation from the section editor or editor-inchief. Revised versions of previously rejected manuscripts are treated as new submissions.

PRE-SUBMISSION LANGUAGE EDITING

Please write your text in good English (American usage). Authors who feel their English language manuscript may require editing to eliminate possible grammatical or spelling errors and to conform to correct scientific English may wish to use the English Language Editing service available from Elsevier's Author Services.

POST-PRODUCTION CORRECTIONS

No correction to a paper already published will be carried out without an erratum or corrigendum (as applicable), this applies to articles in press and published within an issue. This means that any change carried out to a paper already published online will have a corresponding erratum or corrigendum published with its own separate DOI. Whether as an article in press or in an issue, if an erratum or corrigendum is published, the online version of the original paper will also be corrected online and the correction notice will mention this. Corrections will only be made if the publication record is seriously affected by the academic accuracy of published information.

Authors' corrections to Supplementary Data are made only in exceptional circumstances (for example major errors that compromise the conclusion of the study). Because the Supplementary Data is part of the original paper and hence the published record, the information cannot be updated if new data have become available or interpretations have changed.

ETHICS

Please see our information pages on Ethics in publishing and Ethical guidelines for journal publication.

CARE AND USE OF ANIMALS

Authors must make it clear that experiments were conducted in a manner that avoided unnecessary discomfort to the animals by the use of proper management and laboratory techniques. Experiments shall be conducted in accordance with the principles and specific guidelines presented in Guide for the Care and Use of Agricultural Animals in Research and Teaching, 4th edition, 2020 (found here; and, if applicable, Guide for the Care and Use of Laboratory Animals (United States Department of Human Health and Services, National Institutes of Health, Publication Number ISBN 0-309-05377-3, 1996); or Guide to the Care and Use of Experimental Animals, 2nd ed. Volume 1, 1993 (Canadian Council on Animal Care). Methods of killing experimental animals must be described in the text. In describing surgical procedures, the type and dosage of the anesthetic agent must be specified. Intra-abdominal and intrathoracic invasive surgery requires anesthesia. This includes caponization. The editor-in-chief may refuse to publish manuscripts that are not compatible with these guides. If rejected solely on that basis, however, the paper may be resubmitted for reconsideration when accompanied by a written verification that a committee on animal care in research has approved the experimental design and procedures involved.

THIRD PARTY COPYRIGHT

As a general rule, permission should be sought from the rights holder to reproduce any substantial part of a copyrighted work. This includes any text, illustrations, charts, tables, photographs, or other material from previously published sources. For more information on third party permissions, visit https://www.elsevier.com/about/policies/copyright/permissions.

DECLARATION OF COMPETING INTEREST

Corresponding authors, on behalf of all the authors of a submission, must disclose any financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work. Examples of potential conflicts of interest include employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding. All authors, including those without competing interests to declare, should provide the relevant information to the corresponding author (which, where relevant, may specify they have nothing to declare). Corresponding authors should then use this tool to create a shared statement and upload to the submission system at the Attach Files step. Please do not convert the .docx template to another file type. Author signatures are not required.

Preprints

The journal will not accept articles posted to preprint servers prior to, or during peer review, for consideration for publication.

ROLE OF THE FUNDING SOURCE

You are requested to identify who provided financial support for the conduct of the research and/or preparation of the article and to briefly describe the role of the sponsor(s), if any, in study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication. If the funding source(s) had no such involvement then this should be stated.

Funding body agreements and policies

Elsevier has established a number of agreements with funding bodies which allow authors to comply with their funder's open access policies. Some funding bodies will reimburse the author for the gold open access publication fee. Details of existing agreements are available online. After acceptance, open access papers will be published under a noncommercial license. For authors requiring a commercial CC BY license, you can apply after your manuscript is accepted for publication.

Formatting of funding sources

List funding sources in this standard way to facilitate compliance to funder's requirements: Funding: This work was supported by the National Institutes of Health [grant numbers xxxx, yyyy]; the Bill & Melinda Gates Foundation, Seattle, WA [grant number zzzz]; and the United States Institutes of Peace [grant number aaaa]. It is not necessary to include detailed descriptions on the program or type of grants and awards. When funding is from a block grant or other resources available to a university, college, or other research institution, submit the name of the institute or organization that provided the funding. If no funding has been provided for the research, please include the following sentence: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Elsevier Researcher Academy

Researcher Academy is a free e-learning platform designed to support early and mid-career researchers throughout their research journey. The "Learn" environment at Researcher Academy offers several interactive modules, webinars, downloadable guides and resources to guide you through the process of writing for research and going through peer review. Feel free to use these free resources to improve your submission and navigate the publication process with ease.

COPYRIGHT

Upon acceptance of an article, authors will be asked to complete a 'Journal Publishing Agreement' (see more information on this). An e-mail will be sent to the corresponding author confirming receipt of the manuscript together with a 'Journal Publishing Agreement' form or a link to the online version of this agreement.

Author Rights

As an author you (or your employer or institution) have certain rights to reuse your work. More information.

Elsevier supports responsible sharing

Find out how you can share your research published in Elsevier journals.

OPEN ACCESS

This is an open access journal: all articles will be immediately and permanently free for everyone to read and download. To provide open access, this journal has an open access fee (also known as an article publishing charge APC) which needs to be paid by the authors or on their behalf e.g. by their research funder or institution. Permitted third party (re)use is defined by the following Creative Commons user licenses: Creative Commons Attribution (CC BY): lets others distribute and copy the article, to create extracts, abstracts, and other revised versions, adaptations or derivative works of or from an article (such as a translation), to include in a collective work (such as an anthology), to text or data mine the article, even for commercial purposes, as long as they credit the author(s), do not represent the author as endorsing their adaptation of the article, and do not modify the article in such a way as to damage the author's honor or reputation.

Creative Commons Attribution-Non Commercial-No Derivs (CC BY-NC-ND): for noncommercial purposes, lets others distribute and copy the article, and to include in a collective work (such as an anthology), as long as they credit the author(s) and provided they do not alter or modify the article.

Open access fee

The open access publication fee for this journal for research articles and review articles is USD 2000, excluding taxes. The open access publication fee is USD 1500 if the corresponding author is a member of the Poultry Science Association. The open access publication fee for applied research notes is USD 1000, excluding taxes, or USD 750, excluding taxes, if the corresponding author is a member of Poultry Science Association. (Note: The corresponding author must be a Poultry Science Association member before the article is accepted for the discount to apply.) Learn more about Elsevier's pricing policy: https://www.elsevier.com/openaccesspricing.

Shortly after acceptance, the corresponding author will be contacted regarding license options, funding information, and payment of the Open Access fee.

PREPARATION OF MANUSCRIPT MANUSCRIPT FORMATTING

General

Papers must be written in English. The text and all supporting materials must use American spelling and usage as given in The American Heritage Dictionary, Webster's Third New International Dictionary, or the Oxford American English Dictionary. Authors should follow the style and form recommended in Scientific Style and Format: The CSE Manual for Authors, Editors, and Publishers. 2006. 7th ed. Style Manual Committee, Council of Science Editors, Reston, VA.

Preparing the manuscript file

Manuscripts should be typed double-spaced, with lines and pages numbered consecutively, using Times New Roman font at 12 points. All special characters (e.g., Greek, math, symbols) should be inserted using the symbols palette available in this font. Please submit math equations as editable text and not as images. Tables and figure legends should be placed in a separate section at the end of the manuscript (not placed within the text). Figure files should be uploaded as separate files (not embedded in the manuscript).

Use of word-processing software:

It is important that the file be saved in the native format of the word processor used. The text should be in single-column format. Keep the layout of the text as simple as possible. Most formatting codes will be removed and replaced on processing the article. In particular, do not use the word processor's options to justify text or to hyphenate words. However, do use bold face, italics, subscripts, superscripts etc. When preparing tables, if you are using a table grid, use only one grid for each individual table and not a grid for each row. If no grid is used, use tabs, not spaces, to align columns. The electronic text should be prepared in a way very similar to that of conventional manuscripts (see also the Guide to Publishing with Elsevier). Note that source files of figures, tables and text graphics will be required whether or not you embed your figures in the text. See also the section on Electronic artwork.

To avoid unnecessary errors, you are strongly advised to use the 'spell-check' and 'grammar-check' functions of your word processor.

Headings

Major headings

Major headings are centered, boldface, in all capital letters, and consist of SUMMARY, DESCRIPTION OF PROBLEM, MATERIALS AND METHODS, RESULTS AND DISCUSSION, CONCLUSIONS AND APPLICATIONS, and REFERENCES.

Major headings in review articles, field reports, and symposium articles may vary from those listed here, but should include SUMMARY, CONCLUSIONS AND APPLICATIONS, and REFERENCES.

First subheadings

First subheadings are placed on a separate line, begin at the left margin, the first letter of all important words is capitalized, and the headings are boldface and italic. Text that follows a first subheading should be in a new paragraph.

Second subheadings

Second subheadings begin the first line of a paragraph. They are indented, boldface, italic, and followed by a period. The first letter of each important word should be capitalized. The text follows immediately after the final period of the subheading.

TITLE PAGE

The title should be indicative of the content. It should capture the interest of all who might benefit from information in the manuscript. However, the length of the title should be kept to a minimum. The running title should be 30 characters or less, including spaces.

Address and affiliation of authors (listed by first name or initials, middle initial, and last name) should be included. Indicate to whom correspondence should be directed by means of a footnote, with the notation "Corresponding author: (e-mail address)" at the bottom of the title page. Note: JAPR allows a single corresponding author; co-corresponding authors are not permitted. In some instances, the first two authors of a manuscript may be designated as equal contributors. However, the corresponding author should be prepared to justify such designation, if asked by the editorial staff. More than two equal contributors is not permitted under any circumstance.

List 3 to 8 key words or phrases to identify the most important subjects covered by the paper.

Statement of primary audience. To determine appropriateness for the journal and to assist in selecting reviewers, the author should indicate clearly what sector(s) within the poultry com- munity (e.g., flock supervisors, nutritionists, quality assurance personnel, researchers, plant managers, veterinarians) could benefit most from the content of this article.

Changes to authorship

Authors are expected to consider carefully the list and order of authors before submitting their manuscript and provide the definitive list of authors at the time of the original submission. Any addition, deletion or rearrangement of author names in the authorship list should be made only before the manuscript has been accepted and only if approved by the journal Editor. To request such a change, the Editor must receive the following from the corresponding author: (a) the reason for the change in author list and (b) written confirmation (e-mail, letter) from all authors that they agree with the addition, removal or rearrangement. In the case of addition or removal of authors, this includes confirmation from the author being added or removed. Once a paper reaches the proof stage, no changes to the author list are permitted.

ARTICLE STRUCTURE

Summary

The Summary (maximum of 250 words) is not an abstract. It is intended to give readers with diverse backgrounds a general appreciation of the manuscript contents. It should be written so that even those not directly interested in the topic will enjoy reading at least this section to keep abreast of areas other than their own. This section should not include details of materials and methods or a detailed review of the results. Keep the summary free-flowing, giving the reader a general, not specific, idea of what the study revealed. Do not include reference citations in the summary.

Description of problem

This section will acquaint the reader with the problem, citing field experiences where appropriate. Readability is of utmost importance. Detailed literature reviews may not be appropriate for this section. A more extensive citation of references should be included in the Results and Discussion or References section. This section should end with a statement of the objective(s) of the study.

Materials and methods

All sources of products, equipment, and chemicals used in the experiments must be specified parenthetically at first mention in text, tables, and figures [i.e., (model 123, ABC Corp., Provo, UT)]. Model and catalog numbers should be included. Information shall include the full corporate name (including division, branch, or other subordinate part of the corporation, if applicable), city, and state (country if outside the United States), or Web address. Street addresses need not be given unless the reader would not be able to determine the full address for mailing purposes easily by consulting standard references.

Results and discussion

This section begins with observed results and their interpretation. Descriptive subheadings may precede all major paragraphs and changes in subject emphasis. This section should discuss specifically how findings address the problem described in the Description of Problem section and how they are related to published works.

Statements regarding statistically significant differences between treatments in results should be included in the text, tables, and figures. Statements regarding differences should be avoided unless they are supported by statistical analyses and meet the stated level of probability (e.g., $P < 0.05$).

Conclusion and applications

Conclusions and recommendations of the author(s) should be listed numerically. Each statement should be clear, concise, and without discussion. Authors are encouraged to summarize their significant findings, to identify further research needs, and to describe the constraints, economics, and other factors associated with using the results in scientific or commercial applications. Do not include references in this section.

References

References

Citations in text

In the body of the manuscript, refer to authors as follows: Smith and Jones (1992) or Smith and Jones (1990, 1992). If the sentence structure requires that the authors' names be included in parentheses, the proper format is (Smith and Jones, 1982; Jones, 1988a, b; Jones et al., 1993). Where there are more than two authors of one article, the first author's name is followed by the abbreviation et al. More than one article listed in the same sentence of text must be in chronological order first, and alphabetical order for two publications in the same year. Work that has not been accepted for publication shall be listed in the text as: "J. E. Jones (institution, city, and state, personal communication)." The author's own un- published work should be listed in the text as "(J. Smith, unpublished data)." Personal communications and un- published data must not be included in the References section.

References section

To be listed in the References section, papers must be published or accepted for publication. Manuscripts submitted for publication can be cited as "personal communication" or n published data" in the text.

In the References section, references shall first be listed alphabetically by author(s)' last name(s), and then chronologically. The year of publication follows the authors' names. As with text citations, two or more publications by the same author or set of authors in the same year shall be differentiated by adding lowercase letters after the date. The dates for papers with the same first author that would be abbreviated in the text as et al., even though the second and subsequent authors differ, shall also be differentiated by letters. All authors' names must appear in the Reference section. Journals shall be abbreviated according to the conventional ISO abbreviations given in journals database of the

National Library of Medicine. One-word titles must be spelled out. Inclusive page numbers must be provided. Sample references are given below.

N.B. - The online version of JAPR uses a reference format that differs from that prescribed by the journal. The Guide for Authors is the sole source for the reference format. Any papers that do not follow this format risk rejection.

Article:
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.)

TABLES

Tables must be created using the MS Word table feature and inserted in the manuscript after the references section. When possible, tables should be organized to fit across the page without running broadside. Be aware of the dimensions of the printed page when planning tables (use of more than 15 columns will create layout problems). Place the table number and title on the same line above the table. The table title does not require a period. Do not use vertical lines and use few horizontal lines. Use of bold and italic typefaces in the table should be done sparingly; you must define such use in a footnote. Each table must be on a separate page. To facilitate placement of all tables into the manuscript file (just after the references) authors should use "section breaks" rather than "page breaks" at the end of the manuscript (before the tables) and between tables.

Units of measure for each variable must be indicated. Papers with several tables must use consistent format. All columns must have appropriate headings. Abbreviations not found on the inside front cover of the journal must be defined in each table and must match those used in the text. Footnotes to tables should be marked by superscript numbers. Each footnote should begin a new line. Superscript letters shall be used for the separation of means in the body of the table and explanatory footnotes must be provided [i.e., "Means within a row lacking a common superscript differ (P < 0.05)."]; other significant P-values may be specified. Comparison of means within rows and columns should be indicated by different series of superscripts (e.g., a,b, . . . in rows; x-z . . . in columns) The first alphabetical letter in the series (e.g., a or A) shall be used to indicate the largest mean. Lowercase super- scripts indicate $P \leq 0.05$. Uppercase letters indicate $P \leq 0.01$ or less.

Probability values may be indicated as follows: *$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$, and †$P \leq 0.10$. Consult a recent issue of the journal for examples of tables.

Generally, results should be presented to the significant figure of the instrument used to collect the data. For example, results should not be presented to 5 digits when the instrument used only reads to 2 digits.

MISCELLANEOUS USAGE NOTES

Abbreviations

The following abbreviations may be used without definition in JAPR. Plurals do not require "s." Chemical symbols and 3-letter abbreviations for amino acids do not need definition. Other abbreviations should be defined at first use in the summary and the main text, as well as in each table or figure in which they appear. Author-defined abbreviations are boldface at first use in the main text. Abbreviations should not be used in the manuscript title, running title, or to begin a paragraph or sentence. They can be used in section headings if previously defined. This list appears inside the back cover of each issue of the journal.

The following abbreviations may be used without definition in JAPR:

ADF acid detergent fiber
ADFI average daily feed intake
ADG average daily gain
AME apparent metabolizable energy
AMEn nitrogen-corrected apparent metabolizable energy
ANOVA analysis of variance AOAC Association of Official Analytical Chemists
BSA bovine serum albumin
BW body weight
°C Celsius
cDNA complementary DNA
CF crude fiber

cfu colony-forming units (following a numeral)
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
EE ether extract
ELISA enzyme-linked immunosorbent assay
°F Fahrenheit
FCR feed conversion ratio
FE feed efficiency
ft foot
g gram
gal gallon
G:F gain-to-feed ratio
GLM general linear model
h hour
HEPES N-(2-hydroxyethyl)piperazine-N'-2-ethanesulfonic acid
HPLC high-performance (high-pressure) liquid chromatography
ICU international chick units
Ig immunoglobulin
IL interleukin
i.m. intramuscular
in. inch
i.p. intraperitoneal
IU international units
i.v. intravenous
kcal kilocalorie
L liter (also capitalized with any combination, e.g., mL)
lb pound

L:D hours of light:hours of darkness in a photoperiod
LSD least significant difference
m meter
μ micro
M molar
ME metabolizable energy
MEn nitrogen-corrected metabolizable energy
MHC major histocompatibility complex
mRNA messenger ribonucleic acid
min minute
mo month
MS mean squares
n number of observations
NADH reduced form of NAD
NDF neutral detergent fiber
NRC National Research Council
NS not significant
PBS phosphate-buffered saline
PCR polymerase chain reaction
ppm parts per million
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
SAS Statistical Analysis System
s.c. subcutaneous
SD standard deviation
SE standard error
SEM standard error of the mean
SNP single nucleotide polymorphism

SRBC sheep red blood cells

TBA thiobarbituric acid

T cell thymic-derived cell

TME true metabolizable energy

TMEn nitrogen-corrected true metabolizable energy

TSAA total sulfur amino acids

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

FIGURES/ILLUSTRATIONS

General points

- Submit each illustration as a separate file.
- Make sure you use uniform lettering and sizing of your original artwork.
- Embed the used fonts if the application provides that option.
- Aim to use the following fonts in your illustrations: Arial, Courier, Times New Roman, Symbol, or use fonts that look similar.
- Number the illustrations according to their sequence in the text.
- Use a logical naming convention for your artwork files.
- Provide captions to illustrations separately.
- Size the illustrations close to the desired dimensions of the published version.

A detailed guide on electronic artwork is available.

You are urged to visit this site; some excerpts from the detailed information are given here.

Formats

If your electronic artwork is created in a Microsoft Office application (Word, PowerPoint, Excel) then please supply 'as is' in the native document format.

Regardless of the application used other than Microsoft Office, when your electronic artwork is finalized, please 'Save as' or convert the images to one of the following formats (note the resolution requirements for line drawings, halftones, and line/halftone combinations given below): EPS (or PDF):
Vector drawings, embed all used fonts. TIFF (or JPEG): Color or grayscale photographs (halftones), keep to a minimum of 300 dpi. TIFF (or JPEG): Bitmapped (pure black & white pixels) line drawings, keep to a minimum of 1000 dpi. TIFF (or JPEG): Combinations bitmapped line/half-tone (color or grayscale), keep to a minimum of 500 dpi.

Please do not:
- Supply files that are optimized for screen use (e.g., GIF, BMP, PICT, WPG); these typically have a
low number of pixels and limited set of colors;
- Supply files that are too low in resolution;
- Submit graphics that are disproportionately large for the content.

Color artwork
Please make sure that artwork files are in an acceptable format (TIFF (or JPEG), EPS (or PDF), or MS Office files) and with the correct resolution. If, together with your accepted article, you submit usable color figures then Elsevier will ensure, at no additional charge, that these figures will appear in color online (e.g., ScienceDirect and other sites) regardless of whether or not these illustrations are reproduced in color in the printed version. For color reproduction in print, you will receive information regarding the costs from Elsevier after receipt of your accepted article. Please indicate your preference for color: in print or online only. Further information on the preparation of electronic artwork.

Illustration services
Elsevier's Author Services offers Illustration Services to authors preparing to submit a manuscript but concerned about the quality of the images accompanying their article. Elsevier's expert illustrators can produce scientific, technical and medical-style images, as well as a full range of charts, tables

and graphs. Image 'polishing' is also available, where our illustrators take your image(s) and improve them to a professional standard. Please visit the website to find out more.

Figure captions

Ensure that each illustration has a caption. Supply captions separately, not attached to the figure. A caption should comprise a brief title (not on the figure itself) and a description of the illustration. Keep text in the illustrations themselves to a minimum but explain all symbols and abbreviations used.

SUPPLEMENTARY DATA

Supplementary material such as applications, images and sound clips, can be published with your article to enhance it. Submitted supplementary items are published exactly as they are received (Excel or PowerPoint files will appear as such online). Please submit your material together with the article and supply a concise, descriptive caption for each supplementary file. If you wish to make changes to supplementary material during any stage of the process, please make sure to provide an updated file. Do not annotate any corrections on a previous version. Please switch off the 'Track Changes' option in Microsoft Office files as these will appear in the published version.

Ensure that the supplementary material is referred to in the main manuscript at an appropriate point in the text. Supplementary material will be available online only and will not be copyedited, so ensure that it is clearly and succinctly presented, and that the style conforms to the rest of the paper. Also ensure that the presentation will work on any Internet browser. It is not recommended for the files to be more than 2 MB each, although exceptions can be made at the editorial office's discretion.

ADDITIONAL INFORMATION ABOUT ACCEPTED MANUSCRIPTS

PROOFS

Corresponding authors will receive an e-mail with a link to their proof. Please annotate and upload your edits on the PDF version. All instructions for proofing will be given in the e-mail we send to authors.

We will do everything possible to get your article published quickly and accurately. Please use this proof only for checking the typesetting, editing, completeness and correctness of the text, tables and figures. Significant changes to the article as accepted for publication will only be considered at this stage with permission from the Editor. It is important to ensure that all corrections are sent back to us in one communication. Please check carefully before replying, as inclusion of any subsequent corrections cannot be guaranteed. Proofreading is solely your responsibility.

ARTICLES IN PRESS

For JAPR, manuscripts arrive at Elsevier and go through the production process until the final versions are ready to publish. These are then published on the journal's articles in press page. They will remain on the page up until the issue that they are assigned to is published.

OFFPRINTS

The corresponding author will, at no cost, receive a customized Share Link providing 50 days free access to the final published version of the article on ScienceDirect. The Share Link can be used for sharing the article via any communication channel, including email and social media. For an extra charge, paper offprints can be ordered via the offprint order form which is sent once the article is accepted for publication.

Reporting sex- and gender-based analyses

Reporting guidance

For research involving or pertaining to humans, animals or eukaryotic cells, investigators should integrate sex and gender-based analyses (SGBA) into their research design according to funder/sponsor requirements and best practices within a field. Authors should address the sex and/or gender dimensions of their research in their article. In cases where they cannot, they should discuss this as a limitation to their research's generalizability. Importantly, authors should explicitly state what definitions of sex and/or gender they are applying to enhance the precision, rigor and reproducibility of their research and to avoid ambiguity or conflation of terms and the constructs to which they refer (see Definitions section below). Authors can refer to the Sex and Gender Equity in Research (SAGER) guidelines and the SAGER guidelines checklist. These offer systematic approaches to the use and editorial review of sex and gender information in study design, data analysis, outcome reporting and research interpretation - however, please note there is no single, universally agreed-upon set of guidelines for defining sex and gender.

Definitions

Sex generally refers to a set of biological attributes that are associated with physical and physiological features (e.g., chromosomal genotype, hormonal levels, internal and external anatomy). A binary sex categorization (male/female) is usually designated at birth ("sex assigned at birth"), most often based solely on the visible external anatomy of a newborn. Gender generally refers to socially constructed roles, behaviors, and identities of women, men and gender-diverse people that occur in a historical and cultural context and may vary across societies and over time. Gender influences how people view themselves and each other, how they behave and interact and how power is distributed in society. Sex and gender are often incorrectly portrayed as binary (female/male or woman/man) and unchanging whereas these constructs actually exist along a spectrum and include additional sex categorizations and gender identities such as people who are intersex/have differences of sex development (DSD) or identify as non-binary. Moreover, the terms "sex" and "gender" can be ambiguous—thus it is important for authors to define the manner in which they are used. In addition to this definition guidance and the SAGER guidelines, the resources on this page offer further insight around sex and gender in research studies.

Open access

Please visit our Open Access page for more information.

VITA

Raquel Medeiros Horn, filha de Marcelo Ferreira Horn e Neide Medeiros Horn, nascida em 27 de setembro de 1999, em Rio Pardo – RS. Realizou o ensino fundamental na Escola Estadual de Ensino Fundamental Ramiz Galvão e ensino médio no Instituto Estadual de Educação Ernesto Alves, concluindo os estudos em dezembro de 2016. Em 2017 iniciou a graduação em Zootecnia na Universidade Federal do Rio Grande do Sul. Fez parte do grupo de pesquisa Aviário de Ensino e Pesquisa, supervisionado pelo professor PhD. Sergio Luiz Vieira, desde setembro de 2017, totalizando 5 anos entre a graduação e o mestrado. De janeiro a abril de 2021, foi estagiária na empresa Carrer Alimentos, na cidade de Garibaldi – RS, tendo a oportunidade de conhecer a cadeia de produção de frangos de corte. No último semestre da faculdade, em 2022, foi estagiária na empresa Granja Santa Lívia, na cidade de Garibaldi – RS, tendo contato com a produção de frangos de corte e na parte de pesquisas científicas dentro da área de produção. Formou-se em julho de 2022. Em abril de 2022 ingressou como aluna de mestrado com dedicação exclusiva no Programa de Pós-Graduação em Zootecnia da UFRGS, sob orientação do professor Ph.D. Sergio Luiz Vieira. Além de ter se envolvido em diversos projetos de pesquisa ao longo do seu mestrado, teve a oportunidade de participar de eventos científicos internacionais, onde realizou apresentações orais em inglês sobre trabalhos desenvolvidos no Aviário de Ensino e Pesquisa. No segundo semestre de 2023 realizou a troca de grau de mestrado para doutorado através de progressão, onde foi submetido à banca de defesa de Dissertação em novembro de 2023.