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PROGRAMA DE PÓS-GRADUAÇÃO EM ZOOTECNIA

RECONSIDERANDO A SUPLEMENTAÇÃO DE MICROMINERAIS NA NUTRIÇÃO DE FRANGOS DE CORTE

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“Não importa quão grande sejam os talentos ou os esforços, há coisas que só precisam de seu tempo."

- Warren Buffett

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RECONSIDERANDO A SUPLEMENTAÇÃO DE MICROMINERAIS NA NUTRIÇÃO DE FRANGOS DE CORTE [1]

Autor: Yuri Junqueira Olabarriaga

Orientador: Sergio Luiz Vieira

Resumo - Microminerais como zinco (Zn), manganês (Mn), ferro (Fe) e cobre (Cu) são essenciais para o crescimento animal. O objetivo deste estudo foi avaliar os efeitos do aumento da suplementação de microminerais inorgânicos na presença de fitase para frangos de corte. O experimento foi conduzido em delineamento inteiramente casualizado, em esquema fatorial 2 × 4, com oito tratamentos e nove repetições de 25 aves. Um total de 1.800 frangos de corte Cobb × Cobb 500 recebeu dietas formuladas com Zn (24,3, 54,3, 84,3 e 144,3 mg/kg), Mn (21,8, 51,8, 81,8 e 141,8 mg/kg), Fe (193,3, 213,3, 233,3 e 253,3 mg/kg) e Cu (7,5, 11,5, 15,0 e 22,5 mg/kg), no período de 1 a 35 dias de idade. Selênio (0,5 mg/kg) e iodo (1 mg/kg) foram incluídos nos mesmos níveis em todos os tratamentos. Não houve interação entre fitase e microminerais para nenhuma das variáveis avaliadas ($P > 0,05$). No entanto, a suplementação de microminerais afetou significativamente o desempenho e o consumo de ração aos 7 e 21 dias, bem como o comprimento da tíbia e a digestibilidade ileal aparente. A fitase melhorou o desempenho dos frangos e a conversão alimentar aos 7, 21 e 35 dias, além de aumentar a matéria seca do conteúdo ileal, o peso da tíbia e o teor de cinzas ósseas ($P < 0,05$). Em conclusão, a inclusão excessiva de microminerais pode afetar negativamente a digestibilidade da energia, no entanto, o desempenho se mantém mesmo com a redução dos níveis de suplementação.

Palavras-chave: Fitase, frangos de corte, suplementação, microminerais.

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RECONSIDERING TRACE MINERALS SUPPLEMENTATION IN BROILER NUTRITION[1]

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Abstract – Trace minerals such as zinc (Zn), manganese (Mn), iron (Fe), and copper (Cu) are essential for animal growth. The aim of this study was to evaluate the effects of increasing supplementation of inorganic trace minerals in the presence of phytase for broilers. The experiment was conducted in a completely randomized 2 × 4 factorial design with eight treatments, and nine replications of 25 birds each. A total of 1,800 Cobb × Cobb 500 broilers were fed diets formulated with Zn (24.3, 54.3, 84.3, and 144.3 mg/kg), Mn (21.8, 51.8, 81.8, and 141.8 mg/kg), Fe (193.3, 213.3, 233.3, and 253.3 mg/kg), and Cu (7.5, 11.5, 15.0, and 22.5 mg/kg) from 1 to 35 d. Selenium (0.5 mg/kg) and iodine (1 mg/kg) were included at the same levels across all treatments to avoid confounding effects. There were no interactions between phytase and trace minerals for any evaluated response ($P > 0.05$). However, the trace mineral supplements significantly affected performance and feed intake at 7, 21 d, tibia length and apparent ileal digestibility. Phytase improved broiler performance while improving feed conversion ratio at 7, 21 and 35 d, as well as dry matter of ileal contents, tibia weight and ash ($P < 0.05$). In conclusion, excessive inclusion of trace minerals may negatively affect energy digestibility, however, performance remains unchanged even when supplementation levels are reduced.

Keywords: Broiler, supplementation, phytase, trace mineral.

[1]Master of Science Dissertation in Animal Science – Faculdade de Agronomia, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil. (53 p.), January 2026.

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LISTA DE ABREVIATURAS

Cu	Cobre
BWG	Body weight gain
FCR	Feed conversion ratio
Fe	Ferro
FI	Feed intake
I	Iodo
Mn	Manganês
Se	Selênio
Zn	Zinco

CAPÍTULO I

INTRODUÇÃO

Os microminerais, são essenciais para o desenvolvimento e a saúde dos frangos de corte, desempenhando papéis fundamentais no metabolismo e na fisiologia das aves. Entre os principais microminerais estão o zinco, manganês, ferro, cobre, que apesar de serem necessários em quantidades mínimas, são indispensáveis para diversas funções vitais (UNDERWOOD, 1977; BAO & CHOCT, 2009; ZORODDU et al., 2019).

O zinco exerce um papel fundamental para a ação de várias enzimas envolvidas na digestão e no metabolismo de proteínas, além de garantir a integridade da pele e o bom funcionamento do sistema imunológico (SUTTLE, 2010). A falta de zinco pode resultar em problemas ósseos, crescimento retardado e maior suscetibilidade a doenças. O manganês, por sua vez, é importante para o metabolismo de carboidratos, proteínas e lipídios, além de contribuir para a formação óssea e a reprodução. Sua deficiência pode levar a deformidades ósseas e queda na produtividade das aves (UNDERWOOD, 1977). O ferro por sua vez é essencial para a produção de hemoglobina, responsável pelo transporte de oxigênio no corpo, a falta desse mineral pode ajudar a desenvolver anemia, comprometendo o crescimento e a eficiência alimentar (SUTTLE, 2010), já o cobre é necessário para a formação de colágeno, elastina e melanina, e sua deficiência pode resultar em problemas no desenvolvimento ósseo e na imunidade das aves (MEDEIROS, 2016).

O uso de fontes inorgânicas de microminerais na alimentação animal é uma prática consolidada. Contudo, avanços na compreensão da biodisponibilidade desses minerais e a introdução de enzimas como a fitase nas formulações têm revolucionado as estratégias de suplementação. Esse ajuste fino não só promove o equilíbrio nutricional, mas também contribui para uma menor excreção de minerais no ambiente, mitigando impactos ambientais (COWIESON, 2017; WALK & RAO, 2020). Assim, garantir que as rações atendam adequadamente as exigências desses microminerais é vital para garantir um bom desempenho e a saúde das aves comerciais, além de contribuir para a produtividade e rentabilidade.

A suplementação dos microminerais na dieta de frangos é comumente adicionada como óxidos, sulfatos e carbonatos e seguem recomendações de suplementação como Aviagen (2022), Cobb (2022), e Rostagno et al. (2024). É

importante garantir que as quantidades sejam adequadas para evitar tanto a deficiência quanto o excesso, que também pode ser prejudicial. Um bom manejo nutricional inclui a monitoração dos níveis de microminerais na dieta e ajustes conforme necessários para manter a saúde e a produtividade das aves.

A nutrição de frangos de corte tem sido aprimorada ao longo dos anos, e a suplementação de microminerais, bem como sua utilização juntamente com fitase, está sendo amplamente estudada. Portanto os microminerais, embora presentes em quantidades mínimas nas dietas de frangos de corte, desempenham papeis crucias para uma boa manifestação de comportamento e resposta desses animais no campo.

O objetivo deste estudo é determinar se há diferenças de desempenho e outros parâmetros técnicos aplicando níveis crescentes de suplementação de microminerais para frangos de corte oriundos de fontes inorgânicas, visando reduzir, manter ou melhorar a eficiência produtiva de carne.

REVISÃO BIBLIOGRÁFICA

Uso de microminerais na avicultura

Os microminerais, embora presentes em quantidades mínimas nas dietas de frangos de corte, desempenham um papel crucial para o bom funcionamento de processos metabólicos, imunológicos e estruturais desses animais. Zinco, manganês, ferro, cobre são componentes fundamentais para a saúde, crescimento e eficiência produtiva das aves (UNDERWOOD, 1977; SUTTLE, 2010). A demanda por essas substâncias está intimamente ligada à sua função em sistemas enzimáticos, síntese de proteínas, metabolismo energético e proteção antioxidante, refletindo diretamente na performance. Além disso, as deficiências desses minerais podem comprometer o desenvolvimento ósseo, o transporte de oxigênio, a imunidade e a integridade dos tecidos, impactando negativamente a produtividade da cadeia avícola (BAO & CHOCT, 2009; ZORODDU et al., 2019).

O uso de fontes inorgânicas de microminerais na alimentação animal é uma prática consolidada. Contudo, avanços na compreensão da biodisponibilidade desses minerais e a introdução de enzimas como a fitase nas formulações têm revolucionado as estratégias de suplementação. A fitase, ao quebrar o fitato e liberar fósforo e outros minerais ligados, aumenta a absorção de nutrientes como zinco, manganês, ferro e cobre, permitindo a redução dos níveis de suplementação na dieta sem comprometer o desempenho das aves. (WALTERS, 2019). Esse ajuste fino não só promove o equilíbrio nutricional, mas também contribui para uma menor excreção de minerais no ambiente, mitigando impactos ambientais e otimizando custos de produção.

Portanto, é importante destacar o papel individual de cada micromineral na dieta de frangos de corte, as interações entre eles e a crescente relevância da fitase no contexto de suplementação mineral. Além disso, há uma busca para utilização de níveis mais baixos de suplementação, uma estratégia promissora para equilibrar desempenho animal, sustentabilidade e eficiência econômica no setor avícola.

Importância dos microminerais na nutrição de aves

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; VALLEE & AULD, 2021). 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). 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 deste mineral no plasma sanguíneo , na membrana plasmática, queda na atividade de ALP, alterações no conteúdo de proteínas (UNDERWOOD, 1977; SUTTLE, 2010).

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 e Mn-superóxido dismutase (UNDERWOOD, 1977; SUTTLE, 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). 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, coração e ossos ((UNDERWOOD, 1977; SUTTLE, 2010). 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 et al, 1999), a perose, caracterizada por deformidades articulares em aves jovens, é uma síndrome associada à deficiência de Mn (LEESON & SUMMERS, 2001; XIA, et al., 2022). 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 et al, 1999).

O Fe é um micromineral essencial envolvido em processos fundamentais do metabolismo celular, atuando como componente estrutural de diversas enzimas relacionadas ao transporte de elétrons, especialmente os citocromos. Além disso, o Fe participa de reações catalisadas por oxidases e oxigenases que envolvem a ativação do oxigênio molecular, bem como do transporte de oxigênio por meio da hemoglobina e da mioglobina, nas quais está presente na forma de ferro heme (WIJAYANTI et al,. 2004; ZORODDU et al., 2019). A hemoglobina e a mioglobina apresentam estrutura semelhante, ambas contendo o grupamento heme complexado à porfirina, essencial para a ligação ao oxigênio. Enquanto a hemoglobina possui quatro grupos heme, a mioglobina contém apenas um. Aproximadamente 70% do ferro corporal total encontra-se associado a essas proteínas, sendo o restante armazenado principalmente na ferritina, que atua como reserva metabólica do mineral (LEESON & SUMMERS, 2001; FEIJO et al., 2023). O Fe também participa de reações de oxidação e redução no metabolismo energético, incluindo etapas do ciclo de Krebs, (LEESON & SUMMERS, 2001; ABBASPOUR et al., 2014). Além do metabolismo energético, o Fe é indispensável para a síntese e o reparo do DNA, atuando como cofator de enzimas como DNA polimerases, helicases, nucleases e ribonucleotídeo redutases, sendo, portanto, essencial para a manutenção da integridade genômica e da função celular (ABBASPOUR et al., 2014; ZHANG, 2017). A absorção do ferro ocorre principalmente no duodeno e jejuno e é influenciada pela forma química do mineral, ou seja, heme ou não heme devido ao seu estado oxidativo e as demandas fisiológicas do organismo. O Fe heme é absorvido de maneira mais eficiente por meio de transportadores específicos, enquanto o Fe não heme depende de etapas de redução e transporte ativo. A regulação sistêmica do metabolismo do ferro é mediada pela hepcidina, que ajusta a absorção, o armazenamento e a mobilização do mineral de acordo com as necessidades do animal (TAKO & GLAHN, 2011)

O Cobre é vital para a dieta das aves, e está envolvido em muitos processos fisiológicos e bioquímicos nos organismos, assim como os outros microminerais citados. Suttle (2010), citou que o Cu desempenha um papel crucial nas funções reprodutivas e no desenvolvimento ósseo, estando intrinsecamente ligado às operações de diversas enzimas e proteínas, 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). 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;; 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 et al., 1981; VIEIRA, 2007; SOSTER, et al., 2023). 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, 1994; SCHMIDT et al., 2005; BERTECHINI, 2007).

Uso de fitase na nutrição de aves

A enzima fitase tem sido amplamente utilizada na alimentação de frangos de corte para melhorar a digestibilidade de fósforo fítico, presente em grande parte dos ingredientes vegetais das dietas, como o milho (0,18%) e o farelo de soja (0,36%) (ROSTAGNO, et al., 2024). Ao liberar o fósforo ligado ao fitato, a fitase também promove a liberação de outros minerais, como zinco, manganês, ferro e cobre aumentando sua biodisponibilidade. Além de melhorar o aproveitamento dos minerais pela ave, a utilização de fitase reduz a necessidade de adição de fontes inorgânicas de fósforo e microminerais, resultando em menor custo de produção e menores impactos ambientais devido à redução da excreção mineral.

Estudos demonstram que a inclusão de fitase nas dietas de frangos de corte pode aumentar significativamente a absorção de microminerais, melhorando o desempenho animal sem a necessidade de suplementação excessiva (WALTERS et al., 2019; FEIJO et al., 2023; MARIA et al., 2024). Além disso, a redução da quantidade de fósforo e minerais excretados nas fezes das aves é um benefício importante, pois contribui para diminuir a poluição ambiental, especialmente em solos e águas próximos às granjas.

Esse aspecto é o que torna a fitase fundamental devido a sua contribuição para a sustentabilidade econômica, pois com promovendo a degradação do fitato e a consequente liberação de minerais, é possível ajustar as formulações de rações para reduzir os níveis de suplementação de microminerais sem comprometer o crescimento das aves. Isso resulta em uma menor dependência de fontes externas de minerais, que muitas vezes são caras, e, ao mesmo tempo, otimiza a eficiência alimentar. Em um setor que enfrenta constantes desafios de formulação a custo mínimo.

Dietas das aves

Os ingredientes utilizados nas rações de frangos de corte, como milho, soja e outros grãos, contêm microminerais em suas composições naturais, embora em quantidades variáveis e muitas vezes de baixa biodisponibilidade. Além de ingredientes vegetais com certas quantidades de microminerais, temos outras fontes como calcário, fosfato bicálcico, fontes que acumulam mg/kg de Fe e Mn por exemplo (NRC, 1994; ROSTAGNO et al., 2024). Portanto ao formularmos uma dieta para frangos de corte, devemos estar atentos também a quantidade de microminerais presente em cada ingrediente e avaliar o seu resultado junto com a suplementação indicada, e assim podendo inferir se a suplementação é devida. Contudo, apesar de ingredientes conter níveis de microminerais, a sua disponibilidade para o animal é questionada, devido a sua forma química para absorção no intestino animal.

Ajustes na suplementação de microminerais

Nas últimas décadas, tem havido um crescente interesse em ajustar os níveis de suplementação de microminerais nas dietas de frangos de corte. Esse movimento se dá principalmente por duas razões: o impacto ambiental da excreção excessiva de minerais e a otimização dos custos de produção. A suplementação de microminerais inorgânicos, como óxidos e sulfatos, em níveis elevados, pode levar a uma maior excreção de resíduos, o que não apenas sobrecarrega o meio ambiente com metais pesados, como também desperdiça nutrientes valiosos.

Um fator a ser considerado é a individualização das dietas. Diferentes fases de desenvolvimento das aves e condições ambientais podem demandar ajustes específicos nos níveis de microminerais. Ao invés de seguir um padrão fixo de suplementação, as dietas podem ser adaptadas com base em análises periódicas das necessidades nutricionais e do perfil mineral da dieta base, otimizando a absorção dos

nutrientes. Essa abordagem precisa não só diminui os custos, mas também evita os efeitos adversos de uma suplementação excessiva (KEBREAB et al., 2016; ARAUJO et al., 2023).

HIPÓTESES E OBJETIVOS

HIPÓTESES

O ajuste da suplementação de microminerais inorgânicos, com ou sem a utilização de fitase, atingem a mesma eficiência ou melhoram parâmetros zootécnicos.

OBJETIVO GERAL

Avaliar o desempenho zootécnico em frangos de corte alimentados em dietas com diferentes níveis de suplementação de microminerais, com e sem fitase.

OBJETIVO ESPECÍFICO

Determinar a suplementação ideal de microminerais para frangos de corte.

Avaliar os efeitos da suplementação de microminerais com ou sem a utilização fitase na performance, rendimento de carcaça, parâmetros ósseos e sanguíneos e na digestibilidade de frangos de corte.

CAPÍTULO II

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Reconsidering Trace Minerals Supplementation in Broiler Nutrition

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Abstract: Trace minerals such as zinc (Zn), manganese (Mn), iron (Fe), and copper (Cu) are essential for animal growth. The objective of this study was to evaluate the effects of increasing supplementation levels of inorganic trace mineral in the presence of phytase for broilers. The experiment was conducted in a completely randomized design using a 2 × 4 factorial arrangement with eight treatments, and nine replicates of 25 birds in each floor pen. A total of 1,800 Cobb × Cobb 500 broilers were fed diets formulated with Zn (24.3, 54.3, 84.3, and 144.3 mg/kg), Mn (21.8, 51.8, 81.8, and 141.8 mg/kg), Fe (193.3, 213.3, 233.3, and 253.3 mg/kg), and Cu (7.5, 11.5, 15.0, and 22.5 mg/kg) from 1 to 35 d. Selenium (0.5 mg/kg) and iodine (1 mg/kg) were included at the same levels across all treatments to avoid confounding effects. There were no interactions between phytase and trace minerals for any evaluated response ($P > 0.05$). However, the trace mineral significantly affected performance and feed intake at 7, 21 d, tibia length and apparent ileal energy digestibility. Phytase improved broiler performance while improving feed conversion ratio at 7, 21 and 35 d, as well as dry matter digestibility, tibia weight and ash ($P < 0.05$). In conclusion, excessive inclusion of trace minerals may negatively affect energy digestibility, however, performance remains unchanged even when supplementation levels are reduced.

INTRODUCTION

Trace minerals are essential for growth and health of broiler chickens, participating in key metabolic and physiological processes. Minerals such as Zn, Mn, Fe and Cu are important for immune functions and bone development, mostly involved with enzyme activity through their involvement in metalloenzymes, proteins and interactions (Underwood, 1977; Bao & Choct, 2009; Zoroddu et al., 2019). Although trace minerals have distinct biological functions, some share intestinal transport pathways, resulting in competitive interactions when supplied in excess (Vieira, 2008; Suttle, 2010), as a result, high levels of dietary trace minerals impair nutrient uptake, affecting metabolism, synthesis of enzymes and lead to environmental impacts (Oberleas et al., 1999; Woyengo & Nyachoti, 2011).

Trace mineral supplementation of broiler feeds typically is usually accomplished with inorganic sources such as oxides, sulphates, and carbonates. Common industry recommendations include Zn (120, 100, 73.5 mg/kg), Mn (120, 100, 78.4 mg/kg), Fe (20, 40, 53.6 mg/kg), and Cu (16, 15, 11.2 mg/kg), according to Aviagen (2022), Cobb (2022), and Rostagno et al. (2024), respectively. Nutricionists often follow these guidelines to prevent mineral deficiencies, however, recent studies indicate that reducing trace mineral supplementation does not necessarily compromise

body weight gain or overall performance (Franklin et al., 2022; Feijó et al., 2023; Maria et al., 2024).

Phytase is widely added to poultry diets because birds have very low endogenous synthesis of this enzyme, as a consequence, its inclusion is common in corn–soybean meal (SBM) diets, which typically contain approximately 0.18 to 0.38% phytic acid. The primary function of phytase is to hydrolyze phytate, releasing P and other bound minerals for absorption, thus reducing the formation of phytate-nutrient complexes. Therefore, phytase improves the availability and digestibility of trace minerals present in feed ingredients (Cowieson et al., 2006; Walk & Rama Rao, 2020) and reduces their environmental impact by minimizing mineral excretion (Knowlton et al., 2004; Woyengo & Nyachoti, 2011.

Due to the excessive use of trace minerals supplementation and the complex interactions among them, mineral nutrition research has been applied to modernize the industry, and it remains essential to reduce costs. Therefore, the objective of the present study was to evaluate the effects of increasing supplementation of inorganic trace mineral (Zn, Mn, Fe and Cu) without or with phytase on growth performance and nutrient digestibility in broiler chickens.

MATERIALS AND METHODS

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

Bird Husbandry and Dietary Treatments

A total of 1,800 1-d-old male Cobb × Cobb 500 chicks were randomly placed into 72 floor pens (1.62 × 1.60 m^2). Each floor pen was equipped with one 15 kg tube feeder and three nipple drinkers allowing *ad libitum* access to water and mash feeds. Temperature at placement was 32 °C, which was adjusted daily to maintain bird comfort throughout the study. Lighting was provided 24 h continuously throughout the first week and further following a 16:8 (Light:Dark) periods until the end of the study.

Chicks were given two phase feeding programs with starter and grower diets (Table 1). Chicks were randomly allocated into dietary treatments using a 2 × 4 factorial arrangement (with or without added phytase), having four graded increases supplemental of inorganic trace minerals (Zn, Mn, Fe and Cu). Each treatment was replicated nine times; therefore, there were a total of 8 treatments with 9 replicates of twenty-five birds each. Feeds were formulated with energy and nutrients to provide adequate live performance (2,950 kcal/kg AME and 22.6% CP, 1.0% Ca and 0.58% non-phytate P (nPP), from 1 to 7 d), (3,050 kcal kg/kg AME and 20.6% CP 0.80% Ca and 0.40% nPP, from 8 to 35 d).

The phytase utilized was a commercially available product (Ronozyme HiPhorius, 40,000 FYT/g, Novozymes A/S, Bedshared, Denmark). This was used at 60 g/t to deliver 2,400 FYT/kg. Phytase was added to the feeds without assigning values to P, Ca and energy value to ensure a clear assessment of overall performance. The phytase was added to the feeds in 1.5 kg mixes diluted with SBM.

Supplemental Zn, Mn, Fe and Cu was laboratory-grade sulfates ($ZnSO_4 \cdot 7H_2O$, $MnSO_4 \cdot H_2O$, $FeSO_4 \cdot 7H_2O$ and $CuSO_4 \cdot 5H_2O$). The supplementation of Zn, Mn, Fe, and Cu increased progressively across treatments. Treatment 1 received no supplementation and relied only on the minerals present in the corn–SBM diet, treatment 2 received (30, 30, 20, and 4 mg/kg), treatment 3 (60, 60, 40, and 7.5 mg/kg), and treatment 4 the highest levels (120, 120, 60, and 15 mg/kg), respectively. An indigestible marker (Celite, Celite Corp., Lompoc, CA) was added at 1% in the

grower feeds. The trace minerals were added with phytase in 1.5 kg mixes diluted with SBM to the feed. Phytase activity in feeds were analyzed as done by Engelen et al. (1994) and expressed in phytase yield units (FYT, defined as the activity that releases 1 μmol of inorganic phosphate from 5.0 mM sodium phytate/min at pH 5.5 and 37 °C).

Growth Performance, Ileal Contents and Carcass Yield

Body weight gain (BWG), feed intake (FI) and feed conversion ratio corrected for the weight of dead birds (FCR) were evaluated at 7, 21, 28 and 35 d. Ileal contents were collected from all birds at 35 d following euthanasia by electrical stunning at 45 V for 3 s from a section of intestine between Meckel's diverticulum to approximately 2 cm cranial to the ileoceca junction. Contents were flushed with distilled water into plastic containers, pooled by floor pen, immediately frozen in liquid nitrogen, and stored in a freezer at −20 °C until lyophilized (Christ Alpha 1-8 LD Freeze Dryer, Newtown, UK). Feeds and freeze-dried samples of ileal contents were ground to pass a 0.5-mm screen in a grinder (Tecnal, TE-631/2, São Paulo, Brazil; MF10 basic, IKA-Werke GmbH & Co. KG, Staufen, Germany). Five birds per experimental unit at 35 d were selected within ±5% of the average pen weight to evaluate carcass and cut yields. Slaughtering was conducted after birds were individually weighed, manual evisceration were done. Eviscerated carcasses without feet and heads were chilled in slush ice for 2 h, allowed to drip for 2 min, and then weighed again. Carcasses were cut into commercial parts by trained processing plant personnel.

Dry matter (DM) analysis in all samples was performed after oven drying at 105 °C for 12 h (method 934.01; AOAC International, 2006). Ileal contents, and feed samples were analyzed for gross energy (GE) using a calorimeter calibrated with benzoic acid as a standard (IKA Werke, Parr Instruments, Staufen, Germany). Crude protein (N × 6.25) was determined by the combustion method (method 968.06; AOAC International, 2006). Acid insoluble ash in feed and ileal samples were determined as described by Vogtmann et al. (1975) and Choct & Annison (1992). Apparent ileal digestibility of DM and energy and ileal digestible energy (IDE) were calculated using the following equations (Kong & Adeola, 2014).

Blood and bone sampling

Blood samples were taken by heart punctures prior to stunning and slaughter from four broilers randomly selected from each floor pen. Obtained blood was partially transferred into 0.5 mL test tubes containing EDTA for hematocrit (Ht) and hemoglobin (Hb) analysis.

The tibiae of four birds from each floor pen were collected and had the surrounding muscle tissue removed. Tibiae were measured for weight, DM, then defatted and ashed for mineral content as well as feed samples (AOAC International, 2006). Tibia morphometry was done using a micrometer (Model IP65, Mitutoyo Corp., Kawasaki, Japan) in the caudal zone and cranial region with these values being averaged for statistical analysis. Tibia breaking strength was evaluated using a texture analyzer (TA.XTPlus, Texture Technologies, Hamilton, MA, United States), according to the method proposed by Shim et al. (2012).

Statistical analyses

Data were tested for homoscedasticity and normality of the variance analyses (Shapiro and Wilk, 1965). Normally distributed data was submitted to a two-way ANOVA (phytase and trace

minerals). Analyses were done using the GLM procedure of SAS (2012) with significance accepted at $P \leq 0.05$. Mean separation was done using the Tukey multiple-range test when the model effect was significant (Tukey, 1991).

RESULTS

The trace minerals analyzed in the experimental feeds were close to the expected from diet formulation. The analyzed phytase were for starter (2382.5±1261.8), grower (2396.3±1248.6) (Table 1), therefore, diets were considered acceptable for the experimental assessment originally planned. Analyses of variance were conducted with the analyzed data. There were no interactions between phytase and trace minerals for some evaluated response, except for tibia characteristics ($P \leq 0.05$) (Table 4).

Table 1. Ingredient and nutrient composition of feeds having supplemental phytase and graded increases of trace minerals.[1]

Ingredient, %	Starter (1 to 7)	Grower (8 to 35)
Corn, 7.8%	51.84	55.20
Soybean meal, 45%	39.85	35.36
Soybean oil	3.26	4.28
Dicalcium phosphate	2.62	1.66
Limestone	0.76	0.84
Salt	0.47	0.47
DL-Methionine, 88%	0.37	0.34
Lysine sulphate, 62.4%	0.22	0.24
L-Threonine, 98.5%	0.12	0.10
Choline chloride	0.22	0.24
Vitamin and mineral mix[2]	0.27	0.27
Celite[3]	-	1.00
Total	100.00	100
Calculated nutrient composition, % unless noted		
AME_n, kcal/kg	2,950	3,050
Crude protein	22.49 (23.88±0.70)	20.68 (20.27±0.29)
Ca	1.00(1.00±0.04)	0.80(0.82±0.04)
Available P	0.58	0.40
Digestible P	0.49	0.35
Total P	0.81 (1.01±0.03)	0.63 (0.63±0.04)
Total phytate[4]	0.24	0.23
Na	0.20	0.20
Choline, mg/kg	2,500	2,500
Dig. Lys	1.26	1.16
Dig. TSAA	0.94	0.88
Dig. Thr	0.85	0.77
Dig. Trp	0.25	0.22
Dig. Arg	1.41	1.28
Dig. Val	0.95	0.88
Mn, mg/kg	25.35(46.1±3.89)	21.80(41.2±2.26)
Zn, mg/kg	25.80(53.0±6.65)	24.30(46.8±3.04)
Fe, mg/kg	234.10(376.7±14.99)	193.29(294.4±21.64)
Cu, mg/kg	8.31(9.7±0.28)	7.52(8.2±1.34)
Phytase, FYT/kg[5]	2,400(2,382.5±1,262)	2,400(2,396±1,249)

[1]Formulated supplementation levels of Mn, Zn, Fe, and Cu by adding laboratory-grade $MnSO_4 \cdot H_2O$, $ZnSO_4 \cdot 7H_2O$, $FeSO_4 \cdot 7H_2O$, and $CuSO_4 \cdot 5H_2O$, were for Mn: 0, 30, 60, and 120 mg/kg; for Zn:

0, 30, 60, and 120 mg/kg; for Fe: 0, 20, 40, and 60 mg/kg; and for Cu: 0, 4, 7.5 and 15 mg/kg. The analyzed values in phases with and without phytase were, Starter - for Mn: 46.1±3.89, 74.0±3.39, 101.7±2.83, 174.3±19.80 mg/kg; for Zn: 53±6.65, 78.0±1.70, 140.2±6.29, 213.6±11.31 mg/kg; for Fe: 376.7±14.99, 386.6±11.38, 416.5±58.34, 449.1±22.27 mg/kg; and for Cu: 9.7±0.28, 12.8±3.82, 19.2±4.17, 25.65±2.47 mg/kg; Grower - for Mn: 41.2±2.26, 54.3±2.19, 96.9±0.64, 133.0±11.46 mg/kg; for Zn: 46.8±3.04, 66.6±7.85, 106.3±28.85, 129.7±5.30 mg/kg; for Fe: 294.4±21.64, 306.6±31.0, 313.0±21.78, 332.3±0.07 mg/kg; and for Cu: 8.15±1.34, 10.40±2.69, 14.30±5.09, 20.95±5.02 mg/kg.

[2]Composition per kilogram of feed: vitamin A, 11,000 KIU; vitamin D3, 4,000 KIU; vitamin C, 50 mg; vitamin E, 55 KIU; vitamin K3, 3 .000 mg; vitamin B12, 25 g; thiamin, 2.300 mg; riboflavin, 7.000 mg; vitamin B6, 4 g; pantothenic acid, 12 g; folic acid, 2.000 mg; biotin, 250 mg, Selenium, 300 mg, complexed trace mineral Se, 1 ppm.

[3]Indigestible marker, Celite.

[4]Phytate values calculated based in analyses of NIRS, considering the levels of 0.18% for corn and 0.38% for soybean meal, adjusted proportionally to the composition of the diets.

[5]Ronozyme HiPhorius 40,000 FYT/g, Novozymes A/S, Bagsvaerd, Denmark.

Trace minerals levels significantly affected BWG at 21 d and FI at 21 and 28 d (Table 2), apparent ileal digestibility for all responses analyzed (Table 6) as well as tibia length (Table 4) ($P < 0.05$). However, there were no differences in trace minerals for any of the responses analyzed for performance at 35 d (Table 2), carcass yield (Table 3), the remaining parameters assessed in the tibia (Table 4) and Ht and Hb at 35 d (Table 5) ($P > 0.05$).

Table 2.Growth performance of broilers as affected by different supplementation levels of trace minerals.

Item				1 to 7 d			8 to 21 d			22 to 35 d			1 to 35 d		
				BWG[1], g	FCR	FI, g	BWG, g	FCR	FI, g	BWG, g	FCR	FI, g	BWG, g	FCR	FI, g
Phytase, FYT/kg[2]															
0				136	1.074	147	902	1.300	1,172	1,513	1.513	2,292	2,551	1.415	3,609
2,400				141	1.051	148	938	1.259	1,182	1,493	1.528	2,277	2,573	1.402	3,607
Trace minerals, mg/kg[3]															
Mn	Zn	Fe	Cu												
21.8	24.3	193.3	7.5	136[b]	1.062	146	918[ab]	1.277	1,173[ab]	1,496	1.510	2,257	2,550	1.403	3,577
51.8	54.3	213.3	11.5	139[ab]	1.071	148	926[ab]	1.281	1,185[ab]	1,507	1.523	2,296	2,572	1.412	3,631
81.8	84.3	233.3	15	142[a]	1.054	149	939[a]	1.282	1,202[a]	1,504	1.534	2,303	2,584	1.415	3,657
141.8	144.3	253.3	22.5	139[ab]	1.063	148	894[b]	1.287	1,149[b]	1,511	1.516	2,283	2,544	1.409	3,584
SEM				0.771	0.004	0.620	5.255	0.004	5.353	0.011	0.005	0.015	0.009	0.003	0.013
P-value main factors															
Phytase				0.0001	0.0043	0.4594	<.0001	<.0001	0.2626	0.1266	0.0791	0.4618	0.3151	0.0232	0.8877
Minerals				0.0098	0.5518	0.3122	0.0194	0.8728	0.0149	0.9376	0.1777	0.3352	0.4426	0.3621	0.1247
Phytase x Trace minerals				0.0920	0.2291	0.0948	0.1796	0.0804	0.3776	0.3641	0.4198	0.7169	0.8057	0.5583	0.9395

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

[1]Chick body weight at the placement was 41.71 ± 0.57, BWG = body weight gain; FCR = feed conversion ratio corrected for the weight of dead birds; FI = feed intake.

[2]Ronozyme HiPhorius 40,000 FYT/g, Novozymes A/S, Bagsvaerd, Denmark.

[3]Analyzed values in phases with and without phytase were, Starter - for Mn: 46.1±3.89, 74.0±3.39, 101.7±2.83, 174.3±19.80 mg/kg; for Zn: 53±6.65, 78.0±1.70, 140.2±6.29, 213.6±11.31 mg/kg; for Fe:

376.7±14.99, 386.6±11.38, 416.5±58.34, 449.1±22.27 mg/kg; and for Cu: 9.7±0.28, 12.8±3.82, 19.2±4.17, 25.65±2.47 mg/kg; Grower - for Mn: 41.2±2.26, 54.3±2.19, 96.9±0.64, 133.0±11.46 mg/kg; for Zn: 46.8±3.04, 66.6±7.85, 106.3±28.85, 129.7±5.30 mg/kg; for Fe: 294.4±21.64, 306.6±31.0, 313.0±21.78, 332.3±0.07 mg/kg; and for Cu: 8.15±1.34, 10.40±2.69, 14.30±5.09, 20.95±5.02 mg/kg.

Table 3. Carcass, abdominal fat and commercial cuts of broilers at 35 d, %.

Phytase, FYT/kg[3]				Carcass	Abdominal Fat	Back	Breast	Wings	Legs
None				77.6	0.73	26.5	34.9	9.74	28.6
2,400				77.7	0.68	26.6	34.6	9.84	28.7
Minerals, mg/kg[2]									
Mn	Zn	Fe	Cu						
21.8	24.3	193.3	7.5	77.7	0.72	26.3	35.1	9.71	28.6
51.8	54.3	213.3	11.5	77.7	0.68	26.5	34.9	9.76	28.5
81.8	84.3	233.3	15	77.6	0.73	26.7	34.6	9.79	28.7
141.8	144.3	253.3	22.5	77.5	0.70	26.8	34.2	9.89	28.9
SEM				0.098	0.016	0.079	0.127	0.028	0.073
Phytase				0.6256	0.6274	0.2816	0.1820	0.0843	0.3416
Minerals[2]				0.7560	0.1356	0.1354	0.0650	0.1259	0.2198
Phytase*Minerals				0.2053	0.1016	0.0912	0.2367	0.2164	0.1012

[a>b] Means with different letters in the same column indicate significant differences (P ≤ 0.05).

[1]Analyzed values in phases with and without phytase were, Starter - for Mn: 46.1±3.89, 74.0±3.39, 101.7±2.83, 174.3±19.80 mg/kg; for Zn: 53±6.65, 78.0±1.70, 140.2±6.29, 213.6±11.31 mg/kg; for Fe: 376.7±14.99, 386.6±11.38, 416.5±58.34, 449.1±22.27 mg/kg; and for Cu: 9.7±0.28, 12.8±3.82, 19.2±4.17, 25.65±2.47 mg/kg; Grower - for Mn: 41.2±2.26, 54.3±2.19, 96.9±0.64, 133.0±11.46 mg/kg; for Zn: 46.8±3.04, 66.6±7.85, 106.3±28.85, 129.7±5.30 mg/kg; for Fe: 294.4±21.64, 306.6±31.0, 313.0±21.78, 332.3±0.07 mg/kg; and for Cu: 8.15±1.34, 10.40±2.69, 14.30±5.09, 20.95±5.02 mg/kg.

[2]Ronozyme HiPhorius 40,000 FYT/g, Novozymes A/S, Bagsvaerd, Denmark.

Table 4. Tibia characteristics of broiler chickens at 35 d of age.[1]

Phytase, FYT/kg[3]				Weight, g	DM, %	Ash, %	Breaking strength, kgf	Length, cm
None				11.9	46.7	20.9	48.5	9.09
2,400				12.4	46.7	21.4	49.4	9.12
Minerals, mg/kg[2]								
Mn	Zn	Fe	Cu					
21.8	24.3	193.3	7.5	12.2	46.7	21.1	49.6	8.95[b]
51.8	54.3	213.3	11.5	11.9	46.6	21.3	48.6	9.17[ab]
81.8	84.3	233.3	15	12.1	46.2	20.9	48.3	9.13[ab]
141.8	144.3	253.3	22.5	12.5	47.1	21.3	49.5	9.18[a]
SEM				0.169	0.239	0.165	1.065	0.443
Phytase				0.0468	0.9444	0.0539	0.5669	0.6659
Minerals[2]				0.5990	0.4923	0.5075	0.9228	0.0448
Phytase*Minerals				0.4505	0.1886	0.4896	0.8740	0.6723

[a>b] Means with different letters in the same column indicate significant differences (P ≤ 0.05).
[1]Weight, tibia bone weight (g); Ash, tibia ash content (%); DM, dry matter in tibia (%).
[2]Analyzed values in phases with and without phytase were, Starter - for Mn: 46.1±3.89, 74.0±3.39, 101.7±2.83, 174.3±19.80 mg/kg; for Zn: 53±6.65, 78.0±1.70, 140.2±6.29, 213.6±11.31 mg/kg; for Fe: 376.7±14.99, 386.6±11.38, 416.5±58.34, 449.1±22.27 mg/kg; and for Cu: 9.7±0.28, 12.8±3.82, 19.2±4.17, 25.65±2.47 mg/kg; Grower - for Mn: 41.2±2.26, 54.3±2.19, 96.9±0.64, 133.0±11.46 mg/kg; for Zn: 46.8±3.04, 66.6±7.85, 106.3±28.85, 129.7±5.30 mg/kg; for Fe: 294.4±21.64, 306.6±31.0, 313.0±21.78, 332.3±0.07 mg/kg; and for Cu: 8.15±1.34, 10.40±2.69, 14.30±5.09, 20.95±5.02 mg/kg.
[3]Ronozyme HiPhorius 40,000 FYT/g, Novozymes A/S, Bagsvaerd, Denmark.

Table 5. Blood parameters of broilers as affected by increased dietary of minerals with or without phytase.[1]

Phytase, FYT/kg[3]				**Ht, %**	**Hb, g/dL**
None				30.7	11.1
2,400				30.7	10.7
Minerals, mg/kg[2]					
Mn	Zn	Fe	Cu		
21.8	24.3	193.3	7.5	31.3	10.8
51.8	54.3	213.3	11.5	29.5	10.5
81.8	84.3	233.3	15	30.3	11.4
141.8	144.3	253.3	22.5	31.6	10.9
SEM				0.546	0.208
Phytase				0.9786	0.2250
Minerals[2]				0.0839	0.1547
Phytase*Minerals				0.8151	0.7188

[a>b] Means with different letters in the same column indicate significant differences (P ≤ 0.05).
[1]Analyzed values in phases with and without phytase were, Starter - for Mn: 46.1±3.89, 74.0±3.39, 101.7±2.83, 174.3±19.80 mg/kg; for Zn: 53±6.65, 78.0±1.70, 140.2±6.29, 213.6±11.31 mg/kg; for Fe: 376.7±14.99, 386.6±11.38, 416.5±58.34, 449.1±22.27 mg/kg; and for Cu: 9.7±0.28, 12.8±3.82, 19.2±4.17, 25.65±2.47 mg/kg; Grower - for Mn: 41.2±2.26, 54.3±2.19, 96.9±0.64, 133.0±11.46 mg/kg; for Zn: 46.8±3.04, 66.6±7.85, 106.3±28.85, 129.7±5.30 mg/kg; for Fe: 294.4±21.64, 306.6±31.0, 313.0±21.78, 332.3±0.07 mg/kg; and for Cu: 8.15±1.34, 10.40±2.69, 14.30±5.09, 20.95±5.02 mg/kg.
[2]Ronozyme HiPhorius 40,000 FYT/g, Novozymes A/S, Bagsvaerd, Denmark

Table 6. Apparent ileal digestibility of broilers as affected by increased dietary of minerals with or without phytase, on dry matter (DM) basis.[1]

Phytase, FYT/kg[3]				**DM, %**	**IDEC, %**	**IDE, kcal/kg**
None				67.0	72.6	3,295
2,400				68.3	73.2	3,319
Minerals, mg/kg[2]						
Mn	Zn	Fe	Cu			
21.8	24.3	193.3	7.5	67.2[b]	71.9[b]	3,227[b]
51.8	54.3	213.3	11.5	68.0[ab]	73.2[ab]	3,342[a]

81.8	84.3	233.3	15	69.1[a]	74.1[a]	3,362[a]
141.8	144.3	253.3	22.5	66.5[b]	72.4[b]	3,296[ab]
SEM				0.347	0.307	13.901
Phytase				0.0113	0.1911	0.2194
Minerals[2]				0.0021	0.0069	0.0002
Phytase*Minerals				0.3740	0.5840	0.0631

[a>b]Means with different letters in the same column indicate significant differences (P ≤ 0.05).
[1]DM = Dry matter; IDEC = Ileal digestible energy coefficient; IDE = Ileal digestible energy.
[2]Analyzed values in phases with and without phytase were, Starter - for Mn: 46.1±3.89, 74.0±3.39, 101.7±2.83, 174.3±19.80 mg/kg; for Zn: 53±6.65, 78.0±1.70, 140.2±6.29, 213.6±11.31 mg/kg; for Fe: 376.7±14.99, 386.6±11.38, 416.5±58.34, 449.1±22.27 mg/kg; and for Cu: 9.7±0.28, 12.8±3.82, 19.2±4.17, 25.65±2.47 mg/kg; Grower - for Mn: 41.2±2.26, 54.3±2.19, 96.9±0.64, 133.0±11.46 mg/kg; for Zn: 46.8±3.04, 66.6±7.85, 106.3±28.85, 129.7±5.30 mg/kg; for Fe: 294.4±21.64, 306.6±31.0, 313.0±21.78, 332.3±0.07 mg/kg; and for Cu: 8.15±1.34, 10.40±2.69, 14.30±5.09, 20.95±5.02 mg/kg.
[3]Ronozyme HiPhorius 40,000 FYT/g, Novozymes A/S, Bagsvaerd, Denmark.

Phytase improve BWG at 21 and 28 d and FCR in all pahses (Table 2), while increasing tibia weight and ash (Table 4), and showed difference in DM of ileal digestibility (P ≤ 0.05). Nevertheless, phytase supplementation did not affect BWG at 35 d, FI in all phases (Table 2), carcass yield (Table 3), tibia DM, breaking strength, length and tibia morphometry (Table 4), Ht and Hb (Table 5), IDEC and IDE of ileal digestibility (P > 0.05). Mortality followed normal patterns, with no significant differences among the trial.

DISCUSSION

Trace minerals such as Zn, Mn, Fe and Cu are essential components of numerous metabolic processes that influence broiler growth, immune response, and bone development (Underwood, 1977; Bao & Choct, 2009). Consequently, extensive research has focused on optimizing dietary supplementation of these trace elements to ensure adequate physiological functions while maintaining production efficiency. In recent years, attention has also turned to reducing or replacing the excessive inclusion of inorganic trace minerals, given their availability in feedstuffs and potential contribution to environmental contamination through manure excretion from broilers and pigs diets (Dozier III et al. 2003; Bao & Choct, 2009; Xiong et al. 2023).

In the present study, no interaction was observed between phytase and trace mineral levels for most evaluated parameters, indicating independent effects. This aligns with previous findings (Mohanna & Nys, 1999; Philippi et al., 2024).

Trace mineral supplementation affected BWG at 21 days and FI at 21 and 28 d (P < 0.05), but these effects were not maintained at later stages as well as Franklin et al. (2022) and Trairatapiwan et al. (2025). The lack of differences in BWG, FCR, and carcass yield at 35 d suggests that birds were able to compensate later in growth, possibly due to sufficient mineral availability from feedstuff and increased efficiency of absorption mechanisms supported by Franklin et al. (2022) and Trairatapiwan et al. (2025).

An unexpected response was observed between the two highest mineral levels, 3 and 4, at 21d, where a lower BWG was found with higher supplementation. Yang et al. (2011) and Franklin et al. (2022), in a study using different doses, reported no

differences in broiler performance when supplementing varying levels of inorganic trace minerals, which is consistent with studies evaluating individual supplementation of Zn, Mn, Fe, and Cu (Dozier III et al., 2003; Altevogt et al., 2026, unpublished; Feijo et al,. 2023; Soster et al., 2023; Maria et al., 2024), the analyzed dietary levels of Zn, Mn, and Cu were close to the requirements recommended by the NRC (1994), which are 40, 60, and 8 mg/kg, respectively. However, for Fe, the analyzed concentration exceeded the requirement of 80 mg/kg recommended by the NRC (1994) or 53.6 mg/kg according to Rostagno et al. (2024). Thus, a possible explanation relates to the elevated Fe content in the present study's diets, resulting from natural contributions of ingredients such as limestone and dicalcium phosphate, as also demonstrated by Feijo et al. (2024). The analyzed Fe concentration ranged from 294 to 449 mg/kg across phases, which may have influenced the observed responses. Similar findings were reported by Yang et al. (2011), who observed reductions in weight gain ($P \leq 0.05$) when supplementing 200 mg/kg of Fe in a basal diet containing 185.7 mg/kg up to 21 d. Likewise, Akter et al. (2017) and Bai et al. (2019) found differences in weight gain at 24, 35 and 42 d when evaluating Fe levels above basal contributions. Feijó et al. (2024) reported the opposite, as their study showed that the dietary contribution of iron from limestone and dicalcium phosphate did not affect BWG until 28 d in diets containing between 57.6 to 223.7 mg/kg of Fe, however, studies assessing high Fe supplementation have demonstrated negative effects on broiler performance and reductions in nutrient digestibility including impacts on Ca and P digestibility and apparent metabolizable energy (Akter et al., 2017; Feijo et al., 2024). High dietary Fe can also promote the formation of Fe-phytate complexes, hindering phytate hydrolysis by phytase (Maenz et al., 1999; Akter et al., 2015). In this study, similar effects were observed for energy digestibility and IDE between the lowest and highest levels ($P < 0.05$), raising the possibility that high doses of trace minerals may have interfered with performance.

Phytase supplementation improved BWG at 21 and 28 days and enhanced FCR over the entire experimental period. This agrees with extensive literature demonstrating that phytase increases phosphorus and calcium availability, but also releases bound trace minerals, thereby improving nutrient utilization and growth performance (Cowieson et al., 2006; Woyengo & Nyachoti, 2011; Walters et al., 2019; Walk & Rama Rao, 2020). Nevertheless, authors emphasize that phytase responses can vary across studies, as they are influenced by multiple interacting factors, and one silent factor is minerals sources and concentrations which are recognized as one of the key determinants of the enzyme's efficacy (Sandberg et al., 1993; Dersjant-Li et al., 2015; Saensukjaroenphon et al., 2020; Philippi et al., 2024).

The reduction observed in tibia length with lower mineral levels aligns with the essential roles of Zn, Mn, Fe, and Cu in skeletal development as reviewed by Bao & Choct, (2009) and Suttle (2010). However, since tibia weight and ash content were unaffected ($P > 0.05$), it appears that the mineral reduction primarily influenced bone morphometry, in the other hand the use of phytase increase tibia weight and ash possible due the main minerals present in the tibia Ca and P ($P \leq 0.05$) according to (Suttle 2010; Philippi et al., 2024; Liu et al., 2020).

Hematological parameters (Ht and Hb) between treatments indicates that neither phytase supplementation nor the reduction of trace minerals compromised the broilers at 35 d ($P > 0.05$). This supports the notion that reductions in supplemental trace minerals can be achieved without adverse effects which enhances mineral bioavailability and reduces the need for excessive supplementation (Bao & Choct, 2009).

CONCLUSIONS

Overall, the findings indicate that broilers can maintain normal growth and carcass performance up to 35 days even with reduced trace mineral supplementation. The naturally occurring trace minerals in corn–SBM diets appear sufficient to support growth, suggesting that current supplementation levels may exceed actual nutritional needs. In addition, excessive minerals inclusion may negatively affect nutrient digestibility and possible impact enzyme activity, reinforcing the need for further studies to clarify these interactions. Taken together, the results demonstrate that lowering inorganic trace minerals supplementation is a feasible strategy to reduce environmental impact without compromising bird performance.

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Appendix

The appendix is an optional section containing details and data supplemental to the main text.

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549
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CAPÍTULO III

CONSIDERAÇÕES FINAIS

De modo geral, os resultados indicam que frangos de corte conseguem manter crescimento normal e desempenho de carcaça até os 35 dias de idade, mesmo com níveis reduzidos de suplementação de microminerais. Os microminerais naturalmente presentes nas dietas à base de milho e farelo de soja mostraram-se suficientes para sustentar o desempenho produtivo, sugerindo que os níveis atualmente praticados de suplementação podem estar acima das reais exigências nutricionais das aves. Além disso, a inclusão excessiva de microminerais pode afetar negativamente a digestibilidade dos nutrientes e possivelmente interferir na atividade enzimática, reforçando a necessidade de novos estudos para elucidar essas interações. Em conjunto, os resultados demonstram que a redução da suplementação de microminerais inorgânicos é uma estratégia viável sem comprometer o desempenho zootécnico das aves.

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APÊNDICES

Apêncice 1: Normas para publicação de artigos no periódico Brazilian Journal of Poultry Science.

Brazilian Journal of Poultry Science Guide to Authors[1]

Available at: https://www.scielo.br/j/rbca/grid

ABOUT THE JOURNAL

Brief Background

The Brazilian Journal of Poultry Science is published quarterly, and the Journal will consider only original research material relevant to the field of poultry science for publication. Considered subject areas will include Immunology, Biochemistry and Cellular Biology, Housing and Environment, Wasting Control, Avian Diseases, Nutrition, Genetic Improvement, Physiology and Breeding, Management, Egg Production, Meat Technology, and Wild and Exotic Birds and Quail Production.

The Journal's main objective is to publish complete scientific and technical papers as well as literature reviews in the area of poultry science written by researchers and poultry science specialists. Authors wishing to submit a review, guest editorial or technical review should contact the Journal's Editor.

Open Science Compliance

The Brazilian Journal of Poultry Science upholds the principles of open science, fostering a research environment that prioritizes transparency, collaboration, and the free exchange of knowledge. To ensure our commitment to open science, we have integrated the following practices into our editorial policy and operational procedures:

1. Our editorial policy explicitly states our alignment with open science principles, highlighting our dedication to making research outputs openly accessible whenever possible.

2. We welcome submissions of manuscripts deposited on recognized preprint servers, acknowledging the value of preprints in facilitating early dissemination and feedback within the research community.

3. We require authors to cite, reference, and, where ethically and legally permissible, make the research data underlying their findings available. This practice promotes transparency and enables data verification and reuse, strengthening the research's robustness.

4. We encourage our peer reviewers to consider the availability of underlying research data and other open science practices when evaluating manuscripts. This approach ensures that reviewers have access to all relevant information necessary for a comprehensive research assessment.

The Journal's policies and practices align with the DOAJ criteria for open science. Adhering to these standards contributes to a global movement towards a more open and equitable research landscape.

The Journal allows free access to published articles, contributing to the fast dissemination of published research results and promptly providing the scientific support necessary for developing ongoing research and expanding the citation of articles.

All articles published in the Journal since its beginning in 2000 are freely available on the SciELO portal.

Ethics in Publication

The Journal is dedicated to complying with good practices. It follows norms and recommendations for standards of ethics and responsibility in scientific communication established by national and international institutions, among which the following stand out: COPE, Equator Network, ICMJE, Fapesp and Good Practices Guide Strengthening Ethics in Scientific Publication.

The Brazilian Journal of Poultry Science is committed to ethics and quality in publication. We comply with standards of ethical behavior expected of all parties involved: authors, editors and reviewers in the publication. Authors, Editors and Reviewers are encouraged to study and follow all standards of good scientific research practice.

To promote the predominance of originality of texts, the Journal adopts duplication-checking programs with texts already published, Rev. Odontol. The Journal does not accept plagiarism or any other unethical behavior in any instance. When plagiarism is detected, the author(s) are informed, and the report generated by the software used is presented. When there is doubt or questioning, the Editor contacts the corresponding author and the authors' affiliation or funding institutions involved in the development of the research to inform of the article rejection.

When submitting articles to the Journal, authors declare that their originality and guarantee that the work has not been published and is not in the process of review/evaluation in any other journal.

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When suspecting ethical misconduct, the Editor-in-chief will assess the situation to clarify the problem. Corrections or clarifications may be published by the Journal if necessary.

The Editor-in-Chief will resolve cases not listed in these rules. Occasionally, when there is a challenge to the Journal's decision, a committee of editorial board members and those external to the Journal is set up.

Focus and Scope

The publication of the Brazilian Journal of Poultry Science is coordinated by the Publishing Committee of Fundação de Apoio à Ciência e Tecnologia Animal – FACTA (Foundation of Animal Science and Technology – FACTA). All published research data and conclusions are of the authors' full responsibility.

All submitted manuscripts are evaluated in an anonymous, confidential, and impartial peer review. Manuscripts should be submitted in English only.

Digital Preservation

The Journal follows the standards defined in the SciELO Program's Digital Preservation Policy.

Indexing Sources

- CAB Abstracts
- CrossRef
- DOAJ – Directory Open Access Journals
- ISI Web of Science
- Latindex
- Scimago
- Scopus

Bibliographic Journal Information

- Proper title: Brazilian Journal of Poultry Science
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Websites and Social Media

- Instagram https://www.instagram.com/facta.wpsab
- Site: https://facta.org.br/rbca-bjps/

Editorial Policy

The Journal is committed to open science, and our editorial policy reflects this by championing the broadest possible access to research outputs.

Submission of a manuscript to the Brazilian Journal of Poultry Science implies that:

1. It has not been previously published;
2. It has not been submitted for publication elsewhere;
3. All authors have approved the submission;
4. All authors have obtained permission from their employer or Institution to publish it and
5. Relevant permissions, including ethical approval, have been obtained. Papers describing experiments demonstrating a lack of concern for current ethical and welfare standards will not be considered for publication.
6. Data on the authors and related institutions can not be changed after the publication.

Authors should carefully consider the list and order of authors before submitting their manuscript and provide the final list at the time of the original submission. Changes to authorship (addition, deletion, or rearrangement) after submission will only be considered in exceptional circumstances at the Editor's discretion. Any such request must be clearly communicated to the Editor, and all authors must agree to the changes.

Authors share collective responsibility for the work. Each author is accountable for ensuring that questions regarding the accuracy or integrity of any part of the work are appropriately investigated and resolved.

The submission is online. Other correspondence should be sent by email to revista@facta.org.br.

Preprints

To ensure that all preprints submitted to the Brazilian Journal of Poultry Science are treated with transparency and integrity, we ask authors to supply the following information:

(a) preprint identification: the authors should send information about the preprint, including title, author(s), name of the repository in which it was published, date of publication, and DOI;

(b) relationship with the submitted paper: the authors should state the relation of the preprint with the paper submitted to the journal, e.g., the preprint is a previous version, or contains supplementary information; and

(c) conflicts of interest: the authors should inform whether there are any conflicts of interest concerning the preprint, such as financing from a company or institution with an interest in the research.

Peer Review Process

- The process of reviewing manuscripts adopted by the Journal is anonymous peer review.

Consists of the following three stages:

1. Preliminary analysis of the structure of the paper: this stage focuses on ensuring compliance with the general guidelines defined by the editorial

policy, regarding the journal's focus and scope, the relevance and contribution of the research, and the similarity among the submitted papers. Certificates from human and animal ethics committees are required during the submission process. The journal may reject the paper if there are doubts regarding the presented documents. Papers that do not follow these criteria will be returned to the authors for corrections as many times as necessary. If the papers do not follow the norms of the journal or are otherwise inadequate, they may be rejected in the initial evaluation; otherwise, they are submitted for peer reviewing.

2. Forwarding to editors and reviewers: Each paper that follows the norms will be submitted to the evaluation of the chief editor, who then nominates associate editor(s) to evaluate the approved paper. After receiving the text, the associate editor evaluates its scientific method and merit and sends it to at least two ad hoc reviewers of institutions other than that of the author(s).

- Reviewers will issue an opinion through a ScholarOne form recommending one of the following outcomes:
  - Approval
  - Minor revision
  - Major revision
  - Rejection
    - After analyzing the opinion, the editor(s) forward it to the chief editor, who makes a decision and forwards it to the authors. The reviewed manuscript must be submitted online through ScholarOne Manuscripts by the same author that sent the original version. The reviewed version of the paper should be re-submitted along with a letter commenting on each change requested by the reviewer(s). The authors must provide valid reasoning for unaccepted suggestions. It is recommended that Word settings are adjusted to keep the identity of the authors secret when they make corrections or suggestions directly into the text. The reviewed paper and the letter are initially evaluated by the chief and associate editors, who then forward them to the reviewers, when requested.
  - In case of rejection of the paper by one out of the two reviewers, the associate editor decides whether to send it for the appraisal of a third reviewer. The chief editor is responsible for the final decision on the acceptance or rejection of papers.

3. The corrected paper is then sent to the reviewers for a new analysis. After approval, the paper is processed in its final form. The final version of the manuscript is sent to the corresponding author by e-mail for his approval of the typeset article in PDF. If necessary, the author has 72 hours to make any corrections and send the final reviewed version. After this deadline, only minor changes are accepted.

- After the approval of the manuscript and before the beginning of the publication process, the author(s) receive an e-mail with instructions regarding the payment of the publication fee. After payment confirmation, the paper undergoes language and reference revisions, followed by formatting.

Open Data

Authors can make their published articles available in institutional or other repositories. If there is supplementary research data, the corresponding author must provide the manuscript's location, nature, referencing, and declaration of availability.

The following links support supplemental data information:

- TOP Guide
- Research data citation guide
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Fees

The BJPS does not charge to submit the article.

The Journal charges the fees after the article is approved for publication. The author(s) will be charged US$ 500,00 (five hundred dollars) per edited article, and the payment should be made before publication. The fees will cover the expenses of English polishing, reference checking, and editing the final proof. No reprints will be supplied to authors as the articles are shown at www.scielo.br/rbca.

Ethics and Misconduct, Correction and Retraction Policy

Submission of an article implies that the manuscript described has not been previously published (except in the form of an abstract, published lecture or academic thesis). The article will first be evaluated for compliance with the Journal's standards and analyzed using plagiarism detection software by the technical advisor.

Corrections and retractions

Authors are expected to carefully consider the list and sequence of authors before submitting their manuscript and forward the definitive list of authors at the time of submission. No additions or changes to authorship will be permitted during the evaluation stage or after acceptance of the submitted text.

The article that has already been published, in which misconduct is identified, remains indexed in the Journal's database and has been retracted. The retraction documents and the reason for the retraction are referenced through communication from the author and published in the same Journal. The retraction may be partial when the misconduct applies to a specific part of the article without compromising the entirety of the published research.

The Journal initiate the retraction process after receiving formal communication to the Editor-in-Chief and will communicate to SciELO. The communication must accompany the retraction text stating why the article will be retracted.

The article cannot be “unpublished”. Cases of errors or failures, regardless of nature or origin, that do not constitute misconduct are corrected through errata. The Journal will publish erratum, corrections or retractions as quickly as possible. Any additions and modifications to the submitted text must be made only before acceptance of the manuscript and only if approved by the Editor-in-Chief of the Journal.

Policy on Conflict of Interest

Authors are required to disclose any potential conflict of interest. The conflict of interest may be personal, commercial, political, academic, or financial. Conflicts of interest may occur when authors, reviewers, or editors have interests that may influence the preparation or evaluation of manuscripts. When submitting the manuscript, authors are responsible for recognizing and disclosing financial or other conflicts that may have influenced the work. If there is, even potentially, a conflict of interest, the author(s) must inform it in a signed document attached to the submission platform.

Authors must identify in the manuscript all financial support obtained to carry out the study and other personal connections related to the research.

Adoption of similarity software

The Journal uses the software Grammarly/Plagiarism to identify plagiarism.

Upon receipt, every manuscript submitted to the Journal is checked for plagiarism using Grammarly. The maximum percentage accepted is 10%.

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Gender and Sex Issues

Manuscripts submitted to Brazilian Journal of Poultry Science must observe the principles of the Guideline on Sex and Gender Equity in Research (Sex and Gender Equity in Research – SAGER). According to the guideline, the terms sex (biological attribute) and gender (shaped by social and cultural circumstances) must be used carefully to avoid any confusion.

The Brazilian Journal of Poultry Science follows the equity of gender policy in the composition of the Editorial Board.

Ethics Committee and Good Practices in Research

Articles involving studies on humans or animals, either directly or indirectly, in whole or in part, and covering all areas of knowledge, must include a statement in the Materials and Methods section confirming that the study was submitted to, evaluated, and approved by the relevant Ethics Committee. This statement should specify the name of the Committee, the Institution, and the CAAE (Certificate of Presentation of Ethical Appreciation) number or a similar document.

Authors must ensure that their work is entirely original. If they have used the work or words of others, they must provide proper citations or quotations and obtain the necessary permissions.

When authors utilize generative AI and AI-assisted technologies in the writing process, these tools should be employed solely to enhance the readability and language of the work. The application of such technologies must be conducted under human oversight and control. The authors are responsible and accountable for the content of their manuscript.

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The Brazilian Journal of Poultry Science encourages Authors to self-archive their accepted manuscripts by publishing them on personal blogs, institutional repositories, and academic social media, as well as posting them on their social media, as long as the complete citation to the journal website version is included.

INSTRUCTIONS TO AUTHORS

- Use the following template: Revista Brasileira de Ciência Avícola/ Brazilian Journal of Poultry Science
- Manuscript should be submitted via ScholarOne.

Types of Documents Accepted

- Full-length article
- Short communications and Case Reports
- Technical article
- Guest Editorial and Invited Review

Authors' Contribution

Please declare which collaboration each author had using the template directions. Remember that the authorship must be limited to those who have contributed substantially to the work reported. The authorship will not be changed after the manuscript's acceptance.

Manuscript Preparation

Full-length article:

It should contain the results of original research, which contributes in a relevant way to the development of poultry science. It must be stated if part of the results has been published previously as a summary or short paper in scientific events. Priority will be given to manuscripts presenting new concepts, methodologies, or innovative experimental approaches.

The manuscript should have the following sections:

Title

Abstract

Introduction

Material and Methods

Results

Discussion

Conclusions – if applicable

References

Acknowledgements should be included after Discussion.

The sections Results and Discussion can be presented jointly if preferred. The Abstract should contain up to 250 (two hundred and fifty) words, followed by the keywords in alphabetic order, limited to 5 (five) words corresponding to words or expressions that identify the article's contents.

Short communications and Case Reports:

Should have the same layout as full-length papers, including the headings (Introduction, Abstract, Material and Methods, Result, Discussion, Acknowledgments, and References). They should be presented in a text of up to 1000 words (plus Abstract and References) and contain no more than three tables and/or figures.

Technical article:

Technical articles should present the development of new methodologies and/or techniques that can be applied to improve poultry production. These should follow the editorial norms and include all sections of the scientific article.

Guest Editorial and Invited Review:

Both Guest Editorial and Invited Review will be published by invitation only. The review should follow the norms of the scientific article without the sub-items of Material and Methods, Results and Discussion, and preserving all others present in a full-length manuscript.

Article Submission Format

Use the following template: Revista Brasileira de Ciência Avícola/ Brazilian Journal of Poultry Science

This template outlines the typical sections you can include in a manuscript. Each section has a recommended style, accessible through the “Styles” menu in Word. Remember that some sections are optional, and the specific structure may vary depending on the type of article (e.g., review papers might have a more flexible format).

For any questions, please contact the Journal’s editorial office at revista@facta.org.br

Manuscript should be submitted via ScholarOne.

- **Language:** English
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- **Abstract:** A single paragraph of about 200 words maximum. For research articles, ab-stracts should give a pertinent overview of the work. We strongly encourage authors to use the following style of structured abstracts, but without headings: (1) Background: Place the question addressed in a broad context and highlight the purpose of the study; (2) Methods: briefly describe the main methods or treatments applied; (3) Results: summarize the article’s main findings; (4) Conclusions: indicate the main conclusions or interpretations. The abstract should be an objective representation of the article and must not contain results that are not presented and substantiated in the main text.
- **Keywords:** List three to eight pertinent keywords specific to the article and common within the subject.

- **Author's:** Complete names, complete affiliations and ORCID are required for publication. The complete address of the first author must be informed (Institution, correspondence email, and phone).

- **Funding:** Please acknowledge receiving funds from a funding agency or other source.

- **Data availability statement:** We encourage all authors to share their research data. Please provide details regarding where data can be found or state that data will be available upon request.

Digital Assets

Tables: Must be numbered consecutively with Arabic numerals in the text. Tables must have a descriptive title. All explanatory information should be given in a footnote below the table. All abbreviations must be defined in this footnote, even if they are explained in the text. Tables must be understandable without referring to the text.

Illustrations (photographs, graphs, drawings): Must be numbered consecutively with Arabic numerals. All figures should be submitted on separate pages with the title of the article, name(s) of the author(s), and an indication of the part of the text where they should appear.

Photographs, figures, and scanned material must be sent in high resolution (minimum 600 dpi, .tif or .jpg format). The figures will be published in black and white. A previous expense agreement is needed if the author wishes to publish color photos and or figures.

Citations and References

References: We accept the adapted Vancouver norm. The author's last name and initials should be arranged in alphabetic order. When a source has more than one author, their names are separated by commas. If a source has more than three authors, list the first three followed by '*et al*.' (in italics). The complete title of the Journal should be mentioned. Please add the link of the article DOI by the end of the reference.

Examples:

– Electronic journal article with DOI number: Bakst MR, Gupta K, Akuffo V. Comparative development of the turkey and chicken embryo from cleavage through hypoblast formation. Poultry Science 1997; 76(1):83-90. https://doi.org/10.1093/ps/76.1.83

Rodrigues I, Silva R, Menezes J, *et al*. High Prevalence of multidrug-resistant nontyphoidal Salmonella recovered from broiler chickens and chicken carcasses in Brazil. Brazilian Journal of Poultry Science 2020;22(1). https://doi.org/10.1590/1806-9061-2019-1206

–Book:
Lawrie RA. Ciência da carne. 6th ed. Porto Alegre: Artmed Editora; 2005.

– Chapter in a book:
Rosa PS. Cama para frangos de corte. In: Macari M, Mendes A.A, Menten JFM, Naas IA. Produção de frangos de corte. 2 nd ed. Campinas: FACTA; 2014 p.153-180. ISBN: 9788589327077

– Theses/ Dissertation
Carvalho DA. Caracterização fenotípica e genotípica de galinhas nativas canelas-preta. [dissertation]. Diamantina (MG): Universidade Federal dos Vales do Jequitinhonha e Mucuri; 2016b [cited 2021 Nov 20]. Available from: http://acervo.ufvjm.edu.br/jspui/handle/1/1022

Quotations in the text: State the author's last name, followed by the year in parenthesis. In the case of two authors, both should be stated. In the case of more than two authors, the first author's last name should be given the quotation followed by the expression *et al*. (in italics).

Examples:

Simon (1996)

Silva & Silva (1988)

Briceno *et al*. (1987)

Units:

The International Metric System must be used for units and abbreviations.

Scientific names of microorganisms:

Must follow Berg's Manual recommendation.

Offsprints:

The Journal does not offer offprints.

Manuscript Proof:

This will be sent to the corresponding author, who should be identified on the manuscript's cover page. Corrected proof should be returned within three days, preferably by fax. The Editor reserves the right to forward the manuscript to press without submitting the final proof to the author. The Editor shall not be held responsible for any mistakes in the final publication.

Contact

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Rua Barão de Paranapanema, 146 – Sala 72, Bloco A, Bosque, Cep: 13026-010 Campinas, SP, Brasil

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VITA

Yuri Junqueira Olabarriaga, filho de Eduardo Delgado Olabarriaga e Isabel Cristina Junqueira, nascido em 31 de maio de 1998, em Porto Alegre – RS. Realizou o ensino fundamental e ensino médio no Colégio Concórdia de Porto Alegre, concluindo os estudos em dezembro de 2015. 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 agosto de 2019, totalizando 8 anos entre a graduação e o mestrado. De novembro a agosto de 2023, foi estagiário na empresa Agrogen Desenvolvimento Genético, na cidade de Montenegro– RS, tendo a oportunidade de conhecer a cadeia de produção de matrizes de corte. Formou-se em 16 de setembro de 2023. Em abril de 2024 ingressou como aluno 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 sobre trabalhos desenvolvidos no Aviário de Ensino e Pesquisa. No primeiro semestre de 2026 está encaminhando a sua continuidade nos estudos e irá iniciar o doutorado na Universidade Laval, Quebec -CA.