UNIVERSIDADE ESTADUAL PAULISTA – UNESP
CÂMPUS DE JABOTICABAL

# EFEITO DA PROTEÍNA BALANCEADA SOBRE A OTIMIZAÇÃO BIOLÓGICA E ECONÔMICA DE FRANGOS DE CORTE E MATRIZES PESADAS

**Jefferson Moraes Azevedo**
**Zootecnista**

**2020**

UNIVERSIDADE ESTADUAL PAULISTA – UNESP
CÂMPUS DE JABOTICABAL

# EFEITO DA PROTEÍNA BALANCEADA SOBRE A OTIMIZAÇÃO BIOLÓGICA E ECONÔMICA DE FRANGOS DE CORTE E MATRIZES PESADAS

**Msc. Jefferson Moraes Azevedo**

**Orientadora: Profa. Dra. Nilva Kazue Sakomura**

Tese apresentada à Faculdade de Ciências Agrárias e Veterinárias – Unesp, Campus de Jaboticabal, como parte das exigências para a obtenção do título de doutor em Zootecnia.

**2020**

A994e

Azevedo, Jefferson Moraes
Efeito da proteína balanceada sobre a otimização biológica e econômica de frangos de corte e matrizes pesadas / Jefferson Moraes Azevedo. -- Jaboticabal, 2021
100 p. : tabs.

Tese (doutorado) - Universidade Estadual Paulista (Unesp), Faculdade de Ciências Agrárias e Veterinárias, Jaboticabal
Orientadora: Nilva Kazue Sakomura

1. Nutrição animal. 2. Aminoácidos na nutrição animal. 3. Aves domésticas Alimentação e rações. I. Título.

Sistema de geração automática de fichas catalográficas da Unesp. Biblioteca da Faculdade de Ciências Agrárias e Veterinárias, Jaboticabal. Dados fornecidos pelo autor(a).

Essa ficha não pode ser modificada.

## CERTIFICADO DE APROVAÇÃO

TÍTULO DA TESE: EFEITO DA PROTEÍNA BALANCEADA SOBRE A OTIMIZAÇÃO BIOLÓGICA E ECONÔMICA DE FRANGOS DE CORTE E MATRIZES PESADAS

**AUTOR: JEFFERSON MORAES AZEVEDO**
**ORIENTADORA: NILVA KAZUE SAKOMURA**

Aprovado como parte das exigências para obtenção do Título de Doutor em ZOOTECNIA, pela Comissão Examinadora:

Profa. Dra. NILVA KAZUE SAKOMURA (Participaçao Virtual)
Departamento de Zootecnia / FCAV / UNESP - Jaboticabal

Pós-doutorando MATHEUS DE PAULA REIS (Participaçao Virtual)
Departamento de Zootecnia / FCAV / UNESP - Jaboticabal

Ph.D. JULIANO CESAR DE PAULA DORIGAM (Participaçao Virtual)
Evonik Nutrition & Care GmbH / Evonik - Alemanha

Prof. Dr. LUCIANO HAUSCHILD (Participaçao Virtual)
Departamento de Zootecnia / FCAV / UNESP - Jaboticabal

Dra. NAYARA TAVARES FERREIRA (Participaçao Virtual)
Trouw Nutrition / Guelph/Canadá

Jaboticabal, 22 de outubro de 2020

## DADOS CURRICULARES DO AUTOR

JEFFERSON MORAES AZEVEDO, filho de Gilson azevedo e Ivonete Chagas de Moraes, nascido no dia 31 de janeiro de 1988 em Tabira, Pernambuco. Ingressou no curso de Zootecnia na Universidade Federal Rural de Pernambuco (UFRPE), Campus de Serra Talhada em março de 2009, recebendo em agosto de 2014 o título de Zootecnista. Em setembro do mesmo ano ingressou em nível de mestrado no Programa de Pós-Graduação em Zootecnia da Universidade Federal Rural de Pernambuco (UFRPE) Campus do Recife, obtendo o título de mestre em Zootecnia em 2016. Em 2017 ingressou em nível de doutorado do Programa de Pós-Graduação em Zootecnia da Universidade Estadual Paulista "Júlio de Mesquita Filho" (UNESP) – Faculdade de Ciências Agrárias e Veterinárias, Campus de Jaboticabal, tendo sua pesquisa financiada pelo Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq, sob orientação da Profa. Dra. Nilva Kazue Sakomura, submetendo-se à defesa da tese em outubro de 2020.

# SUMÁRIO

CAPÍTULO 1 – Considerações gerais .......... 1
Introdução .......... 1
Revisão de literatura .......... 3
Importância da proteína balanceada para as aves .......... 3
Otimização econômica da densidade nutricional .......... 5
Composição corporal na vida produtiva de matrizes pesadas .......... 10
Referências bibliográficas .......... 12
CAPÍTULO 2 - Response of broilers to dietary balanced protein 1. Feed intake and growth .......... 18
Abstract .......... 20
Introduction .......... 21
Materials and methods .......... 23
Results .......... 26
Discussion .......... 29
References .......... 34
CAPÍTULO 3 - Response of broilers to dietary balanced protein 2. Determining the optimum economic level of protein .......... 49
Abstract .......... 51
Introduction .......... 52
Materials and methods .......... 55
Results .......... 58
Discussion .......... 60
References .......... 65
CAPITULO 4 - Balanced protein for broiler breeder hens from 55 to 65 weeks of age .......... 73
Abstract .......... 75
Introduction .......... 76
Materials and Methods .......... 78
Results .......... 80
Discussion .......... 83
References .......... 88
CAPÍTULO 5 - Implicações .......... 100

# EFEITO DA PROTEÍNA BALANCEADA SOBRE A OTIMIZAÇÃO BIOLÓGICA E ECONÔMICA DE FRANGOS DE CORTE E MATRIZES PESADAS

**RESUMO –** O objetivo do estudo é avaliar as respostas de frangos de corte e matrizes pesadas submetidos a diferentes níveis de proteína balanceada de acordo com o conceito de proteína ideal e, baseado nestas respostas, propor uma abordagem para otimização econômica, avaliando os impactos entre as estratégias nutricionais que se fundamentam no máximo desempenho biológico em comparação a uma que busque máximo retorno econômico. Para isso, dois experimentos foram realizados. No primeiro experimento, foi avaliado a resposta de frangos de corte das linhagens Ross e Cobb em função de diferentes concentrações proteína balanceada na dieta e, divididas em quatro fases de alimentação (Inicial) 1 a 14; (Crescimento) 15 a 28; (Final I) 29 a 42 e (Final II) 43 a 56 dias de idade. Foram utilizados seis tratamentos (concentrações de proteína balanceada na ração), arranjados em esquema fatorial (6 níveis de proteína balanceada x 2 linhagens x 2 sexos) perfazendo 24 tratamentos com quatro repetições de 26 aves, totalizando 2.496 aves distribuídas em 96 parcelas experimentais. As rações foram produzidas utilizando a técnica da diluição, onde uma ração com alto conteúdo proteico (A=283 g/kg) foi diluída com uma ração de baixo conteúdo de proteína (B=117g/kg), produzindo os seis níveis crescentes de proteína balanceada para cada fase. As duas dietas foram elaboradas para conter igual teor de energia metabolizável (EMAn), atendendo as exigências de vitaminas, minerais e a relação ideal dos aminoácidos. Foram avaliadas as variáveis de desempenho (peso corporal, ganho de peso, consumo de ração e ingestão de proteína), composição química (água, proteína, gordura e cinzas), rendimento de cortes (carcaça, peito, pernas (coxa+sobrecoxa), asas e restante). O consumo de ração em todos os períodos, em ambas as linhagens e sexos, aumentou à medida que o nível de proteína na dieta diminuiu e, em seguida, diminuiu acentuadamente nos níveis mais baixos de proteína. Somente aos 14 dias o consumo de ração diferiu entre as linhagens e os sexos, apresentando assim interação significativa; em todos os outros casos, as O consumo de ração diferiu apenas entre os sexos. Aos 14 dias, a resposta no peso corporal diferiu entre as linhagens e o sexo, enquanto em todas as outras amostragens eles diferiram apenas entre os sexos. A resposta na produção de carcaça, peito e asa aos 14 dias foi a mesma para ambas as linhagens e sexos, mas diferiu entre linhagens e sexos aos 28 dias. Aos 42 e 56 dias, a resposta diferiu apenas entre os sexos. A resposta no peso da perna (coxa mais sobrecoxa) aos 14 dias foi a mesma para ambas as linhagens e sexos, mas depois disso diferiu apenas entre os sexos. O conteúdo de lipídios corporais aumentou linearmente inicialmente e depois quadraticamente conforme o conteúdo de proteína da dieta foi reduzido. A análise econômica identificou que, usando como base os valores de marcado atuais, o conteúdo de proteína da dieta que maximizou a margem sobre o custo da ração foi sempre maior para machos do que para fêmeas e para aves vendidas processadas em relação àquelas vendidas vivas. Usando lisina como aminoácido de referência, o ótimo econômico no período inicial para machos vendidos vivos foi obtido com uma concentração de 12,1 g lisina/kg sendo 14,1 g/kg quando essas aves são vendidas abatidas; para as fêmeas os valores equivalentes foram 11,3 e 13,7 g/kg, respectivamente. Quando o custo dos ingredientes que contêm proteína foi aumentado em 25%, ou a receita gerada com a venda do produto reduzida em 25%, o nível econômico ideal de proteína dietética aumentou em comparação com o valor do preço base, sendo este aumento maior para as aves vendido vivas. O oposto ocorreu quando os custos foram aumentados ou as receitas diminuíram 25%. Em síntese, a análise econômica identificou que, dependendo de o cenário econômico, preconizar o máximo desempenho poderá originar perdas econômicas, e que buscar ajustar os níveis de proteína da dieta de acordo com as mudanças do cenário econômico parece ser a estratégia mais viável para o aumento da rentabilidade de um sistema de produção de frangos de corte. No segundo experimento, foi avaliado o desempenho produtivo e composição corporal de matrizes pesadas submetidas a 5 níveis de proteína balanceada em duas quantidades diárias de oferta de ração. Para isso um total de 200 de aves reprodutoras (Ross 308) com 55 semanas de idade foram distribuídas aleatoriamente em gaiolas individuais. Os tratamentos foram constituídos por cinco diferentes concentrações de proteína balanceada ofertadas em duas quantidades diárias (150 a 170 g/dias) perfazendo um delineamento inteiramente casualisado alocado em arranjo fatorial com 10 tratamentos de 20 repetições. Não houve interação ($p > 0,05$) entre a quantidade de ração ofertada (FA) e a proteína balanceada da dieta (BP) para nenhuma variável avaliada. A produção de ovos (EP) não foi influenciada ($p > 0,05$) pelos tratamentos, mas o peso dos ovos (EW) e a massa de ovo (EO) aumentaram com os níveis de BP, mas não foram afetados pela FA. O ganho de peso corporal (BWG) e a retenção de proteína corporal (BPR) também aumentaram com a BP, mas não foram afetados pela FA, enquanto a retenção de gordura corporal (BFG) teve um incremento apenas com a FA. Consequentemente, a energia total retida no corpo (BPRt) aumentou tanto com PA quanto AF, enquanto a energia corporal retida como proteína (BPRp) e gordura (BPRg) foram influenciadas apenas pela BP e FA, respectivamente. A energia total retida (TER) também aumentou com os dois fatores, enquanto a produção total de calor (THP) reduziu com a BP e aumentou com a FA. Mesmo no final da vida produtiva, as matrizes de corte são capazes de manter seu desempenho reprodutivo alterando a composição corporal e consequentemente afetando a partição de energia.

**Palavras chave**: Aminoácidos na nutrição, Aves domésticas alimentação e rações, Nutrição animal

**EFFECT OF BALANCED PROTEIN ON THE BIOLOGICAL AND ECONOMIC OPTIMIZATION OF BROILER CHICKENS AND BROILER BREEDER HENS**

**ABSTRACT** - The objective of the study is to evaluate the responses of broiler chickens and broiler breeders subjected to different levels of balanced protein according to the ideal protein concept and, based on these responses, to propose an approach for economic optimization, evaluating the impacts between the nutritional strategies that are based on maximum biological performance compared to one that seeks maximum economic return. For this, two experiments were carried out. In the first one, the response of broilers from Ross and Cobb strains was evaluated according to different concentrations of balanced protein in the diet and divided into four feeding phases (Initial) 1 to 14; (Growth) 15 to 28; (Final I) 29 to 42 and (Final II) 43 to 56 days of age. Six treatments (balanced protein concentrations in the ration) were used, arranged in a (6 balanced protein levels x 2 strains x 2 sexes) factorial scheme, making 24 treatments with four replications of 26 birds, totaling 2,496 birds distributed in 96 experimental plots. The diets were produced using the dilution technique, where a diet with a high protein content (A = 283 g / kg) was diluted with a diet with a low protein content (B = 117g / kg), producing the six increasing levels of protein balanced for each phase. Both diets were designed to contain an equal content of metabolizable energy ($AME_n$), meeting the requirements of vitamins, minerals and the ideal ratio among amino acids. The performance variables (body weight, weight gain, feed intake and protein intake), chemical composition (water, protein, fat and ash), cut-up performance (carcass, breast, legs (thigh + drumstick), wings and remainder). Feed intake in all periods, in both strains and sexes, increased as the level of protein in the diet decreased and then decreased markedly at the lowest levels of protein. Only at 14 days did feed consumption differ between strains and sexes, thus showing significant interaction; in all other cases, feed consumption differed only between the sexes. At 14 days, the response in body weight differed between strain and sex, while in all other samples they differed only between sexes. The response in carcass, breast and wing production at 14 days was the same for both strains and sexes, but differed between strains and sexes at 28 days. At 42 and 56 days, the response differed only between the sexes. The response in the weight of the leg (thigh plus thigh) at 14 days was the same for both strains and sexes, but after that it differed only between the sexes. The body lipid content increased linearly initially and then quadratically as the protein content of the diet was reduced. The economic analysis identified that, based on the current labelled values, the protein content of the diet that maximized the margin over feeding cost was always higher for males than for females and for poultry sold processed in relation to those sold alive. Using lysine as a reference amino acid, the optimum economic in the initial period for males sold live was obtained with a concentration of 12.1 g lysine/kg, and 14.1 g/kg when these birds are sold slaughtered; for females, the equivalent values were 11.3 and 13.7 g/kg, respectively. When the cost of protein-containing ingredients was increased by 25%, or the revenue generated by selling the product reduced by 25%, the ideal economic level of dietary protein increased compared to the base price, this increase being greater for the birds sold alive. The opposite occurred when costs were increased or revenues decreased by 25%. In summary, the economic analysis identified that, depending on the economic scenario, supporting maximum performance may result in economic losses, and that seeking to adjust the dietary protein levels according to the changes in the economic scenario seems to be the most viable strategy for the increased profitability of a broiler production system. In the second experiment, the productive performance and body composition of broiler breeders subjected to 5 levels of balanced protein in two daily amounts of feed offer were evaluated. For this, a total of 200 broiler breeder hens (Ross 308) at 55 weeks of age were randomly assigned to individual cages. The treatments consisted of five different concentrations of balanced protein offered in two daily quantities (150 or 170 g/days) making a completely randomized design allocated in a factorial arrangement with 10 treatments of 20 replicates. There was no interaction ($p > 0.05$) between the amount of feed offered (FA) and the balanced diet protein (BP) for any variable evaluated. Egg production (EP) was not influenced ($p>0.05$) by treatments, but egg weight (EW) and egg mass (EO) increased with BP levels, but were not affected by FA. Body weight gain (BWG) and body protein retention (BPR) also increased with BP, but were not affected by FA, while body fat retention (BFR) increased only with FA. Consequently, the total energy retained in the body (BER) increased with both BP and FA, while the body energy retained as protein (BERp) and fat (BERf) were influenced only by BP and FA, respectively. Total retained energy (TER) also increased with both factors, while total heat production (THP) decreased with BP and increased with FA. Even at the end of the productive life, the broiler breeders are able to maintain their reproductive performance by changing the body composition and consequently affecting the energy partition.

**Keywords**: Amino acids in nutrition, Poultry food and feed, Animal nutrition

unesp UNIVERSIDADE ESTADUAL PAULISTA
"JÚLIO DE MESQUITA FILHO"
Câmpus de Jaboticabal

# CERTIFICADO

Certificamos que o projeto de pesquisa intitulado **"Efeito da proteína balanceada sobre a otimização biológica e econômica em frangos de corte"**, protocolo nº 001592/18, sob a responsabilidade da Prof.ª Dr.ª Nilva Kazue Sakomura, que envolve a produção, manutenção e/ou utilização de animais pertencentes ao Filo Chordata, subfilo Vertebrata (exceto o homem), para fins de pesquisa científica (ou ensino) - encontra-se de acordo com os preceitos da lei nº 11.794, de 08 de outubro de 2008, no decreto 6.899, de 15 de julho de 2009, e com as normas editadas pelo Conselho Nacional de Controle de Experimentação Animal (CONCEA), e foi aprovado pela COMISSÃO DE ÉTICA NO USO DE ANIMAIS (CEUA), da FACULDADE DE CIÊNCIAS AGRÁRIAS E VETERINÁRIAS, UNESP - CÂMPUS DE JABOTICABAL-SP, em reunião ordinária de 08 de fevereiro de 2018.

| | |
|---|---|
| Vigência do Projeto | 02/03/2017 a 02/03/2020 |
| Espécie / Linhagem | *Gallus gallus domesticus* / Cobb 500, Ross 308 |
| Nº de animais | 2.880 |
| Peso / Idade | 45g / 1 dia |
| Sexo | Ambos os sexos |
| Origem | Pluma Agrovícula – Descalvado - SP |

Jaboticabal, 08 de fevereiro de 2018.

Fabiana Pilarski

**Profª Drª Fabiana Pilarski**
Coordenadora – CEUA

UNIVERSIDADE ESTADUAL PAULISTA
"JÚLIO DE MESQUITA FILHO"
Câmpus de Jaboticabal

# CERTIFICADO

Certificamos que o projeto intitulado **"Efeito da ingestão de proteína balanceada sobre o desempenho produtivo e composição corporal de matrizes pesadas"**, protocolo nº 015231/17, sob a responsabilidade da Profª. Drª. Nilva Kazue Sakomura, que envolve a produção, manutenção e/ou utilização de animais pertencentes ao Filo Chordata, subfilo Vertebrata (exceto o homem), para fins de pesquisa científica (ou ensino) - encontra-se de acordo com os preceitos da lei nº 11.794, de 08 de outubro de 2008, no decreto 6.899, de 15 de julho de 2009, e com as normas editadas pelo Conselho Nacional de Controle de Experimentação Animal (CONCEA), e foi aprovado pela COMISSÃO DE ÉTICA NO USO DE ANIMAIS (CEUA), da FACULDADE DE CIÊNCIAS AGRÁRIAS E VETERINÁRIAS, UNESP - CÂMPUS DE JABOTICABAL-SP, em reunião ordinária de 05 de outubro de 2017.

| | |
|---|---|
| Vigência do Projeto | 08/11/2017 a 17/01/2018 |
| Espécie / Linhagem | *Gallus gallus* / Ross e Hubbard |
| Nº de animais | 200 |
| Peso / Idade | 4 kg / 45 semanas |
| Sexo | Fêmeas |
| Origem | Lavinesp – Laboratório de Ciências Avícolas da Unesp |

Jaboticabal, 05 de outubro de 2017.

**Profª Drª Lizandra Amoroso**
Coordenadora – CEUA

Faculdade de Ciências Agrárias e Veterinárias
Via de Acesso Prof. Paulo Donato Castellane, s/n - 14884-900 - Jaboticabal - SP - Brasil
tel 16 3209 2600 fax 3202 4275 www.fcav.unesp.br

# CAPÍTULO 1 – Considerações gerais

## Introdução

A avicultura de corte é uma das atividades mais importantes do setor agropecuário brasileiro. Somente no ano de 2019 o Brasil produziu 13,25 milhões de toneladas de carne de frango, sendo que 32% deste montante foi destinado ao mercado externo (ABPA, 2020). O que torna a atividade estratégica para o desenvolvimento econômico e geração de renda no país.

Ao mesmo tempo, o sucesso da atividade está ligado ao investimento mútuo entre as esferas pública e privada, no intuito de gerar tecnologias que propiciem o aumento da produtividade de forma cada vez mais sustentável. Para isso, pesquisas na área de genética, sanidade, nutrição, dentre outras, são desenvolvidas com o objetivo de proporcionar a continuidade na busca pelo aumento da eficiência e sustentabilidade.

Nesse sentido, a nutrição das aves exerce papel estratégico na busca por melhores índices produtivos, econômicos e ambientais. A proteína por exemplo, é um dos nutrientes mais caros na formulação de dietas para aves, chegando a contribuir com até 45% do custo total da ração (Sakomura e Silva, 1998). Além do elevado preço dos ingredientes proteicos, a preocupação com o desempenho das aves mediante o fornecimento de rações com excesso ou deficiência de aminoácidos induziu à elaboração de rações baseadas no conceito de proteína ideal também chamada de proteína balanceada, cujo princípio é o atendimento das exigências com base na relação ideal entre os aminoácidos essenciais e a lisina. Assim, a formulação de rações focada no balanceamento do teor aminoacídico da dieta permitiu não somente uma redução dos custos de produção, mas também aumentos expressivos na eficiência de utilização da proteína dietética, assim como a redução na excreção de nitrogênio, atenuando os impactos negativos que essa atividade pode causar ao meio ambiente (Donato, et. al., 2016).

Quando nenhum outro fator está limitante, frangos de corte respondem ao aumento de consumo de proteína até alcançar o seu máximo potencial genético

(Eits et al., 2002). Entretanto, para que o máximo desempenho seja obtido é necessário que o perfil aminoacídico da proteína esteja dentro do conceito de proteína ideal evitando assim limitação ou antagonismo entre os aminoácidos da dieta (Sakomura et al., 2014). Já para matrizes de frangos de corte o efeito da proteína balanceada depende da fase de produção em que essa ave se encontra (Ekmay et al. 2003). Sendo que a deposição proteica corporal, principalmente aquela ligada a deposição no peito, não é um fenômeno desejado para essa categoria animal (Silva, 2017).

Estudos de dose resposta permitem estimar o nível ótimo de concentração de um determinado nutriente na ração por meio do ajuste de uma equação de predição, onde a resposta do animal é utilizada como uma variável dependente e o consumo do nutriente como variável independente (Robbins et al., 1979). Por meio dessa metodologia, é possível estimar a concentração proteica ideal da ração de frangos de corte e matrizes pesadas (Eits et al., 2002; Ekmay, 2011; Pesti et al., 2009; Steenhuisen e Gous, 2016), utilizando um modelo matemático com bom ajuste aos dados observados, permitindo que uma estimativa acurada da resposta das aves à ingestão de proteína seja estimada.

Dependendo do mercado onde estão inseridos, os produtores podem contemplar todas as etapas de produção de frangos de corte, indo desde o início da cadeia até a mesa do consumidor, outros entretanto, podem ficar atribuídos por etapas específicas como a produção e entrega de animais vivos as empresas processadoras, isso faz com que as aves possam ser comercializadas em diferentes formas; ave viva, carcaça ou em partes, portanto, a forma de comercialização deve ser levada em consideração na estimativa do o ótimo econômico pois tem impacto sobre a rentabilidade do sistema (Eits et al., 2005b; Kenny et al., 2005). Dessa forma, a predição do rendimento das partes a serem comercializadas é um importante avanço na determinação de um modelo econômico. Estudos sugerem que o crescimento dos diferentes componentes corporais compartilha, muitas vezes, taxas crescimento correlacionadas entre si podendo assim ser estimadas por meio de equação de crescimento relativo, sejam elas alométricas ou isométricas (Danisman e Gous, 2011; Danisman e Gous, 2013; Sakomura et al., 2011). Entretanto, ainda existe a necessidade de predizer o rendimento da carcaça e das partes de frangos de corte alimentados com ração contendo diferentes níveis de proteína balanceada. Já para matrizes pesadas, o fator eclodibilidade entra como uma característica importante na determinação do ótimo econômico, uma vez que, o número de pintainhos viáveis por matriz é a variável de maior importância econômica desse tipo de produção (Silva, 2017). O que torna fatores como produção de ovos e eclodibilidade indispensáveis para o cálculo do ótimo econômico.

Nesse sentido, objetiva-se com o presente estudo determinar os níveis ótimos, biológico e econômico, de suplementação de proteína balanceada para o peso vivo, carcaça e cortes de frangos de corte. Pretende-se ainda, avaliar o efeito da proteína balanceada sobre a composição corporal e performance produtiva em matrizes de frangos em fase final de produção.

## Revisão de literatura

### Importância da proteína balanceada para as aves

As proteínas são moléculas de estruturas diversas, porém, sintetizadas a partir de apenas 20 aminoácidos diferentes, dos quais onze são tidos como essenciais por não serem sintetizados no organismo em velocidade suficiente para atender as necessidades do animal, devendo assim serem fornecidos pela dieta (Bertechini, 2012). No organismo animal, essas moléculas desempenham diversas funções e além de compor a maior parte dos componentes celulares, ainda estão envolvidas em quase todas as reações metabólicas, desde o transporte intercelular, cofatores metabólicos ou até a funções mecânicas como a contração muscular (Marzzoco, 2015).

Na dieta das aves, a proteína deve ser fornecida balanceada de acordo com o conceito de proteína ideal, evitando assim a carência ou excesso de aminoácidos (Wecke e Liebert, 2013). O conceito de proteína ideal considera a relação ideal entre os aminoácidos essenciais e a lisina, no intuito de evitar possíveis antagonismos entre estes e maximizar a eficiência destes na dieta (Sakomura et al., 2014). Este conceito passou a ser utilizado na prática, juntamente com a comercialização dos aminoácidos cristalinos. Anterior ao desenvolvimento do conceito de proteína ideal, a formulação de dietas baseava-se apenas no conceito de proteína bruta para atendimento das exigências nutricionais das aves (Beterchini, 2012), portanto, era necessária a formulação de uma ração com alto teor de proteína bruta com o intuito de atender todos os aminoácidos essenciais. Contudo, essa prática pode reduzir as eficiências produtiva e econômica, por não considerar os efeitos prejudiciais do excesso de nitrogênio da ração e antagônico entre os aminoácidos quando proporcionalmente desbalanceados (Morris et al., 1999; Wu, 2013). De maneira oposta, o fornecimento de proteína balanceada de acordo com o conceito de proteína ideal, tem proporcionado enormes avanços na busca pelo aumento da eficiência produtiva e econômica (Wecke e Liebert, 2013).

Sabe-se que embora a relação aminoacídica ideal possa ser diferente em relação a fase produtiva, esta não se altera em relação ao conteúdo energético e proteico da ração, ou mesmo em relação ao potencial genético de crescimento ou fatores ambientais (Backer, 2003; Rostagno et al., 2017). Contudo, fatores como conteúdo energético, proteico, fatores ambientais, potencial genético e aspectos sanitários podem afetar de maneira relevante as exigências de aminoácidos em termos quantitativos (Rostagno et al., 2017; Sakomura et al., 2014, Wecke e Liebert, 2013). Devendo-se nesses casos, considerar o ajuste dos demais aminoácidos essenciais da dieta para que se mantenha a proporção ideal considerando a mudança na exigência em relação a esses fatores (Rostagno et al., 2017).

Ao mesmo tempo que é evidenciado forte relação entre o conteúdo de proteína balanceada e os índices de desempenho produtivo como ganho de peso diário (Aftab et al., 2009; Kumar et al., 2016) e conversão alimentar (Baker e Ham, 1994; Wijtten et al., 2004; Lemme et al., 2006). A temperatura ambiental ou até mesmo o programa de luz também podem afetar na eficiência de reposta à proteína balanceada (Awad et al., 2014; Mlaba et al., 2015).

De forma semelhante, várias pesquisas têm demonstrado que a proteína quando fornecida de forma balanceada pode afetar os índices de deposição de proteína e gordura na carcaça (Corzo et al., 2002; Mlaba et al., 2015; Kumar et al., 2016), que apresenta relação direta com a eficiência produtiva e econômica.

Também é evidente que a redução de proteína balanceada na dieta reduz os níveis séricos de nitrogênio e, consequentemente, a produção de ácido úrico, ao mesmo tempo que aumenta os níveis de triglicerídeos circulantes (Awad et al., 2014), resultando em uma alteração na excreção de nitrogênio (Kumar et al., 2016). Concomitantemente, pode atuar sobre os coeficientes de alometria de deposição de tecidos na carcaça e nos cortes (Gous, 2014), o que corrobora a ideia da influência da proteína balanceada da dieta sobre a eficiência produtiva e econômica.

Dessa maneira, conhecer o efeito da proteína balanceada em linhagens modernas, e sua influência sobre a composição corporal das matrizes e suas proles é imprescindível para a otimização da eficiência produtiva e econômica dos empreendimentos avícolas.

**Otimização econômica da densidade nutricional**

Apesar das constantes flutuações de mercado, tanto nos preços de venda da ave quanto nos preços de compra dos principais insumos utilizados na produção avícola (Aho, 2020), é comum essas flutuações não serem consideradas para a tomada de decisão dos níveis de proteína e aminoácidos praticados nas dietas de frangos de corte (Cerrate e Corzo, 2019; Gonzalez-Alcorta et al., 1994). Nesse sentido, há uma busca constante pela maximização do ganho de peso, ou a otimização da conversão alimentar, priorizando-se dessa forma a maximização do desempenho biológico mesmo quando uma redução nesse desempenho poderia trazer, em alguns casos específicos, uma maximização do retorno econômico (Cerrate e Corzo, 2019).

Em contraponto, diversos autores têm estudado as diferenças entre buscar o máximo desempenho produtivo ou o máximo desempenho econômico, e perceberam que melhorias substanciais na performance econômica podem ser obtidas se as flutuações do mercado forem consideradas na tomada de decisão da densidade nutricional das dietas (Cerrate e Waldroup, 2009a, 2009b; Eits et al., 2005b; Gonçalves et al., 2015; Gonzalez-Alcorta et al., 1994; Guevara et al., 2004; Waller, 2007; Pack et al., 2003; Pesti et al., 2009; Talpaz et al., 1986; Vendenov e Pesti, 2010)

Para tal aplicação, é importante o nutriente em questão tenha forte impacto sobre o custo da ração e, consequentemente, sobre o custo de alimentação. Nesse sentido, a proteína e os aminoácidos da dieta são pontos chave na otimização, pois compreende parte importante no custo da dieta de frangos de corte (Eits et al., 2005b; Sakmoura et al., 1998).

É sabido que a ingestão de proteína dietética exerce grande influência sobre o crescimento e rendimento dos principais cortes das aves (Eits et al., 2005a) e, consequentemente, sobre a eficiência produtiva e econômica dos empreendimentos avícolas (Gous et al., 2006). Dessa forma, a elaboração de modelos que visem não somente a otimização biológica, mas também a otimização econômica da ingestão desse nutriente é uma ferramenta imprescindível para promover melhorias econômicas a para esses empreendimentos (Eits et al., 2005b). Ao mesmo tempo, um programa alimentar que busque a otimização econômica deve levar em consideração, no mínimo, a maximização da margem de lucro sobre o custo de alimentação promovido pelo aumento ou redução da concentração do nutriente na dieta (Sakomura e Rostagno, 2016), considerando também que essa margem pode ser alterada de acordo com o produto a ser comercializado – ave viva, carcaça ou cortes (Gous e Berhe, 2006, Eits et al., 2005b).

Dessa forma, um modelo de otimização baseado em proteína balanceada deve ponderar a mudança no custo da ração conforme o conteúdo aminoácidos essenciais da dieta é alterado, assim como o retorno econômico observado por essa alteração (Eits et al., 2005b; Basurco et al., 2015), o que por sua vez dependerá da forma de comercialização da ave.

Levando em consideração que o ótimo econômico é o ponto onde a margem de lucro sobre o custo de alimentação é maximizada (Cerrate e Waldroup, 2009a; Eits et al., 2005b; Kemp et al., 2005), e que as variações do mercado exercem forte impacto sobre esse ponto, é possível entender que várias são as metodologias que podem ser utilizadas para proceder esse cálculo (Kay et al., 2016). Dentre elas, a que tende a ser mais utilizada nos trabalhos publicados na área da avicultura é a que retoma de forma simples a diferença entre o retorno econômico e o custo de alimentação (Cerrate e Waldroup, 2009a, 2009b; Eits et al., 2005b; Gonçalves et al.,2015; Gonzalez-Alcorta et al., 1994; Guevara et al., 2004; Waller, 2007) sendo calculado por meio da diferença entre o retorno e o custo:

MCA ($/ave) = *Retorno (*$/av*e) - custo de alimentação (*$/ave*)*

Onde, MCA é a margem sobre o custo de alimentação; o *retorno* é calculado pela multiplicação do peso estimado pelo preço/kg recebido pela venda do produto:

Retorno ($/ave) = *Peso da ave* (kg*)* * *Preço de venda* ($/kg)

E o custo de alimentação ($/ave) é obtido pela multiplicação do consumo das aves (kg) em determinado nível do nutriente, pelo preço da ração naquele nível ($/kg):

Custo de alimentação ($/ave) = *Consumo de ração* (kg*)* * *Preço da ração* ($/kg)

Por esse método, o ótimo econômico é estimado no ponto onde a margem entre o retorno econômico e o custo de alimentação é maximizado, como pode ser observado na Figura 1.

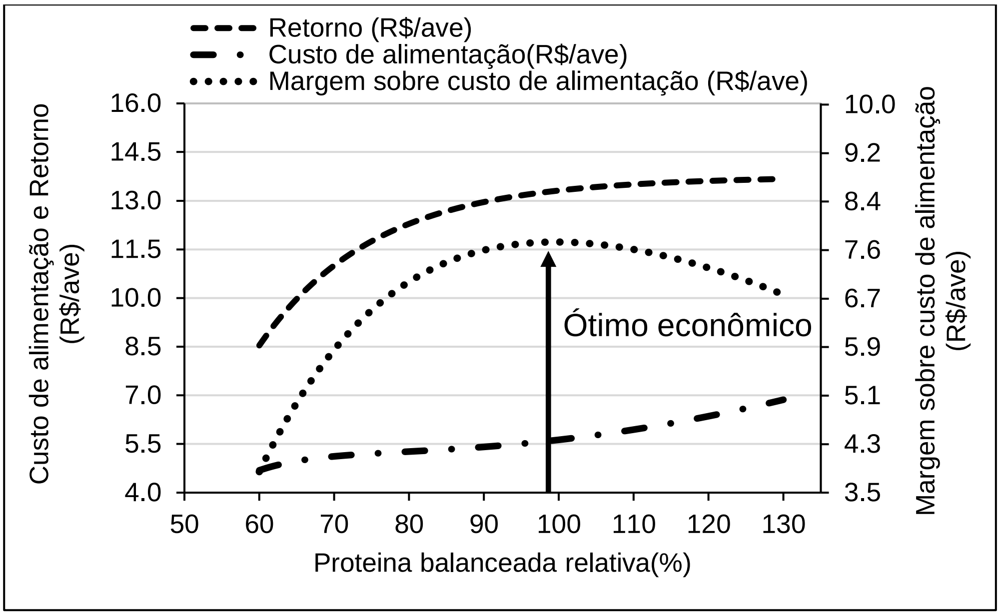


Figura 1 – Exemplo de ótimo econômico sendo calculado pela diferença entre o retorno econômico e o custo de alimentação

Outra forma bastante comum de calcular o ponto de ótimo econômico é por meio dos retornos marginais (Kay et al., 2016; Pack et al., 2003; Pesti et al., 2009; Talpaz et al., 1986; Vendenov e Pesti, 2010;), que utiliza a teoria dos mínimos retornos para estimar o ponto onde o uso de determinado recurso (nutriente) maximiza o retorno econômico (Talpaz et al., 1986). Por essa metodologia, é entendido que a rentabilidade de um sistema melhora até o ponto onde o custo marginal supera o retorno marginal, dessa forma, enquanto o retorno marginal (RM) é maior que o custo marginal (CM) o aumento da produção aumenta o lucro, isso porque a receita adicional excede o custo adicional de produzi-la. Por outro lado, se o retorno marginal for menor que custo marginal, o aumento da produção diminuirá o lucro. Por essa metodologia, o ponto de ótimo econômico é, portanto, aquele onde a receita marginal é igual ao custo marginal (Kay et al., 2016) como pode ser visto na Figura 2.

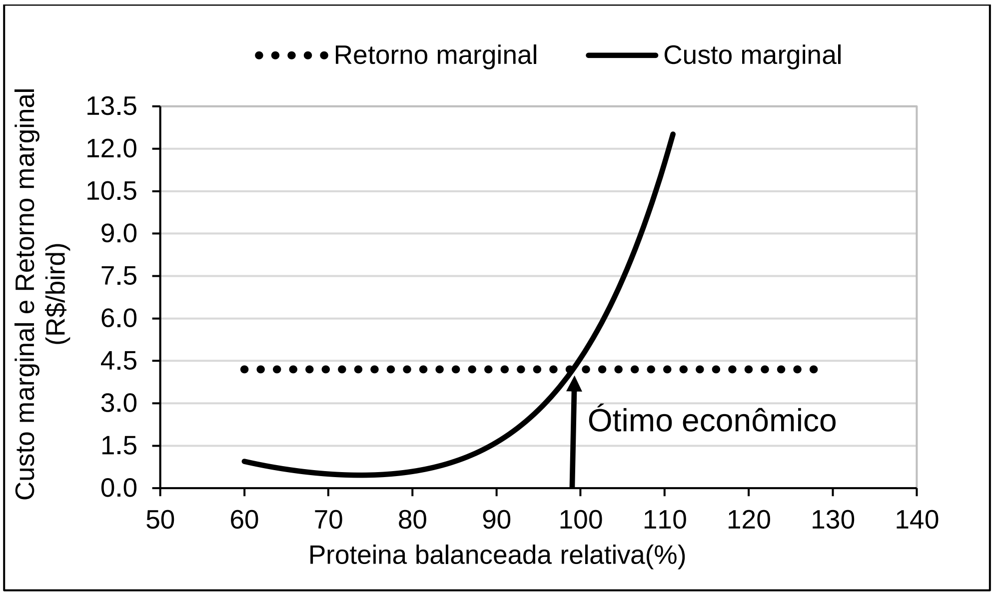


Figura 2 - Exemplo do ótimo econômico sendo calculado pela lei dos mínimos retornos

Apesar das diferentes formas de se proceder esse tipo de otimização, não é esperado haver diferenças entre as estimativas de ótimo econômico independentemente da metodologia que se opte para proceder o cálculo. Sendo essas estimativas ligadas apenas as respostas da ave a aos fatores mercadológicos.

O ponto que talvez seja mais interessante na metodologia da otimização econômica é a ideia de que a exigência da ave pode ser visto como um valor que varia de acordo com as flutuações de mercado, sendo a interação entre a resposta da ave e as variáveis de mercado os fatores determinantes da concentração nutricional aplicado na prática (Gous, 2014). Dessa forma, vários trabalhos têm avaliado os impactos das flutuações do mercado e da resposta da ave sobre o ponto de ótimo econômico (Cerrate e Corzo, 2019). Muitos deles têm relatado haver grandes diferenças entre as exigências para maximização da resposta biológica, e àquela que deveria ser praticada para maximizar a resposta econômica. Segundo Eits et al. (2005) o nível ideal de proteína balanceada que maximiza o retorno econômico de frangos de corte vendidos vivos é cerca de 10% menor que o nível ideal para maximizar o retorno econômico das aves vendidas processadas em forma de corte. Essa diferença aumenta para 14,6% se o preço de venda dos cortes aumentar em 40%. De forma semelhante Pack et al. (2003) também relataram haver diferença de 10% entre o nível ideal de lisina para maximizar o retorno econômico de frangos de corte vendidos vivos e àquele para maximizar o retorno econômico pela venda do peito. Esses autores também observam que o nível ideal de treonina para máximo lucro diminui apenas 3% mesmo quando o aumento do preço do L-aminoácido aumenta em cerca de 35%. Cerrate e Waldroup, (2009b) estimaram que há um aumento de cerca de 3% no nível ideal de proteína balanceada para máximo retorno econômico quando o preço de venda das aves aumentou 25%, sendo que esse aumento melhorou a margem de lucro em 36%. Por outro lado, quando o preço de venda das aves diminuiu 25%, o nível ideal de proteína balanceada para máximo retorno diminuiu 3,29% demonstrando que, não considerar as flutuações do mercado na tomada de decisão do nível ótimo de aminoácidos e/ou proteína que serão praticados na ração poderia implicar em uma piora, ou no mínimo uma perda de oportunidade de ganhos econômicos dos empreendimentos avícolas. Sendo assim, o entendimento do ponto ótimo biológico e econômico em relação ao consumo de proteína balanceada é relevante devido ao fato de se obter maior flexibilidade no momento da tomada decisão sobre a nutrição de frangos de corte, permitindo uma nutrição mais dinâmica, tornando-se cada vez mais uma ferramenta indispensável a empreendimentos que buscam melhorias de rentabilidade.

**Composição corporal na vida produtiva de matrizes pesadas**

A constante busca do aumento da produtividade por meio do melhoramento genético em frangos de corte tem sido um fator de sucesso dentro da avicultura industrial. Por meio dessa ferramenta, tem-se alcançado ganhos expressivos na eficiência alimentar e rendimento de corte dessas aves (Silva, 2017).

Com essas mudanças, é visto que a composição corporal desses animais também tem mudando com o passar dos anos, aumentando seus potencias de deposição proteica e diminuindo sua capacidade de deposição lipídica (Havenstein et al., 2003a; Havenstein et al., 2003b)

Por outro lado, apesar dessas características serem desejáveis e, portanto, selecionados para frangos de corte, para matrizes pesadas, essa alta deposição de proteína juntamente com uma menor deposição de gordura pode ser um problema a depender da fase de produção (Ekmay, 2011; Silva, 2017). Uma vez que, o aumento do tecido proteico corporal gera um aumento na exigência de energia para sustenta-lo, o que possibilita muitas vezes o desvio de energia que deveria ser utilizada para produção de ovos para a mantença desse tecido proteico (Ekmay, 2013). Cenário que pode ser ainda pior em aves com quantidades de reservas lipídicas corporais reduzidas, dado que as reservas de lipídicas corporais são capazes de sustentar a produção de ovos por alguns dias mesmo em casos onde a ingestão de energia é muito menor que a necessária para manter a produção (Nonis e Gous, 2012). O que ressalta a ideia de haver um conflito de interesses entre o que é desejado geneticamente para as matrizes e aquilo que é desejado para suas proles, tornando ainda mais desafiador o trabalho dos nutricionistas dessa categoria animal.

É visto que, matrizes pesadas em início de período reprodutivo, por volta das 22 semanas de vida, apresentam maior rendimento de músculo de peito em relação a idades mais avançadas (Van-Emous et al., 2015) sendo que quando estas entram em pico de produção há uma tendência de aumento na taxa degradação de proteína do *Pectoralis major* (Caldas et al., 2018; Vignale et al., 2016), o que ampara a ideia de que essas aves se utilizam do turnover proteico corporal para sustentar a produção de ovos (Caldas et al., 2018). Sendo que esse mecanismo fica ainda mais importante em momentos de pico de produção. Mas parecendo continuar durante toda a vida reprodutiva da ave, uma vez que ao final da fase produtiva, que ocorre por volta das 60 semanas de idade, há um menor rendimento de peito em comparação as fazes anteriores (Van-Emous et al., 2015).

A ideia de que as aves mobilizam reservas corporais proteicas para dar sustentação a produção de ovos não é nova, nesse sentido alguns autores como Nonis e Gous, (2016) ressaltam ainda que como o conteúdo proteico corporal dessas aves continuam relativamente estáveis durante a fase de postura, não seria obrigatório considerar a exigência para esse tipo de deposição em aves dessa categoria. Porém, em trabalho recente Caldas et al. (2018) encontraram evidências de que ao final da vida produtiva, matrizes pesadas aumentaram a deposição de proteína corporal enquanto reduziam as reservas lipídicas, como pode ser visto na Figura 3 abaixo:

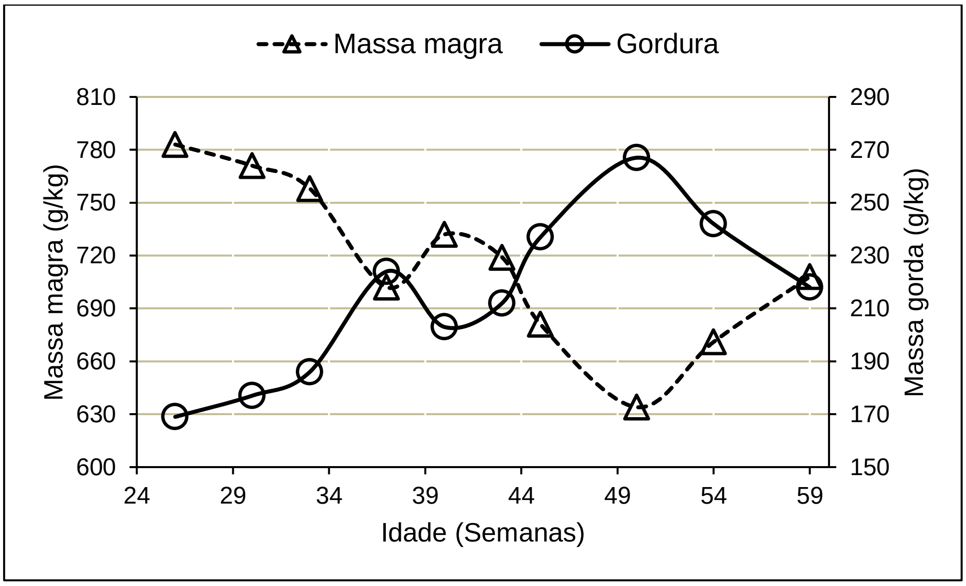


Figura 3 - Deposição de tecidos corporais em matrizes pesadas de 25 a 59 semanas (Adaptado de Caldas et al., 2018)

Esse comportamento, segundo os autores poderia estar relacionado a diminuição da taxa de postura também observada nessa fase, indicando que em situações como essa o excesso de proteína na dieta poderia está sendo desviado para a deposição proteica, uma vez que a demanda para deposição em ovo é diminuída pela menor produção. Esses resultados são um indicativo de que, embora as exigências para crescimento proteico corporal não sejam tão importantes em fase de pico de produção, seria importante considera-las a partir do momento em que as aves começam a diminuir a produção. Isso porque, um aumento da deposição de carne magra no corpo nessa fase pode ter um efeito negativo tanto do ponto de vista biológico quanto do ponto de vista econômico; primeiro que essas aves estarão chegando em fase de descarte, e o aumento desse tipo de tecido terá pouca utilidade para suporte da produção de ovos, como seria comum em pico de postura; segundo porque isso pode significar um aumento na energia de mantença para sustentar esse aumento de tecido o que poderia desviar energia da produção de ovos (Ekmay et al., 2013); terceiro porque excesso de proteína pode aumentar o número de ovos maiores que 65g o que está ligado a menor eclodibilidade (Shafey, 2002). Além disso, alguns resultados demonstram que, apresar de a redução proteica ter efeito negativo sobre a produção de ovos da reprodutora, pode ter efeito positivo sobre o desempenho das proles (Lessuise et al., 2017).

Todos esses resultados indicam que a nutrição de matrizes de frangos de corte em fase final de produção apresenta fatores intrínsecos que a diferem das fases anteriores. Além do mais, caso essa possibilidade de redução proteica na dieta se confirme, seria possível se obter ganhos expressivos do ponto de vista econômico.

**Referências bibliográficas**

ABPA (2020) **Relatório anual 2020**. Disponível em: http://abpa-br.org/relatorios/

Aftab U (2009) Response of Broilers to Practical Diets with Different Metabolizable Energy and Balanced. **Brazilian Archives of Biology and Technology** 11: 169-174.

Aho P (2020) **Fast or Slow Return to Normal?** Aviagen, 3 p. (Aviagen. Broiler economics vol. 28)

Awad EA, Fadlullah M, Zulkifli I, Farjam AS, Chwen LT (2014) Amino acids fortification of low-protein diet for broilers under tropical climate: ideal essential amino acids profile. **Italian Journal of Animal Science** 13: 270-274.

Baker DH, Han Y (1994) Ideal amino acid profile for chicks during the first three weeks post-hatching. **Poultry Science** 73: 1441-1447.

Baker DH (Eds. 2) (2003) Ideal Amino Acid Patterns for Broiler Chicks. In: D'Mello JPF. **Amino acids in animal nutrition**. Edinburgh: CABI Publishing, p.187-202.

Bertechini AG (2012) Nutrição de monogátricos. Lavras: UFLA, 392 p.

Basurco V, Vieira SL, Serafini NC, Santiago GO, Angel CR, Gonzalez-Esquerra R (2015) Performance and economic evaluation of feeding programs varying in energy and protein densities for broiler grillers. **Applied poultry research** 24: 304-315.

Caldas JV, Hilton K, Boonsinchai N, England JA, Mauromoustakos A, Coon CN (2018) Dynamics of nutrient utilization, heat production, and body composition in broiler breeder hens during egg production. **Poultry Science** 97: 2845-2853.

Cerrate S, Waldroup PW (2009a) Maximum profit feed formulation of broilers: 1 Development of a feeding program model to predict profitability using non-linear programming. **International Journal of Poultry Science** 8: 205-215.

Cerrate S, Waldroup PW (2009b) Maximum profit feed formulation of broilers: 2 Comparison among different nutritional models**. International Journal of Poultry Science** 8: 216-228.

Cerrate S, Corzo A (2019) Lysine and Energy Trends in Feeding Modern Commercial Broilers. **International Journal of Poultry Science** 18: 28-38.

Corzo A, Moran ET, Hoehler D (2002) Lysine need of heavy broiler males applying the ideal protein concept. **Poultry Science** 81: 1863-1868.

Danisman R, Gous RM (2011) Effect of dietary protein on the allometric relationships between some carcass portions and body protein in three broiler strains. **South African Journal of Animal Science** 41: 194-208.

Danisman R, Gous RM (2013) Effect of dietary protein on performance of four broiler strains and on the allometric relationships between carcass portions and body protein. **South African Journal of Animal Science** 43: 25-37.

Donato DCZ, Sakomura NK, Silva EP, Troni AR, Vargas L, Guanoni MAN, Meda B (2016) Manipulation of dietary methionine + cysteine and threonine in broilers signi fi cantly decreases environmental nitrogen excretion. **Animal** 10: 903-910.

Eits RM, Kwakkel RP, Verstegen MWA, Stoutjesdijk P, Greef KH de (2002) protein and lipid deposition rates in male broiler chickens: separate responses to amino acids and protein-free energy. **Poultry Science** 81: 472-480.

Eits RM, Kwakkel RP, Verstegen MWA, den Hartog LA (2005a) Dietary balanced protein in broiler chickens. 1. A flexible and practical tool to predict dose-response curves. **British Poultry Science** 46: 300-309.

Eits RM, Giesen G, Kwakkel RP, Verstegen m w a, Hartog LADEN (2005b) Dietary balanced protein in broiler chickens .2. An economic analysis. **British poutry science** 46: 310-317.

Ekmay RD (2011) **Protein utilization and requirements in broiler breeders**. 186 f. Tese (Doctor of Philosophy in Poultry Science) – University of Arkansas, Fayetteville.

Ekmay RD, Beer M de, Mei SJ, Manangi M, Coon CN (2013) Amino acid requirements of broiler breeders at peak production for egg mass, body weight, and fertility. **Poultry Science** 92: 992-1006.

Gonçalves CAI, Almeida MA, Faria-Júnior MJA, Pinto MF, Garcia-Neto M (2015) Accuracy of nonlinear formulation of broiler diets: maximizing profits. **Brazilian Journal of Poultry Science** 17: 173-180.

Gonzalez-Alcorta MJ, Dorfman JH, Pesti GM (1994) Maximizing profit in broiler production as prices change: A simple approximation with practical value. **Agribusiness** 10: 389-399.

Gous RM, Morris TR, Fisher, C (Eds.) (2006) Mechanistic modelling in pig and poultry production. Wallingford: CAB International, 331p.

Gous RM (2014) Modelling as a research tool in poultry science. **Poultry Science** 93: 1-7.

Gous RM, Berhe ET (2006) Modelling Populations for Purposes of Optimization. In.: Gous RM, Morris TR, Fisher C (Eds.) **Mechanistic modelling in pig and poultry production**, Cambridge: CABI Publishing, p. 76-96.

Guevara VR (2004) Use of nonlinear programming to optimize performance response. **Poultry Science** 83: 147-151.

Havenstein GB, Ferket PR, Qureshi MA (2003a) Growth, liveability, and feed conversion of 1957 versus 2001 broilers when fed representative 1957 and 2001 broiler diets. **Poultry Science** 82: 1500-1508.

Havenstein GB, Ferket PR, Qureshi MA (2003b) Carcass composition and yield of 1957 versus 2001 broilers when fed representative 1957 and 2001 broiler diets. **Poultry Science** 82: 1509-1518.

Kemp C, Fisher C, Kenny M (2005) Genotype-nutrition interactions in broilers; response to balanced protein in two commercial strains. In: 15th EUROPEAN SYMPOSIUM ON POULTRY NUTRITION, **Anais**… Balatonfüred: CABI, p. 54-56.

Kenny M, Kemp C, Fisher C (2005) What protein levels will maximise margin? **International Poultry Production** 12: 11-17.

Key DR, Edwards MW, Duffy A P (Eds.8) (2015) Farm management, New York: McGraw-Hill, 466p.

Kumar CB, Gloridoss RG, Singh KC, Prabhu TM, Suresh BN (2016) Performance of broiler chickens fed low protein, limiting amino acid supplemented diets formulated either on total or standardized ileal digestible amino acid basis. **Asian-Australasian Journal of Animal Sciences** 29: 1616-1624.

Lesuisse J, Li C, Schallier S, Leblois J, Everaert N, Buyse J (2017) Feeding broiler breeders a reduced balanced protein diet during the rearing and laying period impairs reproductive performance but enhances broiler offspring performance. **Poultry Science** 1: 1-11.

Marzzoco A, Torres BB (2015) Bioquímica básica. Rio de Janeiro: Guanabara Koogan, 404p.

Mlaba PP, Ciacciariello M, Gous RM (2015) The effect of dietary protein on breast meat yield of broilers reared on different daylengths. **South African Journal of Animal Science** 45: 39-48.

Morris TR, Gous RM, Fisher C (1999) An analysis of the hypothesis that amino acid requirements for chicks should be stated as a proportion of dietary protein. world's poultry science journal 55: 1-22.

Nonis MK, Gous RM (2012) Broiler breeders utilise body lipid as an energy source. **South African Journal of Animal Science** 42: 369-378

Nonis MK, Gous RM (2016) Changes in the feather-free body of broiler breeder hens after sexual maturity. **Animal Production Science** 56: 1099-1104.

Pack M, Hoehler D, Lemme A (2003) Economic assessment of amino acid responses in growing poultry. In.: D’Mello JBF (Eds.2) **Amino acids in animal nutrition.** Edinburgh, CABI Publishing, p. 459-316.

Pesti GM, Vedenov D, Cason JA, Billard L (2009) A comparison of methods to estimate nutritional requirements from experimental data. **British Poultry Science** 50: 16-32

Robbins KR, Norton HW, Baker DH (1979) Estimation of nutrient requirements from growth data. **The Journal of Nutrition** 109: 1710-1714.

Rostagno HS, Albino LFT, Hannas MI, Donzele JL, Sakomura NK, Costa FGP (Eds. 4) (2017) Tabelas brasileiras para aves e suínos, Viçosa: UFV, 488p.

SAKOMURA, N.K.; SILVA, R (1998) Conceitos aplicáveis à nutrição de não ruminantes. **Cadernos Técnicos da Escola de Veterinária da UFMG** 22: 125-146.

Sakomura NK, Gous RM, Marcato SM, Fernandes JBK (2011) A description of the growth of the major body components of 2 broiler chicken strains. **Poultry Science** 90: 2888-2896.

Sakomura NK, Rostagno HS (Eds.) (2007) Métodos de pesquisa em nutrição de monogásticos, Jaboticabal: Funep, 262p.

Sakomura NK, Silva JHV, Costa FGP, Fernandez JB, Hauschild L (Eds.) (2014) Nutrição de não-ruminantes, Jaboticabal: Funep, 678p.

Shafey TM (2002) Effects of egg size and eggshell conductance on hatchability traits of meat and layer breeder flocks. **Asian- Australian Journal Animal Science** 15: 1-6.

Silva M (2017) **Alimentação das matrizes pesadas modernas: uma abordagem holística**. Sul América: Aviagen, 16p. (Aviagen, Tech Notes).

Steenhuisen E, Gous RM (2016) The response of broiler breeder hens to dietary balanced protein. **South African Journal of Animal Science** 46: 269-277.

Talpaz H, De-La-Torre JR, Sharpe PJH, Hurwitz S (1986) Dynamic optimization model for feeding of broilers. **Agricultural Systems** 20: 121-132.

Van-Emous RA, Kwakkel RP, van Krimpen MM, Hendriks WH (2015) Effects of dietary protein levels during rearing and dietary energy levels during lay on body composition and reproduction in broiler breeder females. **Poultry Science** 92: 2091-2100.

Vedenov D, Pesti GM (2010) An economic analysis of a methionine source comparison response model. **Poultry Science** 89: 2514-2520.

Vignale K, Caldas J v, England JA, Boonsinchai N, Sodsee P, Putsakum M, Pollock ED, Dridi S, Coon CN (2016) The effect of four different feeding regimens from rearing period to sexual maturity on breast muscle protein turnover in broiler breeder parent stock. **Poultry Science** 96: 1219-1227.

Waller A (2007) **Economic Approach to Broiler Production**. Europe: Aviagen, 4p. (Aviagen, Tech Notes).

Wecke C, Liebert F (2013) Improving the reliability of optimal in-feed amino acid ratios based on individual amino acid efficiency data from n balance studies in growing chicken. **Animals** 3: 558-573.

Wijtten PJA, Prak R, Lemme A, Langhout DJ (2004) Effect of different dietary ideal protein concentrations on broiler performance**. British poutry science** 45: 504-511.

Wu G (Eds.) (2013) Amino acids – biochemistry and nutrition, Boca Raton: Taylor & Francis Group, 458p.

**CAPÍTULO 2 - Response of broilers to dietary balanced protein 1. Feed intake and growth**

Este capítulo foi submetido e está de acordo com as normas da **Animal Production Science**

# RESPONSE OF BROILERS TO DIETARY BALANCED PROTEIN 1. FEED INTAKE AND GROWTH

Jefferson Moraes Azevedo[1], Matheus de Paula Reis[1], Robert M. Gous[2], Juliano César de Paula Dorigam[3], Bruno Balbino Leme[1], Nilva Kazue Sakomura[1]

[1]Universidade Estadual Paulista (Unesp), Faculdade de Ciências Agrárias e Veterinárias, Jaboticabal, São Paulo, Brazil.

[2] School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, South Africa.

[3]Evonik Nutrition & Care GmbH, Rodenbacher Chaussee 4, 63457 Hanau-Wolfgang, Germany.

**ABSTRACT**

The objective of this study was to describe the response of male and female broilers of two commercial strains to a range of dietary balanced protein levels. A total of 2,496 sexed chicks (equal numbers of Ross 308 and Cobb 500) were used. Six dietary balanced protein levels x two strains x two sexes (24 treatments) were randomly allocated to 96 floor pens, using four replications of 26 chicks each. Feed intake, body weight, feed conversion efficiency (FCE), carcass weight and the weights of breast without skin, thigh plus drum (leg) and wing were measured at 14, 28, 42 and 56 days of age. Feed intake in all periods in both strains and sexes increased as the dietary balanced protein level decreased, and then decreased markedly at the lowest balanced protein levels. Only at 14 d did the responses differ between strains and sexes; in all other cases the responses differed only between sexes. At 14 d the response in body weight differed between strains and sex whilst at all other samplings they differed only between sexes. The response in carcass, breast and wing yield at 14 d was the same for both strains and sexes, but differed between strains and sexes at 28 d. At 42 and 56 d the response differed only between sexes. The response in leg (thigh-plus-drum) weight at 14 d was the same for both strains and sexes but thereafter differed between sexes only. Body lipid content increased linearly initially and then quadratically as dietary protein content was reduced. Appropriate equations are presented for describing the above responses, and these could be used to calculate the optimum economic level of balanced protein to be used under different economic circumstances.

**Keywords**: Body weight, feed intake, breast weight, leg weight, body lipid content

## INTRODUCTION

The decision as to the optimum amount of dietary balanced protein to feed to commercial broilers should be based on both biology and economics. Broiler genotypes are constantly changing due to the selection pressures applied by geneticists, as are the relative costs of protein-containing ingredients and the revenue derived from the sale of product. Whereas linear programming is used to formulate feeds at minimum cost (Cerrate and Waldroup, 2009a) this does not necessarily produce feeds that will maximise profitability on the farm: to do so, account must be taken of the response expected of the broilers being fed the resultant feeds, the cost of feeding and the revenue expected from the sale of the birds (Eits *et al*., 2005b; Cerrate and Waldroup, 2009b; Gous, 2014b). Estimation of the optimum economic levels of balanced protein to include in such feeds requires knowledge of the response of each breed and sex to a range of dietary protein contents.

Conventionally, experiments dealing with responses of broilers to protein or to limiting amino acids have been designed to determine the amino acid level or intake that maximizes growth or feed efficiency (Pack *et al*., 2003; Vedenov and Pesti, 2010) without considering marginal costs and revenue, in spite of this concept being proposed long ago (Fisher *et al*., 1973; Clark *et al*., 1982). Ideally, the response of broilers to balanced amino acid mixtures (balanced protein) should be measured (Eits *et al*., 2005b) from which the relevant calculations can be made to determine the optimum economic levels to be used under different circumstances.

As dietary balanced protein content is reduced, changes will occur in feed intake, in body weight gain and in carcass composition, all of which will influence the resultant costs and returns. Feed intake will increase as the balanced protein level is reduced since birds will try to consume sufficient to enable them to grow at their potential (Emmans, 1981; Gous *et al*., 1990) but as the balanced protein level is decreased further, feed intake will be constrained and a reduction in growth will occur, reducing revenue. Furthermore, as these responses are likely to differ between strains and sexes (Marcu *et al*., 2013), it is of value to measure the responses of broilers of different strains and sexes.

As broilers are sold in different ways (live, processed, cut-up and further-processed) and at different ages and body weights in different parts of the world, valuable information can be gained by sampling birds at different ages to measure the weight of carcass and saleable body parts resulting from the feeding of a range of balanced protein contents. We hypothesized that the response of male and female broilers of different strains to a range of dietary balanced protein contents would differ and hence the optimum economic dietary balanced protein level would need to be calculated separately for each.

The objective of this study was to describe the response of broiler chickens to balanced protein and to demonstrate differences between strain and sexes at different ages of slaughter, from which calculations could be made to determine the optimum economic levels of balanced protein to be used under different circumstances.

## MATERIALS AND METHODS

The study was performed in accordance with the Ethical Committee on the Use of Animals of the São Paulo State University (UNESP), School of Agricultural and Veterinarian Sciences, Jaboticabal (Process 001592/2018; approved at 08/02/2018).

*Bird husbandry and experimental design*

The trial was conducted at the Poultry Science Laboratory of Sao Paulo State University (UNESP), School of Agricultural and Veterinarian Sciences. Two thousand four hundred and ninety six day-old broilers, obtained from a commercial hatchery, were used in the trial that continued to 56 days of age. Two strains were used, namely, Ross 308 (1,248 chicks) and Cobb 500 (1,248 chicks), equally divided between females and males within each strain. A total of 24 treatments was randomly distributed in 96 experimental units, being four replicates of 26 birds each. The treatments were designed as a factorial (6 x 2 x 2), making use of six balanced protein levels, two strains, and two sexes.

At the start (day 0) birds were individually weighed and distributed in floor pens (experimental unit), containing wood shavings, nipple drinkers, and tubular feeders. They had free access to water and feed throughout the experimental period. Exhaust fans and pad cooling were used to maintain the temperature, humidity and air renewal automatically, as per breeder guidelines (Ross 308, 2018, Cobb 500, 2019). Lighting was continuous until 7 d of age and a 12L:12D cycle was used thereafter. Chicks were vaccinated at hatching against Mareks and Gumboro disease, at 12 d they were vaccinated against Newcastle disease (via drinking water) and at 16 d against Gumboro disease (via drinking water).

*Experimental diets*

Six levels of balanced protein were designed using the dilution technique of Fisher and Morris (1970). A low- and a high-protein basal diet was formulated (Table 1) to contain 5.3 and 17.9 g digestible lysine (dLys)/kg, respectively, each feed containing 13.2 MJ ME/kg. The amino acid balance used, which was the same in both basal feeds, was that recommended by Rostagno *et al*. (2017), as were the major and minor mineral contents, and energy. The sequential dilution of the high protein basal with the low protein basal produced a range of balanced protein levels from 0.60 to 1.30 of the recommended level for dLys. The feeding programme was divided into four two-week phases (1 to 14, 15 to 28, 29 to 42, and 43 to 56 d), with dietary balanced protein levels being reduced in each subsequent period but with the same relative difference between levels being maintained (Table 2).

[Tables 1 and 2 near here]

Before feed processing, the ingredients corn, soybean meal, soy protein concentrate, and wheat were analyzed for amino acid and crude protein content, using near-infrared spectroscopy (NIR). Feeds were formulated based on digestible amino acid contents using the digestibility coefficient from Brazilian Tables for Poultry and Swine (Rostagno *et al*., 2017). After blending, each diet was sampled for amino acid quantification using high-performance liquid chromatography (HPLC).

*Data collection*

At the beginning and end of each phase, birds and feed were weighed for the measurements of body weight gain and feed intake. Mortality was verified daily to correct feed intake and calculate feed conversion efficiency (FCE). At the end of each phase, two birds per pen were randomly selected for the evaluation of carcass yield, according to Sakomura and Rostagno (2017). After 12 hr of fasting the sampled birds were weighed and euthanized followed by bleeding. The feathers, viscera, feet, and head were removed and the carcass was weighed. Carcass yield was calculated as the ratio of carcass to live body weight. Breast without skin, thigh plus drum (leg) and wing were individually weighed after which all the parts from each bird were stored in plastic bags at -20 °C for further processing. The frozen body (viscera, feet, head, blood, and cuts) was milled using an industrial grinder, homogenized, weighed and frozen at -80 °C for subsequent pre-drying. Samples of approximately 100 g were freeze-dried over 72 hours at -80 °C and -10 ATM (Edwards SuperModulo, Thermo Fisher Scientific, Waltham, MA), weighed and milled using a micro-grinder. Fat was extracted in an AnkomXT15 (ANKOM Technology, Macedon, NY) fat extractor (AOAC method 920.39) using petroleum ether as a solvent.

*Statistical analysis*

The main aim of this study was to produce equations describing the response of broilers to balanced protein that could be used to calculate feeding costs and revenue generated from the sale of the whole bird, the eviscerated carcass or from the sale of the individual parts. It was expected that some equations might be common to males or females of each strain whilst others would be specific to each strain and sex. To test whether the responses differed between strains and/or sexes, non-linear regression with groups (GenStat, VSN International 2017) was used, the groups being strain and sex.

Responses were described for four cumulative stages of growth, corresponding to the feeding periods used, namely, 1 to 14, 1 to 28, 1 to 42 and 1 to 56 d, using two exponential models:

Exponential model (EM), $y=A + B * (R^x)$, where A + B is the y-intercept, R is the exponential base, and x is the level of balanced protein as a proportion of requirement.

Exponential curve with non-horizontal asymptote or Line plus exponential (LPE), $y=A_1 + B_1 * (R^x) + C * x$ where $A_1$ and C are the y-intercept and slope of the linear segment, respectively. $B_1$ is the y-intercept of the exponential segment and R is the exponential base.

The Akaike information criterion (AIC) (Akaike, 1974) was used to choose the appropriate model: that with the lower AIC value was used to describe the response variable.

Treatment means were determined using ANOVA (GenStat, VSN International 2017).

## RESULTS

The analysed contents of amino acids and crude protein in the diet were in agreement with calculated values (Table 1).

The mean performance (body weight, feed intake and FCE) of male and female broilers of the two strains used in the trial, to 14, 28, 42 and 56 d, is given in Table 3. Feed intake and body weight both increased with dietary protein content and then decreased at the highest levels of protein. These responses are illustrated in Fig. 1.

With just two exceptions (Ross males and females at 42 d), FCE improved with dietary protein content.

[Table 3 near here]

[Figure 1 near here]

The line plus exponential equation best fitted the responses in feed intake to dietary balanced protein content (Table 4). Only in the first period (14 d) was there a significant three-way interaction between balanced protein level, strain and sex, with the term A in the equation differing for each strain and sex. In this first period the remaining coefficients differed between the sexes but, as with all periods thereafter, the sexes within each strain exhibited the same response to dietary balanced protein so separate equations were required only for each sex within each period.

[Table 4 near here]

With respect to body weight, the responses in the first period differed considerably from those in later periods (Table 4). The line plus exponential equation best fitted the data to 14 d, and separate A, B and C coefficients were required to predict the body weight of males and females of each strain, with the R coefficient being the same for all combinations of strain and sex. In the three subsequent periods the exponential asymptote equation best fitted the data, in all cases with the A and B coefficients differing between sexes only, and the R coefficient being common to all combinations of strain and sex.

Body lipid content of birds on the various treatments at the end of each phase of growth is given in Table 3. The leanest birds in all cases were those fed the highest protein feed, with the fattest birds being those on either the lowest or second-lowest balanced protein level. In the first two periods, as dietary balanced protein content increased the lipid content in both males and females decreased linearly, and at the same rate, with females being fatter than their male counterparts (Table 5). In the periods ending at 42 and 56 d a significant quadratic response was evident, with responses being parallel, but with a different constant term, in the two sexes.

[Table 5 near here]

The mean weights of carcasses after evisceration, of birds on the feed treatments at the four ages at which measurements were taken, are given in Table 6. As with body weight, carcass weight increased with dietary balanced protein content and then decreased in most cases on the feed with the highest balanced protein content. At 14 d, one 4-parameter equation common to both strains and sexes adequately described the response to dietary protein, whereas at 28 days four separate equations were needed, one for each combination of strain and sex. The goodness of fit improved considerably in this period compared with that at 14 d ($R^2$ of 95.7 *vs*. 62.4). In the final two periods separate equations were needed for the two sexes, but no differences were evident between strains within a sex.

[Table 6 near here]

Mean breast weight, thigh and drum weight, and wing weight for the various treatments at the four periods of measurement are given in Table 6. As with mean body weight, the weights of these components all increased with dietary balanced protein content and reached a peak on, or just below the feed with the highest protein content. At 14 d the responses to dietary balanced protein did not differ between strains or sexes (Table 7) so single equations could be used to predict the weight of these three components on any given level of dietary balanced protein, At 28 d, breast weight and wing weight differed between strains and sexes necessitating four separate equations to be used in each case to predict the weight of these components. Leg weight differed only between sexes, resulting in two separate equations being required. By 42 d no differences could be detected between strains within each sex, thus for all three components, separate equations were required only for each sex at both 42 and 56 d.

[Table 7 near here]

**DISCUSSION**

The major objective of this study was to describe the response to dietary balanced protein of males and females of two current commercial strains of broiler. The variables of particular interest were those needed for calculating feeding cost and revenue at different stages of growth, thus feed intake, body weight, and the yield of the more important parts that generate income for the producer, at 14, 28, 42 and 56 d were measured. It was assumed that the responses would differ between strains and sexes so separate equations were initially generated for each strain x sex and then these were compared to determine whether a common equation could be used instead.

In choosing the amino acid balance to be used in the trial feeds, and the level of these amino acids to be regarded as ‘the requirement’, i.e. the proportion 1.0, consideration was given to the range of amino acid-to-lysine ratios that have been published in the literature for such a purpose, and to the lysine levels recommended for broilers of different ages. Such ratios have been published by Rostagno *et al*.

(2017), Mack *et al*. (1999), Cobb (2018) and Aviagen (2019), among others. As would be expected, these ratios vary widely between authors, as shown in Table 8. The ratios chosen for this trial (Rostagno *et al*., 2017) fall well within the range in both the early and later stages of growth, as indicated in the table. The extent to which the different ratios would influence the results of such a study would arguably be considerably less than the range of balanced protein levels chosen here, and it is unlikely that the shape of the response curves would have changed had a different set of amino acid-to-lysine ratios been used given the relatively small differences between publications. Conversely, the dietary lysine content chosen (Rostagno *et al*., 2017) to represent 'the requirement' (13.8 g/kg) is higher than those suggested by Aviagen (2019) (12.8 g/kg) and by Cobb (2018) (12.2 g/kg). When viewing the responses to balanced protein presented here, these differences should be borne in mind, as the 'requirement' chosen would represent 1.08 times the Aviagen recommendation and 1.13 times that of Cobb.

[Table 8 near here]

The central tenet of the theory of feed intake regulation by Emmans (1981) is that birds will attempt to meet their requirement for the first-limiting nutrient in the feed offered and may be prevented from doing so if constrained by the prevailing effective temperature or gut capacity. Also important is the ability of the bird to store excess energy consumed as body lipid (Gous *et al*., 1990; Gous, 2010; 2014b) resulting in differences in the rate at which feed intake may be increased as the limiting nutrient content is reduced, as illustrated by Kemp *et al*. (2005). In support of this hypothesis, in all periods, feed intake increased and then decreased as the balanced protein content was reduced, similar to the response reported by Eits *et al*.

(2005), the highest intake occurring at either 0.85 or 0.70 of the recommended level (Fig. 1). This refutes the conventional wisdom that birds ‘eat to satisfy an energy requirement’ (Leeson *et al*., 1996; Veldkamp *et al*., 2005) which implies that dietary protein will have no influence on food intake. For an accurate prediction of the feeding cost it is imperative to predict feed intake on different levels of balanced protein.

Differences between genotypes and sexes in feed intake and body weight were evident at 14 d but the genotypes thereafter responded similarly to dietary protein resulting in only two equations being required (for males and females) to describe these responses. The genetic potential of the Cobb and Ross strains have recently been described (Gonçalves *et al*., 2020; Vargas *et al*., 2020), with the Cobb strain reportedly being the more precocious. Differences in performance between strains appeared to diminish as the broilers aged. At the later stages of growth the reduction in food intake on the lowest dietary protein level among females was considerably less than that in males (Fig. 1). It is likely that this is the result of the greater ability of females to fatten (Gous *et al*., 1990; Gous, 2010; Gonçalves *et al*., 2019) enabling them to overconsume energy to a greater extent than males in their attempt to consume sufficient of the first-limiting nutrient in the feed. The same difference in the rate of decline in feed intake below the maximum was evident at 56 d between males of the Ross and Cobb strains, with Cobb males being able to consume more than Ross males (7556 vs. 7063 g on the lowest protein feed), suggesting that they have a greater propensity to fatten. This is consistent with observations by Kemp *et al*. (2005). The Cobb strain was numerically fatter in both sexes on the lowest protein feed offered (Table 3).

Up to the age of 14 d, each strain and sex responded differently in body weight to the balanced protein level in the feed (Tables 3 and 4). Nevertheless, the highest body weight was achieved in all cases on the base (1.00) level of dietary protein. As the birds aged, and differences between strains within each sex disappeared, the heaviest male body weights were achieved on the protein level 1.15 times the base level whilst the heaviest females continued to be those fed the base level. The amino acid levels at which maximum body weight is achieved, especially in males, are considerably higher than those recommended by Aviagen (2019) and Cobb (2018).

Whereas FCE was highest in almost all cases on the highest dietary protein content offered this does not mean that maximum profit would be achieved on this feed. This would apply also to body weight, where it may not in all cases be economically justifiable to feed broilers to maximise body weight at an age. Consideration must be taken of the cost of feeding the birds, i.e. feed cost x amount consumed, and the value of the returns from the sale of the product. Revenue from the sale of product will depend on what is being sold (live or dressed birds, carcass portions or meat) and the value of these products.

Where birds are sold dressed it is the carcass weight that is of interest, and in this exercise the response in carcass weight did not follow that in body weight in the early period of growth. At 14 d only one equation was required to describe the response in carcass weight whereas four were needed to describe the response in body weight, and at 28 d, where the response in body weight was described using separate equations for males and females, separate equations were required for each strain x sex when describing carcass weight at that age. At the two later sampling periods, separate equations were required only for the two sexes for both body and carcass weight, although at 56 d the description of carcass weight required an additional coefficient in the exponential equation (Table 4). To predict carcass weight, therefore, the equations given in Table 4 would be more accurate than using a fixed proportion of body weight over all ages, strains and sexes.

Consumer demand for poultry products differ throughout the world, as do the costs of the different products. Statistics by the National Chicken Council (2020) indicate that in 1962 83% of broilers in the U.S. were sold whole, 15% were sold cut-up or as parts, and 2% were sold further processed. They forecast that in 2015 this would have changed to 11, 40 and 49%, respectively. Consumer preferences even within a given country change over time. It is useful, therefore, to be able to predict the weights of the different parts such that the revenue generated for the sale of parts can be estimated under different circumstances. In this exercise the breast, leg (thigh plus drum) and wing were separated from the carcass and weighed, and the equations presented in Table 6 enable the weights of these parts, at different ages, for different levels of dietary balanced protein and for the two sexes, to be predicted.

In most broiler markets the consumer does not differentiate between carcasses of different levels of fatness, unlike the pork industry where pig carcasses are graded by back fat thickness and carcass muscling (American Meat Science Association, 2020). However, this may change in the future if consumers discriminate against fat carcasses, so it is useful to have a means of determining the effect of dietary protein content on carcass fatness, hence the inclusion of equations for such predictions in Table 5. When consumers are prepared to pay more for a lean broiler carcass this factor will need to be considered when determining the optimum economic level of protein to use in broiler feeds.

In conclusion, males and females of the two broiler strains evaluated here differed in their response to balanced protein throughout the 56-d experimental period, these differences being of a greater magnitude than those between strains. The changes that occurred with balanced protein content could be ascribed mainly to the effect of balanced protein on feed intake, demonstrating the importance of being able to predict feed intake if changes in body weight and carcass composition are to be predicted. Appropriate equations have been presented that describe the responses of the variables measured in this trial such that calculations may be made of the optimum economic level of balanced protein to use under different economic circumstances.

## REFERENCES

Akaike H, (1974) A new look at the statistical model identification. *IEEE Transactions on Automatic Control* **19**, 716-723.

American Meat Science Association (2020) Pork quality [Online]. Available at: https://meatscience.org/TheMeatWeEat/topics/fresh-meat/grades-of-meat. (Verified 5 July, 2020)

AVIAGEN (2019) Ross Broiler Nutrition Specifications [Online]. Available at: http://eu.aviagen.com/assets/Tech_Center/Ross_Broiler/RossBroilerNutritionSpecs2019-EN.pdf. (Verified 5 July, 2020)

Cerrate S, Waldroup PW (2009a) Maximum profit feed formulation of broilers: 1 Development of a feeding program model to predict profitability using non-linear programming. *International Journal of Poultry Science* **8**, 205-215.

Cerrate S, Waldroup PW (2009b) Maximum profit feed formulation of broilers: 2 Comparison among different nutritional models. *International Journal of Poultry Science* **8**, 216-228.

Clark FA, Gous RM, Morris TR (2015) Response of broiler chickens to well - balanced protein mixtures well-balanced protein mixtures. *British Poultry Science* **1668**, 433-446. doi:10.1080/00071688208447976.

COBB (2018) Cobb 500 Broiler performance and nutrition supplement [Online]. Available at: https://cobbstorage.blob.core.windows.net/guides/3914ccf0-6500-11e8-9602-256ac3ce03b1. (Verified 5 July, 2020)

Corzo A, Kidd MT, Burnham DJ, Miller ER, Branton SL, Gonzalez-Esquerra R (2005) Dietary Amino Acid Density Effects on Growth and Carcass of Broilers Differing in Strain Cross and Sex 1. *Journal of Applied Poultry Science* **14**, 1-9.

Danisman R, Gous RM (2011) Effect of dietary protein on the allometric relationships between some carcass portions and body protein in three broiler strains. *South African Journal of Animal Science* **41**, 194-208.

Danisman R, Gous RM (2013) Effect of dietary protein on performance of four broiler strains and on the allometric relationships between carcass portions and body protein. *South African Journal of Animal Science* **43**, 25-37.

EFG Software (2020) EFG Broiler Growth Model [Online]. Available at: https://www.efgsoftware.net. (Verified 5 July, 2020)

Eits RM, Giesen G, Kwakkel RP, Verstegen MWA, Den-Hartog LA (2005) Dietary balanced protein in broiler chickens . 2. An economic analysis. *British Poultry Science* **46**, 310-317. doi:10.1080/00071660500126482.

Emmans GC (1981) A model of the growth and feed intake of ad libitum fed animals, particularly poultry. *Computers in Animal Production* **103**, 103-110.

Fisher C, Morris TR (1970) The determination of the methionine requirement of laying pullets by a diet dilution technique. *British Poultry Science* **2**, 67-82. doi:10.1080/00071667008415793.

Fisher C, Morris TR, Jennings RC (1973) A model for the description and pre-diction of the response of laying hens to amino acid intake. *British Poultry Science* **14**, 469-484. doi:10.1080/00071667308416054.

Gonçalves CA, Sakomura NK, Pereira Da Silva E, Artoni SMB, Suzuki RM, Gous RM (2019) Dual energy X-ray absorptiometry is a valid tool for assessing in vivo body composition of broilers. *Animal Production Science* **59**, 993-1000. doi:10.1071/AN17637.

Gous RM, Emmans GC, Broadbent LA, Fisher C (1990) Nutritional effects on the growth and fatness of broilers. *British Poultry Science* **31**, 495-505. doi:10.1080/00071669008417281.

Gous RM (2010) Nutritional limitations on growth and development in poultry. *Livestock Science* **130**, 25-32. doi:10.1016/j.livsci.2010.02.007.

Gous RM, Emmans GC, Fisher C (2012) The performance of broilers on a feed depends on the feed protein content given previously. *South African Journal of Animal Science* **42**, 63-73 doi:http://dx.doi.org/10.4314/sajas.v42i1.8.

Gous RM (2014a) Modeling as a research tool in poultry science. *Poultry Science* **93**, 1-7. doi:http://dx.doi.org/10.3382/ps.2013-03466.

Gous RM (2014b) A model to optimize broiler productivity In 'Nutritional Modelling in Pigs and Poultry'. (Eds NK Sakomura, RM Gous, I Kyriazakis, L Hauschild) pp. 175-187. (CABI: Wallingford)

Kemp C, Fisher C, Kenny M (2005) Genotype-nutrition interactions in broilers; response to balanced protein in two commercial strains. In "Proc. 15th Eur. Symp. Poult. Nutr.", Balatonfüred, Hungary. (Balatonfüred, Hungary)

Leeson S, Caston L, Summers JD (1996) Broiler response to diet energy. *Poultry Science* **75**, 529-535. doi:10.3382/ps.0750529.

Mack S, Bercovici D, Groote GDE, Leclercq B, Lippens M, Pack M, Schutte JB, Van-Cauwenberghe S (1999) Ideal amino acid profile and dietary lysine specification for broiler chickens of 20 to 40 days of age Ideal amino acid profile and dietary lysine specification for broiler chickens of 20 to 40 days of age. *British Poultry Science* 40, 257-265. doi:10.1080/00071669987683.

Marcu A, Vacaru-opri I, Dumitrescu G, Petculescu L, Marcu A, Nicula M, Pe I, Dronca D, Kelciov B, Mari C (2013) The Influence of Genetics on Economic Efficiency of Broiler Chickens Growth. *Animal Science and Biotechnologies* **46**, 339-346.

National Chicken Council (2020) How broilers are marketed [Online]. Available at: https://www.nationalchickencouncil.org/about-the-industry/statistics/how-broilers-are-marketed/ (Verified 5 July, 2020)

Pack M, Hoehler D, Lemme A (2003) Economic assessment of amino acid responses in growing poultry. “Amino acids Animal Nutrition” (Eds JBF D’Mello) p. 459-316. (CABI Publishing: Edinburgh)

Rostagno HS, Albino LFT, Hannas MI, Donzele JL, Sakomura NK, Costa FGP (Eds) (2017) ‘Brazilian tables for poultry and swine’ (Eds). (UFV: Viçosa)

Sakomura NK, Rostagno HS (Eds) (2016) ‘Métodos de Pesquisa em Nutrição de Monogástricos’ (Funep: Jaboticabal)

Sigolo S, Deldar E, Seidavi A, Bouyeh M, Prandini A (2019) Effects of dietary surpluses of methionine and lysine on growth performance, blood serum parameters, immune responses, and carcass traits of broilers serum parameters, immune responses, and carcass traits of broilers. *Journal of Applied Animal Research* **47**, 146-153. doi:10.1080/09712119.2019.1583571.

Sterling KG, Pesti GM, Bakalli RI (2006) Performance of Different Broiler Genotypes Fed Diets with Varying Levels of Dietary Crude Protein and Lysine. *Poultry Science* **85**, 1045-1054.

Taschetto D, Vieira SL, Angel R, Favero A, Cruz RA (2012) Responses of Cobb x Cobb 500 slow feathering broilers to feeding programs with increasing amino acid densities. *Livestock Science* **146**, 183-188. doi:10.1016/j.livsci.2012.03.013.

Vargas L, Sakomura NK, Leme BB, Antayhua F, Reis M, Gous R, Fisher C (2020) A description of the potential growth and body composition of two commercial broiler strains. *British Poultry Science* **4**, 454-4640. doi:10.1080/00071668.2020.1716300.

Vedenov D, Pesti GM (2010) An economic analysis of a methionine source comparison response model. *Poultry Science* **89**, 2514-2520. doi:10.3382/ps.2010-00640.

Veldkamp T, Kwakkel R, Ferket P, Kogut J, Verstegen M (2003) Growth responses to dietary lysine at high and low ambient temperature in male turkeys. *Poultry Science* **84**, 273-282. doi:10.1093/ps/82.11.1733.

VSN International (2017) Genstat 17th edition (VSN Ltd: Hemel Hempstead)

Table 1. Ingredient and nutrient composition in the low and high balanced protein feeds.

| Ingredient | Low protein basal (g/kg) | High protein basal (g/kg) |
|---|---|---|
| Corn (78.8 g CP/kg) | 680 | 417 |
| Wheat Bran-Middlings | 150 | - |
| Soybean Meal (450 g CP/kg) | 53.0 | 302 |
| Soy Protein Concentrate (600 g CP/kg) | - | 159 |
| Potassium chloride | 2.90 | - |
| Soybean oil | 52.7 | 73.3 |
| Dicalcium phosphate | 18.8 | 17.6 |
| Limestone | 10.2 | 9.01 |
| Salt | 1.19 | 3.80 |
| Sodium Bicarbonate | 5.00 | 1.00 |
| Vitamin and mineral premix[a] | 2.00 | 2.00 |
| DL-Methionine 990 | 0.70 | 6.05 |
| L-Lysine HCl 780 | 2.51 | 4.42 |
| L-Threonine 980 | 0.28 | 2.43 |
| L-Valine 990 | - | 2.02 |
| Choline chloride 600 | 1.00 | 1.00 |
| Inert filler | 20.0 | - |
| TOTAL | 1000 | 1000 |
| | Composition (g/kg)[b] | |
| MEn (MJ/kg)[c] | 13.2 | 13.2 |
| Crude protein | 104 (112) | 280 (282) |
| Lysine dig. | 5.3 (6.0) | 17.9 (18.9) |
| Methionine dig. | 2.3 (2.6) | 9.6 (9.2) |
| Met + Cys dig. | 3.9 (4.7) | 13.3 (13.2) |
| Threonine dig. | 3.5 (3.9) | 11.8 (12.3) |
| Tryptophan dig. | 1.0 (-) | 3.2 (-) |
| Arginine dig. | 5.4 (5.8) | 19.0 (18.9) |
| Isoleucine dig. | 3.2 (3.6) | 11.2 (12.1) |
| Leucine dig. | 8.9 (9.6) | 20.8 (22.2) |
| Histidine dig. | 2.5 (2.6) | 6.8 (7.1) |
| Phe + Tyr dig. | 7.1 (-) | 22.1 (-) |
| Valine dig. | 4.1 (4.9) | 13.8 (14.7) |

[a]Content/kg of premix: beta-carotene = 6.34 mcg retinol activity equivalent; cholecalciferol = 63.86 mcg; alpha-tocopherol = 14.87 mg; menadione = 1.8 mg; thiamine = 2.00 mg; riboflavin = 4.50mg; pyridoxine = 2.50 mg; folate = 2.00 mg; Niacin = 30.00 mg; Calcium Pantothenate = 11.74 mg; Folic Acid = 0.75 mg; Biotin = 0.01 mg; Iron = 43.44 mg; Copper = 8.56 mg; Manganese = 56.0 mg; Zinc = 43.45 mg; Iodine = 0.56 mg; Selenium = 0.34 mg.

[b]Values inside parentheses refer to crude protein (CP) and amino acid analysed.

cNitrogen-corrected apparent metabolizable energy.

**Table 2.** Proportions of high and low protein basal feeds used for each dietary treatment and feeding phase, and the resultant digestible lysine (g/kg) and protein (g/kg) contents

| Period | Proportions of basal diets and resulting dietary levels | Treatment number and proportion of recommendation | | | | | |
|---|---|---|---|---|---|---|---|
| | | T1 (0.60) [a] | T2 (0.70) | T3 (0.85) | T4 (1.00) | T5 (1.15) | T6 (1.30) |
| 1-14 | High protein | 0.24 | 0.35 | 0.51 | 0.67 | 0.84 | 1.00 |
| | Low protein | 0.76 | 0.65 | 0.49 | 0.33 | 0.16 | 0.00 |
| | Lysine dig. (g/kg) | 8.27 (8.86) | 9.65 (10.5) | 11.7 (13.2) | 13.8 (14.9) | 15.9 (16.7) | 17.9 (19.0) |
| | Protein (g/kg) | 146 (150) | 165 (167) | 194 (199) | 223 (223) | 252 (254) | 280 (282) |
| 15-28 | High protein | 0.11 | 0.21 | 0.37 | 0.52 | 0.67 | 0.83 |
| | Low protein | 0.89 | 0.79 | 0.63 | 0.48 | 0.33 | 0.17 |
| | Lysine dig. (g/kg) | 6.65 (7.20) | 7.95 (8.21) | 9.90 (10.1) | 11.9 (12.6) | 13.8 (14.3) | 15.8 (17.0) |
| | Protein (g/kg) | 123 (13.1) | 141 (14.3) | 168 (17.1) | 196 (19.6) | 223 (22.6) | 250 (25.1) |
| 29-42 | High protein | 0.04 | 0.13 | 0.26 | 0.4 | 0.54 | 0.67 |
| | Low protein | 0.96 | 0.87 | 0.74 | 0.6 | 0.46 | 0.33 |
| | Lysine dig. (g/kg) | 5.73 (6.46) | 6.88 (6.95) | 8.61 (8.75) | 10.3 (11.4) | 12.1 (12.1) | 13.8 (14.0) |
| | Protein (g/kg) | 110 (117) | 126 (132) | 150 (158) | 174 (178) | 199 (202) | 223 (227) |
| 43-56 | High protein | 0.00 | 0.09 | 0.21 | 0.34 | 0.47 | 0.6 |
| | Low protein | 1.00 | 0.91 | 0.79 | 0.66 | 0.53 | 0.4 |
| | Lysine dig. (g/kg) | 5.28 (6.04) | 6.36 (6.74) | 7.97 (8.06) | 9.58 (10.3) | 11.2 (11.8) | 12.8 (13.6) |
| | Protein (g/kg) | 104 (112) | 119 (127) | 141 (144) | 164 (167) | 186 (191) | 209 (215) |

[a] Digestible lysine content as a proportion of that recommended by Rostagno et al. (2017)

[b] Values between parentheses refer to total lysine analysed

[c] Values between parentheses refer to total protein analysed

Table 3. Mean feed intake (g), body weight (g), feed conversion efficiency (g feed/kg gain) and body lipid content (g/kg) of male (M) and female (F) broilers of Cobb and Ross strains, at 14, 28, 42 and 56 d, fed a range of balanced protein (BP) feeds

| | 1 to 14 | | | | 1 to 28 | | | | 1 to 42 | | | | 1 to 56 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ross | | Cobb | | Ross | | Cobb | | Ross | | Cobb | | Ross | | Cobb | |
| BP[a] | M | F | M | F | M | F | M | F | M | F | M | F | M | F | M | F |
| Feed intake (g) | | | | | | | | | | | | | | | | |
| 0.60 | 462 | 460 | 534 | 478 | 1932 | 1855 | 2116 | 1985 | 4316 | 4128 | 4544 | 4210 | 7063 | 6526 | 7556 | 6564 |
| 0.70 | 489 | 482 | 567 | 492 | 2157 | 2046 | 2341 | 2037 | 4986 | 4450 | 5061 | 4318 | 8471 | 6992 | 8162 | 6738 |
| 0.85 | 505 | 459 | 562 | 531 | 2218 | 1914 | 2379 | 2094 | 5012 | 4357 | 5224 | 4406 | 8614 | 7067 | 8484 | 7029 |
| 1.00 | 477 | 465 | 550 | 509 | 2130 | 1947 | 2271 | 2034 | 4961 | 4346 | 5037 | 4256 | 8366 | 6901 | 8054 | 6733 |
| 1.15 | 463 | 442 | 508 | 494 | 2098 | 1832 | 2200 | 1935 | 4924 | 4113 | 5011 | 4177 | 8286 | 6695 | 8020 | 6403 |
| 1.30 | 430 | 434 | 497 | 458 | 1992 | 1827 | 2121 | 1858 | 4756 | 4106 | 4783 | 4011 | 7887 | 6488 | 7453 | 6258 |
| RMSE[b] | 19.7 | | | | 51.7 | | | | 103 | | | | 225 | | | |
| Body weight (g) | | | | | | | | | | | | | | | | |
| 0.60 | 403 | 418 | 454 | 416 | 1032 | 1014 | 1144 | 1104 | 2027 | 1934 | 2180 | 2034 | 3086 | 2911 | 3426 | 2962 |
| 0.70 | 452 | 464 | 519 | 460 | 1288 | 1237 | 1415 | 1237 | 2649 | 2321 | 2666 | 2261 | 4142 | 3399 | 4022 | 3329 |
| 0.85 | 502 | 478 | 546 | 519 | 1506 | 1310 | 1604 | 1380 | 2998 | 2540 | 3078 | 2555 | 4640 | 3764 | 4548 | 3715 |
| 1.00 | 509 | 498 | 556 | 525 | 1579 | 1411 | 1669 | 1416 | 3115 | 2672 | 3200 | 2639 | 4801 | 3816 | 4602 | 3809 |
| 1.15 | 507 | 487 | 526 | 522 | 1632 | 1378 | 1648 | 1426 | 3336 | 2695 | 3278 | 2632 | 4847 | 3806 | 4695 | 3701 |
| 1.30 | 483 | 487 | 525 | 495 | 1599 | 1403 | 1659 | 1409 | 3208 | 2680 | 3197 | 2610 | 4789 | 3837 | 4564 | 3721 |
| | 17.2 | | | | 41.8 | | | | 84.6 | | | | 159 | | | |
| FCE[c] (g gain/kg feed) | | | | | | | | | | | | | | | | |
| 0.60 | 764 | 800 | 757 | 766 | 511 | 521 | 521 | 535 | 459 | 458 | 471 | 473 | 430 | 439 | 448 | 445 |
| 0.70 | 822 | 859 | 827 | 833 | 576 | 582 | 587 | 587 | 522 | 511 | 519 | 514 | 484 | 480 | 488 | 488 |
| 0.85 | 895 | 932 | 883 | 883 | 658 | 647 | 657 | 639 | 589 | 572 | 582 | 571 | 533 | 526 | 531 | 523 |
| 1.00 | 962 | 963 | 920 | 933 | 720 | 701 | 717 | 676 | 619 | 604 | 627 | 611 | 568 | 547 | 567 | 560 |
| 1.15 | 987 | 989 | 937 | 955 | 756 | 727 | 730 | 716 | 668 | 644 | 646 | 621 | 579 | 562 | 580 | 572 |
| 1.30 | 1007 | 1007 | 956 | 972 | 780 | 742 | 763 | 736 | 665 | 641 | 660 | 640 | 601 | 585 | 607 | 588 |
| RMSE | 22.6 | | | | 11.2 | | | | 12.9 | | | | 15.2 | | | |
| Body lipid content (g/kg) | | | | | | | | | | | | | | | | |
| 0.60 | 84.4 | 110 | 106 | 123 | 155 | 170 | 166 | 188 | 178 | 198 | 173 | 197 | 212 | 232 | 221 | 248 |
| 0.70 | 92.9 | 99.1 | 102 | 117 | 156 | 180 | 170 | 168 | 160 | 178 | 164 | 185 | 190 | 214 | 199 | 217 |
| 0.85 | 85.7 | 100 | 95.2 | 100 | 122 | 141 | 132 | 137 | 142 | 159 | 140 | 161 | 138 | 166 | 154 | 165 |
| 1.00 | 76.6 | 80.3 | 104 | 91.4 | 99.4 | 116 | 108 | 119 | 113 | 122 | 114 | 119 | 129 | 137 | 125 | 136 |
| 1.15 | 69 | 67.8 | 83.7 | 70.9 | 71.1 | 82 | 84.3 | 89.8 | 88.4 | 95.7 | 90.3 | 105 | 98.4 | 139 | 99.7 | 136 |
| 1.30 | 64.2 | 63.7 | 66.7 | 70.7 | 60 | 74.8 | 60.9 | 75.2 | 85.1 | 84.3 | 85.7 | 80.5 | 86.7 | 126 | 84.4 | 135 |
| RMSE | 6.4 | | | | 14.9 | | | | 35.1 | | | | 66.1 | | | |

[a] Balanced protein content as a proportion of that recommended by Rostagno et al. (2017) [b] Root mean square error, [c] Feed conversion efficiency

Table 4. Coefficients of relevant exponential equations [a, b] for predicting mean feed intake (g), body weight (g) and carcass weight of male and female Cobb and Ross broilers at 14, 28, 42 and 56d in response to dietary balanced protein (BP)[c]

| Age | | Feed intake | | | | Body weight | | | | Carcass weight | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Male | | Female | | Male | | Female | | Male | | Female | |
| | | Ross | Cobb | Ross | Cobb | Ross | Cobb | Ross | Cobb | Ross | Cobb | Ross | Cobb |
| 14 | A | 671 | 736 | 657 | 694 | 776 | 850 | 628 | 803 | 445 | | | |
| | B | -3097 | | -3097 | | -2293 | -2425 | -2328 | -1357 | -3642 | | | |
| | C | -180 | | -180 | | -243 | -219 | -209 | -102 | -94.2 | | | |
| | R | 0.003 | | 0.003 | | 0.0242 | | | | 0.0035 | | | |
| | $R^2$ | 95.7 | | | | 95.7 | | | | 62.4 | | | |
| 28 | A | 2754 | | 2426 | | 1646 | | 1416 | | 1450 | 1194 | 1269 | 1190 |
| | B | -6.40E+05 | | -3.40E+05 | | -3.90E+04 | | -2.40E+04 | | -12384 | -7917 | -12022 | -9157 |
| | C | -534 | | -456 | | | | | | -198 | -132 | -61.3 | -139 |
| | R | 4.70E-06 | | | | 8.67E-04 | | | | 5.58E-03 | | | |
| | $R^2$ | 73.1 | | | | 93.2 | | | | 95.7 | | | |
| 42 | A | 5821 | | 5113 | | 3266 | | 2679 | | 2482 | | 2027 | |
| | B | -1.22E+06 | | -6.25E+05 | | -5.78E+04 | | -3.49E+04 | | -47080 | | -29412 | |
| | C | -788 | | -821 | | | | | | | | | |
| | R | 5.08E-06 | | | | 1.49E-03 | | | | 1.58E-03 | | | |
| | $R^2$ | 97.2 | | | | 95.8 | | | | 96.0 | | | |
| 56 | A | 10543 | | 8360 | | 4758 | | 3799 | | 5064 | | 3908 | |
| | B | -6.80E+05 | | -3.20E+05 | | -2.31E+05 | | -1.34E+05 | | -36809 | | -23353 | |
| | C | -2177 | | -1536 | | | | | | -1028 | | -732.3 | |
| | R | 5.66E-05 | | | | 2.29E-04 | | | | 8.02E-03 | | | |
| | $R^2$ | 88.5 | | | | 92.9 | | | | 93.2 | | | |

[a] exponential asymptote, A+B*(RBP).

[b] line plus exponential, A+B*(RBP)+C*BP.

[c] BP content is given as a proportion of that recommended by Rostagno et al. (2017).

Table 5. Coefficients of relevant linear or quadratic equations for predicting body lipid content (g/kg) of male and female Cobb and Ross broilers at 14, 28, 42 and 56 d in response to dietary balanced protein (BP)[a]

| Term | 14 d | 28 d | 42 d | 56 d |
|---|---|---|---|---|
| Constant | 190 | 303 | 366 | 542 |
| BP linear | -0.885 | -1.724 | -2.88 | -6.019 |
| BP quadratic | - | - | 0.0062 | 0.0233 |
| Sex M | -36.3 | -13.4 | -14.5 | -28.9 |
| BP lin x Sex M | 0.305 | - | - | - |
| $R^2$ | 66.8 | 91.7 | 93.4 | 86.8 |

[a] Balanced protein content as a proportion of that recommended by Rostagno et al. (2017).

Table 6. Mean weights of carcass and cut-up parts of male (M) and female (F) broilers of Cobb and Ross strains, at 14, 28, 42 and 56 d, fed increasing levels of balanced protein (BP)

| | 1 to 14 | | | | 1 to 28 | | | | 1 to 42 | | | | 1 to 56 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ross | | Cobb | | Ross | | Cobb | | Ross | | Cobb | | Ross | | Cobb | |
| BP[a] | M | F | M | F | M | F | M | F | M | F | M | F | M | F | M | F |
| Carcass weight (g) | | | | | | | | | | | | | | | | |
| 0.60 | 248 | 263 | 286 | 268 | 654 | 609 | 722 | 710 | 1339 | 1350 | 1379 | 1348 | 2274 | 2076 | 2458 | 2196 |
| 0.70 | 300 | 296 | 337 | 298 | 838 | 826 | 913 | 809 | 1788 | 1598 | 1831 | 1573 | 2875 | 2483 | 2877 | 2430 |
| 0.85 | 329 | 313 | 367 | 339 | 979 | 876 | 1061 | 902 | 2101 | 1811 | 2196 | 1801 | 3295 | 2804 | 3432 | 2619 |
| 1.00 | 330 | 323 | 366 | 339 | 1049 | 964 | 1110 | 968 | 2245 | 1866 | 2238 | 1755 | 3590 | 2693 | 3331 | 2731 |
| 1.15 | 325 | 315 | 329 | 331 | 1104 | 893 | 1085 | 979 | 2306 | 1844 | 2285 | 1841 | 3634 | 2799 | 3507 | 2664 |
| 1.30 | 316 | 310 | 339 | 325 | 1075 | 959 | 1105 | 934 | 2356 | 1904 | 2277 | 1787 | 3365 | 2689 | 3266 | 2607 |
| RMSE[b] | 13.3 | | | | 46.5 | | | | 89.5 | | | | 132 | | | |
| Breast weight (g) | | | | | | | | | | | | | | | | |
| 0.60 | 72 | 77 | 78 | 75 | 201 | 182 | 224 | 217 | 397 | 408 | 415 | 396 | 656 | 645 | 791 | 680 |
| 0.70 | 96 | 90 | 101 | 91 | 256 | 272 | 294 | 251 | 577 | 526 | 594 | 509 | 940 | 849 | 962 | 801 |
| 0.85 | 106 | 97 | 115 | 105 | 327 | 298 | 367 | 307 | 734 | 645 | 776 | 638 | 1190 | 992 | 1213 | 985 |
| 1.00 | 107 | 99 | 109 | 106 | 358 | 337 | 387 | 325 | 852 | 697 | 806 | 634 | 1373 | 1075 | 1227 | 1037 |
| 1.15 | 105 | 101 | 104 | 101 | 390 | 311 | 376 | 333 | 838 | 675 | 874 | 664 | 1366 | 1078 | 1332 | 1036 |
| 1.30 | 100 | 96 | 110 | 94 | 396 | 327 | 384 | 318 | 866 | 713 | 877 | 658 | 1280 | 1034 | 1258 | 1011 |
| RMSE[b] | 6.2 | | | | 22.7 | | | | 41.2 | | | | 61.4 | | | |
| Leg (thigh and drum) weight (g) | | | | | | | | | | | | | | | | |
| 0.60 | 75 | 77 | 82 | 75 | 195 | 180 | 215 | 211 | 416 | 396 | 424 | 401 | 686 | 576 | 713 | 595 |
| 0.70 | 84 | 87 | 97 | 84 | 248 | 237 | 269 | 225 | 537 | 450 | 538 | 440 | 827 | 668 | 802 | 669 |
| 0.85 | 92 | 88 | 108 | 94 | 287 | 246 | 297 | 251 | 611 | 490 | 627 | 510 | 909 | 731 | 963 | 669 |
| 1.00 | 99 | 96 | 109 | 99 | 310 | 255 | 314 | 267 | 647 | 527 | 647 | 490 | 964 | 725 | 949 | 747 |
| 1.15 | 101 | 93 | 96 | 99 | 326 | 259 | 324 | 280 | 697 | 531 | 670 | 540 | 1004 | 753 | 930 | 708 |
| 1.30 | 97 | 94 | 105 | 96 | 315 | 293 | 330 | 282 | 723 | 562 | 674 | 525 | 954 | 737 | 918 | 698 |
| RMSE[b] | 5.9 | | | | 16.1 | | | | 28.5 | | | | 35.5 | | | |
| Wing weight (g) | | | | | | | | | | | | | | | | |
| 0.60 | 27 | 29 | 34 | 32 | 74 | 70 | 79 | 82 | 140 | 143 | 147 | 138 | 218 | 198 | 228 | 205 |
| 0.70 | 34 | 36 | 38 | 36 | 93 | 95 | 100 | 90 | 181 | 168 | 187 | 161 | 271 | 234 | 269 | 236 |
| 0.85 | 38 | 38 | 40 | 40 | 108 | 100 | 119 | 100 | 217 | 185 | 214 | 194 | 304 | 249 | 312 | 247 |
| 1.00 | 38 | 43 | 41 | 41 | 117 | 106 | 124 | 110 | 221 | 192 | 226 | 192 | 331 | 249 | 305 | 245 |
| 1.15 | 38 | 37 | 43 | 41 | 122 | 98 | 120 | 108 | 237 | 191 | 223 | 201 | 333 | 254 | 330 | 255 |
| 1.30 | 37 | 37 | 40 | 41 | 118 | 111 | 123 | 106 | 236 | 197 | 233 | 187 | 314 | 238 | 313 | 243 |
| RMSE[b] | 2.4 | | | | 5.5 | | | | 10.1 | | | | 13.3 | | | |

[a] Balanced protein content as a proportion of that recommended by Rostagno et al. (2017).

[b] Root mean square error

Table 7. Coefficients of relevant exponential equations [a, b] for predicting the weights of breast, leg (thigh + drum) and wing of males and females of the Cobb and Ross strains of broiler at 42 and 56 d in response to dietary balanced protein (BP)[c].

| Age | | Breast | | | | Leg | | | | Wing | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Male | | Female | | Male | | Female | | Male | | Female | |
| | | Ross | Cobb | Ross | Cobb | Ross | Cobb | Ross | Cobb | Ross | Cobb | Ross | Cobb |
| 14 | A | 135 | | | | 98.9 | | | | 51.5 | | | |
| | B | -3212 | | | | -2206 | | | | -484 | | | |
| | C | -27.1 | | | | | | | | -9.81 | | | |
| | R | 0.0008 | | | | 0.0005 | | | | 0.003 | | | |
| | $R^2$ | 68.9 | | | | 55.0 | | | | 58.8 | | | |
| 28 | A | 667 | 567 | 428 | 582 | 353 | | 313 | | 155 | 107 | 132 | 125 |
| | B | -2885 | -2203 | -2027 | -2449 | -3160 | | -554 | | -1863 | -718 | -1682 | -1212 |
| | C | -182 | -158 | 12.8 | -170 | | | | | -17.09 | 6.105 | -0.858 | -8.446 |
| | R | 0.0253 | | | | 5.01E-03 | | | | 3.18E-03 | | | |
| | $R^2$ | 91.7 | | | | 92.0 | | | | 90.3 | | | |
| 42 | A | 1492 | | 1205 | | 750 | | 595 | | 246 | | 214.3 | |
| | B | -5666 | | -4139 | | -4111 | | -2659 | | -3544 | | -2750 | |
| | C | -379 | | -312 | | | | | | | | | |
| | R | 0.0396 | | | | 1.13E-02 | | | | 2.07E-03 | | | |
| | $R^2$ | 95.2 | | | | 93.4 | | | | 89.9 | | | |
| 56 | A | 2159 | | 1861 | | 1032 | | 796 | | 346.9 | | 274 | |
| | B | -9554 | | -7672 | | -39403 | | -24823 | | -13768 | | -7462 | |
| | C | -521 | | -508 | | | | | | | | | |
| | R | 0.0275 | | | | 3.25E-04 | | | | 3.74E-04 | | | |
| | $R^2$ | 93.0 | | | | 92.2 | | | | 89.6 | | | |

[a] exponential asymptote, A+B*(RBP)

[b] line plus exponential, A+B*(RBP)+C*BP

[c] BP content is a proportion of that recommended by Rostagno et al. (2017)

Table 8. Minimum and maximum amino acid-to-lysine ratios during two phases of growth of broilers published in the literature [a], and those used in the present trial

| | Amino acid-to-lysine ratio | | | | |
|---|---|---|---|---|---|
| Amino | 0 - 21 d | | 22 - 42 d | | Used in |
| acid | min | max | min | max | trial |
| met | 35 | 41 | 35 | 42 | 39 |
| m&c | 50 | 76 | 58 | 78 | 71 |
| thr | 59 | 68 | 63 | 67 | 65 |
| val | 69 | 76 | 74 | 81 | 75 |
| ile | 58 | 68 | 63 | 71 | 65 |
| arg | 97 | 107 | 103 | 112 | 105 |
| trp | 15 | 16 | 15 | 19 | 16 |

[a] Rostagno et al. (2017), Mack et al. (1999), Cobb (2018), Aviagen (2019)

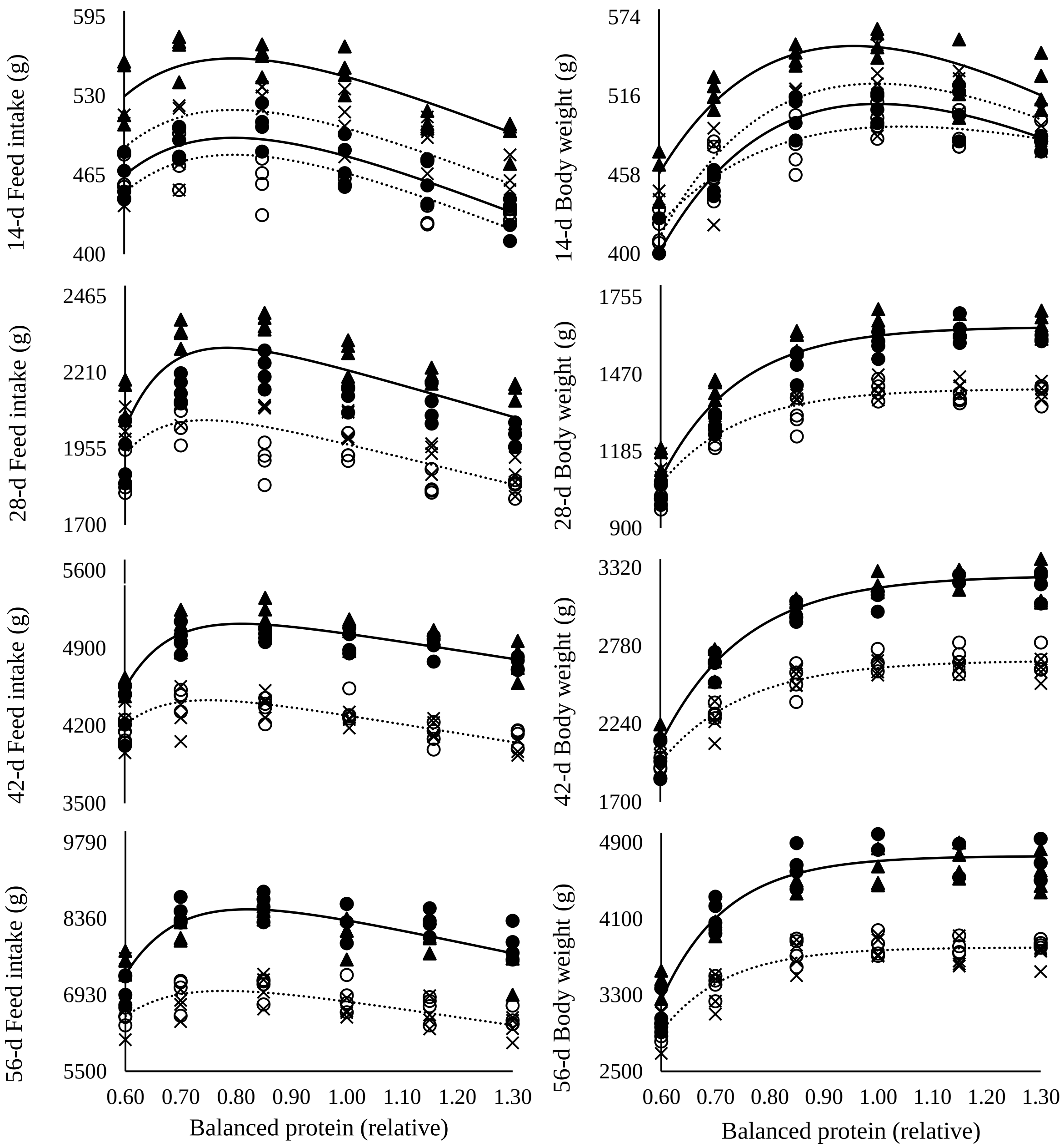


**Figure 1.** Fitted responses (solid line for male and dotted line for female) and observed responses in feed intake and body weight for Cobb male (▲), Ross male (●), Cobb female (✳), and Ross female (○) broilers at four ages, to increasing levels of balanced protein. Balanced protein content is given as a proportion of that recommended by Rostagno et al. (2017).

## CAPÍTULO 3 - Response of broilers to dietary balanced protein 2. Determining the optimum economic level of protein

Este capítulo foi submetido e está de acordo com as normas da **Animal Production Science**

**Response of broilers to dietary balanced protein:**

**2. Determining the optimum economic level of protein**

Jefferson Moraes Azevedo[1], Matheus de Paula Reis[1], Robert Mervin Gous[2], Juliano Cesar de Paula Dorigam[3], Rony Riveros Lizana[1], Nilva Kazue Sakomura[1]

[1]Universidade Estadual Paulista (Unesp), Faculdade de Ciências Agrárias e Veterinárias, Jaboticabal, São Paulo, Brazil

[2] School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, South Africa

[3] Evonik Nutrition & Care GmbH, Rodenbacher Chaussee 4, 63457 Hanau-Wolfgang, Germany

**ABSTRACT**

The two objectives of this study were to update the description of the responses of broiler genotypes to dietary protein, and to make use of these descriptions to demonstrate that the optimum economic level of the balanced protein is not static, as implied by tables of nutrient requirements, but varies according to economic conditions. Responses of male and female broilers, reported in a companion paper (Azevedo *et al*. 2020), were used to calculate feed intake and weights of body, carcass, breast, leg and wing at 28, 42 and 56 d of age as functions of dietary balanced protein. Cost of feeding and revenue generated for live, dressed and further-processed birds were calculated from which the margin over feeding cost was generated separately for males and females at three ages and for three different products. Using baseline values for the cost of protein-containing ingredients and revenue for the different components sold, the dietary protein content that maximised margin over feed cost was always higher for males than for females, and for birds sold further-processed than for those sold live. Using lysine as the reference amino acid, the optimum in the starter period for males sold live was 12.1 g lysine/kg and for further processed, 14.1 g/kg; for females, the equivalent values were 11.3 and 13.7 g/kg, respectively. Where the cost of protein-containing ingredients was increased by 25%, or the revenue generated from the sale of product reduced by 25%, the optimum economic level of dietary protein increased compared with the baseline value, this increase being greatest for birds sold live. The opposite pertained when the costs increased or revenues decreased by 25%. The results demonstrate the extent to which economic factors influence the optimum economic level of dietary balanced protein to be fed to broilers.

**Keywords**: amino acids, economic optimization, feeding cost, gross margin, revenue.

## INTRODUCTION

Nutritionists generally make use of tables of nutrient recommendations or requirements when formulating feeds, at least cost, for growing broilers in commercial operations. Such recommendations are made available by learned societies (National Research Council, 1994), breeding companies such as Aviagen (2019) and Cobb (2018), and by some universities (Rostagno *et al*, 2017). By virtue of these values being fixed, no account is taken of changes in supply and demand other than possibly to change the protein sources in each formulation.

Fisher (2008) reasoned that the predominant model used in poultry nutrition, the idea of a 'nutrient requirement', which is seen as a characteristic of the broiler and is the nutrient level required to support 'maximum' or 'optimum' production levels, is outdated and needs to be replaced with one in which nutritional decisions are made entirely in terms of the objectives of the business. With this approach, which applies systems thinking and modelling to the problem of feed formulation, nutrient levels are chosen that will maximize margin or perhaps combine with some other business objective. The 'needs' of the broiler in this case are not considered when making decisions about what nutrient levels to use. This is the principle on which the Reading Model was based (Fisher *et al*. 1973), in which the optimum economic intake of amino acids for laying hens becomes the basis on which their feeds are formulated. Feeding animals to achieve some commercial objective rather than feeding them to meet a ‘requirement’ makes good business sense, but requires a paradigm shift in the attitude of nutritionists to feed formulation: the nutrition of the broilers must be integrated into the management of the business.

There appears to be a reluctance by many nutritionists to move from using fixed ‘requirements’ to this more dynamic, economics-based approach possibly because the information required is difficult to generate and update. Among the factors to be considered are the potential protein growth rate of the genotype, the effect of different nutrient concentrations and energy-to-protein ratios on food intake, carcass composition and protein gains, and the constraints placed on birds by the environment and by the feed which prevent them from consuming the necessary amount of a feed to grow at their potential (Gous, 2015). Equally important when determining the optimum feeds and feeding programme for a flock of broilers is the manner in which the birds will be sold, whether at the farm gate, processed or further processed. This is perhaps the most neglected of all criteria influencing the profitability of a broiler enterprise, with far too much emphasis conventionally being placed on the feed conversion ratio and other non-economic criteria (Gous, 2015).

Many studies have attempted to develop practical and empirical tools to encourage nutritionists to move away from using fixed requirements for broilers (Pack and Schutte, 1995; Pack *et al*. 2003; Sterling *et al*. 2005; Eits *et al*. 2005; Cerrate and Waldroup, 2009a; Cerrate and Waldroup, 2009b; Vedenov and Pesti, 2010; Basurco *et al*. 2015). In these studies, various factors were taken into account in calculating the margin used to optimise the feeds, including the genotype, sex, cost of ingredients, age of bird when sold, and form in which the bird was sold, although not all studies were of the response of broilers to protein: some measured the response to energy instead (Cerrate and Waldroup 2009a). Of particular importance are the responses of the birds in feed intake and composition of growth to dietary balanced protein, as these responses are used to calculate the cost of feeding and the returns derived from the sale of product. Significant changes have taken place in broiler genotypes since the last empirical exercise was done on optimising the protein content of broiler feeds, with potential growth rates having increased considerably since then (Vargas *et al*, 2020). It is therefore of value to measure the response of some of the latest genotypes to balanced protein and to determine to what extent the amino acid recommendations of the past still pertain, even without taking account of changes in costs and returns. But of greater importance is the demonstration that the potential exists for broiler producers to increase the profitability of their enterprise by taking account of economic factors when deciding on the amino acid levels to be used in the feeds for their broilers.

This study had two objectives. The first was to update the description of the responses of the latest broiler genotypes to dietary protein, given that these genotypes have been shown to grow considerably faster than those used previously (Vargas *et al*. 2020). The second objective was to demonstrate that the optimum economic level of dietary balanced protein for growing broilers is not static, but varies according to many factors such as age, sex, manner in which the product is sold, and the relationship between the cost of the protein-containing ingredients used in the formulation of feeds and the value of the product sold. Results of the first objective have been published in a companion paper (Azevedo *et al*, 2020), whilst the data generated from that protein response trial, using the latest Cobb and Ross genotypes currently available to the Brazilian market, have been used here to address the second objective.

## MATERIALS AND METHODS

The data used in this analysis were obtained in a study conducted at the Poultry Science Laboratory of São Paulo State University (UNESP), School of Agricultural and Veterinarian Sciences, Jaboticabal. The study was approved by the Ethical Committee on the Use of Animals (Process 001592/2018; approved at 08/02/2018). The procedure used to evaluate the response to balanced protein has been fully described in the first part of this study (Azevedo *et al*., 2020), so only a brief description follows.

The response trial made use of sexed Cobb 500 and Ross 308 broilers. The feeding programme was divided into four phases, 1-14, 15-28, 29-42 and 43-56 d, in which birds received one of six levels of balanced protein that were adjusted downwards in each succeeding phase, the relative levels of protein between the six feeds remaining the same in each phase. The amino acid balance applied was that recommended by Rostagno *et al*. (2017) with three levels of balanced protein being chosen below, and two levels above the requirement, i.e. 0.60, 0.70, 0.85, 1.00, 1.15 and 1.30. The 24 treatments (6 protein levels x 2 strains x 2 sexes) were randomly distributed among 96 experimental units of 26 birds each, with 4 replicates of each treatment.

Two broilers from each pen were sampled at the end of each phase for measurements of carcass weight and the weights of breast minus skin, leg (thigh and drum) and wing. Appropriate equations were fitted to these data and to the live weights and food intakes to describe the response to balanced protein to 28, 42 and 56 d of age.

*Predicting the optimum economic level of dietary protein*

When referring to levels of balanced protein, lysine was used as the reference amino acid, with all other amino acids being kept in the same ratio to lysine as that used in the tables of recommendations by Rostagno *et al*. (2017). The equations derived by Azevedo *et al*. (2020) to describe the biological response of broilers of two strains and two sexes to balanced protein were used to estimate the level of balanced protein (lysine), relative to the recommendation of Rostagno *et al*. (2017), that would maximize margin over feed cost under various scenarios. These scenarios included differences in the way in which broilers were sold (whole, carcass or cut-up), changes in the cost of protein-containing ingredients and changes to the selling price of product. Because there were so few differences within sexes between broiler strains in the response to dietary protein measured by Azevedo *et al*. (2020), the economic calculations in this exercise were applied to male and female broilers of only one strain, given that the responses to dietary protein in all cases differed between sexes.

Margin over feed cost was calculated as the difference between the revenue derived from the sale of product and the cost of feeding the broiler to that stage of growth. The cost of feeding was calculated as the product of the amount and the cost of feed consumed. The equations used to describe the amount of feed consumed (Azevedo, 2020) included the periods 0 – 14, 0 – 28, 0 – 42 and 0 – 56 d during which time four different feeds were fed, hence the calculation of cost of feeding took account of the relevant feed cost (Table 1) and feed intake during each period. Apart from using base feed ingredient prices, two additional scenarios were used in which the prices of the protein-containing ingredients used in the feeds (soybean oilcake meal, soy protein concentrate, DL-methionine, L-lysine, L-threonine and L-valine) were either decreased or increased by 25% (Table 1).

[Table 1 near here]

Revenue derived from the sale of product was calculated by multiplying the weight of the product sold with the price paid for the product. Comparisons were made between three forms in which the broilers were sold, namely, live, dressed (carcass) or as parts, the latter being breast, leg (thigh plus drum) and wing portions. In addition to the price obtained for dressed birds, income was derived from the sale of giblets, feet and head. The same additional income was obtained when selling cut-up portions, but in addition, some income was derived from the sale of the remainder of the carcass. The base prices paid for these products are given in Table 2. Two additional scenarios were investigated, in which these prices were either decreased or increased by 25% to determine the effect on the optimum economic dietary protein level.

The optimum economic level of dietary balanced protein relative to the recommendations of Rostagno *et al*. (2017) for each scenario was obtained by fitting a quadratic function to the data, using the proportions of dietary protein as the independent variable and margin over feed cost as the dependent variable. The level of dietary balanced protein, as a proportion of the requirement, that maximised margin over feed cost for each scenario was derived from the quadratic function.

## RESULTS

The local cost (US$/100 kg), obtained in May of 2020, for protein-containing ingredients included in the formulation of the six basal feeds used as the baseline in this exercise were 35 for soybean oilcake meal, 179 for soy protein concentrate, 323 for DL-methionine, 251 for L-lysine, 580 for L-threonine and 1,421 for L-valine. Based on these ingredient prices, the cost of each of the 24 feeds (6 levels of dietary protein x 4 feeding periods) is given in Table 1, together with their respective digestible lysine and crude protein contents. Feeds offered in the first 14 d are included, as these differed from those given during the following two weeks, and separate equations were derived (Azevedo *et al*., 2020) to predict food intakes in each of these periods. Also presented in the Table is the cost of each of these feeds when the protein-containing ingredient prices were either decreased or increased by 25%.

The cost of feeding broilers to 28, 42 and 56 d of age was calculated by applying the relevant equations in Azevedo *et al*. (2020) to calculate food intake and then multiplying this by the relevant food cost.

Based on the local cost price of whole and processed broilers, of breast, thigh and drum, and wing portions, and of the giblets, feet, head and remainder (Table 2) the revenue derived from the sale of these products at 28, 42 and 56 d of age was calculated from the relevant equations published by Azevedo *et al*. (2020). The most expensive product per kg weight is the wing portion, followed by the breast portion. The whole bird is the least expensive product per kg of weight.

[Table 2 near here]

Margin over feed cost, calculated as the difference between the income derived from the sale of product and the cost of feeding the bird to that age, for male and female broilers offered the six balanced protein series, when sold whole, processed or as parts, is given in Table 3 and Figure 1. In all cases, margin increased with the age of the birds sold, with the highest margins being from those birds sold as portions. The margin derived from the sale of male birds was higher than when females were sold except when the lowest balanced protein level was fed and the birds were harvested at 28 d. Margins at each age and for each sex, irrespective of the way in which the birds were sold, increased as the dietary balanced protein content increased, and then declined at the highest levels of balanced protein (Figure 1). This curvilinear response in margin with dietary balanced protein enables the optimum dietary balanced protein level to be determined for different scenarios.

[Table 3 near here]

[Figure 1 near here]

The dietary balanced protein level, as a percentage of that defined by Rostagno *et al*. (2017) as the recommended level, that maximised margin over feed cost for each of the chosen scenarios, is given in Table 4. In all cases (age at sale and product sold) the optimum economic balanced protein level was higher for males than for females, the difference being greatest when the birds are sold live (5.0 vs. 4.3 vs. 4.1% for live, dressed and parts, respectively). The optimum economic balanced protein levels for birds sold live were between 9.6 and 14.6% lower than the recommended, and between 3.6 and 7.8% lower when the birds were processed before being sold. The optimum levels for cut-up birds varied from 1.1% below (females at 28 d) to 3.0% above (males at 42 d) the protein level recommended by Rostagno *et al*. (2017).

The effect of decreasing or increasing the cost of the protein-containing ingredients used in formulating the feeds on the optimum economic balanced protein level, expressed as a percentage of that recommended by Rostagno *et al*. (2017), is given in Table 4. The difference in margin between males and females increases when the cost of feed decreases or the value of product increases, and *vice versa*. In all these scenarios, the tendency remains for the optimum economic level of dietary balanced protein to be lowest for females and for birds sold live, and highest for males and for birds sold further-processed. Where the cost of dietary balanced protein is reduced, or the price of product increases, the optimum economic balanced protein level is in most instances higher than recommended by Rostagno *et al*. (2017) whereas for the case where protein ingredient prices are increased or product prices decreased, the optimum economic balanced protein level is usually close to the recommended level.

[Table 4 near here]

## DISCUSSION

The main objective of this exercise was to demonstrate that the optimum economic level of dietary balanced protein for growing broilers is not static, but varies according to many factors such as age, sex, manner in which the product is sold, and the relationship between the cost of the protein-containing ingredients used in the formulation of feeds and the value of the product sold. The concept of taking account of costs and returns when determining the optimum level of balanced protein to feed to poultry was addressed long ago by Heuser (1941) and Fisher *et al*. (1973), and empirical approaches to determining these changing optimum levels have been published by, among others, Pesti *et al*. (1986), Mack *et al*. (2000), Pack *et al*. (2003) and Eits *et al*. (2005). A useful means of demonstrating the dynamic nature of the optimum economic level of dietary balanced protein for broilers is to use an empirical approach, making use of appropriate experimental data. This process was used in the current study.

The way in which we decided to present the results of this exercise was to compare the optimum economic levels under different scenarios with the fixed recommendations of Rostagno *et al*. (2017). This in itself is contentious, as these recommended levels differ markedly from those of Aviagen (2019) and Cobb (2018), for example, thereby demonstrating the folly of attempting to describe nutrient requirements as fixed values. The digestible lysine content chosen (Rostagno *et al*., 2017) to represent 'the requirement' (13.8, 11.9, 10.3 and 9.6 g/kg) is higher in the initial period than those suggested by Aviagen (2019) (12.8, 11.5, 10.2 and 9.6 g/kg) and by Cobb (2018) (12.2, 11.2, 10.2 and 9.7 g/kg), although the values are similar in the final two periods. When viewing the responses to balanced protein presented here, these differences should be borne in mind, as the 'requirement' chosen in period 1 would represent 1.08 times the Aviagen recommendation and 1.13 times that of Cobb.

Even without comparing the present results with any given recommendations it is obvious that the optimum economic protein contents vary considerably as circumstances change. Note for example the wide discrepancy in the optimum, under current conditions, when the birds are sold either live or further processed at 56 d: when converted to dietary lysine contents, the optimum for males sold live is 12.1 g lysine/kg (0.878 of 13.8) and for further processed, 14.1 g/kg; for females the difference is even greater, being 11.3 and 13.7 g/kg respectively. Then note the large difference between males and females under these scenarios and it becomes clear that broiler producers who follow fixed amino acid recommendations do not benefit financially to the same extent as those who adjust these levels on the basis of current conditions. These differences increase with changes to the cost of dietary protein and to the price realised per kg of product.

As the financial conditions improve for the producer (lower cost of dietary protein or higher revenue for product) the optimum economic levels of dietary balanced protein increase. The biggest change from the ‘current’ situation would be for producers selling birds live, where the lower cost of balanced dietary protein would result in up to a 14% higher optimum dietary balanced protein level (from 0.82 to 0.93 times the recommended level for females sold live at 56 d). For those birds sold processed or cut-up the increase in the optimum economic level of balanced protein is more modest, being around 4 to 5% when the cost of dietary balanced protein falls, and only 2 to 3% when the price of the product increases by the same margin. The increase in optimum balanced protein level is the same, under these conditions, for both males and females (Table 4).

When the cost of dietary balanced protein increases, or the product price drops, the optimum balanced protein level drops below that in the ‘current’ conditions, the pattern of change being similar to that when cost of protein is reduced: the difference in optimum balanced protein level when the birds are sold live *vs*. cut-up remains the same, and it always pays to feed higher levels of protein to males than to females. The biggest changes from the ‘current’ levels of dietary protein are, in this case, when males and females are sold live and the product price drops by 25%, resulting in the optimum decreasing from 0.88 to 0.74 times the recommended level in the case of males, and from 0.82 to 0.71 in females. This is a more severe decrease than the equivalent when the cost of dietary protein is increased by the same margin.

Where the optimum economic level of balanced protein decreases to 0.93 of the Rostagno *et al*. (2017) recommendations, these would coincide with the Aviagen (2019) recommendations; and similarly, if the optimum level dropped further, to 0.88 of the recommendations used here, these would coincide with the Cobb (2018) recommendations. It is instructive to apply these levels in Fig. 1 in place of the Rostagno *et al*. (2017) recommendations Thus, it is possible to find recommendations similar to the optimum economic levels calculated here, but only if these are lower than those used in this exercise. In all cases where the optimum is higher than the base levels used here, these are higher than any book values and therefore constitute an opportunity for broiler producers to increase their profits under the conditions that resulted in these high optimum economic levels of protein.

The above exercise demonstrates clearly that an opportunity exists for improving broiler profitability with the use of a dynamic approach when determining the amino acid levels to use in a given feeding programme, as opposed to using tables of nutrient recommendations or requirements. All the factors that have been taken into account in the above exercise will vary in different parts of the world, making it impossible to define a universal set of optimum economic levels of amino acids that may be applied everywhere. Due consideration must be given of the responses of male and female broilers of the given genotype to dietary protein, and the costs and returns involved. A major problem with the use of this empirical approach to defining the optimum levels of amino acids to be used is that genotypes vary in their response to dietary protein, and genotypes are continually being changed by genetic selection processes. Updating the equations describing the response to dietary protein of each new genotype would be necessary unless a mechanistic approach were used, in which case the optimum economic feeds and feeding programme would be generated whenever necessary simply by updating the model with the latest genotype description and relevant costs and returns (Fisher, 2015; Gous, 2015).

Instead of using tables of nutrient recommendations or requirements to define the amino acid levels to use in a given feeding programme for broilers, the opportunity exists for improving the profitability of the enterprise by considering the response of the genotype to balanced protein, together with the cost of dietary protein and the returns that are generated by the sale of product. Such decisions are best made with the use of simulation models that take account of changes in potential growth of broilers over time, that predict food intake and the growth and chemical composition of the body and all the relevant parts that are sold. Such information can then be used to calculate the cost of feeding and the revenue derived from the sale of product, and hence the optimum economic level of balanced protein.

**REFERENCES**

AVIAGEN (2019) Ross Broiler Nutrition Specifications [Online]. Available at: http://eu.aviagen.com/assets/Tech_Center/Ross_Broiler/RossBroilerNutritionSpecs2019-EN.pdf. (Verified 5 July, 2020)

Azevedo JM, Reis MP, Gous RM, Leme BB, Dorigam JCP, Sakomura NK (2020) Response of broilers to balanced protein. 1. Feed intake and growth. Submitted to Animal Production Science.

Basurco V, Vieira SL, Serafini NC, Santiago GO, Angel CR, Gonzalez-Esquerra R (2015) Performance and economic evaluation of feeding programs varying in energy and protein densities for broiler grillers. Applied poultry researche 24, 304-315.

Cerrate S, Waldroup PW (2009a) Maximum profit feed formulation of broilers: 1 Development of a feeding program model to predict profitability using non linear programming. International Journal of Poutry Science 8, 205-215.

Cerrate S, Waldroup PW (2009b) Maximum profit feed formulation of broilers: 2 Comparison among differen nutritional models. International Journal of Poutry Science 8, 216-228.

COBB (2018) Cobb 500 Broiler performance and nutrition supplement [Online]. Available at: https://cobbstorage.blob.core.windows.net/guides/3914ccf0-6500-11e8-9602-256ac3ce03b1. (Verified 5 July, 2020)

Eits RM, Giesen G, Kwakkel RP, Verstegen MWA, Den-Hartog LA (2005) Dietary balanced protein in broiler chickens . 2. An economic analysis. British Poultry Science 46, 310-317. doi:10.1080/00071660500126482.

Fisher C (2008) Improving nutrition through modelling. In ‘27th Annual WPSA Scientific Day’pp. 20-32 (World Poultry Science Association: Pretoria)

Fisher C (2015) An overview of poultry models. In ‘Nutritional Modelling for Pigs and Poultry’. (Eds NK Sakomura, RM Gous, I Kyriazakis, L Hauschild) pp. 1-21. (CABI: Wallingford)

Fisher C, Morris TR, Jennings RC (1973) A model for the description and prediction of the response of laying hens to amino acid intake. British Poutry Science 14, 469-484.

Gous, RM (2015) A model to optimize broiler productivity. In ‘Nutritional Modelling for Pigs and Poultry’. (Eds NK Sakomura, RM Gous, I Kyriazakis, L Hauschild) pp. 175 – 187. (CABI: Wallingford)

HEUSER GF (1941) Protein in poultry nutrition – a review. Poultry Science 20, 362-368.

Mack S, Hohler D, Pack M (2000) Evaluation of dose-response data and implications for com¬mercial formulation of broiler diets. In ‘Proceedings Australian Poultry Science Symposium’ pp. 82-87. (University of Sydney: Sydney)

Pack M, Schutte JB (1995) Sulfur amino acid requirement of broiler chicks from fourteen to thirty-eight days of age. 2. Economic evaluation. Poultry science 74, 488-493. doi:10.3382/ps.0740488.

Pack M, Hoehler D, Lemme A (2003) Economic assessment of amino acid reposnses in growing poultry. “Amin. acids Anim. Nutr.” (Eds JBF D’Mello) p. 459-316. (CABI Publishing: Edinburgh)

Pesti GM, Arraes A, Miller BR (1986) Use of the quadratic growth response to dietary protein and energy concentrations in least-cost feed formulation. Poultry Science 65, 1040-1051.

Rostagno HS, Albino LFT, Hannas MI, Donzele JL, Sakomura NK, Costa FGP (Eds) (2017) ‘Brazilian tables for poultry and swine’ (Eds). (UFV: Viçosa)

Sterling KG, Vedenov DV, Pesti GM, Bakalli RI (2005) Economically optimal dietary crude protein and lysine levels for starting broiler chicks. Poultry Science 84, 29-36. doi:10.1093/ps/84.1.29.

Vargas L, Sakomura NK, Leme BB, Antayhua F, Reis M, Gous R, Fisher C (2020) A description of the potential growth and body composition of two commercial broiler strains. British Poultry Science 0, 1. doi:10.1080/00071668.2020.1716300.

Vedenov D, Pesti GM (2010) An economic analysis of a methionine source comparison response model. Poultry Science 89, 2514-2520. doi:10.3382/ps.2010-00640.

**Table 1.** Digestible lysine (g/kg) and crude protein (g/kg) contents of feeds used in determining the cost of feeding male and female broilers, with the corresponding

base feed cost (US$/100 kg) and when the cost of protein-containing ingredients was reduced or increased by 25 %.

| Phase, d | | Balanced protein as proportion of recommended [a] | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0.60 | 0.70 | 0.85 | 1.00 | 1.15 | 1.30 |
| 0 to 14 | Lysine dig. (g/kg) | 8.27 | 9.65 | 11.7 | 13.8 | 15.9 | 17.9 |
| | Crude protein (g/kg) | 146 | 165 | 195 | 223 | 252 | 280 |
| | Feed cost (US$/100 kg) | 24.9 | 26.7 | 29.5 | 32.8 | 37.6 | 66.2 |
| | -25% | 22.8 | 24.0 | 25.8 | 28.0 | 31.4 | 52.8 |
| | 25% | 26.9 | 29.4 | 33.2 | 37.6 | 43.9 | 79.5 |
| 15 to 28 | Lysine dig. (g/kg) | 6.65 | 7.95 | 9.9 | 11.6 | 13.8 | 15.8 |
| | Crude protein (g/kg) | 123 | 141 | 168 | 196 | 223 | 250 |
| | Feed cost (US$/100 kg) | 22.8 | 24.5 | 27.1 | 29.9 | 32.8 | 37.1 |
| | -25% | 21.5 | 22.6 | 24.2 | 26.1 | 28.0 | 31.0 |
| | 25% | 24.2 | 26.5 | 29.9 | 33.8 | 37.6 | 43.1 |
| 29 to 42 | Lysine dig. (g/kg) | 5.73 | 6.88 | 8.61 | 10.3 | 12.1 | 13.8 |
| | Crude protein (g/kg) | 110 | 126 | 150 | 174 | 198 | 223 |
| | Feed cost (US$/100 kg) | 21.7 | 23.2 | 25.4 | 27.6 | 30.3 | 32.8 |
| | -25% | 20.8 | 21.7 | 23.1 | 24.5 | 26.4 | 28.0 |
| | 25% | 22.6 | 24.6 | 27.6 | 30.6 | 34.2 | 37.6 |
| 43 to 56 | Lysine dig. (g/kg) | 5.28 | 6.36 | 7.97 | 9.58 | 11.2 | 12.8 |
| | Crude protein (g/kg) | 104 | 119 | 14 | 164 | 186 | 209 |
| | Feed cost (US$/100 kg) | 21.1 | 22.5 | 24.7 | 26.6 | 28.9 | 31.3 |
| | -25% | 20.4 | 21.3 | 22.7 | 23.9 | 25.4 | 27.0 |
| | 25% | 21.7 | 23.6 | 26.7 | 29.3 | 32.4 | 35.6 |

[a] Digestible lysine levels according to Rostagno et al. (2017)

**Table 2**. Base cost price (US$/bird) of whole and processed broilers and of breast, leg (thigh and drum), and wing portions used in the calculation of revenue derived from the sale of product.

| | Whole bird | Dressed bird | Breast | Leg | Wing | Remainder[1] | Giblets | Feet | Head |
|---|---|---|---|---|---|---|---|---|---|
| Cost price (US$/bird) | 0.60 | 1.00 | 2.00 | 1.18 | 2.20 | 0.50 | 0.30 | 0.20 | 0.10 |

[1]Reminder was calculated as the difference between dressed bird and parts weights (breast + leg + wing).

**Table 3.** Estimated margin over feeding cost [a] (US$/bird) of male and female broilers offered a range of balanced protein (BP) levels when sold whole, dressed or as parts [c].

| Balanced Protein [b] | Day 28 | | Day 42 | | Day 56 | |
|---|---|---|---|---|---|---|
| | Male | Female | Male | Female | Male | Female |
| | Margin from sale of whole bird, US$/bird | | | | | |
| 0.60 | 0.175 | 0.189 | 0.245 | 0.243 | 0.347 | 0.320 |
| 0.70 | 0.255 | 0.235 | 0.390 | 0.327 | 0.523 | 0.424 |
| 0.85 | 0.300 | 0.253 | 0.474 | 0.363 | 0.553 | 0.416 |
| 1.00 | 0.290 | 0.234 | 0.456 | 0.334 | 0.493 | 0.349 |
| 1.15 | 0.257 | 0.200 | 0.376 | 0.264 | 0.381 | 0.243 |
| 1.30 | 0.095 | 0.046 | 0.164 | 0.075 | 0.153 | 0.025 |
| | Margin from sale of dressed bird, US$/bird | | | | | |
| 0.60 | 0.186 | 0.204 | 0.387 | 0.373 | 0.647 | 0.586 |
| 0.70 | 0.289 | 0.283 | 0.629 | 0.523 | 0.934 | 0.779 |
| 0.85 | 0.375 | 0.335 | 0.781 | 0.606 | 1.135 | 0.884 |
| 1.00 | 0.391 | 0.329 | 0.790 | 0.595 | 1.142 | 0.852 |
| 1.15 | 0.369 | 0.293 | 0.720 | 0.532 | 1.006 | 0.721 |
| 1.30 | 0.210 | 0.129 | 0.513 | 0.346 | 0.698 | 0.443 |
| | Margin from sale of parts, US$/bird | | | | | |
| 0.60 | 0.366 | 0.383 | 0.748 | 0.690 | 1.183 | 1.049 |
| 0.70 | 0.523 | 0.512 | 1.123 | 0.955 | 1.706 | 1.434 |
| 0.85 | 0.668 | 0.611 | 1.432 | 1.159 | 2.096 | 1.695 |
| 1.00 | 0.723 | 0.627 | 1.531 | 1.212 | 2.201 | 1.736 |
| 1.15 | 0.728 | 0.596 | 1.496 | 1.169 | 2.116 | 1.632 |
| 1.30 | 0.587 | 0.426 | 1.284 | 0.973 | 1.832 | 1.354 |

[a] Margin calculated using base prices for protein-containing ingredients and product sold

[b] Balanced protein levels recommended by Rostagno et al. (2017) for digestible lysine

[c] Sale of breast, legs (thighs and drums) and wings

**Table 4.** Effect of increases and decreases of 25 % in the cost of dietary protein and in the price of product on the proportion of recommended [a] dietary protein level that maximises margin over feed cost for male and female broilers sold whole, dressed or as parts, at 28, 42 and 56 d of age.

| | Day 28 | | Day 42 | | Day 56 | |
|---|---|---|---|---|---|---|
| | Male | Female | Male | Female | Male | Female |
| | | | Base prices | | | |
| Whole bird | 0.91 | 0.87 | 0.92 | 0.88 | 0.88 | 0.82 |
| Processed bird | 0.97 | 0.92 | 0.97 | 0.94 | 0.95 | 0.91 |
| Cut-up parts | 1.03 | 0.97 | 1.04 | 1.01 | 1.02 | 0.99 |
| | | | Protein ingredient prices – 25 % | | | |
| Whole bird | 0.98 | 0.93 | 1.00 | 0.96 | 0.98 | 0.93 |
| Processed bird | 1.02 | 0.97 | 1.03 | 1.00 | 1.01 | 0.98 |
| Cut-up parts | 1.08 | 1.01 | 1.08 | 1.06 | 1.07 | 1.04 |
| | | | Protein ingredient prices + 25 % | | | |
| Whole bird | 0.86 | 0.81 | 0.85 | 0.80 | 0.77 | 0.71 |
| Processed bird | 0.92 | 0.87 | 0.92 | 0.87 | 0.89 | 0.85 |
| Cut-up parts | 0.99 | 0.93 | 1.00 | 0.97 | 0.98 | 0.95 |
| | | | Product prices – 25 % | | | |
| Whole bird | 0.86 | 0.81 | 0.84 | 0.80 | 0.74 | 0.71 |
| Processed bird | 0.91 | 0.87 | 0.92 | 0.88 | 0.89 | 0.85 |
| Cut-up parts | 0.99 | 0.93 | 1.00 | 0.97 | 0.98 | 0.95 |
| | | | Product prices + 25 % | | | |
| Whole bird | 0.95 | 0.90 | 0.97 | 0.92 | 0.94 | 0.89 |
| Processed bird | 1.00 | 0.95 | 1.01 | 0.97 | 0.99 | 0.95 |
| Cut-up parts | 1.06 | 0.99 | 1.06 | 1.04 | 1.05 | 1.01 |

[a] Balanced protein levels recommended by Rostagno et al. (2017).

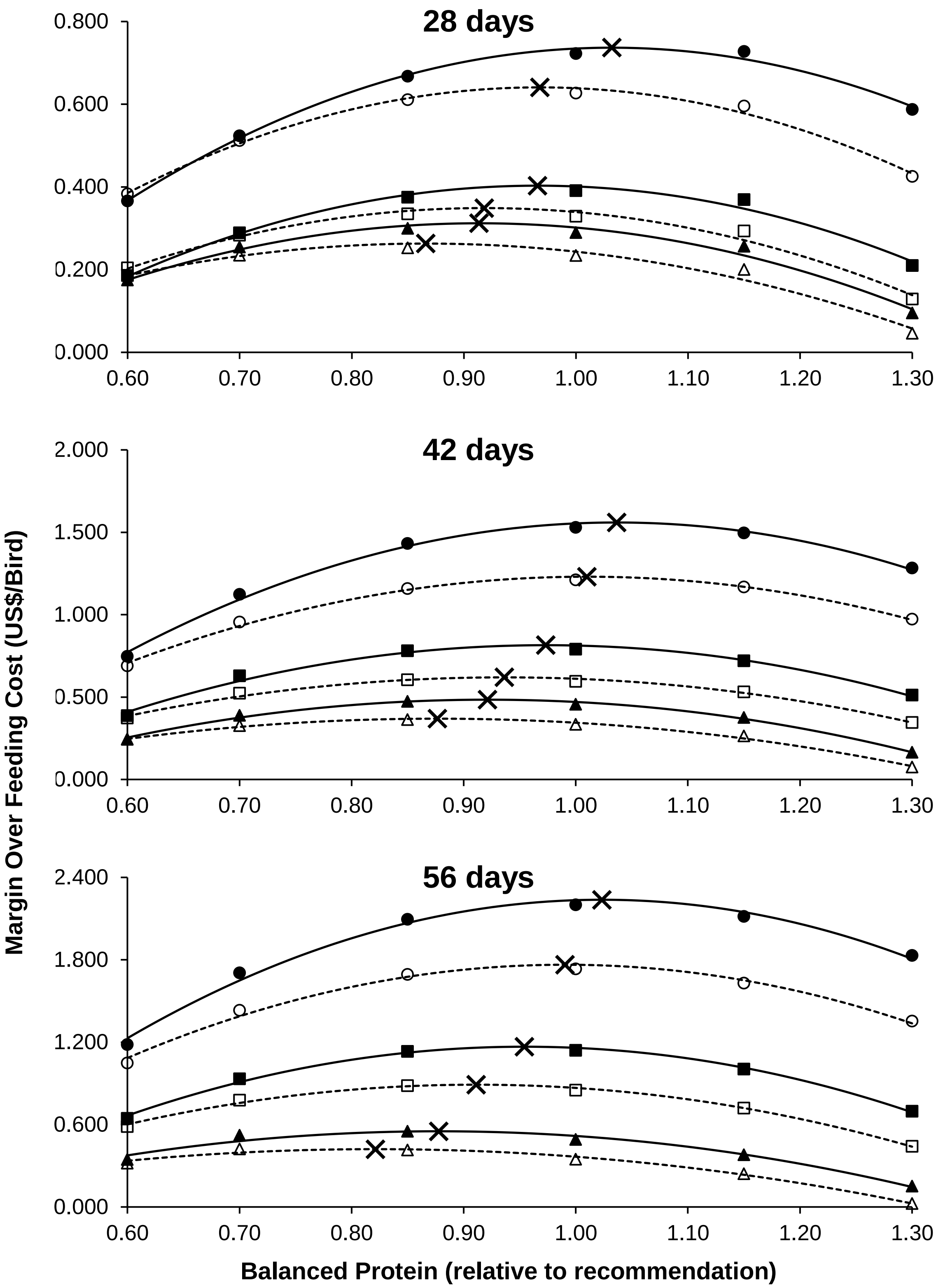


**Figure 1.** Estimated margin over feeding cost for a range of dietary protein levels (relative to the recommendation of Rostagno et al. 2017) for male (solid lines and filled symbol) and female (dashed lines and unfilled symbol) broilers sold whole (▲ and △), dressed (■ and • ), or as parts (● and ○), at three ages. The maximum economic return is indicated by **X**.

## CAPITULO 4 - Balanced protein for broiler breeder hens from 55 to 65 weeks of age

Este capítulo foi submetido e está de acordo com as normas da ***scientia agricola***

**Balanced protein for broiler breeder hens from 55 to 65 weeks of age**

Jefferson Moraes Azevedo[1], Matheus de Paula Reis[1], Rafael Massami Suzuki[1], Rony Riveros Lizana[1], João Batista Kochenborger Fernandes[2], Nilva Kazue Sakomura[1]*

[1]Universidade Estadual Paulista (UNESP), Faculdade de Ciências Agrárias e Veterinárias (FCAV) – Departamento de Zootecnia, Via de Acesso Professor Paulo Donato Castellane S/N - Vila Industrial, 14884-900 - Jaboticabal, SP - Brasil.

[2]Universidade Estadual Paulista (UNESP), Centro de Aquicultura da Unesp, Jaboticabal (CAUNESP) Via de Acesso Professor Paulo Donato Castellane S/N - Vila Industrial, 14884-900 - Jaboticabal, SP - Brasil.

## ABSTRACT

A study was conducted to evaluate the influence of balanced protein (BP) and daily feed allocation (FA) on body composition, productive performance and energy partitioning of broiler breeder hens. A total of two-hundred-55-week-old broiler breeder hens (Ross 308) were housed during 10 weeks in individual cages and randomly assigned to two feed allocations (150 or 170 g day$^{-1}$) and five levels of BP (4.0, 5.0, 6.0, 7.0 or 8.0 g of lysine kg$^{-1}$) performing a factorial scheme (5 x 2) containing 20 replicates of one hen each. Body deposition (protein and lipid) of tree birds from each treatment were assessed by dual-energy X-ray absorptiometry (DXA) at the beginning and at the end of the experiment. There was no two-way interaction ($p>0.05$) between FA and BP for any variables evaluated. Egg production (EP) was not influenced ($p>0.05$) by treatments, but egg weight (EW) and egg output (EO) increased with BP levels whereas were not affected by FA. Body weight gain (BWG) and body protein retention (BPR) also increased with BP but were not affected by FA, whereas body fat retention (BFR) had an increment with FA only. Consequently, total energy retained in the body (BER) was increased both with BP as FA, whereas the body energy retained as protein (BERp) and fat (BERf) were influenced only by the BP and FA, respectively. Total energy retained (TER) was also increased with both factors, whereas total heat production (THP) reduced with BP and increase with FA. Even at the end of the productive life, broiler breeder hens are able to keep its reproductive performance changing the body composition and consequently affecting the energy partitioning.

**Keywords:** Amino acids, nutrient partition, heat production, body composition, egg production.

**Introduction**

The nutrients consumed by a breeder hen is partitioned and used to meet their requirements for maintenance and the remainder part is able to be deposited as body tissue and egg. Although some authors like Rostagno et al. (2017) consider in their factorial models a lysine requirement for body gain, which must be linked to a lean mass accretion, this type of deposition during the laying period in broiler breeders is not advantageous because could siphon nutrients from egg production for a non-productive aim (Ekmay et al., 2014) besides that, leading to an increased maintenance requirement, which would be approximately 30% of balanced protein intake (Sakomura, 2004).

To avoid this scenario, broiler breeder hens are usually reared under restricted feeding programs, in turn of 50% to 60% of *ad libitum* feed intake (Kim et al., 2020) which in part intended to control principally the excess of protein deposition in the body, highlighting the importance for understanding how the dietary protein and daily feed allocations influences their performance (Steenhuisen and Gous, 2016). For this to be accomplished, it is necessary to investigate more than egg production and body weight, but also the body composition and energy retention, which are indicatives of nutrients partitioning and ought to be an important measure to evaluate the response of broiler breeder hens to the quality and quantity of protein in the feed (Morris and Gous, 1988; Steehuisen and Gous, 2016).

The beneficial effect of using balanced protein concept for broiler breeder hens has been defended in several studies (Lesuisse et al., 2017; Steehuisen and Gous, 2016), this is partly because the protein excess in the laying period is also correlated with a low fertility and hatchability of broiler breeders (Van-Emous et al., 2015) which could be linked to the increase of egg weight, since that eggs heavier than 65 g has their hatchability reduced (Shafey, 2001). This could be avoided by reducing the total protein content of the feed provided that it was adjusted the essential amino acid levels of the diet according the ideal protein concept (Steehuisen and Gous, 2016).

In this sense, investigate how the amino acids from the feed are being prioritized by metabolism, i.e. egg production, body deposition, and maintenance plays a central role in the nutrition of broiler breeders, because the body deposition (Caldas et al., 2018) and especially egg production changes as these birds aged (Van-Emous et al., 2015), and these factors are the main driving forces of lysine partitioning for this type of animal (Ekmay et al., 2014). Perhaps for this reason, broiler breeder hens at the end of their productive life, when egg production decrease considerably, tend to increase the deposition of lean mass in the body (Caldas et al., 2018), indicating a low protein requirement at this stage and that some excess protein in the diet could be deposited in the body. In this scenario, energy retained may give an indicative of nutrient usage because the egg production is the responsible for the most of energy retention of broiler breeder hens (Steenhuisen and Gous, 2016).

Therefore, we hypothesize that broiler breeder hens changes their body composition at deficient protein diets to keep the productive performance which it allows the usage of low balanced protein diets as advantageous strategy. The objective of this trial was to evaluate the effect of different levels of balanced protein at two daily feed allocations on productive performance, body composition and heat production of broiler breeder hens at end of productive life.

## Materials and Methods

*Animal use and care*

All the procedures in this study were approved by the institutional Ethics Committee on Animal Use of School of Agricultural and Veterinary Sciences, UNESP – São Paulo State University, Jaboticabal, Brazil, under protocol nº. 015231/17.

*Bird husbandry, experimental design, and diets*

A factorial arrangement (5 levels of balanced protein x 2 feed allocations) was used and the 10 resulting treatments were randomly assigned into forty experimental units (cage - 50 cm length x 50 cm width x 30 cm height), with 20 replicates of one broiler breeder hen each (55-w old, Ross 308). Cages were allocated in a conventional poultry house at Jaboticabal, São Paulo, Brazil (21°25’25’’ S, 48°32’57’’ W, altitude of 615 m) with light program set to 16h00 of light and 08h00 of dark.

Feed (mash form) was offered in two distinct amounts (150 or 170 g day$^{-1}$) and water was provided *ad libitum* throughout all experimental period (ten weeks). Two basal diets were formulated to contain 145 g kg$^{-1}$ of total protein (8.0 g kg$^{-1}$ of lysine) and 80.3 g of protein/kg (4.0 g kg$^{-1}$ of lysine) each, maintaining the ideal ratio of essential amino acids, as recommended by Rostagno et al. (2017). The basal diets were then blended to set up five experimental diets ranging the BP content (Table 1). The lysine content of the feed was considered as BP, once the others essential amino acids followed the ideal protein concept in relation to lysine concentration. The ideal amino acids profile recommended by Rostagno et al. (2017) was used to formulate the dietary BP.

*Performance measurements, body chemical composition and heat production*

The laying performance: egg production (EP) and egg weight (EW) were daily recorded, while egg output (EO) (g bird day$^{-1}$) was calculated multiplying the EP (%) by EW (g). Body weight was measured at the 1st, 6th, and the 10th week of the trial. Feed intake was weekly measured by weighing leftovers at end of each week.

Body deposition (lean mass and fat mass) of tree birds from each treatment (totaling 30 birds) was assessed by dual-energy X-ray absorptiometry (DXA) module Hologic Discovery Wi (Bedford, MA, USA); at the beginning (55-w old) and at the end (65-w old) of the experiment. The chemical contents of body protein and body lipid were estimated from DXA results (lean mass and fat mass) according to Gonçalves et al. (2018). The body protein retention (BPR) and body fat retention (BFR) were calculated considering the gain of these contents during the 10 weeks of experiment.

Total energy retention (TER) was calculated by the sum of the energy retained in egg production (EER) and in body (BER). The energy retained in the body was calculated by the sum of energy retained as protein (BERp) and energy retained as fat (BERf) considering 5.66 kcal g$^{-1}$ of protein deposited and 9.37 kcal g$^{-1}$ of fat deposited (Sakomura and Rostagno, 2016). The energy retained in the egg was calculated taking in account that hens use 2.01 kcal g$^{-1}$ of egg output (Emmans, 1974; Steenhuisen and Gous, 2016). The total heat production (THP) was calculated by difference between ME consumed and total energy retained.

*Statistical analysis*

All statistical procedures were carried out using the software package SAS University (SAS Institute Inc., Cary, NC). All variables were analyzed using GLM procedure, accounting for two factors (balanced protein and feed allocation) and their interaction as the following model: $Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$. Where; $Y_{ijkm}$ is the response variable accounting for each factor's level ($i_{jkm}$), μ is the overall mean of the response variable, α is the main effect of FA, β is the main effect of BP, αβ accounts for the interaction effect between factors and $\varepsilon_{ijk}$ is the model residue. When the effect of BP results in statistical difference, an orthogonal comparison is applied to test the linear and quadratic degree of polynomial. If only first degree was significative, a simple linear regression was fitted to the data, otherwise, the data was fitted to quadratic broken line model (Robbins et al., 2006) to determine the maximum response for BP levels:

$$Y = U * (X < R) * (R - X)^2 + L \qquad [1]$$

where Y is the response, X is the BP levels, and the parameter U (intercept), R (maximum response at X level), and L (plateau response). The broken-line model is defined by a condition where: if X is less then R, the equation assumes a second-degree linear regression behavior. If the value of X is equal or higher than R, $(R\text{-}X)^2$ becomes zero, consequently, the response (Y) is equal to L. Means are presented as mean ± standard deviation. For each result, the significance level was set at 5%.

## Results

### *Feed intake and body composition*

As expected, breeders which were provided 170 g $day^{-1}$ of feed consumed 13% more feed than that from 150 g $day^{-1}$. As well the results on FI, the energy intake (kcal bird day$^{-1}$) and protein intake (g bird day$^{-1}$) also increases numerically with the accretion of the daily feed amount (Table 2) while protein intake also increase linearly as BP was raised.

There was no interaction (*p>0.05*) between factors (BP and FA) for BWG, BPR, or BFR (Table 3), but BWG was influenced (*p<0.01*) both by the daily FA and BP. On average, breeders receiving 170 g day$^{-1}$ of FA were heavier at the end of the trial showing a BWG of 6.84 g day$^{-1}$ greater than hens receiving 150 g day$^{-1}$ of feed. The BWG increased with dietary BP independently of daily FA and achieved its maximum gain at 6.12 g kg$^{-1}$ of dig. lysine (114.6 g kg$^{-1}$ of total protein) according the equation showed in table 4.

Body protein retention (BPR) increased (*p=0.013*) with the BP content but was not affected by FA, the maximum BPR was achieved at 6.35 g kg$^{-1}$ of dig. lysine (118.3 g kg$^{-1}$ of total protein). Although it had not been observed effect of BP on BFR, an increase in deposition of fat mass was remarkable (*p=0.009*) as FA was raised and birds with highest FA deposited 89% more fat per day than birds fed with 150 g day$^{-1}$ (Table 3).

*Laying performance*

The mean effect of feed allocation and the interaction between BP and FA did not influenced (*p>0.05*) the variables EW, EP and EO. However, EW increased linearly with increase of dietary BP independently of daily FA (Table 5), whilst the EO showed a quadratic response in relation to the increase of dietary BP and was maximized at 5.31g kg$^{-1}$ dig. lysine (101.5 g kg$^{-1}$ of total protein) in the feed (Figure 1). Instead, EP was not influenced by any treatments.

*Energy retention and heat production*

The energy retained as protein (BERp) was influenced (*p=0.013*) by the dietary BP and increased quadratically up to the level of 5.51 g $kg^{-1}$ of dig. lysine (104.7 g $kg^{-1}$ of total protein), but was not modified by the daily FA (Table 6). BERf was influenced by FA (*p<0.01*) and birds that received 170 g $day^{-1}$ of feed showed an energy retention 9.0 kcal $day^{-1}$ higher. Dietary BP did not influence the energy retention as fat and was not observed significant interaction between treatments neither for energy retained as fat nor as protein.

The energy retained in the body (BER) was influence by both BP and FA (*p<0.05*), but there was no interaction between factors (*p>0.05*) in this response variable (Table 6). The energy retained in the body increased quadratically in response to dietary BP and achieved the its maximum at 7.05 g $kg^{-1}$ of dig. lysine (129.6 g $kg^{-1}$ of total protein) (Figure 2). Furthermore, hens receiving 170 g $day^{-1}$ of FA retained 50% more energy in the body than hens fed with 150 g $day^{-1}$.

The birds also increased (*p<0.01*) the energy EER with BP level, but not with FA and interaction between factors was not detected (*p>0.05*). The EER increased quadratically with the increment of BP level and achieved the maximum at 5.31 g $kg^{-1}$ of dig. lysine (101.5 g $kg^{-1}$ of total protein) (Figure 2).

Since TER it is calculated as the sum of BER and EER a similar behavior was expected between those variables. In fact, the TER of birds that received 170 g $day^{-1}$ of feed was on average 18% greater than those receiving 150 g $day^{-1}$ of FA. The TER was also influenced (*p<0.01*) by BP of the diet, increasing quadratically (Figure 3) as BP level increased in the feed, achieving a maximum at 5.92 g $kg^{-1}$ of dig. lysine (111.3 g $kg^{-1}$ of total protein) but no interaction was observed between factors.

As expected, the THP had an inverse tendency of that observed in the TER, and decreased quadratically (*p<0.01*) as dietary BP increased (Figure 6). The minimum THP was estimated at 5.85 g $kg^{-1}$ of dig. lysine corresponding to 110.2 g $kg^{-1}$ of total protein. The FA also influenced significantly (*p<0.01*) the THP which increased about 12% in broiler breeder hens that received 170 g of feed $day^{-1}$ (Table 6), meaning a heat production of 36 kcal $day^{-1}$ higher in that birds.

**Discussion**

In order to test our hypothesis that broiler breeder hens fed at different levels of BP and FA could adjust their body composition to allow the reproductive performance impacting on energy partitioning, we formulated isonutritrive diets differing only for balanced protein and amino acid contents. The procedure adopted assures that energy and nutrients are offered to meet or exceed breeder's requirement, excepting for balanced protein, thus it was expected that differences observed between treatments were due to BP levels consumed by breeders.

It is reported in literature that laying birds, fed *ad libitum*, will seek to consume the first limiting nutrient in a feed, herein balanced protein; however, feed a fix amount of feed per breeder is a common practice in industry, given a good reason to test the response of breeders in two distinct feed allowances. Despite the level of BP and feed allowance, breeders consumed about 95% of feed, suggesting that the levels of BP applied in this study does not modified feed intake, probably because of the fix amount of feed offered daily. When crescent levels of BP were offered at restricted daily feed allocation for broiler breeders, a decrease on feed intake over time was observed for breeders receiving the higher levels of balanced protein, which was not observed with hens fed *ad libtum* (Steenhuisen and Gous, 2016).

Body weight gain increased quadratically in response to dietary BP, being quite similar to that results observed in the BPR, which allows to infer that the weight gain was related principally to the lean mass deposition, although the fat deposition may also have had an effect on the weight gain since BFR tended (0,064) to increase as dietary protein was increased. Caldas et al. (2018) reported that broiler breeder hens at end of productive life (from 50 week of age) tended to raise their body lean mass deposition. This type of deposition is related principally to decrease of the breast muscle fractional breakdown rate and increase of the breast muscle fractional synthesis rate as broiler breeder hens aging (Vignale et al., 2016; Vignale et al., 2018). Which is likely associated to the decrease of the egg production with age (Caldas et al., 2018).

Unlike, Nonis and Gous (2012) demonstrated that protein deposition after sexual maturity tends to be negative and body weight gain is generally related to fatty tissue deposition. In this sense, the mobilization of lean tissue is more common at early lay and peak o production but tends to change when the rate of lay decreases which happens around the fiftieth week, period that coincides with the beginning of a decrease in fat mass (Caldas et al., 2018). Contradictory results have been reported in literature, where an increase of protein deposition and fat mobilization was observed in broiler breeder (Cobb) with approximately 50$^{th}$ weeks-old (Caldas et al., 2018; Vignale et al., 2016). In such case, authors suggest that breeder's metabolism will increase the mobilization of fat to meet the requirement for maintenance, which in turn follows the raise on body protein retention (Caldas et al., 2018). In this study, we observed that lays maintained the BPR and BFR, at least from 5.0 g $kg^{-1}$ of dig. lysine, corroborating with Vignale et al. (2018), whom tested different strains and observed that fat and lean mass tended to be kept with aging, but may change depending on strain. Therefore, the modulation of body composition during the laying period could be linked not only to nutritional factors but also to a genetic feature and egg production. Besides that, the positive BPR observed herein from 5.0 g $kg^{-1}$ of dietary lysine suggest that a relevant portion of the dietary amino acid and protein was redirected to deposition in the body which is not advantageous because it is not an objective of this type of enterprise (Table 3).

Regarding laying performance parameters (EW and EO) results suggest that protein:energy ratio influences the egg production traits. It is known that amino acids are demanded both for body and egg deposition (Ekmay et al., 2014), being determinants for the EW, and consequently EO (Lesuisse et al., 2017; Nonis and Gous, 2016; Van-Emous et al., 2015). The EW and EO observed in this study demonstrates that when decreasing levels of BP are offered to breeders, they respond reducing firstly EW until a point where the intake of BP it becomes too drastic and the EP is affected and thus EO decrease rapidly (Figure 2). A higher level of lysine (5.30 g $kg^{-1}$) was required for maximize EO in this study in comparison to the manual recommendations (5.20 g $kg^{-1}$), however, the level of total protein to maximize this variable (101.5 g $kg^{-1}$) was lower than the level recommended by the manual (130 g $kg^{-1}$), suggesting that broiler breeder hens at end of productive life may require lower levels of non-essential amino acids then that recommended by the manual, which could be linked to the large body reserves of breeders and decreased egg production compared to previous phases.

In this sense, it is kwon that the reliance of skeletal lean tissue for protein deposition in yolk usually increase with aging (Ekmay et al., 2014). Furthermore, the protein deposited in the albumen comes mainly from dietary amino acids and are produced in the oviduct in the early hours post ovulation (Muramatsu et al., 1991). Thus, the linear increase observed in the EW as dietary BP was raised (Table 5) agree with this assumption and indicates that broiler breeder hens can use the supply amino acids for egg deposition, which would occur by deposition of albumen directly, or a though a protein-sparing effect, since the reduction of BP caused a decline on daily BPR, which is clearly a response of their metabolism to maintain egg production. On this point of view, it can be inferred that although the reliance of skeletal muscle for yolk formation may be increased when egg production begins to decline (Ekmay et al., 2014), a remarkable source of amino acids may be derivate from the dietary supply.

According to the results observed for severe protein deficiency obtained in the lowest BP level (4.0 g kg$^{-1}$ of dig. lysine) and considering that feed was formulated to meet or exceed the daily requirement of energy (374 kcal day$^{-1}$ at 150 g day$^{-1}$ feed), it is reasonable to assume that both dietary BP and FA influenced the energy partitioning, since TER, BER and EER varied among treatments. It was shown that breeders modified the energy retained in body when feed allowance changes from 150 g day$^{-1}$ to 170 g day$^{-1}$, through the increase of lipid deposition in the body (89% higher in birds feed with 170 g day$^{-1}$). This result was expected since the modulation of energy deposited in body as lipid may be changed depending on current egg production (Nonis and Gous, 2012). In addition, Salas et al. (2016) reported that an important portion of energy required for egg production is met by body fat and lipogenesis, however the dietary energy supply herein was kept within the recommendation even in the low daily FA energy suggesting that the requirements for energy was met mainly by the feed.

The THP decreased quadratically as BP increased and the lowest value was found using 5.9 g $kg^{-1}$ of dig. lysine, suggesting the existence of an “energy-dependent” phase, where the efficiency of protein utilization is reduced, as observed by Gous et al. (2018) in broiler chickens. In a scenario like that, the energy of the diet is a limiting factor for protein deposition, thus the increase of protein will not result in an improvement on protein retained. Steenhuisen and Gous (2016) reported a linear increase on energy retained and similar decrease in total heat production when broilers breeder hens from 28 to 33 weeks of age were fed with distinct levels of balanced protein and feed allocation. The absence of inflexion point observed by these authors are in contrast with the results observed herein, and maybe linked to the age of hens, since newer hens has a higher capacity for increase the egg output in response to BP increase, which in fact was demonstrated by Steenhuisen and Gous (2016).

In conclusion, the balanced protein levels offered to breeders does not affect feed intake at restricted feed allowance but can modify the body composition and consequently energy partitioning. The egg production traits suggest that breeders mobilize body protein to avoid a reduction on egg production, increasing the production of heat because of protein catabolism.

**References**

Bowmaker, J.E.; Gous, R.M. 1991. The response of broiler breeder hens to dietary lysine and methionine. British Poultry Science 32: 1069-1088.

Caldas, J. V.; Hilton, K.; Boonsinchai, N.; England, J.A.; Mauromoustakos, A.; Coon, C.N. 2018. Dynamics of nutrient utilization, heat production, and body composition in broiler breeder hens during egg production. Poultry Science 97: 2845-2853.

Emmans, G, C. 1974. The effects of temperature on the performance of laying hens. p. 79-90. In: Morris, T.R., Freeman, B.M., eds. Energy Requirements of Poultry. British Poultry Science Ltd, Edinburgh, Scotland.

Ekmay, R. D.; Salas, C.; England, J.; Cerrate, S.; Coon, C. N. 2014. Lysine partitioning in broiler breeders is not affected by energy or protein intake when fed at current industry levels. Poultry Science 93: 1737-1744.

Gonçalves, C. A.; Sakomura, N. K.; Silva, E. P.; Artoni, S. M. B.; Suzuki, R. M.; Gous, R. M. 2018. Dual energy X-ray absorptiometry is a valid tool for assessing in vivo body composition of broilers. Animal Production Science 59: 993-1000.

Gous, R. M.; Faulkner, A. S.; Swatson, H. K. 2018. The effect of dietary energy: protein ratio, protein quality and food allocation on the efficiency of utilisation of protein by broiler chickens. Brithish Poultry Science 59: 100-109.

Kim, E.; Wickramasuriya, S. S.; Shin, T. K.; Cho, H. M.; Kim, H. B.; Heo, J. M. 2020. Estimating total lysine requirement for optimised egg production of broiler breeder hens during the early-laying period. Journal of Animal Science and Technology. 62:521-532.

Lesuisse, J.; Li, C.; Schallier, S.; Leblois, J.; Everaert, N.; Buyse, J. 2017. Feeding broiler breeders a reduced balanced protein diet during the rearing and laying period impairs reproductive performance but enhances broiler offspring performance. Poultry Science 1: 1-11.

Morris, T. R.; Gous, R. M. 1988. Partitioning of the response to protein between egg number and egg weight. British Poultry Science 29: 93-99.

Muramatsu, T.; Hiramoto, K.; Okumura, J. 1991. Changes in ovalbumin and protein synthesis in vivo in the magnum of laying hens during the egg formation cycle. Comparative Biochemistry and Physiology B 99: 141-146.

Nonis, M. K.; Gous, R. M. 2012. Broiler breeders utilise body lipid as an energy source. South African Journal of Animal Science 42: 369-378.

Nonis, M. K.; Gous, R. M. 2016. Changes in the feather-free body of broiler breeder hens after sexual maturity. Animal Production Science 56: 1099-1104.

Rostagno, H. S.; Albino, L. F. T.; Hannas, M.I.; Donzele, J.L.; Sakomura, N.K.; Perazzo, F.G.; Saraiva, A.; Teixeira, M.V.; Rodrigues, P.B.; Oliveira, R.F.; Barreto, S.L.T.; Brito, C.O, eds. 2017. Brazilian tables for poultry and swine. UFV press, Viçosa, MG, Brazil.

Robbins, K. R.; Saxton, A. M.; Southern L. L. 2006. Estimation of nutrient requirements using broken-line regression analysis. Journal of Animal Science 84: 155-165.

Sakomura, N. K. 2004. Modeling energy utilization in broiler breeders, laying hens and broilers. Brazilian Journal of Poutry Science 6: 1-11.

Sakomura, N. K.; Rostagno, H. S, eds. 2016. Métodos de pesquisa em nutrição de monogásticos. FUNEP press, Jaboticabal, SP, Brazil (em portugês).

Salas, C.; Ekmay, R. D.; England, J. A.; Cerrate, S.; Coon, C. N. 2016. Mechanisms of lipid mobilization towards egg formation in broiler breeder hens using stable isotopes. Poultry Science 96: 383-387.

Shafey, T. M. 2002. Effects of egg size and eggshell conductance on hatchability traits of meat and layer breeder flocks. Asian-Australian Journal Animal Science 15: 1-6.

Steenhuisen, E.; Gous, R. M. 2016. The response of broiler breeder hens to dietary balanced protein. South African Journal of Animal Science 46: 269-277.

Van-Emous, R. A.; Kwakkel, R. P.; Van-Krimpen, M. M.; Hendriks, W. H. 2015. Effects of dietary protein levels during rearing and dietary energy levels during lay on body composition and reproduction in broiler breeder females. Poultry Science 92: 2091-2100.

Vignale, K.; Caldas, J. V; England, J. A.; Boonsinchai, N.; Sodsee, P.; Putsakum, M.; Pollock, E. D.; Dridi, S.; Coon, C. N. 2016. The effect of four different feeding regimens from rearing period to sexual maturity on breast muscle protein turnover in broiler breeder parent stock. Poultry Science 96: 1219-1227.

Vignale, K.; Caldas, J. V; England, J. A.; Boonsinchai, N.; Sodsee, P.; Pollock, E. D.; Coon, C. N. 2018. The effect of sexual maturity and egg production on skeletal muscle (pectoralis major and gastrocnemius) protein turnover in broiler breeder pure lines. Poultry Science 97: 531-539.

Table 1 – Composition of feed and calculated composition

| Ingredients[1] (g kg-1) | Balanced protein (g kg-1) 4.0 | 5.0 | 6.0 | 7.0 | 8.0 |
|---|---|---|---|---|---|
| Broken rice | 258.3 | 286.2 | 314.2 | 342.1 | 370.0 |
| Maize starch | 233.0 | 174.8 | 116.5 | 58.3 | - |
| Corn | 202.5 | 219.5 | 236.5 | 253.5 | 270.5 |
| Wheat bran | 150.0 | 133.1 | 116.2 | 99.2 | 82.3 |
| Soybean meal | - | 30.6 | 61.2 | 91.7 | 122.3 |
| Peanut meal | 18.3 | 18.3 | 18.4 | 18.4 | 18.4 |
| Corn gluten | 2.0 | 3.3 | 4.5 | 5.7 | 7.0 |
| Soybean Oil | - | 1.4 | 2.8 | 4.1 | 5.5 |
| Limestone | 61.8 | 61.6 | 61.3 | 61.1 | 60.8 |
| Potassium chloride | 2.7 | 2.0 | 1.4 | 0.7 | - |
| Sodium Chloride | 3.8 | 3.7 | 3.7 | 3.7 | 3.6 |
| Inert | 49.6 | 46.0 | 42.4 | 38.8 | 35.3 |
| L-lysine HCl (78%) | 2.66 | 2.91 | 3.17 | 3.42 | 3.67 |
| Dl-methionine (98%) | 1.65 | 2.15 | 2.65 | 3.15 | 3.65 |
| L-isoleucine (99%) | 1.56 | 1.80 | 2.04 | 2.28 | 2.52 |
| L-threonine (99%) | 1.19 | 1.43 | 1.67 | 1.91 | 2.15 |
| L-valine (99%) | 0.85 | 1.03 | 1.20 | 1.38 | 1.56 |
| L-tryptophan (99%) | 0.32 | 0.38 | 0.44 | 0.50 | 0.56 |
| L-arginine (99%) | - | 0.08 | 0.16 | 0.23 | 0.31 |
| L-phenylalanine (99%) | - | 0.01 | 0.02 | 0.04 | 0.05 |
| TOTAL (kg) | 1000 | 1000 | 1000 | 1000 | 1000 |
| Calculated nutrient composition[2] (g kg-1) | | | | | |
| Total protein | 80.3 | 96.5 | 112.7 | 128.8 | 145.0 |
| Chlorine | 1.83 | 1.87 | 1.88 | 1.90 | 1.90 |
| Potassium | 4.87 | 4.87 | 4.87 | 4.87 | 5.00 |
| Sodium | 1.61 | 1.61 | 1.61 | 1.61 | 1.60 |
| Digestible Lysine | 4.00 | 5.00 | 6.00 | 7.00 | 8.00 |
| Digestible Met. + Cist. | 3.68 | 4.60 | 5.52 | 6.44 | 7.36 |
| Digestible Threonine | 3.00 | 3.75 | 4.50 | 5.25 | 6.00 |
| Digestible Tryptophan | 0.96 | 1.20 | 1.44 | 1.68 | 1.92 |
| Digestible Arginine | 4.40 | 5.51 | 6.62 | 7.72 | 8.83 |
| Digestible Valine | 3.52 | 4.40 | 5.28 | 6.16 | 7.04 |
| Digestible Isoleucine | 3.60 | 4.50 | 5.40 | 6.30 | 7.20 |

Each kg of feed contained 8.1 g of dicalcium phosphate, 0.75 g of choline chloride, and 1 g of Vit. + Min as ingredient Premix. Content/kg of premix: Beta-carotene = 11000 UI; Cholecalciferol = 3500 UI; Alpha-tocopherol = 100 mg; Menadione = 5 mg; Thiamine = 3 mg; Riboflavin = 12 mg; Pyridoxine = 4 mg; Folate = 2 mg; Niacin = 55mg; Calcium Pantothenate = 15 mg; Folic Acid = 2 mg; Biotin = 0.25 mg; Iron = 50 mg; Copper = 10 mg; Manganese = 120 mg; Zinc = 110 mg; Iodine = 2 mg; Selenium = 0.30 mg.

[2]Each kg of feed contained 2750 kcal of Metabolizable energy, 26.1 g of calcium, and 2.55 g of available phosphorus.

Table 2 – Daily feed intake (g bird day$^{-1}$), protein intake (g bird day$^{-1}$) and energy intake (kcal bird day$^{-1}$) of broiler breeder hens from 55 to 65 old weeks subjected to five dietary protein level and fed either 150 or 170 g/d.

| BP[1] g kg$^{-1}$ | Feed intake g bird day$^{-1}$ | | | Lysine intake g bird day$^{-1}$ | | | Energy intake kcal bird day$^{-1}$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | Feed allocation (g bird day$^{-1}$) | | | | | | | | |
| | 150 | 170 | Mean | 150 | 170 | Mean | 150 | 170 | Mean |
| 4.0 | 142 | 161 | 151.8 | 0.57 | 0.65 | 0.61 | 392 | 446 | 419.1 |
| 5.0 | 144 | 162 | 152.2 | 0.72 | 0.82 | 0.76 | 396 | 449 | 418.7 |
| 6.0 | 144 | 162 | 153.4 | 0.87 | 0.98 | 0.92 | 397 | 448 | 421.8 |
| 7.0 | 143 | 161 | 152.3 | 1.01 | 1.14 | 1.07 | 395 | 447 | 420.2 |
| 8.0 | 144 | 161 | 151.9 | 1.15 | 1.30 | 1.22 | 396 | 447 | 419.0 |
| Mean | 143 | 162 | | 0.86 | 0.98 | | 395 | 447 | |
| RMSE[2] | 3.31 | | | 0.013 | | | 5.67 | | |

[1]Digestible Lysine in the feed as a reference for balanced protein, [2]Root mean square error, [3]Feed allowance

Table 3 – Mean of initial body weight (Initial BW), body weight gain (BWG), body protein retention (BPR) and body fat retention (BFR) of broiler breeder hens from 55 to 65 old weeks subjected to five dietary protein level and fed either 150 or 170 g/d.

| BP[1] g $kg^{-1}$ | Initial BW kg | | | BWG g day-1 | | | BPR g day-1 | | | BFR g day-1 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feed allocation (g bird $day^{-1}$) | | | | | | | | | | | |
| | 150 | 170 | Mean | 150 | 170 | Mean | 150 | 170 | Mean | 150 | 170 | Mean |
| 4.0 | 3.924 | 3.818 | 3.87 | 1.09 | 5.85 | 3.47 | -0.81 | -0.22 | -0.52 | 0.15 | 1.17 | 0.66 |
| 5.0 | 3.853 | 3.803 | 3.83 | 6.12 | 8.99 | 7.56 | 0.27 | 0.53 | 0.40 | 1.32 | 1.51 | 1.42 |
| 6.0 | 3.918 | 3.94 | 3.93 | 6.84 | 11.57 | 9.21 | 0.55 | 1.11 | 0.83 | 0.85 | 3.08 | 1.97 |
| 7.0 | 3.837 | 3.885 | 3.86 | 7.35 | 11.5 | 9.43 | 1.25 | 0.55 | 0.90 | 1.97 | 2.4 | 2.19 |
| 8.0 | 3.883 | 3.904 | 3.89 | 6.12 | 12.96 | 9.54 | 0.34 | 1.21 | 0.78 | 1.47 | 2.43 | 1.95 |
| Mean | 3.883 | 3.87 | | 5.50b | 10.17a | | 0.32 | 0.63 | | 1.15b | 2.12a | |
| RMSE[2] | | 0.355 | | | 2.788 | | | 0.666 | | | 0.904 | |
| Source of variance | | | | | | | | | | | | |
| FA[3] | | 0.797 | | | <0.001 | | | 0.243 | | | 0.009 | |
| BP | | 0.774 | | | <0.001** | | | 0.013** | | | 0.064 | |
| BPxFA | | 0.867 | | | 0.131 | | | 0.416 | | | 0.371 | |

[1]Balanced protein, [2]Feed allocation, [3]Root mean square error, **Quadratic effect, Values in the same line with different letters means significantly different (p<0.05)

Table 4 – Paramenters of adjusted for quadratic broken equations (± standard deviation) from body weight gain (BWG), body protein retention (BPR), egg output (EO), body energy retention as protein (BPRp), total body energy retention (BER), egg energy retention (EER), total energy retention (TER) and heat production (HP).

| Paramenter | BWG | BPR | EO | BERp | BER | EER | TER | HP |
|---|---|---|---|---|---|---|---|---|
| U | -1.25±0.66 | -0.25±0.22 | 2.77±3.57 | -5.17±2.11 | -2.30±2.43 | -5.56±7.17 | -7.88±3.35 | 8.33±5.37 |
| R | 6.12±0.55 | 6.35±1.03 | 5.31±0.86 | 5.51±0.49 | 7.05±1.59 | 5.31±0.86 | 5.92±0.39 | 5.85±0.59 |
| L | 9.09±0.38 | 0.87±0.18 | 31.29±0.56 | 4.91±0.91 | 24.86±3.82 | 62.78±1.12 | 96.97±1.56 | 322.5±2.92 |
| Lack of fit (p-value) | 0.965 | 0.881 | 0.996 | 0.890 | 0.821 | 0.996 | 0.636 | 0.746 |
| MSE[1] | 13.64 | 0.416 | 34.34 | 13.32 | 169.1 | 11.76 | 15.7 | 551.3 |

[1]Mean squared error

Table 5 – Egg weight (g), egg production (%) and egg output (g/bird/day) of broiler breeder hens from 55 to 65 old weeks subjected to five dietary protein level and fed either 150 or 170 g/d.

| BP[1] g kg$^{-1}$ | Egg weight g | | | Egg production % | | | Egg output g bird day$^{-1}$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | Feed allocation (g bird day$^{-1}$) | | | | | | | | |
| | 150 | 170 | Mean | 150 | 170 | Mean | 150 | 170 | Mean |
| 4.0 | 62.3 | 64.1 | 63.2 | 42.3 | 42.1 | 42.2 | 26 | 27 | 26.6 |
| 5.0 | 63.6 | 66.0 | 64.8 | 47.2 | 48.4 | 47.8 | 30 | 32 | 31.1 |
| 6.0 | 65.9 | 66.3 | 66.1 | 46.6 | 47.9 | 47.3 | 31 | 32 | 31.3 |
| 7.0 | 68.3 | 67.0 | 67.7 | 44.5 | 49.2 | 46.9 | 30 | 33 | 31.4 |
| 8.0 | 67.4 | 67.3 | 67.4 | 47.5 | 46.0 | 46.8 | 32 | 31 | 31.3 |
| Mean | 65.5 | 66.1 | | 45.6 | 46.7 | | 30 | 31 | |
| RMSE[2] | 4.84 | | | 9.58 | | | 5.91 | | |
| Source of variance | | | | | | | | | |
| FA[3] | 0.364 | | | 0.444 | | | 0.176 | | |
| BP | <0.001* | | | 0.084 | | | <0.001** | | |
| BPxFA | 0.512 | | | 0.705 | | | 0.625 | | |

[1]Balanced protein, [2]Feed allocation, [3]Root mean square error, *linear effect **Quadratic effect

Table 6 – Mean body energy retention as protein (BERp), body energy retention as fat (BERf), total body energy retention (BERt) egg energy retention (EER), total energy retained (TER) and total heat production (HP), over experimental period in broiler breeder hens subjected to five dietary protein level and fed either 150 or 170 g/d.

| BP[1] g kg$^{-1}$ | BERp kcal bird day$^{-1}$ | | | BERf kcal day$^{-1}$ | | | BER kcal day$^{-1}$ | | | EER kcal day$^{-1}$ | | | TER kcal day$^{-1}$ | | | THP kcal day$^{-1}$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feed allocation (g bird day$^{-1}$) | | | | | | | | | | | | | | | | | |
| | 150 | 170 | Mean | 150 | 170 | Mean | 150 | 170 | Mean | 150 | 170 | Mean | 150 | 170 | Mean | 150 | 170 | Mean |
| 4.0 | -4.58 | -1.23 | -2.91 | 1.40 | 11.00 | 6.20 | -3.10 | 9.80 | 3.35 | 52.5 | 53.9 | 53.2 | 57.0 | 78.3 | 67.7 | 334.0 | 366.3 | 350.2 |
| 5.0 | 1.51 | 3.01 | 2.26 | 12.40 | 14.10 | 13.25 | 13.90 | 17.10 | 15.50 | 60.1 | 64.6 | 62.4 | 85.2 | 96.0 | 90.6 | 310.6 | 348.6 | 329.6 |
| 6.0 | 3.12 | 6.25 | 4.69 | 8.00 | 28.80 | 18.40 | 8.50 | 35.10 | 21.80 | 61.2 | 64.2 | 62.7 | 89.5 | 102.8 | 96.2 | 307.1 | 344.1 | 325.6 |
| 7.0 | 7.09 | 3.06 | 5.08 | 18.50 | 22.50 | 20.50 | 25.60 | 29.20 | 27.40 | 60.1 | 65.7 | 62.9 | 89.3 | 101.7 | 95.5 | 300.0 | 340.6 | 320.3 |
| 8.0 | 1.92 | 6.83 | 4.38 | 13.70 | 22.70 | 18.20 | 15.70 | 29.60 | 22.65 | 64.0 | 61.6 | 62.8 | 91.1 | 108.0 | 99.6 | 306.6 | 339.5 | 323.1 |
| Mean | 1.81 | 3.58 | | 10.8a | 19.8b | | 12a | 24b | | 60 | 62 | | 82a | 97b | | 311a | 347b | |
| RMSE[2] | 3.77 | | | 8.47 | | | 12.2 | | | 11.86 | | | 13.38 | | | 14.51 | | |
| Source of variance | | | | | | | | | | | | | | | | | | |
| FA[3] | 0.245 | | | 0.009 | | | 0.017 | | | 0.176 | | | <0.001 | | | <0.001 | | |
| BP | 0.013** | | | 0.065 | | | 0.026** | | | <0.001** | | | <0.001** | | | <0.001** | | |
| BPxFA | 0.411 | | | 0.371 | | | 0.516 | | | 0.625 | | | 0.655 | | | 0.862 | | |

[1]Balanced protein, [2]Feed allocation, [3]Root mean square error, **Quadratic effect, Values in the same line with different letters means significantly different (p<0.05)

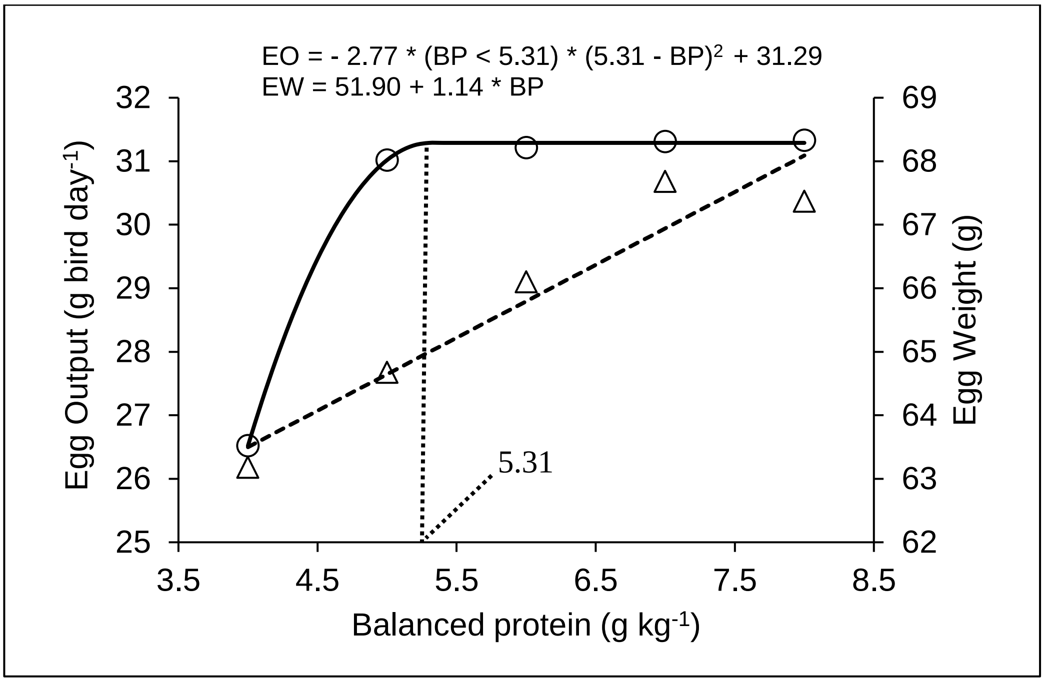


Figure 1 – Egg output (---) and egg weight (——) of broiler breeder hens from 55 to 65 weeks of production fed to five levels of balanced protein.

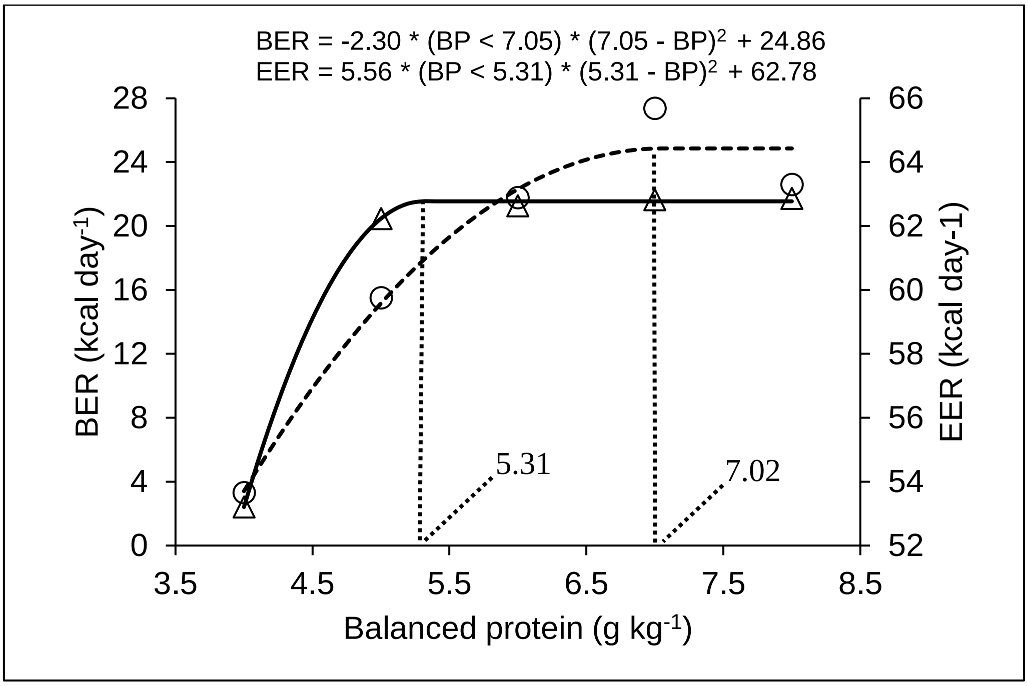


Figure 2 – Egg energy retention (EER (---)) and body energy retention (BER (——)) of broiler breeder hens from 55 to 65 weeks of production fed to five levels of balanced protein

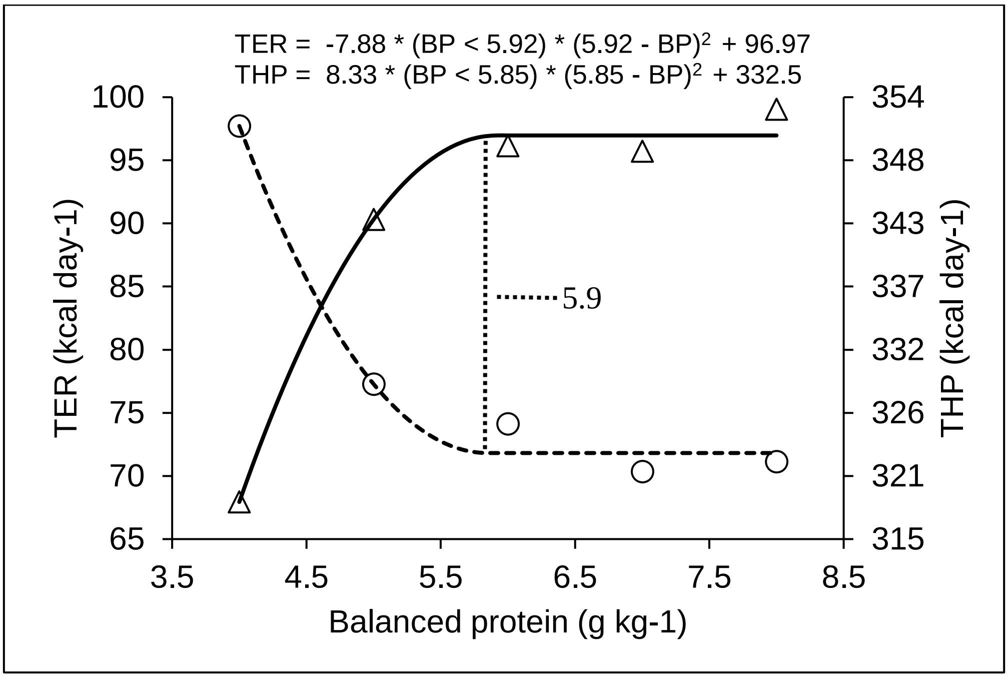


Figure 3 – Total energy retention (---) and total heat production (——) of broiler breeder hens from 55 to 65 weeks of production fed to five levels of balanced protein

## CAPÍTULO 5 - Implicações

O proposito do presente estudo foi atualizar o entendimento acerca da resposta de frangos de corte a proteina balanceada da dieta e de acordo com essas respostas estimar o ótimo econômico de proteina balanceada, enfatizando as diferenças entre o maximo desempenho biológico e o máximo desempenho produtivo. Além disso, também foi o obejtivo do estudo estimar o impacto da proteina balanceada sobre a composição corporal e desempenho produtivo de matrizes de frangos de corte.

Os resultados gerados demonstram que, além de influenciar o ganho de peso e conversão alimentar, a proteina balanceada da dieta tem impacto sobre o consumo de ração de frangos de corte das duas linhagens mais produzidas no Brasil atualmente. Esses resultados quando considereados conjutamente com as flutuações do mercado possibilitaram entender que; manter um nivel fixo de proteina balanceada independente dos preços de compra dos insumos e venda dos produtos na não traz vantagens econômicas.

Já para matrizes de frangos de corte, os resultados demonstraram que essa categoria animal tem uma grande capacidade de retirar nutrientes das reservas corporais para manutenção da produção de ovos, o que torna vantajoso o uso de dieta de baixa proteina bruta desde que mantido os níveis de aminoácidos essenciais de acordo com a recomendações dos manuais.

Ambos os resultados desmonstram um oportunidade de ganhos econômicos para a cadeia podutiva de frangos de corte, e podem ser utilziadas para melhoria da rentabilidade dessa que é uma das mais importantes áreas do agronegócio brasileiro.