UNIVERSIDADE ESTADUAL PAULISTA "JÚLIO DE MESQUITA FILHO"
FACULDADE DE CIÊNCIAS AGRÁRIAS E VETERINÁRIAS CAMPUS DE JABOTICABAL

MODELAGEM DO CRESCIMENTO, MATURAÇÃO SEXUAL E PRODUÇÃO DE OVOS COMO FERRAMENTA PARA ESTIMAR AS EXIGÊNCIAS NUTRICIONAIS DE MATRIZES PESADAS

Nayara Tavares Ferreira
Zootecnista

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Orientador: Profa. Dra. Nilva Kazue Sakomura

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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

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DADOS CURRICULARES DO AUTOR

NAYARA TAVARES FERREIRA – filha de José Carlos Ferreira e Isabel Cristina Balsanelli Tavares nasceu no dia 11 de abril de 1986, na cidade de Ribeirão Preto, São Paulo. Em agosto de 2004 ingressou no curso de Zootecnia na Faculdade de Engenharia da Universidade Estadual Paulista – Campus de Ilha Solteira, São Paulo, graduando-se em novembro de 2008. De abril de 2009 a janeiro de 2010 foi bolsista de Apoio Técnico pela FAPESP, sob orientação da Profa. Dra. Nilva Kazue Sakomura, na Faculdade de Ciências Agrárias e Veterinárias da Universidade Estadual Paulista – Campus de Jaboticabal, São Paulo. Em março de 2010 iniciou o curso de Mestrado em Nutrição e Produção Animal pela Faculdade de Medicina Veterinária e Zootecnia da Universidade de São Paulo – Campus de Pirassununga, onde obteve bolsa pela FAPESP, sob orientação do Prof. Dr. Ricardo de Albuquerque, defendendo a dissertação em dezembro de 2011. Em março de 2012 ingressou no curso de doutorado em Zootecnia, na Faculdade de Ciências Agrárias e Veterinárias da Universidade Estadual Paulista – Campus de Jaboticabal, São Paulo, sob orientação da Profa. Dra. Nilva Kazue Sakomura, obteve bolsa pela FAPESP e defendendo esta tese em março de 2015.

“A mente que se abre a uma nova idéia jamais voltará ao seu tamanho original.”

Albert Einstein

“Agradeço todas as dificuldades que enfrentei; não fosse por elas, eu não teria saído do lugar. As facilidades nos impedem de caminhar. Mesmo as críticas nos auxiliam muito.”

Chico Xavier

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Certificamos que o Protocolo nº 9999/14 do trabalho de pesquisa intitulado **"Modelagem da produção e das exigências nutricionais de aves e peixes - Determinação do potencial genético de crescimento de aves e peixes"**, sob a responsabilidade da Prof.ª Dr.ª Nilva Kazue Sakomura está de acordo com os Princípios Éticos na Experimentação Animal adotado pelo Conselho Nacional de Controle de Experimentação Animal (CONCEA) e foi aprovado pela COMISSÃO DE ÉTICA NO USO DE ANIMAIS (CEUA), em reunião ordinária de 07 de julho de 2014.

Jaboticabal, 07 de julho de 2014.

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MODELAGEM DO CRESCIMENTO, MATURAÇÃO SEXUAL E PRODUÇÃO DE OVOS COMO FERRAMENTA PARA ESTIMAR AS EXIGÊNCIAS NUTRICIONAIS DE MATRIZES PESADAS

RESUMO - Modelos matemáticos têm sido usados como uma ferramenta na nutrição de aves para ajustar os níveis nutricionais para cada fase de criação. No entanto, para a sua aplicação em matrizes pesadas, é necessário para descrever o crescimento do corpo e dos órgãos reprodutivos até à maturidade sexual e a produção de ovos. Assim, o objetivo deste trabalho foi: 1) modelar o crescimento e maturação sexual e estimar a exigência nutricional; 2) simular a exigência nutricional de matrizes criadas sob diferentes programas de iluminação (Programa A: 8 h luz / dia até 100 dias seguido por um aumento nessa idade a 13 h / dia; e Programa B: 8 h luz / dia até 140 dias seguido por aumento nessa idade para 13 h / dia; 3) modelar a produção de ovos de matrizes pesadas; e 4) estimar a exigência nutricional das matrizes em produção. Para a coleta de dados foram realizados 3 experimentos separadamente, sendo a fase de crescimento (1-25 semanas), maturação sexual (18-28 semanas) e produção (24-60 semanas). Na fase de crescimento foram utilizadas 300 matrizes Cobb de 1 dia de idade até 25 semanas. Para fase de maturação sexual, foram realizados abates semanais de 5 aves/semana; e para descrever a produção de ovos foram utilizadas 60 matrizes. As conclusões obtidas foram: 1) a concentração recomendada de lisina, metionina + cistína e treonina para 1 a 2 semanas de idade, são 12,5, 11,0 e 9,4, para 3 a 17 semanas de idade são de 8,6, 6,4 e 5,6; e para 18 a 20 semanas de idade são de 7,0, 5,1 e 4,3 g de aminoácido / kg de ração, respectivamente. 2) Para a simulação de exigência de acordo com o programa de iluminação utilizado, as exigências de lisina estimadas foram 284(±78), 298(±71) para 1-4 semanas de idade, 400(±150), 422(±133) para 5-17 semanas de idade e 537(±204), 561(±171) a 18-22 semanas de idade, para o programa de luz A e B, respectivamente. As exigências de metionina + cistina foram 263(±44), 272(±40) para 1-4 semanas de idade, 320(±90), 333(±80) para 5-17 semanas de idade e 453(±149), 468(±129) para 18-22 semanas de idade, para o programa de luz A e B, respectivamente. As exigências de treonina foram 218(±44), 227(±40) para 1-4 semanas de idade, 266(±83), 279(±73) para 5-17 semanas de idade, e 357(±122), 370(±103) para 18-22 semanas de idade, para o programa de iluminação A e B, respectivamente. 3) O modelo desenvolvido para a produção de ovos é um reflexo preciso das mudanças que ocorrem no número de ovos produzidos por matrizes pesadas, bem como no próprio ovo e em seus componentes ao longo de todo o período de postura. Este modelo pode, assim, ser utilizado na previsão das exigências nutricionais de aves reprodutoras pesadas individuais, que, quando combinado com dados simulados a partir de um grande número de indivíduos, vai descrever com precisão o desempenho que coloca de um rebanho de matrizes pesadas. 4) A recomendação de aminoácidos na dieta seria 3,95 g de Lys e 3,06 g de Met + Cys por kg de ração para aves reprodutoras pesadas no pico da produção alimentadas com 160 g de ração por dia.

Palavras-chave: matrizes pesadas; modelagem, modelo estocástico, requerimento nutricional

MODELING OF GROWTH, SEXUAL MATURITY AND EGG PRODUCTION AS A TOOL TO ESTIMATE THE NUTRITIONAL REQUIREMENTS OF BROILER BREEDERS

ABSTRACT - Mathematical models have been used as a tool in poultry nutrition to adjust the nutritional levels for each breeding phase. However, for its application on broiler breeders it is necessary to describe the growth of the body and reproductive organs up to the sexual maturity and egg production. Thus, the objectives of this study were: 1) Modelling the growth and sexual maturity and estimate the nutritional requirement; 2) Simulate the nutritional requirement of broiler breeders using different lighting programmes (Program A: 8 h light/d to 100 d followed by an increase at that age to 13 h/d; and Program B: 8 h light/d to 140 d at which age the light was increased to 13 h/d); 3) Modelling the egg production of broiler breeder; and 4) Estimate the nutritional requirement of the broiler breeders in egg production. To collect data, 3 experiments were conducted, separately: the growth phase (1-25 weeks), sexual maturity (18-28 weeks) and egg production (24-60 weeks). In the growth phase were used 300 Cobb broiler breeders from 1 day old to 25 weeks. To sexual maturity phase, weekly slaughtering of 5 birds / week to measure the growth of reproductive organs; and to describe the egg production, 60 broiler breeders were used. The conclusions were obtained: 1) The concentration recommended of lysine, methionine + cysteine and threonine, to 1 to 2 weeks of age are 12.5, 11.0 and 9.4; to 3 to 17 weeks of age are 8.6, 6.4 and 5.6; and to 18 to 20 weeks of age are 7.0, 5.1 and 4.3 g amino acid / kg diet, respectively. 2) For the simulation, according to the lighting program used, the lysine requirement estimates were 284(±78), 298(±71) to 1-4 weeks of age, 400(±150), 422(±133) to 5-17 weeks of age and 537(±204), 561(±171) to 18-22 weeks of age, for lighting program A and B, respectively. Methionine + cystine requirements were 263(±44), 272(±40) to 1-4 weeks of age, 320(±90), 333(±80) to 5-17 weeks of age and 453(±149), 468(±129) to 18-22 weeks of age, for lighting program A and B, respectively. Threonine requirements were 218(±44), 227(±40) to 1-4 weeks of age, 266(±83), 279(±73) to 5-17 weeks of age and, 357(±122), 370(±103) to 18-22 weeks of age, for lighting program A and B, respectively. 3) The model developed for the production of eggs is an accurate reflection of the changes that occur in the number of eggs produced by broiler breeders, as well as in the egg itself and in its components over the entire laying period. This model can thus be used in predicting the nutrient requirements of individual broiler breeder hens, which, when combined with simulated data from a large number of individuals, will accurately describe the laying performance of a flock of broiler breeders. 4) The amino acid in the diet recommendation would be 3.95 g and 3.06 g of Lys Met + Cys per kg of feed for broiler breeder hens at peak production of food 160 g of feed per day.

Keywords: broiler breeders; modeling, nutritional requirement, stochastic model.

CAPÍTULO 1 – CONSIDERAÇÕES GERAIS

1. Introdução

Com o aumento mundial no consumo de carne de aves nos últimos anos, a produção de ovos incubáveis para plantéis de frangos de corte tornou-se um componente extremamente importante da indústria avícola. Para isso empresas de matrizes estão continuamente melhorando as linhagens, que exibem melhor crescimento, eficiência alimentar e produtividade.

Nesse aspecto deve ser considerado que a maneira pela qual as matrizes pesadas foram alimentadas no passado não é a forma mais eficaz para alimentar as linhagens modernas, portanto, torna-se imprescindível estimar corretamente os níveis de nutrientes nas dietas. Porém para ter sucesso na alimentação destas aves, a estimativa das necessidades diárias de nutrientes precisa ser conhecida, porém as informações para matrizes pesadas são limitadas, se comparadas com outros tipos de aves domesticadas.

Devido as matrizes pesadas apresentarem características próprias e diferenças evidentes em comparação com poedeiras comerciais, necessitam de estudos específicos para alcançar o máximo potencial destas aves. Aves reprodutoras pesadas diferem de poedeiras comerciais em vários aspectos como por exemplo crescimento corporal e voracidade, sobretudo na distribuição de frequência da postura do ovo e consideráveis reservas lipídicas. Este último aspecto tem sido motivação de vários estudos pelo seu benefício na reprodução, assim como pelo efeito deletério, quando presente em excesso.

Uma das formas de controlar o excesso de reservas lipídicas de matrizes é a restrição alimentar durante o período de criação, por outro lado, o fornecimento deve suprir as necessidades para manutenção do corpo, crescimento e postura do ovo. Os níveis nutricionais do programa de alimentação adotado na fase de crescimento devem ser ajustados para possibilitar a expressão da maturação sexual.

Na fase de produção, as matrizes pesadas apresentam uma peculiaridade no fenômeno da postura em relação às poedeiras. As poedeiras põem um ovo por dia, durante certo número de dias consecutivos e pausam por um ou mais dias. Este ciclo normalmente completa-se com a postura de nove ovos (NONIS e GOUS, 2013), por outro lado, as matrizes pesadas não completam este ciclo e apresentam irregularidade na postura, consequentemente maior período de pausa e ciclos menores. Logo, o fornecimento de ração para matrizes pesadas deve ser ajustado às exigências nutricionais de cada fase para não fornecer em excesso e para que as aves atinjam o máximo potencial genético.

Modelar o crescimento, maturação sexual e a produção de ovos pode possibilitar que nutricionistas venham corrigir a quantidade de ração fornecida ao longo da vida das matrizes, atingindo o potencial genético, reduzindo as reservas lipídicas e minimizando os efeitos da postura irregular destas aves. Além de reduzir o custo com alimentação, esta correção pode prevenir possíveis efeitos deletérios de acúmulo excessivo de gordura da carcaça e consequentemente proporcionar possíveis incrementos na produção de ovos por melhoria na homeostase orgânica.

A forma mais adequada para ajustar os níveis nutricionais, ou uma estratégia de alimentação para cada fase de criação, é através da utilização de modelos de simulação. Com o progresso no processamento de dados, bem como no conhecimento das ciências biológicas, avaliação da produção animal e de nutrientes, houve grande avanço na modelagem matemática, o que dinamizou o desenvolvimento da pesquisa em Nutrição. Porém para a construção desses modelos, é necessário conhecer o potencial dessas aves.

As publicações sobre exigências nutricionais de matrizes são fragmentadas e, grande parte empírica e quase exclusivamente de ensaios de curta duração. Desta forma, este estudo teve como objetivo modelar o crescimento, maturação sexual e produção de ovos de matrizes pesadas, e estimar a exigência nutricional para cada fase.

1.1. Restrição alimentar para matrizes pesadas

A seleção genética para maior ganho de peso e deposição de carne para frangos de corte, tem sido acompanhada pelo aumento do consumo de alimentos

(RENEMA e ROBINSON, 2004). Essa maior ingestão alimentar está negativamente relacionada com o desempenho produtivo de matrizes pesadas, uma vez que afeta a maturidade sexual, composição corporal, tamanho do ovo, produção do ovo e morfologia do ovário (HOCKING, 1987; HOCKING, 1993).

Matrizes pesadas não regularam adequadamente o consumo voluntário para atingir a exigência energética, o que altera o balanço cumulativo entre a regulação da ingestão de alimento entre as refeições proporcionando acúmulo de lipídios em longo prazo (RICHARDS, 2003).

De acordo com Heck *et al.*, 2004, se a ingestão diária de alimentos de matrizes pesadas não fosse restrita ao longo de sua vida a ave seria capaze de atingir à 24° semana de idade, 5,4 kg de peso corporal. Tal prática seria altamente antieconômica, pois o consumo de alimentos seria excessivo e a produção de ovos não atingiria o potencial genético. Por isso, o controle do consumo diário de alimentos de matrizes pesadas é essencial, o que torna a produção destas aves mais difícil e exigente quando comparada às outras aves de exploração comercial. O controle sobre o alimento consumido é feito através de um programa de alimentação restrita, onde a dose diária de proteína e energia tem que ser adequada, mas não excessiva, a fim de atingir a máxima produção (NONIS, 2007).

O consumo de alimento excessivo durante a produção de ovos leva ao aumento do peso corporal e de gordura abdominal, que estão associados com a redução da eficiência produtiva das aves (LEKSRISOMPONG, 2010). De acordo com (RENEMA e ROBINSON, 2004), o uso de restrição alimentar em matrizes pesadas limita a incidência de desordens reprodutivas, proporcionando maior persistência e uniformidade da produção além de evitar o sobrepeso dos animais.

A restrição alimentar durante os períodos de cria, recria e de postura tornou-se um procedimento padrão de gestão em granjas comerciais de matrizes pesadas o que induz a questões importantes sobre os requerimentos para energia, aminoácidos e outros nutrientes essenciais, pois essas aves não têm a oportunidade de satisfazer as suas necessidades nutricionais através do aumento na ingestão de alimentos quando um ou mais destes nutrientes está deficiente. Portanto é dever do nutricionista fornecer a dose diária correta de cada nutriente para atingir a máxima produção de ovos, porém, dada a variação entre as aves dentro do lote, tais decisões precisam ser feitas tanto por razões biológicas como econômicas. Como visto a utilização de programas de restrição alimentar é necessária para matrizes pesadas, tornando imprescindíveis estudos sobre a curva de crescimento ou padrão de crescimento e deposição corporal de proteína e gordura.

1.2. Crescimento e composição dos órgãos reprodutivos de matrizes pesadas

Diferentes linhagens e o sexo podem diferir em vários aspectos, como peso à maturidade, composição e taxas de deposição dos nutrientes corporais, aspectos estes que afetam as características da curva de crescimento, que deve ser avaliada em condições não limitantes (MARCATO, 2007). Para tais avaliações, existe a necessidade da utilização de modelos matemáticos, que expressem com maior precisão o crescimento das aves, em função da idade, para fins de pesquisa e programas de alimentação (GOUS *et al.*, 1999).

Leeson e Summers (1997) concordando com Emmans (1981), afirmaram que uma maneira racional para calcular os requerimentos nutricionais e predizer o consumo de alimento das matrizes pesadas em desenvolvimento, deve iniciar com o conhecimento do potencial de crescimento, pois estão intimamente relacionados.

A maturidade sexual das aves é um fenômeno que vem sendo estudado há algum tempo (LIPPINCOTT, 1921) e sabe-se que o estímulo de luz e o peso corporal tem grande influência na idade à maturidade sexual e na uniformidade do lote em resposta a esse estímulo (Lewis et al., 2003 a 2007).

Seguindo a recomendação de estímulo de luz e peso corporal das companhias de genética, as matrizes pesadas desenvolvem ovário e oviduto após as 20 semanas de idade, e atingem o crescimento máximo por volta das 24 semanas. Neste momento, o total de proteína depositada nesses órgãos corresponde aproximadamente a 20% do total depositado no corpo Silva *et al.,* (2013).

A variação na taxa de maturação dos órgãos reprodutivos significa que a produção de ovos no início será variável além de refletir em possíveis diferenças no número de óvulos em desenvolvimento (OLIVIER *et al.*, 2010).

Bowmaker e Gous (1989), recomendam considerar os órgãos reprodutivos nos modelos para estimar as exigências nutricionais, pois sugerem que o maior suprimento de proteína possa estimular esse desenvolvimento.

A simulação do crescimento e da deposição dos órgãos reprodutivos, através de modelos matemáticos, contribuiu para estimar o peso vivo e o desses órgãos em função da idade, para comparar o crescimento corporal relativo entre sexo, estimar a conversão alimentar diária e padronizar o crescimento para seleção (FREITAS *et al.*, 1983). Além disso, a descrição do crescimento das aves é o primeiro passo para elaboração de modelos de simulação, capazes de predizer as exigências nutricionais e determinar os efeitos de diferentes programas nutricionais e condições ambientais sobre o desempenho das mesmas (GOUS *et al.*,1999).

1.3. Potencial de postura e produção de massa de ovos

O conceito de um potencial de produção de ovos (taxa de postura x peso do ovo) pode ser descrita como a máxima postura de ovo que o genótipo pode atingir quando administrado sob perfeitas condições nutricionais e de produção animal (NONIS, 2007).

De acordo com Gous e Nonis (2010), cinco parâmetros podem caracterizar o potencial de matrizes pesadas, a maturidade de proteína corporal, teor de lipídios, maturidade sexual, taxa de postura ao longo do tempo e peso do ovo em função da idade. Aves põem um ovo por dia, durante certo número de dias consecutivos antes de parar por um ou mais dias. A taxa de produção de ovos é determinada pelo comprimento das sequências de oviposição e pelo número e duração das pausas entre as sequências, e estes fenômenos devem ser previstos.

Johnston e Gous (2003, 2006, 2007a, b, c) e Nonis and Gous (2013) descreveram a produção de ovos, por meio de um modelo que simula sequências de postura de ovos, mudanças nas proporções de gema, albúmen e casca e, consequentemente, a composição química ao longo do tempo.

Emmans e Fisher (1986) descreveram o ovo como uma mistura de gema, albúmen e casca. Dada esta, pode-se prever a produção de ovos em três passos: 1) prever a taxa de produção de gema, 2) prever a partição de gema em gemas individuais, e 3) estimar o peso de albúmen e de casca pelo peso da gema (NONIS, 2007).

Um ovo é descrito como uma mistura de gema, albúmen e da casca, a composição muda com o tempo e genótipo, mas pode ser predita a partir de relações alométricas com o peso de gema. Ovos de gema dupla e casca mole podem acontecer durante o período de postura, reduzindo o número total de ovos incubáveis, além das ovulações internas, que ocorrem aleatoriamente prejudicando a postura (GOUS e NONIS, 2010).

Segundo Johnston e Gous (2007b) as mudanças nas proporções de gema, albúmen e casca com o aumento da idade da ave têm sido observadas e aceitas pelos pesquisadores há mais de meio século. É importante modelar esses fenômenos com sucesso, de modo que os aumentos no peso dos ovos com o avanço da idade das aves são provocados pelo aumento dos três componentes que ocorrem em taxas diferentes. Com o avanço da idade e do aumento de peso de gema e albúmen, a casca torna-se gradualmente mais fina, pois aumenta o peso da casca a uma taxa decrescente em relação ao peso do conteúdo dos ovos. Ambos, peso de albúmen e casca, podem ser previstos através funções alométricas, propostas por Emmans e Fisher (1986), quando se trabalha com duas variáveis em escala não isométricas.

1.4. Requerimento nutricional e o consumo de ração

Devido as matrizes pesadas receberem durante toda a vida alimentação restrita, nutricionistas enfrentam problemas reais na formulação de rações para seus clientes. Pois as exigências nutricionais mudam durante o período de postura, dependendo do potencial de desempenho da ave, da alimentação que está sendo oferecida e do ambiente em que a ave é mantida. O que torna difícil a decisão sobre a composição dos alimentos e horário de alimentação que irá maximizar os retornos, pois as aves não são iguais, não estão alojadas nos mesmos ambientes e os custos de alimentação e as receitas provenientes da venda do produto difere de uma localidade para outra. Assim, as exigências nutricionais expressas como concentração fixa na dieta e os programas de alimentação, que muitos nutricionistas usam como base para suas tomadas decisões nutricionais, são susceptíveis de não ser o mais apropriado para maximizar a produção e minimizar os custos.

Uma abordagem com maior chance de sucesso em determinar os requerimentos do que medir os requisitos por experimentação direta foi proposto por Emmans e Fisher (1986), que sugeriram que uma melhor abordagem para o problema seria em primeiro lugar considerar as características da ave, em segundo lugar definir as escalas de requerimento e em terceiro lugar, considerar a quantidade de cada um dos requerimentos em função de uma unidade metabólica. Energia e os aminoácidos são necessários para o crescimento de tecidos, produção de ovos, manutenção das funções vitais, termo regulação corporal e atividade.

Para o desenvolvimento de programas de alimentação, o foco é nos três componentes primários: manutenção, crescimento e produção de ovos. Alguns fatores que têm impacto sobre o total dos requerimentos nutricionais, como por exemplo a manutenção que é afetada pelo tamanho do corpo, temperatura ambiente e nível de atividade (alojados no piso vs. gaiolas). Em relação ao crescimento, no caso de matrizes pesadas, no período de postura a composição do crescimento tem de ser resolvida: se este é apenas no ganho de lipídios ou também inclui o ganho proteico. Por fim, a produção de ovo é influenciada pela idade da ave e peso do ovo (NONIS, 2007).

Outra questão importante a ser resolvida na estimativa dos requerimentos é em relação à eficiência de utilização dos aminoácidos pelas matrizes pesadas. Ao modelar a utilização de aminoácidos sintéticos em rações matrizes pesadas, três situações devem ser considerados: 1: se não há suplementação de aminoácidos sintéticos, pode ser utilizada a eficiência de 0,6 a 0,8 do primeiro limitante na alimentação; 2: se todos os aminoácidos são (teoricamente) fornecidas de forma sintética, a eficiência será ideal, pois todos os aminoácidos estarão disponíveis para a síntese de proteínas simultaneamente, 3: se uma parte dos aminoácidos é fornecido sob a forma sintética, a eficiência diminuirá em relação ao índice de síntese de aminoácidos ligados a proteínas (Nonis e Gous, 2006). Esses autores afirmam que existem duas possibilidades que podem explicar a menor eficiência de utilização dos aminoácidos pelas matrizes pesadas: uma é que estas aves têm requisitos de manutenção mais elevados por kg de proteína corporal do que as poedeiras comerciais, e o outro é que os aminoácidos podem ser desperdiçados nos processos de formação e reabsorção da gema subsequente, os quais ocorrem em com maior frequencia em matrizes pesadas do que em poedeiras comerciais, porém essas questões precisam ser melhor investigadas.

Uma vez que os valores das constantes nutricionais são conhecidos, é possível prever os requisitos de qualquer genótipo em qualquer estado, mantidos num ambiente de conforto térmico. Porém o problema de prever os requerimentos é reunir as variáveis genéticas e os valores das constantes nutricionais, contudo, após modelar essas variáveis, é possível determinar o consumo de ração desejada através da composição da ração. O consumo de ração desejada é a ingestão que irá permitir que o potencial de postura seja atingido. No entanto, com matrizes pesadas, a questão não é a quantidade de ração que a ave irá consumir voluntariamente, mas que o conteúdo de nutrientes na dieta, uma vez que uma quantidade fixa de ração será imposta diariamente.

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CAPÍTULO 2 – MODEL TO OPTIMISE THE FEEDING OF AMINO ACIDS TO GROWING BROILER BREEDERS

Abstract - Mathematical models have been used as a tool in poultry nutrition to adjust the nutritional levels for each breeding phase. However, for its application on broiler breeders it is necessary to describe the growth of the reproductive organs up to the sexual maturity. This study aims to model the growth of the body and reproductive organs of the broiler breeders and from these results, to calculate daily nutrient requirements (specifically amino acids). In addition, from these requirements, to adjust nutritional programs that best match the requirements at each stage. 300 Cobb broiler breeder hens 1-28 weeks of age were used in the experiment, with 10 replicates of each 30 birds. All birds received the same diet and feed was controlled, according to the strain manual. All birds were weighed weekly, and 5 birds were randomly sampled, at dayold, at 4 and 11 weeks, and weekly from 18 to 28 weeks of age. Sampled organs, defeathered carcass and feathers were subjected to chemical analysis. Two models were fitted, one considering the growth of the body and feathers and a second model adding the growth of ovary and oviduct. The daily requirements amount was converted into a dietary concentration in order to determine the amino acids content required in the feed. Was observed relatively small increase in the daily requirement to meet the needs for ovary and oviduct growth results in a small accretion in the amino acid content of the feed during this period. During the growth phase of the sexual organs, the lysine requirement, for example, increases by 8%, from 660 to 714 mg / d. The concentration recommended of lysine, methionine + cysteine and threonine (g/kg), to 1 to 2 weeks of age are 12.5, 11.0 and 9.4; to 3 to 17 weeks of age are 8.6, 6.4 and 5.6; and to 18 to 20 weeks of age are 7.0, 5.1 and 4.3, respectively.

Keywords: modelling, reproductive organs, requirements

1. Introduction

The broiler breeder do not adequately regulate voluntary intake to achieve energy requirement, which provides an accumulation of lipids in the long term (Richards, 2003). One way to control these excessive lipid reserves is the controlled feeding during the rearing, on the other hand, the supply must meet the needs for growth and maintenance of the body.

Controlled feeding of broiler breeder hens is an accepted practice, used to reduce growth rate, delay sexual maturity and improve reproductive efficiency. Although controlled feeding before the onset of lay is accepted and is subject of extensive research, the effect of releasing the birds from severe controlled feeding at, or just before sexual maturity, has received scant attention. Therefore, nutritional levels of the feeding program adopted in the growth phase should be adjusted to allow the expression of sexual maturation.

Broiler breeders develop ovary and oviduct after 20 weeks and reach their maximum growth about 24 weeks. At this time, total protein deposited in these organs correspond approximately to 20% of the total amount deposited in the body (SILVA *et al.,* 2013). It is speculated that the increased supply of protein can stimulate the development of these organs, in accordance to Bowmaker and Gous (1989), who suggests consider them in the models to estimate the demands.

This study aims to model the growth of the body and reproductive components of the bird and from these results, to calculate daily nutrient requirements (specifically amino acids) by broiler breeder hens during the growth period. In addition, from these requirements, to adjust nutritional programs that best match the requirements at each stage.

2. Materials and Methods

Birds and management

The experiment was carried outat the Poultry Science Lab, São Paulo State University, Faculty of Agriculture and Veterinary Sciences, UNESP, Jaboticabal. 300

Cobb one day old broiler breeder chicks were randomly equaly distributed in 10 floor pens (30 birds/pen) and kept for 28 weeks. The lighting programme followed was 23 hours of light for the first 2 weeks, with gradual reduction of 1h light/day, until 9hr light / day at the 5th week of age. Light stimulation was initiated with an increase to 13 h / d at 23 weeks of age with further increases of 1 h / d every 2 weeks thereafter to stabilize at 16 h light / d.

Treatments and diets

All birds were submitted to four stage feeding program from 0 to 28 weeks of age. Birds received ad libitum feed until 28 d and were submitted to a controlled feeding program (daily restriction) afterwards. The amount of feed was adjusted to the average weight of birds each week in accordance the breeder management guide (Cobb Manual, 2008), to reach the recommended weight. The composition of the diets is presented in Table 1.

Table 1: Composition of feeds (g/kg) used during each specified period

	Period (weeks)			
	0 - 4	5 - 18	19 - 22	23 - 28
Protein	190	154	159	159
ME (MJ/kg)	12.0	11.5	11.9	11.9
Digestible Arginine	11.8	9.21	9.64	9.78
Digestible Isoleucine	7.33	5.44	5.86	6.00
Digestible Leucine	15.4	12. 3	13.0	13.0
Digestible Lysine	9.20	6.44	7.00	7.25
Digestible Methionine	4.23	2.80	2.97	3.31
Digestible Methionine+Cysteine	6.90	4.70	5.30	5.60
Digestible Threonine	6.48	5.01	5.32	5.38
Digestible Tryptophan	2.09	1.65	1.71	1.73
Digestible Valine	7.45	5.73	6.05	6.15
Calcium	10.2	10.5	14.9	29.9
Available phosphorus	4.60	4.30	4.50	4.50
Sodium	1.90	2.10	1.90	1.90

Measurements and Sampling

All birds were weighed weekly, and 5 birds were randomly sampled for carcass analysis, at dayold, at 4 and 11 weeks, and weekly from 18 to 28 weeks of age. Sampled birds were slaughtered using CO_2 (after 36 h of fasting) and the carcass was weighed before and after defeathering. The ovary and oviduct were dissected and weighed as well. The organs, defeathered carcass and feathers were subjected to chemical analysis, each sample being processed separately and homogenized prior to analysis.

Carcass and reproductive organs samples were lyophilized for 72 h under controlled conditions (-50 ºC; -80kPa; VLP20, Thermo Fisher®). Dry matter was determined in a forced air ventilation oven at 105 ºC for 24 h. The samples were defatted (ether extract: method 920.39, XT15 Ankom) and the nitrogen content was quantified by the Kjeldahl method (AOAC, 1995: method 954.01, Kjeltec™ 8400; Foss®). The chemical composition of these samples was used to estimate their protein and lipid contents from which the daily gains in protein and lipid were calculated.

Statistical Analyses

Statistical analyses were performed in SAS 9.1 software (2009) using PROC NLIN. As these broiler breeders were reared on controlled feeding, consistent with commercial practice, the linear model better describes the growth behavior, for this study phase (1 dayold to sexual maturity) compared with the Gompertz (1825) function, which is commonly used to describe potential growth. Thus, linear equations were used to describe the growth of body (BW) and feather-free body (FFBW) from dayold. The following equation most accurately describing the controlled growth recommended by the breeding company (Eq.1).

$$Y = a + b \times Age \qquad \text{Eq.1}$$

where Y is body weight (BW) or feather-free body weight (FFBW) (g) at certain age (*Age*), a is the y-intercept, and b is the slope of the equation.

The feather-free body protein content (BP) and feather-free body fat content (BF) were calculated with exponential equation as a function of feather-free body weight (FFBW) (Eq.2).

$$Y = a \times FFBW_t^{b} \qquad \text{Eq.2}$$

where Y is body protein content (BP) or feather-free body fat content (BF) (g), a is the Y value at age zero (g), constant value, and b is the exponent.

The feathers initially exhibit an accelerated growth, which then slows. To estimate feather weight (FW) the sum of two non-linear equations were used (Eq.3):

$$FW = (W_{maxHi} \times Age/(Age_{Hi} + Age))+(W_{maxLo} \times Age/(Age_{Lo} + Age)) \quad \text{Eq.3}$$

where WmaxHi and WmaxLo are the maximum weights for fast and slow growth respectively (g), and AgeHi and AgeLo are the ages that WmaxHi and WmaxLo achieve the highest growth. By combining Eq.1 for feather-free body growth and Eq.3 for feather growth, an accurate estimative of the growth of the body, as recommended by the breeding company, can be obtained.

Feather protein (FP) was considered 0.88 of the feather weight, calculated though the average of the values of crude protein analysed in the laboratory.

A Gompertz growth function (Eq.4) was used to describe the change in ovary weight (Ova), ovary protein content (OvaP), ovary fat content (OvaF) oviduct weight (Ovi), oviduct protein content (OviP) and oviduct fat content (OviF), all components in g, as a function of age (t, d):

$$W(t) = W_m . e^{-e^{-b(t-t^*)}} \quad \text{Eq.4}$$

where *W(t)* is weight at time t, *t* is the age of bird (day); *Wm* is the weight at maturity (g), *b* is the daily rate of maturity, *e* is the Euler's number and *t** is the age at maturity (days).

Deposition rates of protein and fat (*dP/ dt*) to BP, BF and FP were obtained by the difference between the weights (W_{t+1} - W_t), and for sexual organs it was obtained by differentiating of Gompertz function, resulting in Eq. 5.

$$dP/_{dt} = b . P_m . \ln\left(\frac{P_m}{Pt}\right) \quad \text{Eq.5}$$

where *b* is the daily rate of maturity, P_m is mature body protein (g) weight and P_t is body protein weight at time *t* (g).

Amino acids requirements for maintenance and growth

Amino acid requirements were stablished adopting a model for BW and feather growth and a second model were adding the ovary and oviduct growth.

For estimating amino acid requirements, it was used Fisher's (1998) concept, where it is assumed that the amino acid profile of ideal protein for maintenance and growth has the same amino acid composition of the body. The amino acids required for growth were estimated by using the body protein composition with a coefficient of utilization of 0.8 for all amino acids, listed in Table 2.

Table 2. Amino acid profile (g/kg) adopted for estimating amino acid requirements for broiler breeders.*

	Maintenance[1]	Body protein[2]	Feathers[2]
Arginine	50	68	65
Cysteine	35	11	70
Histidine	10	26	8
Isoleucine	50	40	40
Leucine	32	71	70
Lysine	73	75	18
Methionine	25	25	6
Methionine&Cysteine	60	36	76
Phenylalanine	16	40	45
Phenylalanine&Tyrosine	32	71	95
Tyrosine	16	31	50
Threonine	40	42	44
Tryptophan	10	10	7
Valine	60	44	60

[1] FISHER (1983). [2] EMMANS (1989). *FISHER, 1998. Utilised for body protein growth with an efficiency of 0.80. Assumed composition of protein composition for maintenance.

The daily maintenance requirement for each amino acid was calculated average individual in the flock, considering rates of body and feather protein growth were described above. The requirements were calculated separately for the feather-free body and feathers, being the sum of that required for maintenance of amino acid for each component. This model is described in Eq. 6 below:

$$AA_m = (AA_{Bm}.BP_m^{0.73}.u) + (0.01.FP_t.AA_f) \quad \text{Eq.6}$$

where AA_m is whole body amino acid maintenance requirement (g/d) for the average bird in the population. AA_{Bm} is the amino acid composition of ideal protein for maintenance of the body (Table 2); $BP_m^{0.73}$ is the mature body protein weight (kg); u is the degree of maturity of body protein $(u=BP_t/BP_m)$, 0.01 is the correction factor for feather loss. FP_t is feather protein in time and; AA_f is the amino acid composition of the feathers. According to the genetic potential, broiler breeders reach approximately 5 kg body weight at maturity. To calculate the BP_m and u was considered 18% of the mature protein body (Fisher, 1998), which is equivalent to 900 g.

To calculate the amino acid requirement for growth (AA_g) was used the Eq.7.

$$AA_g = [(\frac{BPd}{k}.AA_{Bg}) + (\frac{FPd}{k}.AA_f)] \qquad \text{Eq.7}$$

where *BPd* is the rate of body protein deposition (g/d); *FPd* is the rate of feather protein deposition (g/d); AA_{Bg} is the amino acid composition of ideal protein for growth of the body (Table 2); and *k* is the efficiency of utilisation for body protein growth with an efficiency of 0.8 (Fisher, 1998).

The amino acid requirement (AA_r) for each age was calculated by the sum of equations 6 and 7, resulting in the Eq.8.

$$AA_r = \left[(AA_{Bm}.BP_m^{0.73}.u) + \left(0{,}01.FP_t.AA_f\right) + (\frac{BPd}{k}.AA_{Bg}) + (\frac{FPd}{k}.AA_f)\right] \qquad \text{Eq.8}$$

In Eq. 9 the additional amount required for the growth of the reproductive organs is added to Eq.8 and this was appliedy from the day that the growth of these organs was initiated.

$$AA_r = Eq.6 + (\left(\left(\frac{BPD_{ova}}{k}\right) + \left(\frac{BPD_{ovi}}{k}\right)\right).AA_{Bg}) \qquad \text{Eq.9}$$

The two terms added here to Eq. 9 are $Bpd_{ova,}$ the rate of protein deposition in the ovary (g/d) and $BPd_{ovi,}$ the rate of protein deposition in the oviduct (g/d). The constant, *k*, is the same as in the Eq. 7.

The daily amount of amino acids required for broiler breeders during the growing period may thus be calculated by applying Eq. 8, or through the equation 9, if the growth of the sexual organs is considered. This daily amount must be converted into a dietary concentration in order to determine the amino acids content required in the feed, for which the amount of feed to be consumed each day needs. Any nutrient which daily requirement and dietary concentration are known may be used for this purpose and thus, specify the dietary content.

Feeding Program

To establish a program of adequate nutrition according to the amino acid requirement for each phase, it was used the requirement calculated above (Eq. 9) divided by feed intake recommended by the breeding company, in its feeding program considering the dietary energy values recommended. Thus, it was obtained the percentage of amino acid at each stage.

3. Results

Describing the growth and composition of body, feathers and reproductive organs

The average feather-free body weights, feathers, ovary and oviduct, and percentage of body protein at each age are presented in Table 3.

Table 3. Mean weights (g) and CV of feather-free body, feathers, ovary and oviduct, and percentage of body protein at each age.

Age	Body Weight		Body Protein		Feather		Ovary		Oviduct		Body Lipid	
Week	(g)	CV	(%)	CV	(g)	CV	(g)	CV	(g)	CV	(%)	CV
22	592	7	16	4	34.4	23	-	-	-	-	5,5	13
71	1333	7	17	5	65.6	15	0.29	25	0.18	31	5,2	14
120	2525	14	16	3	96.7	20	0.82	31	0.43	40	8,3	16
127	2566	37	16	4	87.3	20	0.70	20	0.53	19	9,3	38
134	3043	26	15	4	91.3	27	0.97	5	0.63	35	9,9	26
141	3006	10	16	6	96.8	13	0.99	29	1.28	76	9,8	24
148	3329	11	17	4	149.6	51	9.96	9	16.36	36	11,0	23
155	3257	5	17	5	110.5	18	10.7	12	25.30	25	11,9	26
162	3356	6	17	3	88.0	14	25.2	48	42.48	43	11,8	18
169	3611	15	18	6	127.0	15	41.5	33	59.26	12	10,3	19
176	3502	11	17	11	99.0	8	35.8	44	56.20	29	11,5	31
183	3622	11	17	6	108.4	24	60.8	26	79.65	29	11,7	12
190	3587	16	17	4	106.0	16	61.4	29	68.51	13	10,0	17

Estimates of the models parameters describing the growth and composition of Cobb broiler breeders are given in Table 4. These values were used to describe the growth in body weight (BW), feather-free body weight (FFBW), feather weight (FW), feather-free body protein content (BP) and feather protein content (FP).

Table 4. Estimates of the parameters (± *SE*) that describe the growth of the body weight (BW, g), feather-free body weight (FFBW, g), feather-free body protein (BP, g), feather-free body fat (BF, g) and feathers weight (FW, g).

	A		*b*		R^2
BW[1]	45 (±0.29)		16.71 (±0.46)		0.932
FFBW[1]	43.5 (±0.27)		16.06 (±0.38)		0.949
BP[2]	0.0993 (±0.005)		1.0663 (±0.05)		0.996
BF[2]	0.0099 (±0.0004)		1.2712 (±0.05)		0.983
	WmaxHi	*AgeHi*	*WmaxLo*	*AgeLo*	
FW[3]	23.1 (±0.69)	21.29 (±0.85)	134.9 (±4.05)	110.9 (±3.32)	0.958

[1] Parameter values for Eq.1 – $Y=a+b\times Age$
[2] Parameter values for Eq. 2 - $Y= a + FFBW_t^b$
[3] Parameter values for Eq. 3 - $FW = (W_{maxHi} \times Age/(Age_{Hi} + Age))+(W_{maxLo} \times Age/(Age_{Lo} + Age))$

Estimates of the Gompertz model parameters describing the growth of the ovary and oviduct are given in Table 5.

Table 5. Estimates of the Gompertz parameters (± *SE*) that describe the growth of ovary (Ova), ovary protein weight (OvaP), ovary lipid weight (OvaF) oviduct weight (Ovi), oviduct protein weight (OviP) and oviduct lipid weight (OviF).

	W_m (g)	*b* (/d)	*t** (d)
Ovary	71.94 (±2.58)	0.063 (±0.01)	162 (±1.6)
OvaP	19.11 (±1.02)	0.037 (±0.02)	157 (±8.2)
OvaF	15.12 (±0.70)	0.033 (±0.02)	159 (±9.5)
Oviduct	77.31 (±1.67)	0.079 (±0.01)	155 (±1.2)
OviP	12.97 (±0.56)	0.069 (±0.01)	159 (±1.9)
OviF	1.80 (±0.11)	0.027 (±0.01)	144 (±9.3)

[1] $W(t) = W_m \cdot e^{-e^{-b(t-t^*)}}$, where *W(t)* is weight at time t, *t* is the age of bird (d); *Wm* is the weight at maturity (g), *b* is the rate of maturing, /d, *t** is the age when maximum growth rate occurs (d) and *e* is the Euler's number.

Oviduct develops before the ovary, with a slight difference in *b* and difference of one week until reach the maturity (t*). It is possible that the reproductive potential depends on the rate of growth of these organs. Body reaches maturity before the reproductive organs, fact that should be considered, because understanding this process helps to develop models of nutrient requirements of broiler breeders.

The rates of protein deposition (g/d) in the body, feathers, ovary and oviduct of Cobb broiler breeders to 200 days of age are illustrated in Figure 1 where the difference in the maximum growth rate between the components, which occurs at t*, can be observed.

Due to broiler breeders are raised under a controlled feeding, the growth and protein body deposition have an almost constant behaviour throughout life. Although the feathers grow rapidly until about 28 days, after this period there is a deceleration in growth. This behaviour can be observed by higher deposition at the beginning. Oviduct development is initiated approximately one week before that one of the ovary with their maximum growth rates being achieved approximately 43 and 34 d after the initiation of growth, respectively. In this trial the mean age at which maximum reproductive organ growth rate was achieved was between 155 and 160 d. The first eggs to be laid by these broiler breeders were produced between 23 and 24 weeks of age, and reached 50% of the output at 26° week of age.

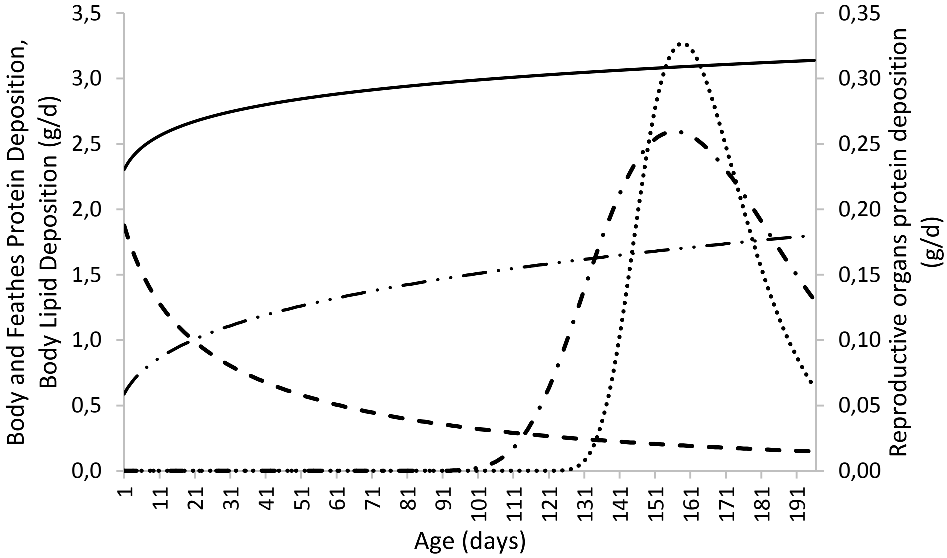

Figure 1. Mean daily rates of protein deposition in body (___), feather (- - -), ovary (_ . _ . _), oviduct (. . . .) and body lipid deposition (_ . . _) of Cobb broiler breeder hens using the equations described in the text.

Estimating Amino Acids requirements

The amino acid requirement was calculated using Eq. 8 and 9, assuming 80% efficiency of amino acid utilization for growth. A comparison of the lysine (for example) requirement per day for Cobb broiler breeders either including or excluding that for the growth of ovary and oviduct is illustrated in Figure 2.

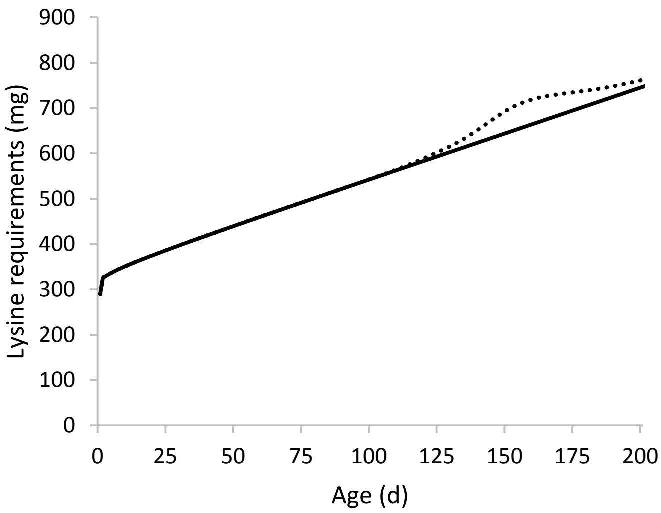

Figure 2. Estimated daily lysine requirement (mg/d) without (solid line) and including (dashed line) the growth of the ovary and oviduct, as a function of age.

The relatively small increase in the daily requirement to meet the needs for ovary and oviduct growth results in a small accretion in the amino acid content of the feed during this period. During the growth phase of the sexual organs, the lysine requirement, for example, increases by 8%, from 660 to 714 mg / d.

It were calculated the amino acids requirements including or excluding sexual organs, through Eq. 8 and 9, considering the composition of the body from the values in Table 2. Weekly mean for each amino acids requirements is presented in Table 6.

Table 6. Mean weekly estimate for each amino acid (mg/d), for Cobb Broiler Breeder hens, showing the additional amounts required, from 17 w, for the growth of ovary and oviduct

Age (w)	ARG		CYS		HIS		ILE		LEU		LYS		MET		M&C		PHE		P&T		TYR		THR		TRP		VAL	
1	392		185		115		237		411		328		109		295		242		461		218		251		53		293	
2	405		182		121		247		421		353		118		300		247		467		220		260		56		302	
3	407		174		125		251		420		370		124		297		245		461		216		262		57		304	
4	413		171		127		257		422		386		129		300		245		460		214		266		58		310	
5	420		171		130		264		426		401		134		305		246		461		215		271		60		317	
6	427		172		133		272		431		416		139		312		248		464		216		277		62		325	
7	436		175		135		280		437		431		144		319		251		469		218		284		64		334	
8	445		179		138		289		443		446		149		328		254		474		220		291		65		344	
9	454		183		140		298		449		460		154		337		257		479		222		298		67		354	
10	463		188		143		307		455		475		159		347		260		485		225		305		69		364	
11	473		193		145		316		462		489		164		357		263		491		228		312		71		375	
12	482		198		148		325		468		503		169		367		266		497		231		320		73		385	
13	492		204		150		334		475		518		174		377		270		504		234		327		75		396	
14	502		209		152		343		481		532		179		388		273		510		237		335		77		407	
15	512		215		155		352		488		546		184		399		277		517		240		342		79		418	
16	522		221		157		362		495		560		189		409		280		523		243		350		81		429	
17	531	3	227	1	159	1	371	2	502	3	575	3	193	1	420	2	283	2	530	3	247	1	358	2	83	0	440	2
18	541	7	233	1	161	3	381	4	509	7	589	7	198	2	431	3	287	4	537	7	250	3	365	4	84	1	451	4
19	551	12	239	2	164	4	390	7	516	12	603	13	203	4	442	6	290	7	544	12	253	5	373	7	86	2	463	8
20	561	20	246	3	166	8	400	12	522	21	617	22	208	7	454	11	294	12	550	21	257	9	381	12	88	3	474	13
21	571	33	252	5	168	13	409	19	529	34	631	36	213	12	465	17	297	19	557	34	260	15	389	20	90	5	485	21
22	581	45	258	7	170	17	419	26	536	47	646	49	218	16	476	24	301	26	564	47	263	20	396	28	92	7	496	29
23	591	49	265	8	173	19	428	29	543	52	660	55	222	18	487	26	304	29	571	52	267	23	404	31	94	7	508	32
24	601	47	271	8	175	18	438	27	550	49	674	51	227	17	499	25	308	27	578	49	270	21	412	29	96	7	519	30

Adding the ovary and oviduct in the equation for calculating the requirements of amino acids, it was observed that the deposition of amino acids linked in tissues, particularly lysine, are more demanding than the amino acids responsible for feathering, such as methionine + cysteine , tryptophan and valine.

Feeding Program

To determine a feeding program and to optimize the feed composition for each phase, it were used the values presented in Table 6 divided by feed intake recommended by the manual line. In Figure 3 are shown the concentrations of amino acid in the diet, weekly, and for phases for each feeding program.

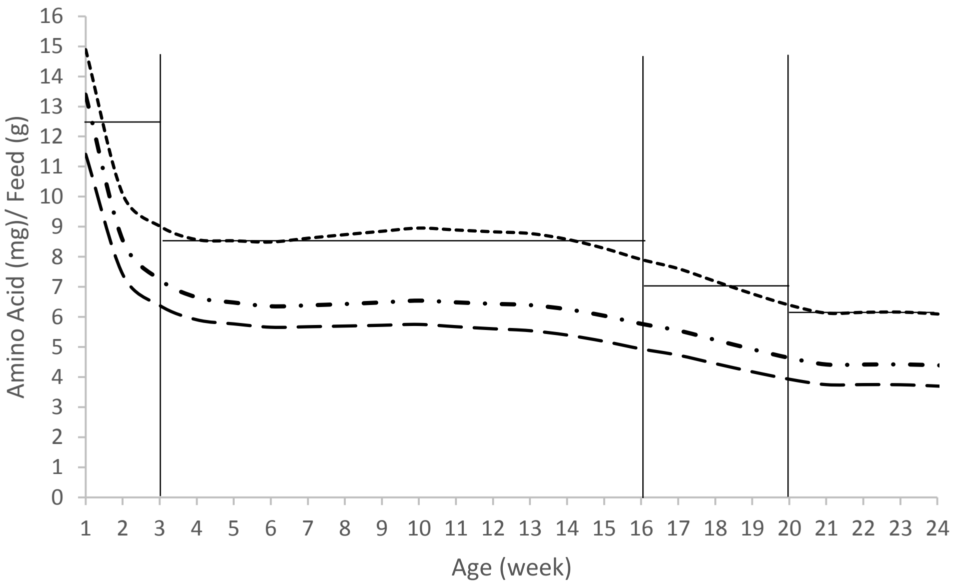

Figure 3: Lysine (- - -), Threonine (— —), Methionine + Cysteine (_ . _ . _) requirements (mg) per food intake (according by the breed manual, g), weekly, and mean of amino acid (___) for each phase

To better illustrate the result of this exercise, the requirements of only the three major amino acids are presented, but this calculation can be done with all the amino acids shown in Table 6. From the values obtained, it was defined the concentration of lysine, methionine + cysteine and threonine (g/kg) and the division of each feeding program so that there is better utilization of diets for each phase (Table 7).

Table 7. Calculated concentrations in the diet (g/kg) of lysine, methionine + cysteine and threonine necessary to meet the requirements of broiler breeder hens for maintenance and growth in the periods 1-2, 3-17 and 18-20 weeks of age from present study and Cobb recommendation

	Present study			Cobb		
	1 - 3	3 - 16	16 - 20	1 - 4	5 - 17	18-22
Lysine	12.5	8.6	7.0	9.2	5.2	6.3
Methionine+Cysteine	11.0	6.4	5.1	6.9	4.5	5.3
Threonine	9.4	5.6	4.3	6.4	4.3	5.2

According to amino acid requirement (Fig. 3) for body growth and for protein deposition, the most appropriate phases of feeding program are 1 to 3, 3 to 16 and 16 to 20 weeks of age. In the present study, it was also calculated for 20 to 25 weeks of age, but at this phase, some birds began to lay eggs, and in this case, the requirement for the production of eggs should be accounted.

4. Discussion

In this study, the approach used was the same concept of Bowmaker and Gous (1989), which considered the growth of the reproductive organs of broiler breeders but in their case, did not account for body and feathers growth before sexual maturity. In the present exercise, body growth, feathers and reproductive organs were considered to determine the daily need of nutrients in broiler breeders, and from these requirements, it was calculated the concentration of each amino acid according to the feed intake recommended by the manual strain, thus, a feeding program was obtained.

Controlled feeding is frequently used to control the body weight of immature and mature broiler breeders, and its effect on body weight is well documented (Hocking, 1993; Renema and Robinson, 2004; Sun et al., 2006; De Beer and Coon, 2007), but not while for the reproductive organs development and they changes in the amino acid requirements, and how much this progress will require of amino acids. As seen in the results, because of feeding program, the protein deposition is almost constant; however, the reproductive organs develop rapidly (Figure 1). It is essential to consider these factors in estimating requirements for this phase in order to have an optimum egg production. Not all broiler breeders grow at the same pace; some birds grows stronger in each phase. In critical periods of rapid growth, chickens are particularly vulnerable. If something goes wrong, then, their development will be impaired, resulting in the chickens coming into lay later or not achieving maximum production.

Leeson and Summers (1983) and Bennett and Leeson (1990) reported that birds restricted to different energy intakes have similar carcass contents for protein. Fisher (1998) also assumed that an adult female breeder has constant protein in the body, considering 18%. The concept of relatively constant protein of the broiler-breeders was useful to estimate the influence of body composition on sexual maturity. Based on concept, it was stipulated protein weight at maturity from the body weight according to the genetic potential.

Regarding to the growth of reproductive organs, there are few data available in the literature for comparative purposes, principally, because the age at sexual maturity in broiler breeder hens can be manipulated by lighting programmes (Lewis et al., 2003). Bowmaker and Gous (1989) also used broiler breeders in their study and found growth rate (b) of the ovary and oviduct 0.105 and 0.134 / d, respectively, higher than those ones found in the present study (0.063 e 0.079) (Table 4). These authors concluded that the age at maturity of both organs occurred at 168 d, but these differences, in b and age at maturity, can be caused by the difference in light stimulus (see Lewis et al., 2003; 2007). According to Bennett and Leeson (1989) growing birds on different energy intakes but similar protein intakes, differing only in terms of lipid content can be compared. Moreover, any differences in sexual maturity probably would be due to the lipid content, in birds of the same lighting program.

The estimate of requirement of amino acid was calculated, through Eq. 8 and 9, from the values estimated by equations for body growth, feathers and reproductive organs. These requirements were calculated based on the theory of Emmans and Fisher (1986; Figure 2), for lysine, and for each amino acid in function of age (Table 6). It is observed that during the period of increased protein deposition of reproductive organs (Figure 1) there was an increased requirement. This fact should be taken into consideration because as observed in this study, Silva et al. (2013) also observed an increase of up to 36% of methionine + cysteine requirement in the phase of sexual maturation in pullets. Consider the growth of reproductive organs to estimate the nutritional requirements, assists in the management of standardizing the weight of flocks of broiler breeders that are outside of proper weight.

As seen in Figure 2, Eq. 9 can be used since the beginning of the growth, because the growth of these organs is extremely small up to approximately 120 days, and consider them in the model does not influence the requirement until this age.

Feeding Program

As previously mentioned, the feeding program for broiler breeders hens, in most cases, is provided according by the breeding manual recommendation to achieve the target of body weight. However, the question is whether the division of the phases and the recommended requirements, along with the feeding program are consistent with growth. Due to logistics of breeding companies, the feed composition cannot be changed every day, so part of this exercise was made to determine the optimum amino acid supply over a period of time, and to choose an average composition for a given period that minimises the under- and over-supply of amino acids during each phase.

The nutritional requirement Tables present differences between the divisions of phases, for example, Cobb’s manual suggests 1-4, 5-17 and 18-23 weeks of age. Rostagno et al. (2011) suggested 1-6, 7-12 e 13-18 weeks of age. In this study, it is suggested that at first two weeks should be paid more attention in relation to nutrient levels, suggesting the first division stage. Because the birds grow rapidly, and doubles its weight in two weeks, so they need more nutrients (Figure 3), with very specific nutritional needs during the first days of life.

The recommendation Cobb's manual (2008) for the first phase (1-4 weeks) for lysine, for example, is 9.21 g / kg of feed. This value is the same average recommended in this study (9.21 g / kg), if is considered the 1 to 15 weeks of age, however using the average for a long period, there is under- and over-supply. Providing diets with levels of protein and consequently amino acid nearest the nutritional requirement is crucial to broiler breeder. Because excessive amounts of protein in the diet takes the animal to adapt, using the protein as a source of energy, leading to increase demands amino acid for maintenance due to increased rate of gluconeogenesis in excess of protein consumed (Rabello *et al*., 2002).

In conclusion, in this study it was elaborate a nutritional program according to the feed intake suggested by the manual, thereby, it was suggested the division of phases (1 to 3 weeks of age), differently from the recommended by the lineage manual, to efficiently meet the birds. Knowing the requirements helps to establish the best nutritional program, and optimize feeding without excesses and deficiencies.

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CAPÍTULO 3 - CONSEQUENCE OF LIGHTING PROGRAMME USED DURING REARING PHASE ON AMINO ACID REQUIREMENTS IN A BROILER BREEDERS FLOCK UP TO SEXUAL MATURITY

Abstract - The aim of this study was to model the changes in body weight and composition in broiler breeder pullets up to the point when all the birds in the flock had laid their first egg, in response to different lighting programmes during the rearing period. The growth of each individual in a population from hatching to the time when its first egg is laid was simulated and then averaged to obtain the mean response of the population to different lighting programmes during the rearing period. Were used equations to estimate body weight, feather weight, body protein and lipid, ovary weight, ovary protein and lipid, oviduct weight, oviduct protein and lipid, as a function of age. Also was estimated age at first egg. From these equations was simulated the growth of each individual in a population using different lighting programmes (Program A: 8 h light/d to 100 d followed by an increase at that age to 13 h/d; and Program B: 8 h light/d to 140 d at which age the light was increased to 13 h/d) during the rearing period. The information about the age, body weight and body composition over the growth period is required in order to determine the amino acid requirements of broiler breeder hens from rearing period until sexual maturity (egg laying period) and the age from first egg in function of the lighting programme. The requirements of lysine were 318(±21), 318(±20) to 1-4 weeks of age, 427(±52), 426(±51) to 5-17 weeks of age and 550(±40), 545(±32) to 18-22 weeks of age, for lighting program A and B, respectively. Methionine + cystine requirements were 282(±19), 281(±19) to 1-4 weeks of age, 337(±37), 336(±36) to 5-17 weeks of age and 431(±26), 428(±22) to 18-22 weeks of age, for lighting program A and B, respectively. Threonine requirements were 238(±13), 238(±12) to 1-4 weeks of age, 282(±27), 281(±26) to 5-17 weeks of age and, 347(±22), 344(±18) to 18-22 weeks of age, for lighting program A and B, respectively. In this study was elaborate a nutritional requirements according to the lighting programme used during the rearing. Know the requirements helps to establish the best nutritional program, and optimize feeding without excesses and deficiencies. These results support the view that a modelling approach has the potential to help nutritionists to make decisions about feeding more efficient broiler breeder flocks of what is possible at the present.

Keywords: amino acids requirement, simulation, stochastic model

1. Introduction

In order to broiler breeders to reproduce effectively the amount of food they consume each day throughout growth and lay must be controlled (Hocking, 1993). Breeding company recommendations (Aviagen, 2013; Cobb 2008) of the amount of a given food to be allocated daily to these birds in both the rearing and laying periods have been fine-tuned over many years on the basis of experience, but no mechanistic model has ever been developed to determine to what extent these recommendations meet the changing nutrient requirements during growth. An important period in the life of the broiler breeder is from the time that sexual development is initiated until the first egg has been laid. During this period, there is a considerable increase in protein deposition in the body as a result of the growth of the ovary and oviduct (Bowmaker and Gous, 1989). However, the initiation of this growth phase does not occur at exactly the same time in all birds in a flock, and the consequence of this range in ages at maturity on the way in which broiler breeders should be fed should be of interest to commercial broiler breeder producers.

The growth rate of ovary and oviduct of broiler breeders was studied by Bowmaker and Gous (1989), and if the growth rates described by Gompertz (1825) growth curves were applied differentially to individuals as they became sexually mature it would be possible to model the effects of different lighting programmes during the rearing period on the consequences of feeding a flock of broiler breeder pullets on protein and lipid growth from 20 to 30 weeks of age.

To determine the consequences of birds achieving sexual maturity over a range of ages it would be necessary to describe the growth of individuals within a sample population of birds from dayold to the time when the last bird in the sample has laid its first egg. The age at sexual maturity of each bird would need to be predicted using the model described by Lewis *et al*. (2007). The changes in photoperiod that constitute a lighting programme for growing broiler breeders exert an influence on the timing of sexual development, and the responses to the individual photoperiods per se are important because they form an integral part of any model that predicts sexual maturity (Morris, 1967 and Lewis and Morris, 2004).

The aim of this study was to model the changes in body weight and composition in broiler breeder pullets up to the point when all the birds in the flock had laid their first egg, in response to different lighting programmes during the rearing period. The growth of each individual in a population from hatching to the time when its first egg is laid was simulated and then averaged to obtain the mean response of the population to different lighting programmes during the rearing period.

2. Materials and Methods

The Body weight (**BW**) and feather-free body weight (**FFBW**) at a specific age were estimated using the following equation (Ferreira *et al.,* in press):

$$Y = \beta_0 + \beta_1 \times Age \qquad \text{[Eq.1]}$$

Where ***Y*** is BW (g) or FFBW (g) at an specific age (***Age***, days); $\boldsymbol{\beta_0}$ is the y-intercept and $\boldsymbol{\beta_1}$ is the slope of the linear equation. The exponential relation between feather-free body protein content (**BP**) or feather-free body lipid content (**BL**) and FFBW provided the following equation:

$$Y = \beta_0 \times FFBW_t^{\,c} \qquad \text{[Eq.2]}$$

where *Y* is BP or BL (g), β_0 is the y-intercept (g), constant value, and ***c*** is the exponent. To estimate feather weight (**FW**) the sum of two non-linear equations (Ferreira *et al.,* in press) were used as follows:

$$FW = (W_{maxHi} \times Age/(Age_{Hi} + Age)) + (W_{maxLo} \times Age/(Age_{Lo} + Age)) \qquad \text{[Eq.3]}$$

Where $\boldsymbol{W_{maxHi}}$ and $\boldsymbol{W_{maxLo}}$ are the maximum weights for fast and slow growth respectively (g), and $\boldsymbol{Age_{Hi}}$ and $\boldsymbol{Age_{Lo}}$ are the ages that $\boldsymbol{W_{maxHi}}$ and $\boldsymbol{W_{maxLo}}$ achieve the highest growth. Feather protein (**FP**) was considered 0.88 of the feather weight (Ferreira *et al.,* in press).

Ovary weight (Ova), ovary protein content (OvaP), ovary lipid content (OvaF) oviduct weight (Ovi), oviduct protein content (OviP) and oviduct lipid content (OviF) were estimated by Gompertz function in function of age as follows:

$$W(t) = W_m . e^{-e^{-b(Age - t^*)}}$$ [Eq.4]

Where ***W(t)*** is weight of variable at time *t (g)*; ***Age*** is the age of the bird (d); ***Wm*** is the weight at maturity (g), ***b*** is the rate of maturity (per day), ***e*** is the Euler's number and ***t**** is the age at which growth is maximised (d). The parameters estimated were used to describe the growth of the broiler breeder hens.

The derivate (*dW/ dt*) of the Gompertz function (Eq.4) for BP, BL, FP and the weight of reproductive organs were used to calculate the depositions of protein and lipid as follows:

$$dW/_{dt} = b . W_m . \ln\left(\frac{Wm}{Wt}\right)$$ [Eq.5]

The parameters estimated and their respective standard deviations (±SD) to describe the growth of body, feathers, ovary and oviduct are shown in Table 1.

Table 1. Values of coefficients* (±SD) used to describe growth of broiler breeders for use in a stochastic model

	β_0		β_1	
BW[1]	45.0 (±0.29)		16.71 (±0.46)	
FFBW[1]	43.5 (±0.27)		16.06 (±0.38)	
	β_0		c	
BP[2]	0.0993 (±0.005)		1.0663 (±0.05)	
BL[2]	0.0099 (±0.0004)		1.2712 (±0.05)	
	W_{maxHi}	Age_{Hi}	W_{maxLo}	Age_{Lo}
FW[3]	23.1 (±0.69)	21.29 (±0.85)	134.9 (±4.05)	110.9 (±3.32)
	W_m (g)	b (/d)	t^* (d)	
Ovary[4]	71.94 (±2.58)	0.063 (±0.01)	162 (±1.6)	
OvaP[4]	19.11 (±1.02)	0.037 (±0.02)	157 (±8.2)	
OvaF[4]	15.12 (±0.70)	0.033 (±0.02)	159 (±9.5)	
Oviduct[4]	77.31 (±1.67)	0.079 (±0.01)	155 (±1.2)	
OviP[4]	12.97 (±0.56)	0.069 (±0.01)	159 (±1.9)	
OviF[4]	1.80 (±0.11)	0.027 (±0.01)	144 (±9.3)	

[*] Coefficients estimated by Ferreira *et al.* (in press).
[1] Parameter values for Eq.1 – $Y = \beta_0 + \beta_1 \times Age$
[2] Parameter values for Eq. 2 - $Y = \beta_0 \times FFBWt^{c}$
[3] Parameter values for Eq. 3 - $FW = (W_{maxHi} \times Age/(Age_{Hi} + Age)) + (W_{maxLo} \times Age/(Age_{Lo} + Age))$
[4] Parameter values for Eq. 4 - $W(t) = W_m \cdot e^{-e^{-b(t-t^*)}}$

The above equations enable changes in the feather-free body protein content to be described from dayold until the bird is sexually mature. However, the age at which the development of the reproductive organs begins is dependent on the lighting programme applied during rearing, and needs to be predicted.

Predicting age at first egg (AFE)

When broiler breeders are large enough to respond to an increase in photoperiod it is assumed that, as in egg-type pullets (Lewis and Morris, 2004), the age at which photosensitivity is acquired in different individuals will form a normal distribution, with the proportion of birds capable of responding (p) at any given age being determined by a mean and SD. However, unlike egg-type pullets broiler breeders exhibit photorefractoriness and this influences the response to increases in photoperiod when these are applied at different ages during growth. Lewis *et al.* (2007) proposed three equations for estimating the age at sexual maturity (mean age when 50% of the birds are laying) in a population of broiler breeders exhibiting photorefractoriness, based on the body weight of the birds at 20 weeks of age and the lighting programme applied during rearing:

$P \leq 10h: y = 208.6-1.18P-20(W-2.1)$ [Eq.6]

$P = 10 < 13h: y = A_{10}+p(A_{13} - A_{10})$ [Eq.7]

$P = \geq 13h: y = 231.4-0.78P-20(W-2.1)$ [Eq.8]

Where y = mean age at 50% egg production (d), P = photoperiod (h), A_{10} = age at 50% egg production for P = 10 h (d) from equation (6). A_{13}=age at 50% egg production for P = 13 h (d) from equation (8), *p* = area under a Normal curve (mean 11.5h, SD = 0.43h) to the left of a Normal deviate x, where x = (P-11.5)/0.43 and W = mean body weight at 20 weeks (kg). Lewis *et al.* (2007) suggested a value for SD of 0.43.

According to Lewis *et al*. (2007) the age at sexual maturity (ASM) of individuals within a population will fall into one of three fractions: the first (1 - p) is unable to respond because of immaturity of the reproductive mechanism, including that due to juvenile photorefractoriness. These have their maturity delayed by a transfer to a stimulatory photoperiod. The second group (p (1 - m)) is able to respond and have their maturity advanced by photostimulation. The third fraction (m) develops spontaneously before they have been transferred to long days and mature as if maintained on the initial photoperiod. The prediction equation [Eq.9] is

$$A = (1 - p) A_2 + p (1 - m) [A_1 - b(A_1 - t)] + pmA_1 \qquad [Eq. 9]$$

Where A is the predicted ASM (d), A_2 is the ASM for birds maintained throughout on the final photoperiod (d) and A_1 is ASM for birds maintained throughout on the initial photoperiod (d). As consequence of the above the shape of the cumulative response curve describing the range of ages at sexual maturity of individuals within a population, from which individual responses may be drawn, will depend on the lighting programme used. It is made up of two normal distributions, one being for responders and the other for non-responders in the population. The two distributions will overlap to varying extents depending on the lighting programme used.

The mean age at which the population becomes photosensitive (y) was calculated from Lewis *et al.* (2007) as Eq.10:

$$y = 141.3 - 20.2\ W \qquad [Eq.10]$$

Where W = body weight at 20 weeks.

The standard deviation (s) of the above mean is dependent on body weight at 20 weeks, and can be calculated (from Lewis et al., 2007) as Eq.11:

$$s = 21.3 - 3.88\ W \qquad [Eq.11]$$

The initiation of the growth of the ovary and oviduct in an individual, in response to hormonal changes in the body just prior to the onset of sexual maturity will occur sometime before the first egg is laid. This time from initiation of sexual development may be predicted with information presented in Table 1. In this exercise to estimate the growth of reproductive organs to the population, according to the lighting program used, it was considered that t* is the ASM calculated by Eq.9.

Simulation of the growth of each individual in a population using different lighting programmes during the rearing period.

A population of 50 broiler breeders was generated with an initial body weight of 0.045±0.005 kg and a feather weight of 0.002±0.0002 kg. These birds were subjected to two different lighting programmes; program A: 8 h light/d to 100 d followed by an increase at that age to 13 h/d and program B: 8 h light/d to 140 d at which age the light was increased to 13 h/d. Body and feather weight gains were calculated using Eq. 1 and 3 from which the 20-week body weight was predicted. This weight was used in Eq.'s 10 and 11 to calculate the mean age at which photosensitivity was achieved in the population, from which the age at first egg was predicted using Eq.'s 6 - 8. On the day that each bird laid its first egg was considered 5 g/week of body weight gain. The mean daily body and feather protein weights were calculated from the individual values simulated.

The model described here was developed in Microsoft Excel® software from Microsoft Office package (Microsoft Corporation, Albuquerque, New Mexico, USA). The model simulates the growth rates of ovary, oviduct and feathers prior to the start of egg lay, according to lighting programme used to estimate nutritional requirements of individual hens. The start point of the performance simulation the flock of broiler breeder hens was the means and standard deviations (SD) values of relevant parameters involved in describing the growth of body, feathers, reproductive organs and AFE .Therefore, both Mean and SD will be given when evaluating the parameters.

The random values were generated from a standardised normally distributed population using the following generalised equation (Ferreira *et al.,* in press):

Vi = ((SQRT (-2×LN(RAND( )))×SIN(2×PI( )×RAND( ))) × SD + Mean [Eq. 12]

Where **Vi** is the standardized normally distributed value (0.1) assigned to the i^{th} hen. **RAND()** is the random number from a rectangular distribution (0.1/12), **SQRT** is square root, **LN** is natural logarithms, **SIN** is sine and **PI** is mathematical constant (3.14159265358979).

The information about the age, body weight and body composition over the growth period is required in order to determine the amino acid requirements of broiler breeder hens from rearing period until sexual maturity (egg laying period) and the age at onset of laying in function of the lighting programme. The information required for developing this simulation model was obtained from Lewis *et al*. (2007), Cobb manual (2008) and a research reported by Ferreira *et al.* (in press).

Modelling the amino acids required for maintenance and growth

Because a population of birds cannot have a 'requirement' for nutrients, the requirements as described here were calculated for individuals drawn randomly from a normal distribution with mean equal to the breeder recommendation for age and a coefficient of variation (CV) of around 10 %, but under user control. The amino acids required by an individual for maintenance and growth of the body, feathers and reproductive organs may be calculated from the weights and rates of growth of these components. Fisher (1998) assumed that the amino acid composition of ideal protein for maintenance and growth was the same as the amino acid composition of the body, and that concept was used here to determine amino acid requirements for maintenance and growth of each individual (Table 2). A coefficient of utilization of 0.8 was used for the conversion of all dietary amino acids to those used for protein growth.

Table 2. Amino acid composition (g/kg) adopted for estimating amino acid requirements for breeders.*

	Maintenance[1]	Body protein[2]	Feathers[2]
Arginine	50	68	65
Cysteine	35	11	70
Histidine	10	26	8
Isoleucine	50	40	40
Leucine	32	71	70
Lysine	73	75	18
Methionine	25	25	6
Methionine&Cysteine	60	36	76
Phenylalanine	16	40	45
Phenylalanine&Tyrosine	32	71	95
Tyrosine	16	31	50
Threonine	40	42	44
Tryptophan	10	10	7
Valine	60	44	60

[1] FISHER (1983). [2] EMMANS (1989). *FISHER, 1998. Utilised for body protein growth with an efficiency of 0.80. Assumed composition of protein maintenance.

For each individual the daily maintenance and growth requirements for each amino acid (A_r) were calculated separately for the feather-free body, for feathers and for the reproductive organs, and then summed. This model is described in Eq. 13 below:

$$A_r = \left[(A_{Bm}.BP_m^{0.73}.u) + (0{,}01.FP_t.A_f) + \left(\frac{Pd_B}{k}.A_{Bg}\right) + \left(\frac{Pd_F}{k}.A_f\right) + \left(\left(\frac{Pd_{ova}}{k} + \frac{Pd_{ovi}}{k}\right).A_{Bg}\right)\right]$$

[Eq.13]

Where A_{Bm} is the amino acid composition of ideal protein for maintenance of body protein (Table 2); $BP_m^{0.73}$ is the mature body protein weight (kg); u is the degree of maturity of body protein ($u=BP_t/BP_m$); $BP_m^{0.73}.u$ is a maintenance unit as described by Emmans and Fisher (1986). Broiler breeder females have the potential to reach a mature body protein weight (BP_m) of about 0.9 kg (Hancock *et al.,* 1995). 0.01 is the correction factor for feather loss (Emmans and Fisher, 1986). FP_t is feather protein at time t; and A_f is the amino acid composition of feathers. Pd_B is the rate of body protein deposition (g/d); Pd_F is the rate of feather protein deposition (g/d); A_{Bg} and A_f are the amino acid compositions for body and feather protein growth; and k = 0.8, which is the efficiency of utilisation of dietary amino acids for body protein growth (Fisher, 1998). Pd_{ova} is the rate of deposition of protein in the ovary (g/d) and Pd_{ovi} is the rate of protein deposition in the oviduct (g/d).

For each of the birds generated above the daily amount of each amino acid required during the growing period was calculated by Eq. 13. These daily requirements were averaged for the sample population for each day of the growing period. To convert the mean requirement to a dietary concentration, in order to determine the amino acids content required in the feed, the amount of feed to be consumed each day is needed. For this exercise, because daily feed intake was not being predicted, the daily intake of feed recommended by the breeding company (Cobb Manual, 2008) was used, and it was assumed that each bird received the same daily amount of feed.

3. Results

Simulation of the growth of each individual in a population using different lighting programmes during the rearing period.

The weight of ovary and oviduct of 210 days of age are illustrated in Figure 1 where can be observed that the lighting program used influences the development of the reproductive organs. The lighting program A (8 h light/d to 100 d followed by an increase at that age to 13 h/d), there is a greater variation in reproductive organs weight of the flock. It is also possible to observe that the ovary and oviduct of birds stimulated by lighting program A started growing before the lighting program B, with greater weight variation throughout the development of organ. This variation in the development of reproductive organs, will result in greater disuniformity of the flock.

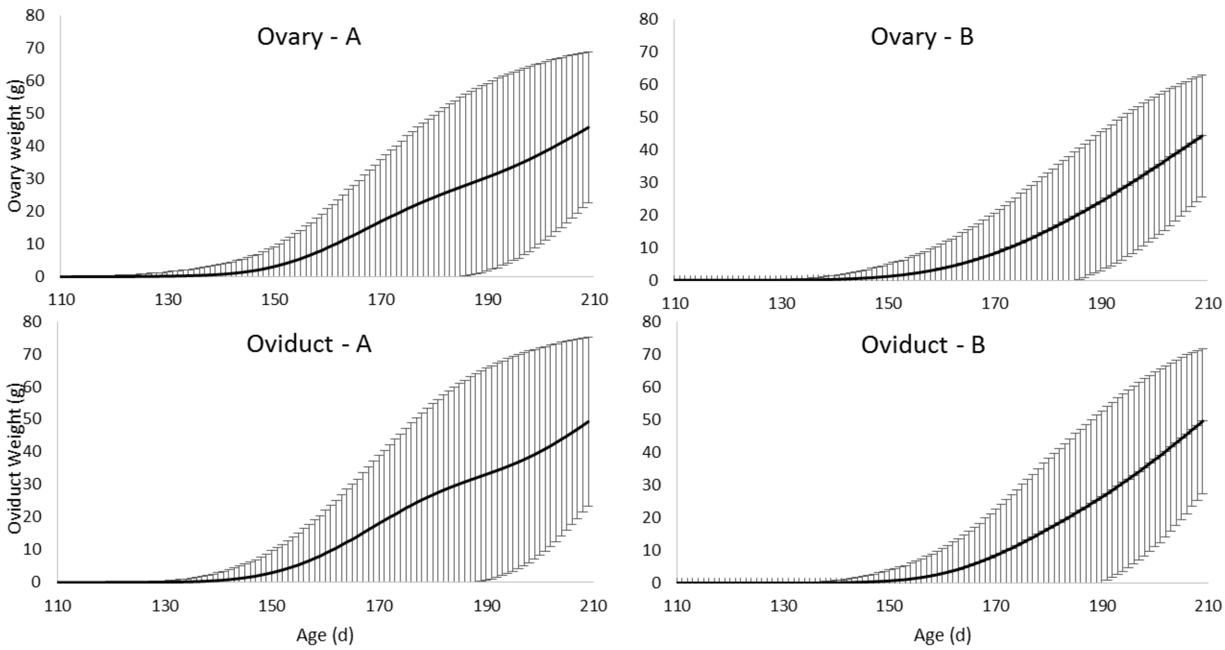

Figure 1: Average weight and SD of ovary and oviduct of broiler breeder hens subjected to two different lighting programmes; 8 h light/d to 100 d followed by an increase at that age to 13 h/d (A), and 8 h light/d to 140 d at which age the light was increased to 13 h/d (B).

Figure 2 shows the cumulative percentage of broiler breeders reached sexual maturity in function of age, according to the lighting program used. Was observed some broiler breeders were responsive to light stimulation, and so reach sexual maturity, while other birds are not responsive, which results in differences in nutritional requirements. This simulation all birds reached sexual maturity at approximately the same age, 245d, however the program A in 50% of the birds began posture with 190 days of age. This discrepancy in age at first egg has consequently higher losses of hatching eggs and incidence of floor eggs.

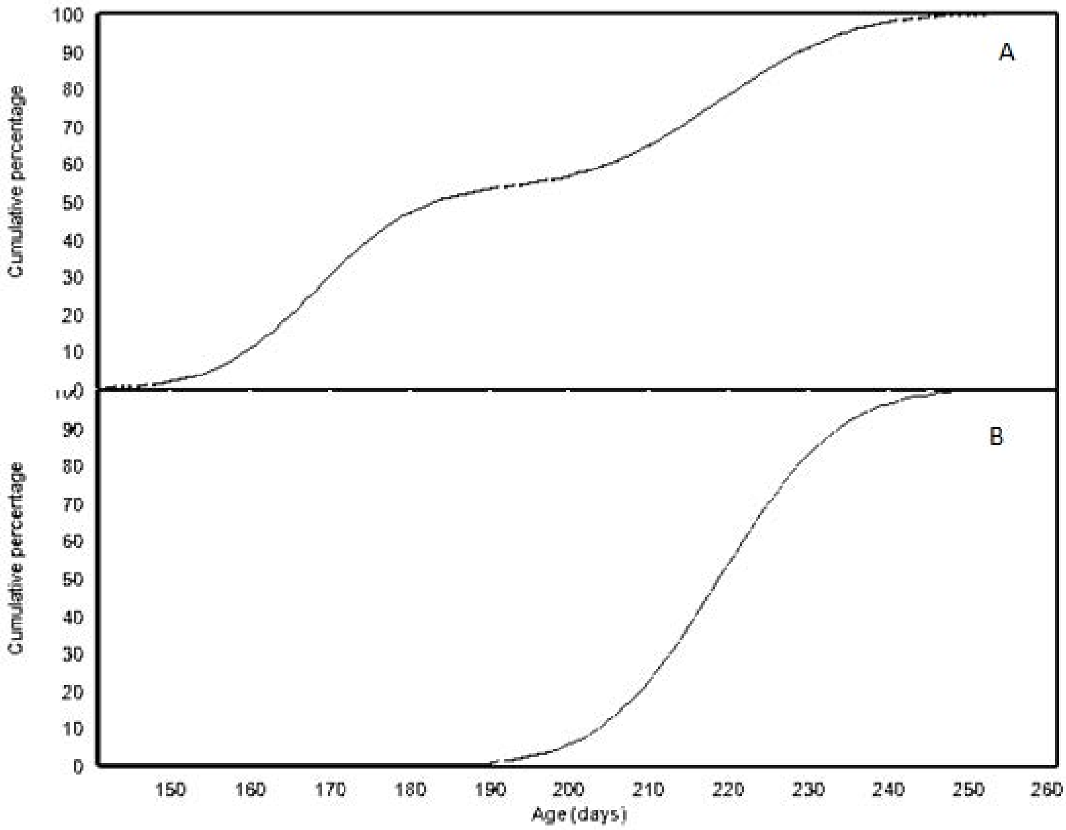

Figure 2. Cumulative percentage of broiler breeders reached sexual maturity in function of age, subjected to two different lighting programmes; 8 h light/d to 100 d followed by an increase at that age to 13 h/d (A), and 8 h light/d to 140 d at which age the light was increased to 13 h/d (B).

Modelling the amino acids required for maintenance and growth

The amino acids requirements were calculated through Eq. 13, considering the composition of the body from the equations in Table 1. The division of phase of age recommended by breeding company was considered to calculate the minimum, mean, maximum and standard deviation of amino acids requirements (Table 3).

At the phase 5 to 17 weeks old, which covers the beginning of growth of reproductive organs, it is observed that the lighting program A presents higher SD compared to another program, which is also observed in the period 18 to 22 weeks of age in larger proportions.

Table 3. The minimum (Min), mean, maximum (Max) and standard deviation (SD) of Lysine, Methionine+Cystine and Threonine requirements (mg/d) of broiler breeders hens for maintenance and growth in the periods 1-4, 5-17 and 18-22 weeks of age from lighting programmes A and B

Age	Lysine				Methionine+Cystine				Threonine			
week	Min	Mean	Max	SD	Min	Mean	Max	SD	Min	Mean	Max	SD
					Lighting program A[1]							
1 – 4	285	318	347	21	265	282	296	19	219	238	254	13
5 – 17	385	427	465	52	315	337	360	37	259	282	302	27
18 – 22	477	550	620	40	391	431	478	26	308	347	387	22
					Lighting program B[2]							
1 – 4	282	318	343	20	264	281	300	19	218	238	255	12
5 – 17	378	426	457	51	309	336	355	36	255	281	299	26
18 – 22	476	545	604	32	387	428	460	22	307	344	378	18

[1] Lighting program A: 8 h light/d to 100 d followed by an increase at that age to 13 h/d
[2] Lighting program B: 8 h light/d to 140 d at which age the light was increased to 13 h/d

To determine the feed composition for each amino acid, was used the values presented in Table 3 divided by feed intake recommended by the manual lineage. The requirements of lysine, methionine + cystine and threonine are presented to illustrate the result of this exercise, but this calculation can be done with all the amino acids.

From the amino acids requirements obtained, for both lighting program simulations, was defined the concentration of lysine, methionine + cystine and threonine (g / kg) in each phase according breeding manual (Table 4).

For the phases in which began the growth of reproductive organs, was observed difference in amino acids concentration in the diet between the two lighting programs. Can be observed greater requirement for lighting program A, due to wide variation in the sexual maturity of birds.

Table 4. Calculated concentrations in the diet (g/kg) and standard deviation (SD) of lysine, methionine+cystine and threonine necessary to meet the requirements of broiler breeder hens for maintenance and growth in the periods 1-4, 5-17 and 18-22 weeks of age from lighting programmes A and B

Age	Lysine		Methionine+Cystine		Threonine	
Week	A[1]	B[2]	A[1]	B[2]	A[1]	B[2]
1 – 4	9.59(±2.5)	9.56(±2.5)	8.59(±2.8)	8.55(±2.7)	7.24(±2.2)	7.21(±2.2)
5 – 17	7.53(±0.5)	7.50(±0.5)	5.95(±0.4)	5.92(±0.3)	4.97(±0.4)	4.90(±0.3)
18 – 22	5.71(±0.5)	5.64(±0.5)	4.46(±0.4)	4.42(±0.4)	3.59(±0.3)	3.52(±0.3)

[1] Lighting program A: 8 h light/d to 100 d followed by an increase at that age to 13 h/d
[2] Lighting program B: 8 h light/d to 140 d at which age the light was increased to 13 h/d

4. Discussion

In this simulation, body, feathers and reproductive organs growth were considered to determine the daily nutrient requirements in broiler breeders in two different lighting programs, and from these requirements, was calculated concentration of each amino acid according to feed intake recommended by the breeding manual.

Due to age at sexual maturity in broiler breeder hens can be affected by lighting programmes (Lewis *et al*., 2003), it is difficult to report the growth of reproductive organs. Thus, the use of mathematical models could help estimate the growth of body, feathers and reproductive organs, but it is important to consider the effect of nutritional requirements, lighting programme used, on the growth and AFE. These help the nutritionists formulate feed more efficiently.

Apart from the genetic variation that would be expected in age at sexual maturity within a population, it has been demonstrated that the lighting programme used during the rearing period of broiler breeders influences the time at which each bird lays its first egg (Lewis *et al.,* 2007). The range of ages at first egg in a flock can be increased considerably by applying an inappropriate lighting programme; with sexual development in some birds is being hindered rather than enhanced when an increase in daylength is given before photorefractoriness in such birds has been dissipated. Subsequent performance in a flock of broiler breeders treated in this way is poor, as measured, amongst others, by a low and prolonged peak rate of lay. Another consequence is that the initiation of the growth of ovary and oviduct would extend over a longer period making it difficult to decide on a feeding strategy that would suit the flock as a whole. Similarly, body protein growth would continue for a longer period in those birds whose sexual maturity has been delayed, leading to a wider range of body weights in the flock once all birds had started laying. But even in a relatively uniform flock of broiler breeders such problems need to be dealt with if the flock is to be fed with precision.

Ferreira *et al.* (in press), reported that because of controlled feeding program, the body protein deposition is almost constant; on the other hand, the reproductive organs develop rapidly. However, depending of lighting programme used, not all birds will grow at the same pace; some birds grows faster stronger in each phase. The fact that some birds be growing whilst others are not (started laying), does that has a variation in requirements, and this variation decreases as more birds begin to lay (Figure 1). As observed in results , a strongly stimulatory lighting programme, similar the lighting programme B, makes most birds to start laying simultaneously (resulting in a sharp rise to peak production), result in a uniform rate of growth of reproductive organs in a flock.

The estimate of requirement of amino acid was calculated, through Eq. 13, from the values estimated by equations for body growth, feathers and reproductive organs. These requirements were calculated based on the theory of Emmans and Fisher (1986). In Table 3 are shown the requeriments in mg/bird/day for lysine, methionine + cystine and threonine in function of age. As observed in the results, because inadequate lighting program the nutritional requirements exhibit more variation. Thus, there will be over and under fed birds with consequent difference in nutrient intake and body composition, compromising the future performance.

The concentration of amino acids shown in Table 4, are similar to those recommended by the Cobb Manual (2008), especially for the first stage (1 to 4 weeks of age). However, for phases that include the growth of reproductive organs, the recommendation of this study is higher than the manual. Bowmaker and Gous (1989) report that should be considered an increasing of daily feed allocation, when the development of reproductive organs begins. Also report that, if the increments are too small, the broiler breeders may not be capable of developing their reproductive organs at the normal rate, nor might they receive the necessary stimulus to begin laying. On the other hand, if the increments are higher and at a high frequency, the advantages accrued by restricting growth rate during rearing would be undone and, apart from a lower egg output, mortality may increase. Providing diets with levels of amino acid nearest the nutritional requirement is fundamental to broiler breeder hens, and appropriate lighting programme, helps accomplish this purpose.

This study shows the effect of lighting programme used during the rearing on nutritional requirements and amino acid concentration in diet. Know the requirements helps to establish the best nutritional program, and optimize feeding without excesses and deficiencies. These results support the view that a modelling approach has the potential to help nutritionists to make decisions about feeding more efficient broiler breeder flocks of what is possible at the present.

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CAPÍTULO 4 – MODELLING THE EGG COMPONENTS AND LAYING PATTERNS OF BROILER BREEDER HENS

Abstract - There is scant information about the reproductive process in broiler breeders, with which to develop a feeding strategy that will be economically optimal for these birds. This study aimed to model the egg production of a flock of broiler breeder hens, using non-isometric equations. The number of eggs produced by 60 broiler breeder hens aged 24–60 weeks was monitored, as was the weight of these eggs and the weights of the components, yolk, albumen and shell. Oviposition sequences and the number and length of pauses between sequences were analysed. Non-isometric functions were applied to predict the weight of the egg; yolk weight was predicted from the age of the hen, while albumen and shell weights were predicted from yolk weight; and egg weight was obtained by summing the component weights. The incidence of soft-shelled and double-yolk eggs was also determinded. Yolk weight (YW, g) can be described as $YW=18.03\times(1-e^{-0.015\times(t-103.4)})\times e^{(0.001\times t)}$, where *t* is the age of the bird (days). The weights of albumen (AW) and shell (SW) were based on YW predictions as follows: $AW=14.38\times YW^{0.375}$ and $SW=0.358\times(YW+AW)^{0.687}$. The rate of double-yolk egg (DY) production is described by: $DY=2.28\times e^{(0.209\times TFE)}$ and the rate of soft-shelled egg (SS) production by: $SS = 1.126+0.148/(1-0.024\times TFE)-0.056\times TFE$, as a function of time from first egg (TFE). On the basis of the results obtained, the model developed here is an accurate reflection of the changes that occur in the number of eggs produced by broiler breeders, as well as in the egg itself and in its components over the entire laying period. This model can thus be used in predicting the nutrient requirements of individual broiler breeder hens, which, when combined with simulated data from a large number of individuals, will accurately describe the laying performance of a flock of broiler breeders.

Keywords: abnormal egg, broiler breeder, egg composition, egg production, modelling.

1. Introduction

The worldwide increase in poultry meat consumption has increased the demand for hatching eggs from broiler breeder flocks and this has focused attention on the importance of this component of the poultry industry. In spite of this increased demand for hatching eggs, very few studies with broiler breeder hens are reported in comparison to those with broilers and laying hens. Moreover, the most part of the information generated are owned by the major broiler breeding companies and may not be openly published. Nevertheless, both nutritionists of broiler breeding companies and researchers have been seeking to develop concepts for these birds. Establishing the most appropriate feeding program for broiler breeders and taking into account their particular physiological characteristics is a major topic of interest and study.

A sensible starting point in the process of designing an optimal feeding programme for broiler breeders is to describe the potential egg output (rate of laying and egg weight) of these birds over the laying period. According to Gous and Nonis (2010), five parameters may be used to describe the potential reproductive performance of broiler breeder hens, being these: age at sexual maturity, changes that occur in internal cycle length, changes in egg weight (yolk, albumen and shell) over time, body protein and body lipid contents at sexual maturity. These parameters are required so that the nutrient requirements of a broiler breeder hen are to be calculated. The rate of egg production of each hen over time is determined by the length of the ovulation sequences and the number and duration of pauses between the sequences that can vary according to strain, nutritional status and lighting program. This physiological process should be modelled together with an adequate nutritional program, to avoid the wastage of nutrients on the one hand and an undersupply of nutrients on the other; that is, the objective should be to provide an economically optimum amount of each nutrient to the flock each day. This implies that such a model should be stochastic in nature, taking account of the variation that occurs between individuals in all of the parameters mentioned above. Because of the relatively small amount of work published on broiler breeders, any research directed at any of the above aspects that describe the reproductive performance of broiler breeders would be welcomed by modellers working in this field.

According to Johnston and Gous (2007b), changes in the proportions of yolk, albumen and shell in relation to age of hen have been observed in laying hens and turkeys by previous researchers (Anderson et al. 1978; Harms and Hussein 1993; Hussein et al. 1993; Reidy et al. 1994; Rossi and Pompei 1995; Ahn et al. 1997; Johnston 2004). Only one paper (Nonis and Gous 2013) has addressed this issue in broiler breeders. Therefore, studying the changes that occur in these components in different broiler breeder strains would enable the observed increase in egg weight and the relative change in egg component weights with age of hen to be more accurately described, thus providing an important tool to understand this phenomenon.

The aim of the present study was, therefore, to collect more data on the changes that occur in internal cycle length, rate of egg production, egg component weights, and the proportion of abnormal eggs laid by broiler breeders from 23 to 60 weeks of age. This information could then be used to improve the accuracy of a model of the reproductive processes in broiler breeders, with a view to improving the way in which their daily nutrient allocation is calculated.

2. Materials and Methods

Birds housing and management

The experiment was conducted at the Laboratory of Poultry Science, São Paulo State University, Faculty of Agriculture and Veterinary Sciences, UNESP, Jaboticabal, Brazil. Sixty broiler breeder hens of Cobb (parent strain) were used. The birds used in this trial, during the period of 1–18 weeks of age, were reared in floor pens on litter. The light management adopted was according to the strain guidelines. All birds received the same diet, and the amount was adjusted according to the average weight of birds each week, according to the lineage guide for each phase.

At the start of the trial, the birds were housed individually in laying cages at 18 weeks of age, to adapt to the facilities and to management. Each bird was considered an experimental unit. The experiment began at 23 weeks of age and ended at 60 weeks of age. The birds were fed a diet based on corn and soybean meal (159 g crude protein/kg and 2850 kcal metabolisable energy/kg of feed), following the recommendations of the breeding company (Cobb 2013). Feed intake was adjusted weekly on the basis of the metabolic bodyweight of each bird. The lighting program used was 16 h of uninterrupted light and 8 h of darkness each day over the entire period.

The model to predict egg production was developed on the basis of observed data for persistence of egg laying, percentage of laying and the proportions of the egg components (yolk, albumen and shell). For this purpose, egg production and egg weight were measured daily.

Analysis of Sequence Characteristics

Data from daily egg production was used from each broiler breeder hen over a laying period of 10 months and was recorded in a Microsoft Excel® spreadsheet. Complete production records were used for the hens from April 2012 to January 2013, when the birds were 60 weeks of age. The complete data file was imported into an Egg Production and Sequence Analyzer program Version 3.00 (Zuidhof et al., 1999), which was used to analyse the performance of each hen in terms of the number of sequences and pauses, number of soft-shelled and double-yolked eggs, mean sequence length, mean pause length and the length of the prime sequence (or the longest sequence that follows several short egg sequences after the onset of lay). The number of ovulations was calculated from the number of single-yolked eggs plus twice the number of double-yolked eggs. The output files were imported back into Excel file, so as to interpret the results. Data were analyzed using SAS statistical software (SAS Institute; Cary, NC) version 9.1, using PROC NLIN to fit nonlinear models.

Modeling Internal Cycle Length (ICL)

Eggs are laid in one or more sequences and separated by a pause period of one or more days, defined by consecutive daily ovipositions (ETCHES and SCHOCH, 1984). The length of a sequence or pause is dependent on ICL (h) that is described by the lag (in hours) between successive ovulations.

The ICL for each hen on a weekly basis was calculated as follows: ICL = (DL/LR) × 100, where DL is the daylength (24 h in this case) and LR is laying rate (%). Johnston and Gous (2006), in order to simulate shorter egg sequences produced by many hens at onset of lay, suggested the use of the following line-plus-exponential equation:

$$ICL = a + b \times (R^{TFE}) + c \times TFE \qquad \text{Eq.[1]}$$

where ICL is the internal cycle length (hours); *a*, *b*, *c* and *R* are fitted coefficients (*a* + *b* is equal to *ICL* when the *TFE* = 0, *R* the rate of decrease and *c* the rate of increase of the curve), while TFE is the time from first egg (days).

Determination of the Egg Components

The egg components (yolk, albumen and shell) were weighed on three consecutive days weekly from 26 to 45 weeks. After this period, sampling was made at 48, 51, 54, 57 and 60 weeks of age and 3,100 eggs were measured in total. The method used to determine the weight of egg components was adopted from Hussein et al. (1993) and Harms and Hussein (1993). After weighing the eggs, they were broken and yolk was separated from albumen. Albumen was discarded and yolk rolled on damp paper towel. Any adhering chalazae were removed from the yolk in this manner. Eggs with ruptured yolk membranes were omitted from further analysis. Only intact yolks were weighed. The two shell halves were carefully washed to remove the albumen then they were left to dry at 21°C for 48 h, before being weighed. The albumen weight was determined by subtracting the yolk and dry shell weights from the initial whole egg weight.

Predicting Egg Weight

Egg weight can be predicted as the sum of three components measured previously, namely, yolk, albumen and shell. The yolk weight (YW, g) was predicted from the age of the bird (*t*, days) using a compartmental model (McMillan et al. 1970), described as:

$$YW_t = a \times [1 - e^{-c \times (t-d)}] \times e^{-x \times t} \qquad \text{Eq. [2]}$$

where YW_t is the yolk weight at age t (days); *a* is the asymptotic value of the yolk weight at the maximum yolk weight; *c* is the daily rate of increase in yolk weight; *d* is the mean initial day of laying; and *x* is the rate of decrease in yolk weight after the peak of yolk weight.

For the linear regression analysis individual egg data were used to determine the allometric coefficients in the equations to predict albumen weight from yolk weight, and to predict shell weight from yolk + albumen weight. Albumen (AW, g) and shell (SW, g) weights were predicted using the allometric functions defined by Emmans and Fisher (1986), as follows:

$AW = a_1 \times YW^{b1}$ Eq. [3]

$SW = a_2 \times ECW^{b2}$ Eq. [4]

where ECW is the weight of the egg contents, i.e. yolk + albumen (g). After estimating each egg component weight, the mean egg weight (EW, g) can be estimated by the following equation:

$EW = YW+AW+SW$ Eq. [5]

Models to predict Abnormalities in egg production

Double-yolked eggs occur when a second follicle in the hierarchy closely follows the first follicle at ovulation (or is produced simultaneously). The rate of double-yolked egg production is higher at the beginning of lay and rapidly decreases with age as observed by previous researches (CHRISTMAS and HARMS, 1982; JOHNSTON and GOUS, 2007c; GOUS and NONIS, 2010). This process can be described by the following equation:

$DY=(DY_{max}-DY_{min}) \times e^{(-k \times TFE)} + DY_{min}$ Eq. [6]

where DY is the proportion of double-yolked eggs; DY_{max} is the DY value when TFE is zero; DY_{min} is the minimal proportion of double-yolked eggs (DY) represented by an asymptotic value; TFE is the time from first egg (weeks) and *k* represents the slope of the exponential function indicating the decrease in the proportion of double-yolked eggs with age. As DY_{min} tends to zero with the bird's age, Eq. [6] can be rewritten as follows:

$DY=DY_{max} \times e^{(-k \times TFE)}$ Eq. [7]

The proportion of soft-shelled (SS) eggs produced was predicted using the following equation:

$$SS = a - b/(1 - R \times TFE) + c \times TFE \qquad \text{Eq. [8]}$$

where SS is the proportion of soft-shelled eggs; TFE is the time from first egg (weeks); *a*, *b, c*, and *R* are coefficients.

The coefficients for double-yolked and soft-shelled eggs were obtained by fitting Eq.[7] and Eq.[8] to data observed daily from 23 to 60 weeks of age.

Evaluation of the Models

The models used to predict ICL, yolk and egg weights, double-yolked eggs and soft-shelled were subjected to residual analysis as described by St-Pierre (2003). The residuals (er) were defined as er = observed – predicted values. To assess the models obtained the residuals (er) were plotted against the predicted values, according to the following model:

$$er = b_0 + b_1 (Y_p - \overline{Y}_p) + \mathcal{E} \qquad \text{Eq.[9]}$$

where er is the residual value; b_0 and b_1 are estimated parameters of the linear regression; Y_p is the predicted value (ICL, EW,YW, DY and SS); $\overline{Y}_p$ is the mean of all predicted values of ICL, EW,YW, DY and SS; and $\mathcal{E}$ is the error of the regression analysis. The slope of *e* regressed on predicted values was used to confirm that the models are unbiased, i.e. the slope (b_1) close to zero. According to St-Pierre (2003) this slope can be calculated by $b_1 = 1 - R^2$, that is, for a value of $R^2 < 1$, there is a positive slope that is greater as the R^2 value is lower. Therefore, a positive or negative slope of *er* on ICL, EW, YW, DY and SS is a test to assess the biased prediction.

3. Results

Analysis of Sequence Characteristics

Table 1 summarizes important sequence characteristics. The number of pauses (50.28) closely followed the number of sequences (51.28) leading to the assumption that for each bird there will be one pause less than the number of sequences. The results show that as the prime sequence length and sequence length increase so the number of sequences and pauses become shorter. Moreover, the high standard deviations associated with the sequence characteristics were an indication that a few individuals with exceptionally short or long prime sequences may have a considerable influence on the mean values, but this is not clear.

Table 1. Number and length of sequences and pauses, total eggs and age at first egg of Cobb broiler breeders, from 23 to 60 weeks of age

Sequence characteristics	Mean	SD*	Min	Max	Range
Prime sequence length (days)	22.38	13.50	4.00	68.00	64.00
Number of sequences	51.28	12.49	19.00‘	77.00	58.00
Number of pauses	50.28	12.49	18.00	76.00	58.00
Sequence length (days)	3.73	1.32	1.87	8.79	6.92
Pause length (days)	1.25	0.28	1.00	2.57	1.57
Total eggs	177.28	24.06	103.00	214.00	111.00
Age first egg (week)	24.68	0.99	22.40	27.90	5.50

*Standard deviation

The mean sequence lengths from 23 to 60 weeks of age are shown in Fig. 1. This figure clearly illustrates the laying cycles of broiler breeder hens with increasing age, starting their laying cycles with short sequences, followed by a rapid increase of the sequence length to the prime sequence at 28 weeks of age, and a subsequent decline thereafter. Mean sequence length reached a maximum between 26 and 31 weeks of age.

Figure 1. Mean sequence lengths for broiler breeders of Cobb strain, from 23 to 60 weeks of age

Internal Cycle Length (ICL)

On the basis of Eq. 1, the estimated values (±s.e.) for parameters a, b, c, and R were 25.4 (±0.435), 8.99 (±1.366), 0.072 (±0.003) and 0.748 (±0.109), respectively. The errors of the coefficients relative to the average values were 1.7% for *a*, 15.2% for *b*, 4.2% for *c* and 14.5% for *R*. Therefore, the equation obtained was

$$ICL=25.4+8.99 \times (0.748^{TFE}) + 0.072\times TFE \quad (p < 0.0001) \qquad \text{Eq. [10]}$$

The decrease in egg production with increasing age can be estimated using Eq. [10]. For the first egg to be laid the internal cycle length needs to be longer than 24 hours. This time will decrease with increasing age; in some birds it will be less than daylength; and will increase again to above 24 hours. The curve fitted with the values predicted by Eq. [1] is shown in Fig. 2.

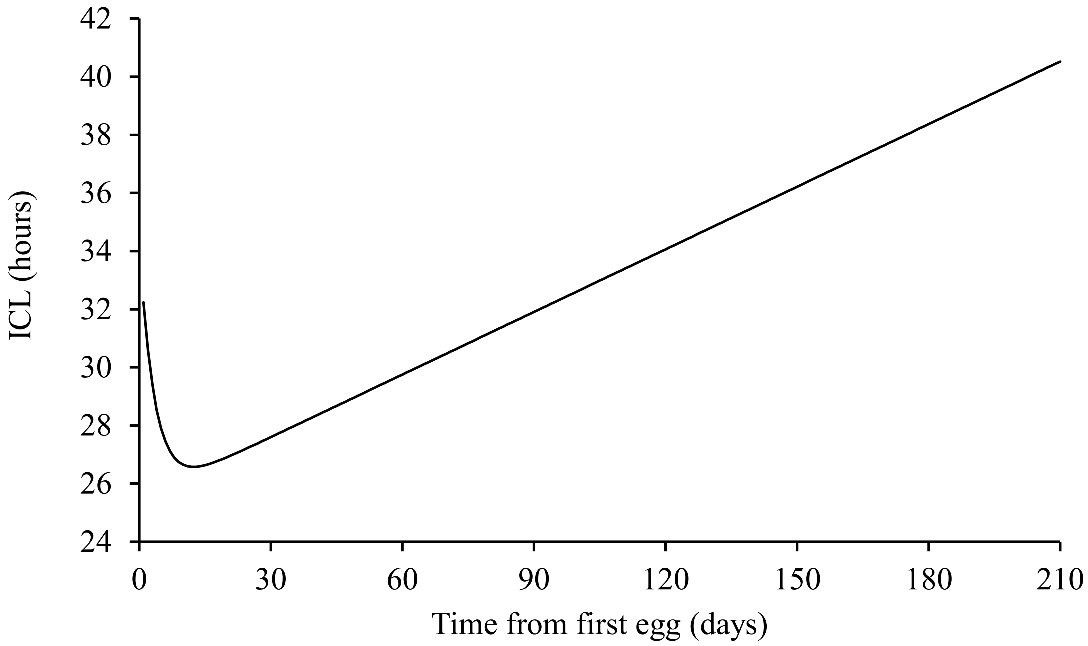

Figure 2. The mean change in internal cycle length over time for broiler breeders

Modeling Egg Component data to Predict egg weight

Modeling Yolk Weight. Yolk weight (YW) was estimated using the observed values in Eq. [2]. The coefficients *a*, *c, d* and *x* estimated for YW were 18.03 (±0.955), 0.015 (±0.002), 103.4 (±4.698) and -0.001 (±0.0001), respectively. The errors of the coefficients relative to the average values were 5.3 % for *a*, 11.3 % for *c,* 4.5 % for *d*, and 21.2 % for *x*. Therefore, the equation obtained was:

$YW = 18.03 \times (1 - e^{-0.015 \times (t - 103.4)}) \times e^{(0.001 \times t)}$, $R^2 = 0.94$ Eq. [11]

The average yolk weight predicted by the resulting equation and the yolk weights observed as a function of the age of the bird are illustrated in Fig. 3.

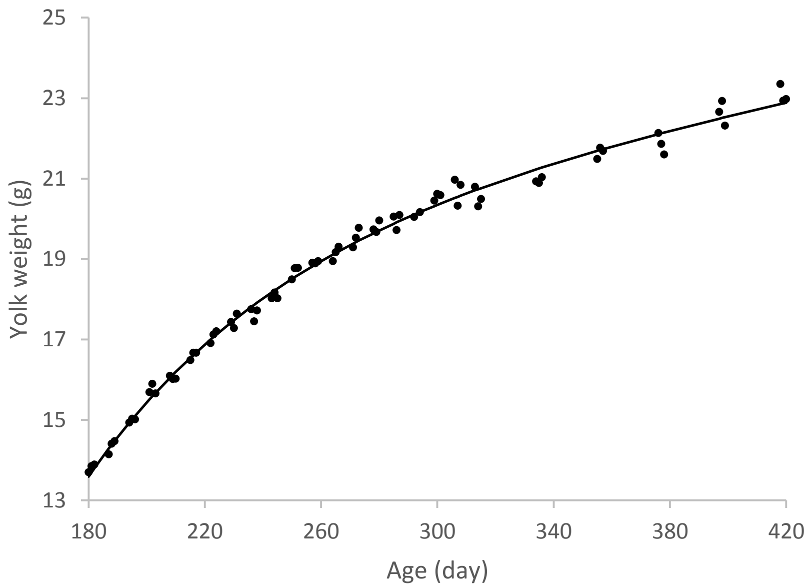

Figure 3. The average yolk weight predicted by equation (——) and observed (●) as a function of the age of the bird.

Evaluation of the Model for Yolk Weight. The slope of the regression of residuals on predicted YW is 0.002 (0.009). Considering the actual R^2 of 0.996, the regression of residuals on observed values is 1-0.996 = 0.004. The similarity of the slope and 1-R^2 is evidence that the model is unbiased.

Modeling Albumen and Shell data. Linear regression analyses were performed using the natural logs (ln) of albumen weight on yolk weight and ln (yolk + albumen) weight on ln shell weight, using individual egg weight data. The coefficients *a* and *b* estimated for AW were 14.38 (±0.388) and 0.375 (±0.009), and for SW they were 0.358 (±0.023) and 0.687 (±0.016), respectively. The standard errors for the estimated coefficients relative to the average values of *a* and *b* were 2.7 and 2.5 % for AW and 6.5 and 2.3 % for SW, respectively. The resulting equations for AW and SW are described as follows:

$AW = 14.38 \times YW^{0.375}$, $R^2=0.99$, $p<0.0001$ Eq. [12]

$SW=0.358 \times CW^{0.687}$, $R^2=0.99$, $p<0.0001$ Eq. [13]

In general, these equations present a good fit of the data observed as can be seen in Fig. 4.

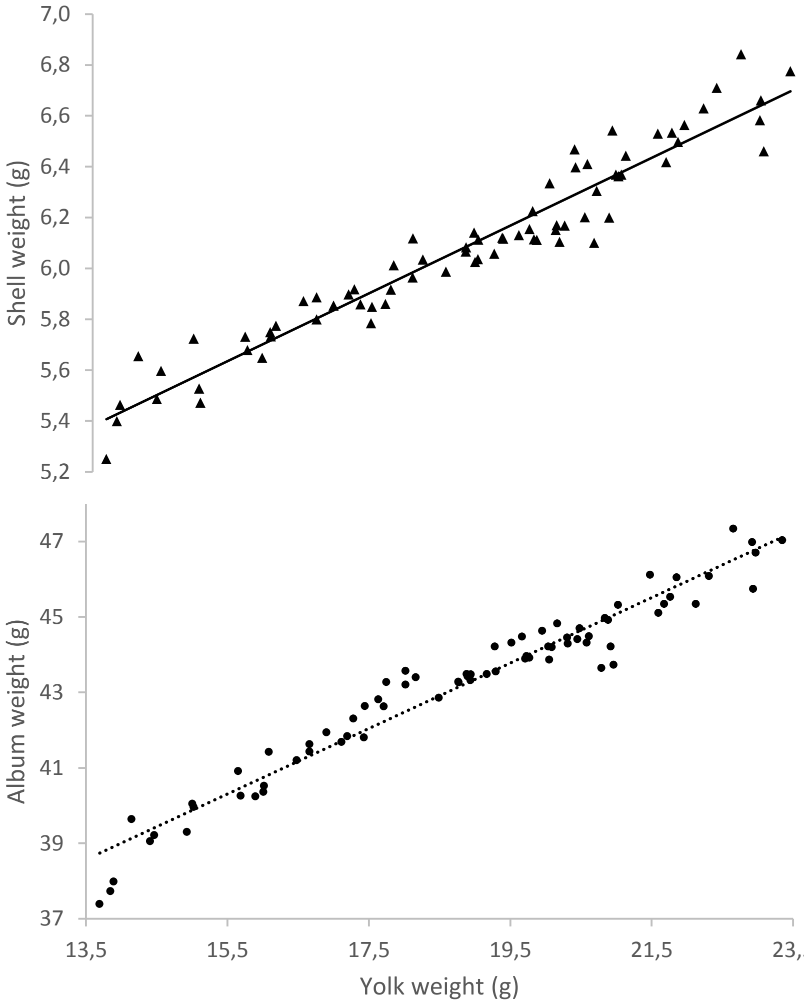

Figure 4. The relationship between shell weight (▲▲▲) and albumen weight (●●●) with yolk weight.

Predicting Egg Weight from Egg Components. The proportions of the predicted values for YW, AW and SW for 3,100 eggs in the laying period from 23 to 60 weeks of age are shown in Fig. 5. As the age of broiler breeder hens increased, the mean proportion of yolk increased, but the proportion of albumen and shell decreased. The model can be used to analyze the changes in the component proportions at a given age.

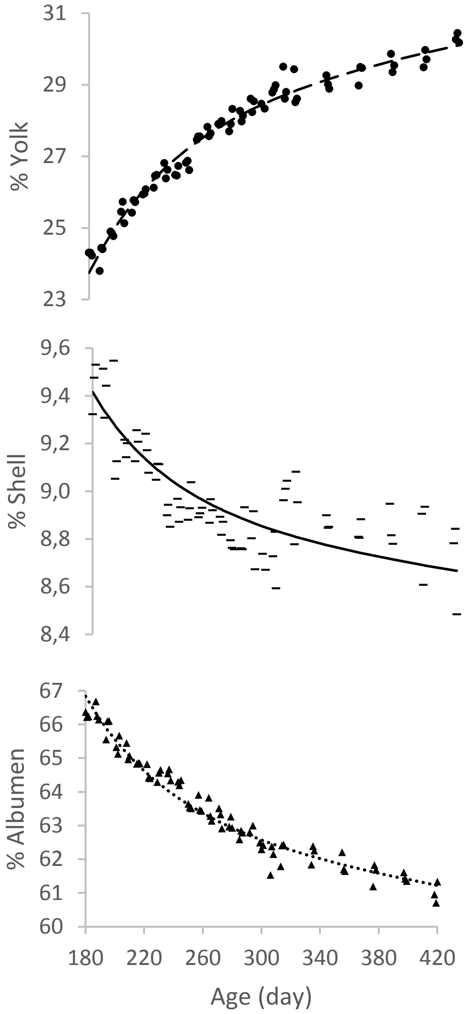

Figure 5. Relationship between the observed proportions of yolk (●●●), shell (_ _ _) and albumen (▲▲▲), in the egg and predicted (_ _ _), (___) and (. . . .), respectively with age. Data from 60 Cobb hens from 23 to 60 weeks of age

Equations 11, 12 and 13 were integrated into a model to predict egg weight, based on egg component weights over the entire laying period (YW+AW+SW). These values were plotted together with the mean egg weights observed (Fig. 6). However, it was not possible to obtain a good fit for egg weights at the start of egg production (up to 55 g or 180 days of age), with the predicted weights being overestimated in this period. This factor is associated with a high standard error in the predictions (4-6 g) up to this age, resulting in a variation of 10 %, but for egg weight > 55 g, the error is minimized to 1~1.5 g (~ 1 %).

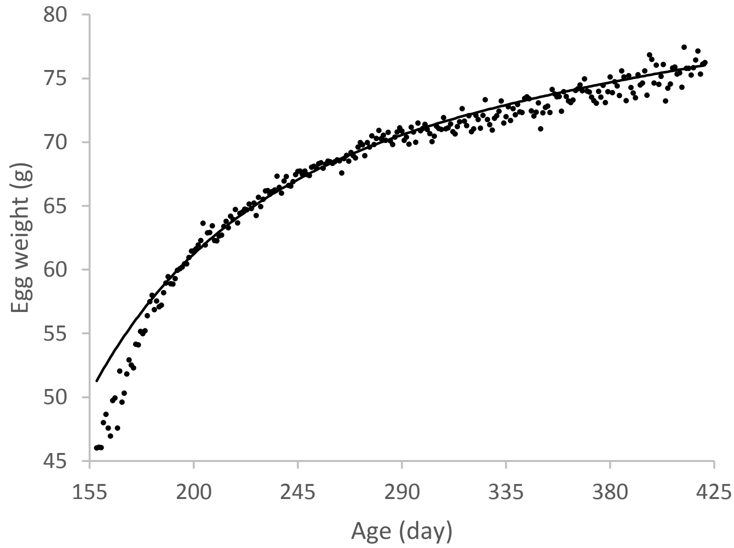

Figure 6. The average egg weight predicted by equation (——), and the weight of eggs observed (·) as a function of age of bird.

Abnormal Egg Production

Double-yolked Eggs. The estimated values (±SE) of the parameters DY_{max} and k obtained in Eq. [7] were 2.275 (±0.363) and 0.209 (±0.036), respectively. The errors of the coefficients relative to the average values were 15.9 % for DY_{max} and 17.0 % for k. The resultant equation was:

$DY=2.275 \times e^{(0.209\times TFE)}$, R^2=0.80 Eq. [14]

On the basis of individual observations of egg production, it was observed that the chance of a double-yolked egg being laid by the flock was ~0.59% (0.006 of all eggs laid). The minimum proportion of double-yolked eggs relative to total eggs produced was observed in our study to be 0.047% after 8–9 weeks, starting from the age at first egg. The curve illustrating the proportion of double-yolked eggs produced, starting from the age at first egg, is shown in Fig. 7.

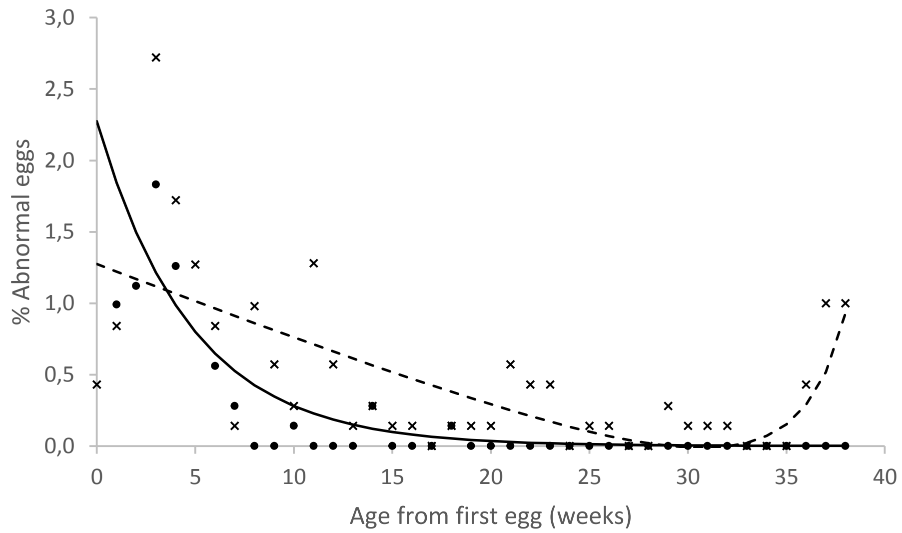

Figure 7. Relationship between the observed occurrence of double-yolked (●●●) and soft-shelled eggs (×××) and estimated (——), (— —), respectively as a function of age of broiler breeder.

Soft-shelled Eggs. The estimated values (±SE) for the parameters *a*, *b*, *R,* and *c* were 1.126 (±0.158), -0.148 (±0.120), 0.024 (±0.001) and -0.056 (±0.015), respectively. The errors of the coefficients relative to the average values were 14 % for *a*, 81 % for *b*, 4 % for *R* and 26.9 % for *c*. The resultant equation was:

$SS = 1.126 + 0.148 / (1 - 0.024 \times TFE) - 0.056 \times TFE, R^2=0.51$ Eq. [15]

The number of soft-shelled eggs was predicted by Eq. [15] and the proportion relative to the total number of eggs produced for broiler breeder hens of Cobb strain is shown in Fig. 7.

Evaluation of the Model for Egg Weight. The residuals (*er*) calculated by the difference between observed and predicted egg weights were plotted against the predicted values of egg weight (Fig. 8) to evaluate the model obtained.

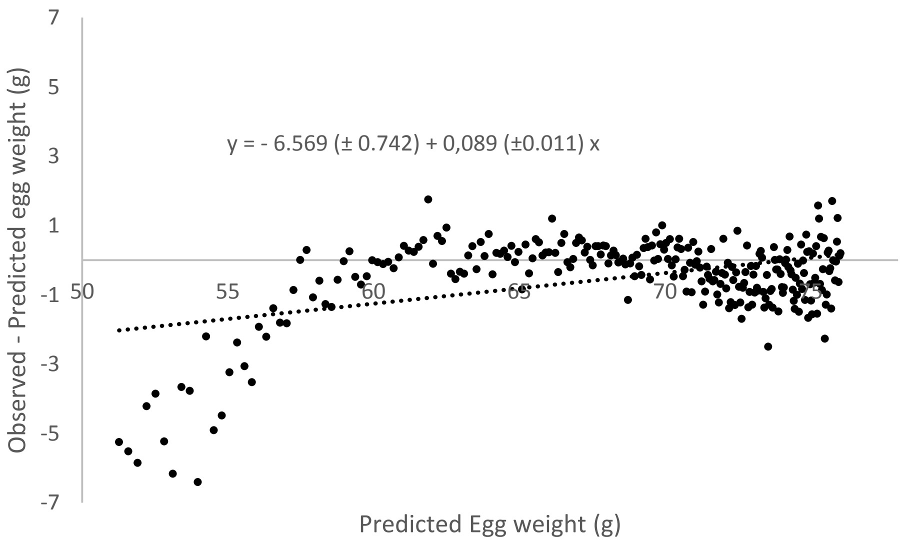

Figure 8. Plot of observed minus predicted egg weight vs. predicted egg weight.

The slope (b_1) of EW was 0.089 (±0.011), and the coefficient of determination (R^2) was 0.975, so the slope is 1 - 0.975 = 0.025. This similarity between the slopes confirmed that the model is unbiased.

4. Discussion

Because of the lack of published information on the reproductive performance of broiler breeders, the aim of the present study was to collect more data on the changes that occur in internal cycle length, rate of egg production, egg component weights and the proportion of abnormal eggs laid by broiler breeders from 23 to 60 weeks of age. The prime sequence or longest sequence seen in the present study (~20 eggs) was equal to that reported by Robinson *et al.* (1992), but considerably greater than that reported by Nonis and Gous (2013), who reported that the longest sequence length observed in one of their studies was only 10 eggs. The data shown in Fig. 1 are very different from those observed by Johnston and Gous (2007*a*) who analysed the egg sequence of laying hens and observed considerably longer sequences. Such differences were expected as broiler breeder hens have not been selected as intensely for reproductive capacity as have commercial laying hens, and consequently, their rates of lay are lower, and they exhibit more irregularity in egg laying, with shorter sequences and longer pauses. According to Robinson *et al.* (1993), egg production rates are positively correlated with the length of the prime sequence, i.e. hens with higher laying rates have longer sequences.

Under normal lighting conditions (16 h of light), the first egg of a sequence is laid early in the morning or about 9–10 h after the onset of darkness. Each subsequent oviposition occurs progressively later in the day, at intervals slightly longer than 24 h, on successive days. During long sequences, oviposition time increases by a similar increment each day (Reynard and Savory 1999). The last egg of a sequence is normally laid during the afternoon (Gilbert and Wood-Gush 1971). Most ovulation sequences end with the absence of a mature follicle in the hierarchy on the day (Gilbert 1972). Several studies support this theory (Gilbert and Wood-Gush 1971; Reynard and Savory 1999; Johnston and Gous 2007*a*; Nonis and Gous 2013).

Hens that lay long sequences usually have very short follicular maturation rates (ICL), of 24 h or less, while hens that have slow rates of follicular maturation, of between 26 and 28 h, lay short sequences of 2–3 days in duration (Etches and Schoch 1984). ICL expresses the lag between successive ovulations and is a measure of the synchronisation between follicle maturation and the circadian rhythm that controls LH release. ICL increases with age, due to the longer time needed to mature the follicles (Johnston and Gous 2003). Therefore, so as to reproduce this curvilinear effect, the ICL needs to be longer than 24 h initially, before decreasing with advancing time from first egg, in some cases to below the daylength, and subsequently increasing to >24 h (Johnston and Gous 2006).

The values found in the present study for the parameters a, b, R and c are 25.44, 8.99, 0.748 and 0.072, respectively, while the equivalent values reported by Gous and Nonis (2010) were 23.05, 2.49, 0.981 and 0.022. Because these parameters have no biological meaning, it is not possible to compare them other than by viewing the resultant graphs. It is, therefore, relatively difficult to find suitable values for the four parameters that produce a realistic mean sequence length for the genotype as well as a rate of lay comparable to the standard performance of the strain, and every experiment in which these parameters are measured will produce a different set of values for the four parameters. For this reason alone, the measurement of ovulation sequences in broiler breeders, as reported here, provides information invaluable to simulation modellers attempting to describe the potential performance of these hens. Because the fitted equation in the present study represented the mean ovulation rate of a population, the reproductive performance of the best producers, whose ICL dropped to <24 h for a period of time, was masked by the poorest producers. In generating individual laying potentials in a stochastic model, the variances of and co-variances between parameters used are as important as the means of each parameter. More accurate estimates of these variances and co-variances can be made as the information on the reproductive performance of broiler breeders is increased.

According to Nonis and Gous (2013), it is preferable to calculate egg weight as the sum of the weights of its three components if the objective is to determine the amount of each essential nutrient required to produce an egg. This is because the relative proportions of the three components change over time; so, using a fixed composition would lead to errors when calculating the nutrients required per g of egg output. Accounting for these changes is possible by predicting both the rate of production of ova and the average yolk weight over time, and then making use of the allometric relationships among the yolk, albumen and shell to calculate the weights of these components (Emmans and Fisher 1986).

Two approaches were used to predict yolk weight (YW) as a function of age, namely, the model proposed by Gous and Nonis (2010) and a compartmental model proposed by McMillan *et al.* (1970). The compartmental model was chosen because prediction bias appeared to be lower and the parameters generated have biological meaning.

The equation used to estimate the weight of the yolk over time fitted the data well (Fig. 3), with good prediction bias. An adequate estimation of yolk weight needs to be made because the values have a direct influence on estimates of shell and albumen weights used in the allometric calculations (Fig. 4). The present study confirmed the suitability of using allometric functions to predict the proportional changes in the egg components (Fig. 4), as proposed by Emmans and Fisher (1986), Johnston and Gous (2007a) and Gous and Nonis (2010).

The estimated allometric coefficients for predicting albumen and shell weight were close to those of Gous and Nonis (2010), who, working with Cobb and Ross broiler breeders, found values ranging from 9.58 to 14.73 and from 0.50 to 0.325 (for *a* and *b* in the albumen equation, respectively) and from 0.188 to 0.194 and from 0.832 to 0.848 (for *a* and *b* in the shell equation, respectively). In their study, Gous and Nonis (2010) found large differences between the two strains. Therefore, it seems essential to establish these parameters for each strain to improve the accuracy of model prediction between strains.

Figures 3–5 illustrate the accuracy of prediction of yolk weight from age and albumen and shell weights by using allometry. The equations used to predict yolk weight as a function of age, and the allometric functions that predicted albumen and shell weight from egg weight, all performed adequately, whereas the combination of these equations for predicting egg weight was less accurate during the initial few weeks of production (Fig. 7). During the first 40 days after sexual maturity, the predicted egg weight was higher than the measured weight. This is partially the result of the lower weight of albumen predicted during this period (Fig. 4). Nonis and Gous (2013) demonstrated that the amount of albumen secreted around the yolk during egg formation varies between individuals and from egg to egg; therefore, it is not unlikely that the proportions of the two components are inconsistent at a given age. Another reason for the error in estimating the initial egg weight is that only a small number of eggs were produced in the initial stages of lay and there was great variation between egg weights, with the birds exhibiting a rapid initial increase in the weight of the components of eggs. Equations that estimate egg weight directly as a function of age are thus likely to fit better than models that estimate each compartment separately through allometric functions, as proposed in the present work, but the added accuracy is of little value compared with the additional information obtained by estimating the weights of the components and adding these together to obtain the egg weight.

As hens become older and yolk and albumen weights increase, the shell becomes thinner because the increase in shell weight takes place at a decreasing rate relative to the egg contents (Johnston and Gous 2007*b*). These results present convincing evidence that the proportions of yolk, albumen and shell change as the hen ages (Fig. 5).

Yu et al. (1992) observed that 0.023 of all eggs laid by broiler breeders between 19 and 29 weeks of age were double-yolked. Gous and Cherry (2004) observed that double-yolked eggs made up from 0.02 to 0.04 of all eggs laid by birds during the period of 25–60 weeks of age, and Ciacciariello and Gous (2005) reported a rate of ~0.04 during the period of 23–56 weeks of age. These rates of production of double-yolked eggs are considerably higher than observed in the trial reported here (0.006), indicating the wide differences in this characteristic among flocks.

It would appear that the fit of the data from Eq. 15 was unsatisfactory in predicting occurrence of soft-shelled eggs (R^2 = 0.51). However, considering that the occurrence of soft-shelled eggs is not normal, this low R^2-value can be explained by the higher variation of these data due to different physiological states in specific situations. As with double-yolked eggs, the incidence of soft-shelled eggs is considerably greater in young broiler breeders, especially when photostimulation occurs early. The incidence is also higher in broiler breeders (0.011 of all eggs laid vs 0.003 in laying hens, as reported by Johnston and Gous 2007c). The likely cause of soft-shelled eggs in older birds is the less efficient absorption and utilisation of dietary calcium for shell formation (Hansen *et al.* 2003). These eggs cannot be used for hatching purposes, thus reducing the number of hatching eggs produced by the hens. A critical stage in the production of eggs for broiler breeders is from photostimulation to peak production. During this time, the number of yellow follicles is influenced by the age at photostimulation, feeding level and bodyweight (Renema *et al.* 1999). Broiler breeder hens that begin to lay before they are sufficiently mature somatically, or are overfed, may exhibit excessive follicular development, which will result in reproductive abnormalities that include the production of abnormal eggs (egg shells of poor quality and double-yolked eggs) and internal ovulations.

5. Conclusion

On the basis of the results obtained, the model developed here is an accurate reflection of the changes that occur in the number of eggs produced by broiler breeders as well as in the egg itself and in its components over the entire laying period. Using the estimates of the means and variances reported in this paper, of each of the parameters involved, this model can thus be used in predicting the nutrient requirements of individual broiler breeder hens, which, when combined with simulated data from a large number of individuals, will accurately describe the laying performance of a flock of broiler breeders. The challenge that remains is to predict the consequences of an inadequate nutrient intake on egg component weights and rate of lay.

6. Acknowledgements

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CAPÍTULO 5 – OPTIMISING THE AMINO ACIDS AND ENERGY CONTENT OF FEEDS FOR BROILER BREEDERS HENS DURING THE LAYING PERIOD

Abstract - The aim of this study was to develop a stochastic model for egg production (EP) of broiler breeder hens in function of age from first egg (AFE) and body weight (BW). Mean AFE (193 d) was estimated from the lighting programme applied during rearing phase using the Bristol-Reading model. The first step was the construction of a diagram incorporating age and BW, at which EP begins, and internal cycle length (($ICL=25.4+8.99\times(0.748^{AFE})+0.072\times AFE$) to determine the rate of ovulation. Yolk weight ($YW=18.03\times[1-e^{-0.015\times(AFE-103.4)}]\times e^{-0.001\times AFE}$), albumen weight ($AW=14.38\times YW^{0.375}$) and shell weight ($SW=0.358\times ECW^{0.687}$) were calculated using allometric functions. The maximum rate of lay was 87 % at 28 weeks of age and declined to 57 % at 60 weeks of age. There were an increase in mean egg weight (from 63 to 77g), YW (from 15 to 23g) and AW (from 40 to 47g). For EP and BW, the daily Lys intake required by the flock increased to 632 mg/d then declined to 563 mg/d by 60 weeks of age. The effective energy requirement of 1020 kJ/d was relatively constant in this period. The recommendation of amino acids in the diet would be 3.95 g of Lys and 3.06 g of Met + Cys per kg of diet for broiler breeder hens at peak production feeding 160 g of feed per day. The EP and BW have direct influence in the estimates for nutrient requirements due to its variability in a population of hens, which should be considered carefully in the stochastic modelling.

Keywords: amino acids requirements, egg production, stochastic modelling

1. Introduction

The model proposed by Gous and Nonis (2010) described in mechanistic terms, the changes in egg production, egg weight and composition that occur during the laying cycle of broiler breeders. Such an approach enables changes and additions to be made to all aspects of the production process. For example, it will accommodate changes in age at first egg resulting from the use of different lighting programmes in the rearing period, or differences in genetic potential laying performance and egg weight, and it is possible to calculate nutrient requirements in individuals and average these in a sample population to obtain calculated estimates of the requirements of a flock of breeders.

This approach has raised a number of issues that were previously ignored by researchers or were subjects of isolated research that were previously unrelated to model development. Such models have been the basis of a number of trials in which measurements have been taken of, for example, rates of growth of the ovary and oviduct prior to the onset of lay (Bowmaker and Gous, 1989; Ferreira *et al*., 2015), changes in internal cycle length over time (Johnston and Gous, 2003), the allometric relationships between yolk, albumen and shell weight (Johnston and Gous, 2007). The daily rate of yolk material deposition measured by McLeod et al. (2014) has assisted in confirming the estimates made by Johnston and Gous (2007). The effect of lighting programme on age at maturity of broiler breeders, and the observation that broiler breeders are photorefractory, as reported by Lewis et al. (1998) has assisted in being able to predict when the reproductive phase of a broiler breeder is initiated. There remain issues that need to be explored in order for such mechanistic models to be updated and improved, the modelling process being an ideal means of identifying gaps in our knowledge of a system.

In the investigation reported here, the way in which broiler breeders should be fed during lay is determined by making use of the approach used by Gous and Nonis (2010) to calculate the mean daily intakes of energy and amino acids required by a laying flock throughout the laying period, and then optimising the feeds and feeding programme during lay using the concept proposed in the Reading Model (Fisher *et al*, 1973). This model suggests that there is an economic optimum daily intake of a nutrient that depends on the marginal cost of the nutrient and the marginal revenue for the product, analogous to the situation in broiler breeder production where a fixed daily amount of each nutrient is supplied to the flock.

2. Materials and Methods

The model described here, developed in MS Excel, simulates potential performance and hence nutrient requirements at an individual bird level, and using appropriate means and standard deviations (SD) for the relevant parameters, performance of a flock of breeding hens is simulated. Therefore, when evaluating the parameters involved in describing the bird, means and SD's are both given. Random numbers from a standardised normally distributed population are generated using the following generalised equation:

$$V_i = ((\text{SQRT}(-2\times\text{LN}(\text{RAND}(\,)))\times\text{SIN}(2\times\text{PI}(\,)\times\text{RAND}(\,))) \times \text{SD} + \text{Mean}$$

where V_i is a standardized normally distributed value (0.1) assigned to the ith bird. RAND() is a random number from a rectangular distribution (0.1/12), SQRT is square root, LN is natural logarithms, SIN is sine and PI is mathematical constant (3.14159265358979). The value Vi is multiplied by the appropriate standard deviation (SD) and this is added to the mean of the population to generate a random number with the required mean and SD.

Determining the amino acid and energy requirements of a broiler breeder hen during her laying period requires information about the age and body weight at which egg production commences, the potential rate of egg production and egg weight, and the changes in internal cycle length, yolk, albumen and shell content, and body composition over the laying period. The information required in developing this simulation model was obtained from various sources, including a research reported by Ferreira *et al.*, 2015.

Describing the bird

As a broiler breeder has not reached somatic maturity by the time laying commences, the body protein content of the bird at time t (BPt) and the mature body protein (BPm) weight must be estimated in order to calculate the maintenance requirements of a hen using the equation recommended by Emmans and Fisher (1986). Breeding companies (Aviagen, 2013; Cobb 2012) recommend a target body weight of between 2.1 and 2.3 kg at 20 weeks, and the composition of the body at this age has been reported to be 180 g protein and 95 g lipid/kg feather-free body weight and 40 g feathers (Fisher, 1998). The composition of the hen at 20 weeks can be calculated from these numbers (Table 1). Appropriate coefficients of variation (CV) of the above weights and concentrations are given in Table 1.

Table 1: Means and coefficients of variation used to describe a broiler breeder at 20 weeks and at maturity

	Mean	Coefficient of Variation
Body weight, g	2340	10
Body protein content, g/kg	180	1
Body lipid content, g/kg	7.5	5
Feather weight, g	95	5
Body protein at maturity, g	900	7

The rates of growth of the ovary and oviduct in broiler breeders to the time when the first egg is laid have been reported by Bowmaker and Gous (1989) and by Ferreira *et al.* (in press). In addition, Ferreira *et al.* (in press) added information about the growth of feathers during this period and argued that the extent to which body and feather protein continue to grow depended on the age at which laying commences, this resulting in differences in body and feather content in different birds within the population. They described how an age at first egg may be assigned to each bird in a sample population using the model developed by Lewis *et al.* (2007), this being a function of the weight of the bird at 20 weeks, the lighting programme to which the birds were subjected during the rearing period, and the mean (± SD) age at which the population of broiler breeders becomes photosensitive.

Describing the Internal Cycle Length (ICL)

Eggs are laid in one or more sequences and separated by a pause of one or more days, defined by consecutive daily ovipositions (Etches and Schoch, 1984). The length of a sequence or pause is dependent on ICL (h), this being responsible for the lag (h) between successive ovulations. The line-plus-exponential equation suggested by Johnston and Gous (2006), and Ferreira *et al.* (2015), Eq.1, was used to describe the change in ICL over time from first egg (TFE).

$$ICL = a + b \times (R^{TFE}) + c \times TFE \qquad Eq.1$$

where ICL is the internal cycle length (hours); *a*, *b*, *c* and *R* are fitted coefficients ($a + b$ is equal to ICL when $TFE = 0$), *R* the rate of decrease and *c* the rate of increase of the curve. A SD of 1.8 hours was used to describe the variation in ICL within a flock.

Calculating Lag and Time of lay

Lag is the difference, in hours, between successive ovipositions, and the total lag is the difference between the first and last ovipositions of a clutch. Lag is dependent on the length of a day (photo- plus scoto-period) (Morris, 1973) so this length must be stipulated in the model. A daylength of 24 h was used in the model described here.

The time of lay (oviposition time) of the first egg of a sequence was taken as 08:00 ± 3 h. Subsequent eggs in the clutch were laid progressively later, this being determined by the length of the lag each day, and the last egg of a sequence was defined as the egg that would have been laid no later than 16:00 ± 0.2 h. The hen would then not lay an egg the following day (pause day), but the cycle would begin two days after the clutch had ended, again at 08:00 ± 3 h.

Predicting Egg Weight

Egg weight can be predicted as the sum of three components: yolk, albumen and shell. The yolk weight (YW, g) may be predicted from the age of the bird (t, d) using a compartmental model (McMillan *et al.,* 1970), and Ferreira *et al.* (20015) described as:

$$YW_t = a \times [1 - e^{-c \times (AFE - d)}] \times e^{-x \times AFE} \qquad Eq.\ 2$$

where YW_t is the yolk weight at AFE (days); *a* is the asymptotic value of the yolk weight at the maximum yolk weight; *c* is the daily rate of increase in yolk weight; *d* is the mean initial day of laying; and x is the rate of decrease in yolk weight after the peak yolk weight.

Individual egg data were used to determine the allometric coefficients in the equations to predict albumen weight from yolk weight, and to predict shell weight from yolk + albumen weight. Albumen (AW, g) and shell (SW, g) weights were predicted using the allometric functions defined by Emmans and Fisher (1986), as follows:

$AW = a_1 \times YW^{b1}$ *Eq. 3*

$SW = a_2 \times ECW^{b2}$ *Eq. 4*

where ECW is the weight of the egg contents, i.e. yolk + albumen (g).

Estimates of the parameters used in the equations to calculate rate of lay and egg weight are shown in Table 2.

Table 2. Values of coefficients used to describe egg production of broiler breeders with estimates of coefficients[1] of variation (CV) for use in a stochastic model

Strain	Cobb	*CV*
Mean age at first egg (AFE*) (d)	193	7.8
Internal cycle length (ICL)	$=a + b \times (R^{TFE}) + c \times TFE$	
A	25.4	1.7
B	8.99	15.2
C	0.072	4.2
R	0.748	14.5
Yolk weight	$=a \times [1-e^{-c \times (AFE-d)}] \times e^{-x \times AFE}$	
A	18.03	5.3
C	0.015	11.3
D	103.4	4.5
X	0.001	21.2
Albumen weight (g)	$= a \times YW^b$	
A	14.38	2.7
B	0.375	2.5
Shell weight (g)	$= a \times ECW^b$	
A	0.358	6.5
B	0.687	2.3

[1] Coefficients estimated by Ferreira et al., 2015. * AFE is age from first egg (d), and TFE is time from first egg (d).

Predicting amino acids and energy required for maintenance

Fisher (1998) assumed that the amino acid composition of ideal protein for maintenance was the same as that of the body. The amount of each amino acid required for maintenance was therefore estimated using the composition of body protein (Table 3).

Table 3. Amino acid compositions (mg/g) utilised for estimating amino acid requirements for breeders (from Lunven *et al*., 1973).

	Body	Yolk	Albumen
Arginine	68	434	330
Cysteine	11	163	178
Histidine	26	148	132
Isoleucine	40	348	331
Leucine	71	548	521
Lysine	75	477	378
Methionine	25	175	240
Methionine&Cysteine	36	338	418
Phenylalanine	40	261	368
Phenylalanine&Tyrosine	71	514	625
Tyrosine	31	253	257
Threonine	42	313	272
Tryptophan	10	121	116
Valine	44	378	429

Broiler breeders have the potential to reach a mature protein weight of approximately 1 kg at somatic maturity (Hancock *et al.,* 1995). However, due to the controlled feeding imposed on the birds during growth and in lay breeder hens do not achieve this potential. Therefore a scaling rule (Taylor, 1980; Emmans, 1989) needs to be applied when calculating a maintenance unit as defined by Emmans and Fisher (1986). The equation (Eq.5) for calculating the daily amino acids requirements for maintenance is given below:

$$AA_r = [(AA_{Bm}.BP_m^{0.73}.u)] \quad \text{mg/d} \qquad \text{Eq.5}$$

where AA_r is the daily requirement for each amino acid, AA_{Bm} is the proportion of the given amino acid in ideal protein (Table 2), $BP_m^{0.73}$ is the mature body protein weight (kg), which can be generated from a random normal distribution with mean and SD given in Table 1, and u is the degree of maturity (BP_t/BP_m). The value of BP_t at the age when the bird lays its first egg (after which body protein growth ceases) may be generated in one of two ways: the first is from a random normal distribution with mean and SD given in Table 1. But where a model such as that described by Ferreira *et al*. (in press) is used, which simulates the growth of the broiler from dayold and accounts for differences in the rate of body and feather protein growth resulting from genetic variation in both body protein growth and in the age at which the bird becomes photosensitive, BP_t derived in this way may be used for each individual in the simulated population.

The effective energy requirement for maintenance (*EEreq*) of the broiler breeder was calculated using Eq. 6 (Emmans and Fisher, 1986):

$$EEreq = M_E . P_m^{0.73} . u \qquad \text{Eq.6}$$

where *MH* is the heat required for maintenance (MJ/d); M_E is 1.63 MJ, the EE needed per unit of maintenance each day; P_m body protein weight at maturity (kg); u is the degree of maturity ($u = BP_t / BP_m$), the same as in Eq.5.

Predicting requirements for yolk and albumen production

The method proposed by Emmans and Fisher (1986) was used to predict the requirements for energy and amino acids for the production of yolk and albumen: the content of each nutrient in each component, namely, 25 kJ and 0.21 g ideal protein/g yolk, 3.6 kJ and 0.13 g ideal protein/g albumen, and 1.2 kJ and 0.04 g ideal protein/g shell are multiplied by the weights of each component. The required intakes of each digestible amino acid were calculated from the nitrogen content of the yolk (27 mg N/g) and albumen (17 mg N/g) produced from the amino acid composition of these two components (Lunven *et al.* 1973), Table 3. It was assumed that the total amount of yolk protein being deposited in all fast-growing follicles was 2 g/d, even when no egg was laid on a given day (Johnson, 1999). The efficiency of converting dietary amino acid to egg protein was assumed to be 0.60 (Nonis, 2006).

Optimising the feeds and feeding programme

A population of 50 hens was simulated by applying the means and SD's given in Tables 1 and 2, and the daily requirements for each hen for EE and for two amino acids (Lys, M&C) were calculated based on her requirements for maintenance and egg output (g/d). These daily requirements were averaged over the population to obtain a mean daily requirement for each nutrient. Using SOLVER in Excel, an optimisation exercise was performed: it was determined the optimum intakes, finding the intake of each nutrient, in two or three phases offered during the laying period, as well as the optimum length of time over which each of these phases should be fed, assuming that only one feed was offered over this period.

After determining the optimal intake to three feeding phases, it was calculated the concentration of nutrients in the diet in two ways: one involved the requirements calculated for the population and the other involved 10% of the maximum individual requirements over the entire period (considering only the broiler breeders in production). For both studies were considered consumption of 160 g of feed per bird.

3. Results

The mean reproductive performance (yolk, albumen and shell weight, egg weight, rate of laying and egg output) of the simulated population of broiler breeders is summarised at four-weekly intervals in Table 4. The maximum rate of lay of 87 % was achieved at 28 weeks of age whereafter this declined to 57 % at 60 weeks of age (Fig. 1). During that time, mean egg weight increased from 63 to 77 g. Yolk and albumen weights 15 to 23 and 40 to 47 g, respectively.

Table 4. The mean of weight of yolk, albumen and shell (g), percentage of lay and Egg output (g/d), at four-weekly intervals of age for theoretical population of broiler breeders.

Age week	Yolk g	Albumen g	Shell g	Egg weight g	Lay %	Egg Output g/d
24	15.0	39.7	5.6	60.3	84	50.4
28	17.1	41.7	5.9	64.6	87	56.0
32	18.6	43.0	6.1	67.7	81	55.1
36	19.7	44.0	6.2	69.9	77	53.8
40	20.6	44.7	6.3	71.6	73	52.2
44	21.3	45.3	6.4	73.0	69	50.2
48	21.9	45.8	6.5	74.1	66	48.6
52	22.4	46.2	6.5	75.1	62	46.8
56	22.9	46.5	6.6	76.0	60	45.3
60	23.4	46.9	6.6	76.9	57	43.9

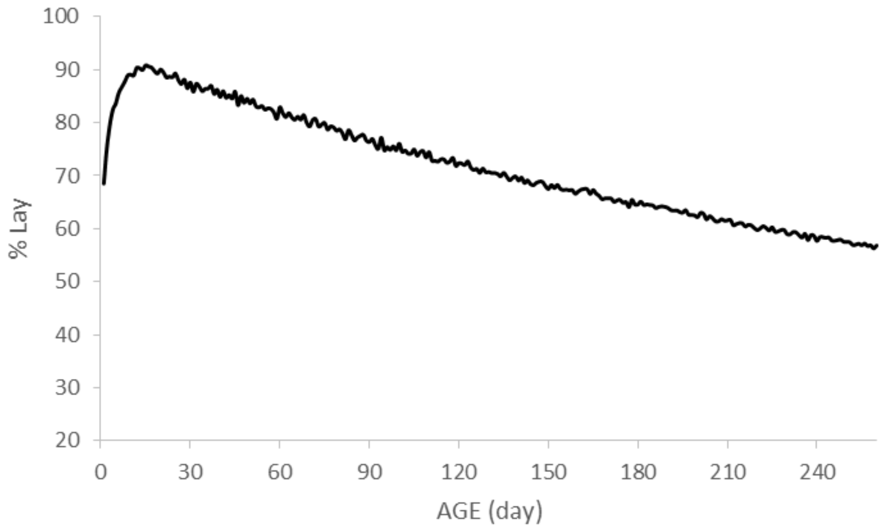

Figure 1. Percentage of lay of a theoretical population of 50 broiler breeders, for 260 days after the first egg using estimates of coefficients given in Table 2.

The minimum, mean and maximum daily intakes of EE, Lys and M&C required by the simulated flock at four-weekly intervals is given in Table 5. The daily intake of Lys required by the flock increased to 730 mg/d then declined to 644 mg/d by 60 weeks whereas the EE required remained relatively constant at 1020 kJ/d.

Table 5. The minimum, mean and maximum daily intakes of EE (kJ/d), Lysine and Methionine+cysteine (mg/d) required by the simulated flock at four-weekly intervals of age for theoretical population of broiler breeders.

Age		Energy			Lysine			Methionine+Cysteine	
Week	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
24	900	1022	1140	418	674	841	289	543	710
28	1023	1068	1116	695	730	807	560	595	671
32	1051	1062	1074	627	695	756	489	557	618
36	978	1047	1110	634	701	760	497	562	620
40	988	1031	1066	618	654	702	480	515	562
44	973	1005	1024	580	624	668	442	486	528
48	965	1000	1047	616	629	646	476	489	506
52	971	1008	1055	621	634	652	481	494	511
56	977	1014	1063	626	640	657	485	498	516
60	983	1020	1070	631	644	662	489	502	520

In the first optimisation exercise, in which a single feed is offered throughout the laying period, the optimum daily nutrient intakes were 1022 kJ EE, 668 mg Lys and 530 mg M&C.

In the second optimisation exercise, a two- and a three-phase feeding programme were investigated. The recommended the optimum daily nutrient intakes for a feeding program in two phases were 1053 - 1022 kJ EE, 695 - 637 mg Lys and 559 - 496 mg M&C, for the first phase, 1 to 20 weeks and second phase, 21 to 37 weeks from egg production, respectively.

The optimum daily nutrient intakes for a feeding program in three phases, 1 to 10, 11 to 20 and 21 to 37 weeks from egg production are 1063, 1044 and 1022 kJ EE, 717, 674 and 637 mg Lys and 582, 535 and 496 mg M&C.

The concentration of amino acids in the diet (g / kg) considered the maximum nutritional requirement (only the broiler breeders in production) and the population (including the birds that were not in production) are shown in Table 6.

Table 6. Calculated concentrations (g/kg) of amino acids necessary to meet the requirements of broiler breeders for maintenance and egg production in the periods 1 to 10, 11 to 20 and 21 to 73 weeks from egg production, for maximum egg production and for the flock.

	Population			Maximum		
	1-10	11-20	21-37	01-10	11-20	21-37
Arginine	4.0	3.7	3.5	5.2	5.4	5.6
Cysteine	1.5	1.4	1.3	2.0	2.1	2.2
Histidine	1.5	1.4	1.3	2.0	2.1	2.1
Isoleucine	3.3	3.0	2.8	4.3	4.5	4.7
Leucine	5.3	4.9	4.6	6.9	7.3	7.5
Lysine	4.5	4.2	4.0	5.8	6.1	6.3
Methionine	2.1	2.0	1.8	2.8	2.9	3.0
Methionine&Cysteine	3.6	3.3	3.1	4.8	5.0	5.2
Phenylalanine	3.3	3.0	2.8	4.3	4.5	4.6
Phenylalanine+Tyrosine	5.8	5.3	5.0	7.6	7.9	8.2
Tyrosine	2.5	2.3	2.2	3.3	3.4	3.5
Threonine	2.9	2.7	2.6	3.8	4.0	4.1
Tryptophan	1.1	1.0	0.9	1.4	1.5	1.5
Valine	3.9	3.6	3.4	5.2	5.4	5.6

It was observed that the nutritional requirement has opposite behavior between the maximum output and population. This behavior is observed because for maximum production has been found increased egg mass with age, but was not considered the decline in egg production, which causes the decrease in requirements, as observed in the population.

4. Discussion

The laying performance of the flock of broiler breeders simulated in this exercise was similar to the Cobb-Vantress standards set for their breeder giving credence to the mechanistic method used to simulate rate of lay. Similarly, the increase in egg weight over time resembled closely the changes that are expected in a commercial broiler breeder flock. But whereas these changes in egg weight can be described using a single equation, the method used here, of simulating the weight of the yolk over time and building up the weight of the egg through the use of allometric relationships between yolk, albumen and shell weight, enables a more accurate estimate to be made of the required amounts of amino acids and energy making up the three components of the egg, as recommended by Emmans and Fisher (1986) and used in the models of Johnston and Gous (2007) and Gous and Nonis (2010).

The Reading Model (Fisher *et al*. 1973) was originally applied to laying hens that had *ad libitum* access to food, and although the economic optimum intake of each amino acid could be calculated, there was no way of knowing how much of each amino acid should be included in the feed to be supplied to the flock because the amount of food that would be consumed by the birds could not be accurately predicted. In broiler breeder production this is less of a problem. Thus, if the economic optimum intake of each nutrient is known, the concentration of that nutrient can be adjusted according to the amount of feed to be offered to the flock each day.

In this exercise, the effect of underfeeding nutrients to the hens was not considered as this would require additional information on the extent to which birds can draw on body reserves of energy and amino acids when the supply of nutrients is limiting. Also, each bird may not receive the amount of feed allocated because some hens are more aggressive than others and would consume more, leaving less for the hens at the lower end of the peck order. It is not known whether there is a correlation between aggressiveness and laying performance: if there were a positive correlation then those hens requiring larger amounts of feed because of a higher egg output could be accommodated and performance would not suffer to the same extent.

Instead of making use of marginal costs and marginal revenues, as applied in the Reading Model, the same principle was used here by assuming that the requirements of 10 % of the population were too costly to be met. This was an arbitrary proportion, but it illustrates the point adequately.

Predicting requirements for yolk and albumen production

Was observed that the requirements for the yolk and albumen increased over the weeks, this being related to the increase of the size of the egg to be formed. However, the egg output decreases with age (Figure 1) and the requirements of daily amino acid also decreases (Gous and Nonis, 2010). These authors calculated the requirement for the production of yolk and albumen according to the weight of these components. Suggested values are apparently smaller than suggested by the present study, since there is a difference between the weights of the components. However, considering the requirement / g of component, the values in both studies are similar. Lysine, for example, in both studies the recommendation is 15.1 and 7.7 mg / g yolk and albumen, respectively. This similarity can be explained because was used the same concept proposed by Emmans and Fisher (1986), to calculate the requirements for body and egg production.

Ekmay et al. (2013) estimated the amino acid requirements for broiler breeders at peak production, and recommend to Lys (916), but these authors considered the body's growth in the calculation. Values above those found in this study compared to 28 weeks (Table 5). This difference occurs mainly because in this study was considered only the maintenance requirements, because it was assumed that protein the body is maintained constant after starting posture, with only fat deposition (Fisher & Gous 2009).

Hurwitz and Bornstein (1973) found similar results and reported that the low requirement of "ideal" protein, compared with that determined with practical diets, suggests that protein per se is usually not the limiting factor in poultry feeds.

Estimating the ideal balance between nutrients in the feed offered

Currently the breeding companies (Aviagen, 2013; Cobb 2012) recommend two feeding programs after the onset of egg production, since the second phase begins around 18 weeks after the onset of lay. This study was calculated nutritional requirement at 1, 2 and 3 phases after the onset of lay, in order to optimize the nutritional program and better supply the requirements. However, the choice should always take into consideration the management of the farm and the economic factor for transport and the use of feed mill.

In this case, broiler breeders in the laying phase, fed daily with 160 g of feed / d, the recommendation for inclusion of nutrients in the diet would be 4.5, 3.6 g of lysine and methionine + cysteine / kg of diet, respectively, for population at peak production. The production of eggs, the weight of the birds and the quality of feed, will directly influence the results of requirement and consequently the concentration of nutrients.

The concentration of nutrients estimated in this study is lower than that recommended by the breed manual. If considered the nutritional recommendations of the manual, the amount of feed offered (DFI) would be less than 160 g, Gous and Nonis (2010) found similar results. These authors reported that the DFI estimate is often considerably lower than the daily allowance, which is rarely the case with broiler breeders, wherein the model predicts a decrease in consumption as the supply of nutrients increases.

It should be taken into consideration that the nutrients partition, the maintenance has priority, followed by the deposition of yolk and albumen. Besides, the egg output is dependent on the nutrients consumed, since the requirements for maintenance and growth of the yolk were met. However, if the intake of the limiting nutrient in the day cannot sustain this minimum egg size, egg production does not occur (Gous and Nonis, 2010). The feeding of a flock of broiler breeders follow a daily pattern, even when no egg laying, the bird consumes the diet. This causes the energy consumed in excess, is deposited on the body.

Whereas 10% of the maximum requirements, the estimated concentration of amino acids increases with the age of the birds. Unlike the provision of feed or dietary energy to breeding birds, the level of dietary protein does not appear to play any major controlling role in the productivity of reproduction; and excess protein may have some negative effects on fertility and hatchability but these effects are not well described (Fisher and Gous, 2009). It is important provide the correct amount of amino acids, because many these are consumed in excess of requirement and this excess must be deaminated and converted to body lipid which is added to that already stored, the energy used in this process being accounted for in the effective energy (EE) system (Emmans & Fisher 1986).

These results support the view that a modelling approach has the potential to help nutritionists to make decisions about feeding more efficient broiler breeder flocks of what is possible at the present (Gous and Nonis, 2010). However, the proposed model is dynamic and can be adapted to these parameters. Improvements can be made in the model and also need to be re-evaluated regularly to keep pace with genetic advancements.

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CAPÍTULO 6 – IMPLICAÇÕES

As matrizes pesadas possuem características peculiares, pois apresentam genética para ganho de peso e produção de ovos, deste modo é imprescindível estudos específicos para auxiliar os nutricionistas elaborarem dietas que contenham os nutrientes necessários para que essas aves alcancem o máximo potencial. As empresas de genética têm uma enorme quantidade de pesquisa feita sobre esta classe de aves, uma vez que são fundamentais na cadeia produtiva de frangos de corte. Entretanto, a maior parte dos dados gerados nessas pesquisas ficam restritos às grandes empresas de melhoramento genético e não são publicados abertamente. Portanto, conhecer as características de crescimento, maturação sexual e postura de matrizes pesadas para um correto manejo nutricional, com dietas balanceadas, que forneçam todos os nutrientes necessários e em quantidade que atinjam sua exigência é de fundamental importância, o que tem sido motivação de vários estudos.

No Capítulo 2 foi abordado o crescimento corporal e dos órgãos reprodutivos, de matrizes criadas sobre restrição alimentar. Os resultados nos permitiram conhecer melhor como é o crescimento e a deposição proteica corporal. Essas informações são fundamentais para elaborar modelos de predição das exigências nutricionais que consigam atender os requerimentos dessas aves sob o manejo nutricional aplicado, sem que haja defict, principalmente durante o crescimento dos órgãos, o que poderia implicar em menor produção de ovos.

Já no capítulo 3, as informações obtidas sob experimentação relatadas no Capitulo 2 e os modelos elaborados, foram utilizados para simular os requerimentos nutricionais através de programas de iluminações empregados durante a fase de cria. Onde foi possível observar que um programa de iluminação inadequado pode sub e super-nutrir o lote ao mesmo tempo, pois algumas aves serão responsivas ao estimulo luminoso enquanto outras não, o que fará com que haja variação nas exigências nutricionais. Com os resultados desse capítulo é possível entender que é imprescindível considerar o programa de iluminação utilizado, e também é possível manipular o modelo para que as aves se desenvolvam mais precocemente ou tardiamente, através do estimulo luminoso, sendo extremamente importante na maturação sexual e uniformidade do lote.

O Capítulo 4, assim como no Capítulo 2, teve como enfoque o ajustar modelos através de dados coletados, porém nesse capítulo foi abordado a produção de ovos e as variações de peso dos ovos e taxa de produção ao longo da vida das matrizes pesadas. Através de um ensaio que teve duração de 23 semanas (inicio da postura) até 60 semanas de idade, foram coletadas informações de produção e poso dos ovos, diariamente, além da composição química, comsumo de ração e peso corporal. Com esses dados foi possível ajustar medelos que predizem a produção e estimar as exigências nutricionais. Para o Capítulo 5, desenvolvemos um modelo estocástico para predizer as exigências nutricionais de matrizes pesadas durante a produção de ovos, onde é possível calcular os requerimentos de acordo com condições do lote, como por exemplo o peso corporal, o programa de ilumiação utilizado durante a fase de cria.

Desta forma, a fim de aprimorar as informações sobre matrizes pesadas, foram expostas nesta tese os dados sobre crescimento e maturação sexual e produção de ovos de aves criadas sobre as recomendações do manual da linhagem, além de exigências nutricionais de aves criadas para uma população de matrizes geradas através de simulações. Foram ajustados modelos estocásticos para predizer as exigências nutricionais das matrizes pesadas, de 1 dia até 60 semanas de idade, considerando a exigência de mantença, penas, deposição do aminoácido no corpo e nas penas, e também o crescimento dos órgãos reprodutivos.

Com os modelos desenvolvidos nessa tese, foi possível a elaboração de uma planilha, que servirá como base para o desonvolvimento de um software, que auxiliará nutricionistas elaborarem programas nutricionais de forma mais eficiente, para lotes de matrizes pesadas, de acordo com os dados de cada lote criado, pois, os modelos sugeridos são dinâmicos e podem ser adaptados.

Por fim, destaca-se que os modelos de predição constituem a base para o desenvolvimento de softwares capazes de simular consequências decorrentes de alterações nos programas de criação das matrizes. Espera-se que estes modelos contribuam para o desenvolvimento do aprendizado, podendo ser utilizados como ferramentas didáticas para o ensino da nutrição, aplicação prática dos modelos (ajudando no planejamento nutricional), e desenvolvimento e aperfeiçoamento de softwares de predição do crescimento, postura e das exigências nutricionais de matrizes pesadas.