UNIVERSIDADE ESTADUAL PAULISTA "JULIO DE MESQUITA FILHO" FACULDADE DE CIÊNCIAS AGRÁRIAS E VETERINÁRIAS

CAMPUS DE JABOTICABAL

MODELOS PARA ESTIMAR CONSUMO E EXIGÊNCIAS NUTRICIONAIS PARA POEDEIRAS COMERCIAIS

Hilda Cristina Palma Bendezu

Zootecnista

JABOTICABAL – SÃO PAULO – BRASIL

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

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TÍTULO: MODELOS PARA ESTIMAR CONSUMO E EXIGÊNCIAS NUTRICIONAIS PARA POEDEIRAS COMERCIAIS

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Jaboticabal, 04 de março de 2016.

DADOS CURRICULARES DO AUTOR

Hilda Cristina Palma Bendezu – filha de Teófilo Palma Torre e Maria Cristina Bendezu de Palma, nasceu no dia 10 de janeiro de 1986, no distrito de Santa Anita, Lima – Perú. Em fevereiro de 2004 ingresso no curso de zootecnia na Faculdade de Zootecnia da Universidad Nacional Agrária la Molina, Lima – Perú. Durante o período de marco de 2006 a agosto de 2008 foi bolsista do programa de Investigación y Proyección Social em Aves y Animales Menores sob orientação da Msc. Gloria Palacios Pinto. Em março de 2011 início o curso de mestrado em zootecnia pela Universidade Estadual Paulista "Júlio De Mezquita Fliho", onde obteve bolsa de estudos do CNPq a traves do programa de estudante – convenio de pós graduação (PEC-PG), sob orientação da Profª. Drª. Nilva Kazue Sakomura, defendendo a dissertação em dezembro de 2012. Em março de 2013 ingresso no curso de doutorado em zootecnia, na mesma instituição e sobre a orientação do Prof. Dr. Euclides Braga Malheiros, obteve bolsa de estudos do CAPES a traves do programa de estudante – convenio de pós graduação (PEC-PG) e defendendo esta tese em marco de 2016.

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SUMÁRIO

MODELOS PARA ESTIMAR CONSUMO E EXIGÊNCIAS NUTRICIONAIS PARA POEDEIRAS COMERCIAIS

RESUMO-O objetivo deste trabalho foi elaborar um modelo para calcular as ingestões de aminoácidos e energia para a fase de maturação sexual e produção de ovos. As exigências de energia, aminoácidos e consumo de ração foram calculados pelo método fatorial, considerando na fase de maturação sexual a quantidade de nutrientes requerida para mantença e a quantidade de nutrientes necessários para crescimento e deposição de nutrientes corporais em cada componente do corpo (ovário, oviduto, corpo livre de penas e penas); na fase de produção foram considerados a quantidade de nutrientes exigida para mantença e a quantidade de nutrientes exigida para a produção de ovos com base no potencial de postura das aves. Foram realizados três ensaios. Os dois primeiros ensaios foram realizados na fase da maturação sexual (de 16 a 28 semanas), no ensaio foram utilizadas 96 aves da linhagem Isa Brown para descrever o crescimento dos órgãos reprodutivos. Duas vezes por semana foram abatidas quatro aves e foi registrado o peso da ave com e sem pena, o peso do ovário e oviduto, adicionalmente se tomara amostra de cada uma destas para posterior analises no laboratório. Nesta mesma fase foi realizado um segundo experimento para avaliar os resultados do consumo predito. Foram utilizadas 76 frangas de 15 a 24 semanas de idade da linagem Hy-Line e ISA-Brown e foi mensurado o consumo diário antes do primeiro ovo. No ensaio da fase de produção (18 a 60 semanas), foram utilizadas 60 aves da linhagem Isa Brown e 60 aves da linhagem Hy-line. Neste período foi registrado a produção, o peso do ovo e o peso dos componentes do ovo (gema, albúmen e casca) das 120 aves. Adicionalmente, foi registrado semanalmente o peso da ave e da sobra de ração para estimar o consumo. Na fase de maturação sexual, os parâmetros de crescimento dos órgãos reprodutivos foram estimados pela equação de Gompertz e com base nestas informações foram calculadas o consumo predito. Os dados do segundo experimento foram para avaliar a acurácia e a precisão dos dados de consumo preditos com base no crescimento do corpo e dos órgãos reprodutivos. O consumo predito sobreestima em 0.41 g/day ($P>0.05$) e 2.65 g/day ($P>0.001$) para Hy-Line e Isa Brown, respectivamente. No ensaio da fase de produção foram calculados a produção da gema, o cumprimento do ciclo interno e o peso dos componentes do ovo e com base nesta informação foi calculada a ingestão da energia efetiva e aminoácidos (lisina e metionina+cistina) para a fase de produção. O peso médio do ovo foi 55.1 g e 59.7 g no pico de produção para a linagem Hy-Line e ISA-Brown. Neste período a ingestão de energia efetiva e lisina foi 1067 kJ/d e 723 mg/d para o indivíduo médio da população de Hy-Line, 1075 kJ/d e 744 mg/d para ISA-Brown. Neste estudo, se fundamenta a utilização da modelagem como ferramenta para predizer o potencial de produção de ovos e consumo de nutrientes. Constituindo informação valiosa para simular respostas com diferentes populações, além de fornecer conhecimento do sistema envolvido na produção.

Palavras-chave: Avaliação, Frangas, População, Uniformidade

MODELS TO ESTIMATE FEED INTAKE AND NUTRITIONAL REQUIREMENTS FOR LAYING HENS

ABSTRACT-The aim of this study was to develop a model to calculate the feed intake and the nutrient requirement for pre-laying and laying phase. energy and amino acids intake were calculated by the factorial method, taking into account the nutrients required for maintenance and growth of each body component (ovary, oviduct, feather-free body and feathers) in the pre-laying phase and in laying phase were considered the amount of nutrients required for maintenance and for egg production. Two trials were carried out in the sexual maturation phase (16-28 weeks), 96 Isa Brown laying hens were used to describe the growth of the reproductive organs. Twice a week, four birds were slaughtered and measured the body weight with and without feather and the weight of the reproductive organs (ovary and oviduct), additionally samples were taken to analysis in the laboratory (dry matter, gross energy and crude protein). A second experiment in the same phase, it was conducted to evaluate the results of predicted feed intake. Seventy six Hy-Line and ISA-Brown pullets from 15 to 24 weeks of age were used to measure daily feed intake before the first egg. In the laying phase (18-60 weeks), sixty laying birds of Isa Brown and Hy-line were used to register the egg production, egg weight and the weight of the egg components (yolk, albumen and shell). The growth parameters of reproductive organs were estimated by Gompertz equation in the pre-laying phase, and based on this information were predicted feed intake. The data of the second experiment were used to evaluate the accuracy and precision of the predicted feed intake based on the growth of body and reproductive organs. The predicted feed intake overestimate 0.41 g / day ($P > 0.05$) and 2.65 g / day ($P > 0.001$) to Hy-Line Brown and Isa Brown, respectively. Yolk production, internal cycle and the weight of egg components was calculated for the laying phase and based on this information was calculated effective energy intake and aminoacids (lysine and methionine plus cystine). The average egg weight was 55.1 g and 59.7 g at peak production for Hy-Line and ISA-Brown strain. In this period the average intake of effective energy and lysine was 1067 kJ / d and 723 mg / d for average Hy-Line birds, 1075 kJ / d and 744 mg / d for ISA-Brown. Mathematical Models is a tool to predict the potential for egg production and nutrient intake. Constituting valuable information to simulate responses to different populations, as well as providing knowledge of the biological system involved in the production.

Keywords: Assessment, Pullets, Population, Uniformity

CAPÍTULO 1 - CONSIDERAÇÕES GERAIS

1. INTRODUÇÃO

A produção de ovos cresceu rapidamente, assim como o número de aves de postura que atualmente é de aproximadamente 4.93 bilhões no mundo. No Brasil, o alojamento de pintainhas de postura aumenta anualmente, tanto para galinhas de ovos branco como para galinhas de ovos vermelhos (MDIC, 2012). As linhagens mais utilizadas no mercado brasileiro são a Hy-line e a Isa Brown que representam 50 e 35 % da produção total de ovos brancos e vermelhos, respectivamente (NETO, 2012). Também destacam-se o aumento da população, o aumento do valor aquisitivo e a diminuição do custo pelo aumento na produtividade dos grãos. Neste contexto, nos próximos anos, a perspectiva da produção de ovos é continuar crescendo.

O avanço genético ao longo dos anos cumpriu um papel importante. Novas linhagens foram geradas com menor peso corporal à maturidade sexual e ganhos significativos na produção e peso de ovos, consequentemente na massa de ovo, resultando em aves com alto potencial genético para produção de ovos (GOUS, 2007). Desta forma, ajustes têm que ser realizados para fornecer quantidades específicas de aminoácidos e energia para que essas aves possam expressar o máximo potencial de produção.

Segundo Johnston e Gous (2003), modelar o crescimento, deposição de nutrientes corporais e o potencial de produção de ovos pode fornecer informações ao nutricionista a respeito da quantidade de nutrientes necessários. Assim, a modelagem permite ao nutricionista corrigir a quantidade de nutrientes necessária para otimizar o desenvolvimento e alcançar o potencial genético. Além da estratégia nutricional, a modelagem pode ser utilizada na estratégia econômica, permitindo o fornecimento de nutrientes na dieta de forma mais eficiente e maximizando o lucro.

As publicações sobre exigências nutricionais de poedeiras são, em grande parte, empíricas e não consideram todas as características que definem o potencial da ave. Neste contexto, a incorporação de modelos poderia ser uma ferramenta útil para o nutricionista na toma das decisões. Contudo, a modelagem requer o conhecimento de cada uma das partes que interagem como uma cadeia de eventos. Assim, este estudo tem como objetivo caracterizar o potencial de crescimento na fase de maturação e o potencial de produção das aves. Desta forma, calculou-se exigências nutricionais pelo potencial genético.

2. REVISÃO DE LITERATURA

Modelagem matemática

Os modelos podem ser utilizados para desenvolver conhecimento do sistema biológico através de uma expressão quantitativa e para testar o efeito das mudanças neste, resultando em ferramenta importante para a toma de decisões na indústria avícola. Na pesquisa avícola, um “modelo” pode representar fenômenos biológicos como crescimento, produção de ovos, incubação, digestão e absorção de nutrientes etc. (RONDÓN et al., 2012). Segundo Thornley and France (2007), os modelos podem ser classificados como estáticos ou dinâmicos, determinísticos ou estocásticos ou ainda como empíricos ou mecanísticos.

Os modelos estáticos descrevem o fenômeno em determinado momento ou instante, porem a predição dos resultados não depende da variável tempo, enquanto que nos modelos dinâmicos inclui o fator tempo como variável independente. Modelos de curva de crescimento podem ser classificados como modelos dinâmicos. Os determinísticos só apresentam uma resposta, em contraste os modelos estocásticos (ou probabilísticos) podem ter uma faixa de possíveis respostas devido a inclusão do o elemento aleatório no modelo. Como resultado, vários modelos matemáticos podem estar envolvidos na implementação dos diversos fatores que participam no sistema biologico.

Modelos utilizados na descrição do crescimento

Existem vários modelos matemáticos que são utilizados para descrever o crescimento e deposição de nutrientes corporais dos animais. Dentre os mais conhecidos estão o Logística, Brody, Robertson, Richards, Bertalanffy e Gompertz (MARCATO, 2007). Atualmente, estes modelos são utilizados com frequência por apresentarem bons ajustes aos dados, porem o mais usado é o Gompertz (Eq 1) devido a maior facilidade no uso pois possui apenas três parâmetros.

$P_t = P_m \times e^{-e^{(-b(t-t^*))}}$ Eq [1]

Onde, P_t é o peso observado no tempo *t,* P_m é peso na maturidade, *b* é a taxa de maturação expresso em dia e *t** é o tempo em que a taxa de crescimento é máxima. Considerando *t** a equação também pode ser escrita também da seguinte forma (EMMANS, 1981):

$P_t = P_m \times e^{-e^{(\ln(-\ln(p_i/p_m))-(b\times t))}}$ Eq [2]

Onde: $t *_{(dias)} = \ln(-\ln(p_i/p_m))\ /b$ Eq [3].

A taxa de deposição (g/dia) é descrita por meio da derivada da equação de Gompertz. Esta particularidade do modelo é importante, pois permite estimar a deposição considerando o peso atual,

$\frac{dP}{dt} = b \times P_t \times \ln(\frac{P_m}{P_t})$ Eq [4].

Modelos utilizados para descrever o potencial de produção de ovos

A poedeira pode ser caracterizada geneticamente ao considerar o peso à maturidade, idade à maturidade sexual, potencial de postura e o peso do ovo ao longo do período de produção (NONIS, 2007). Sabe-se que, o potencial de produção de ovos da ave pode ser descrito como a máxima produção e peso de ovo em que é possível o genótipo alcançar sobre condições ótimas de criação e ao fornecer a quantidade ótima de nutrientes.

Em condições ótimas as frangas podem alcançar a maturidade sexual quando atingem 18 semanas de idade. A maturidade é marcada pelo primeiro ovo. Assim as poedeiras põem um ovo por dia, durante certo número de dias consecutivos, seguidos por pelo menos um dia de pausas. O comprimento da sequência de oviposição mudará ao longo do período de produção.

Numerosos estudos foram realizados para tentar explicar a sequência de oviposição, porém, um dos estudos mais relevantes foi a representação matemática do ciclo ovulatório (ETCHES & SCHOCH, 1984). Com base nesta informação Emmans e

Johnston (EMMANS & FISHER, 1986; JOHNSTON & GOUS, 2006) descreveram o potencial da produção dos ovos em três passos: 1) estimar o potencial de peso da gema, 2) determinar a produção diária considerando a taxa de ovulação determinada pelos valores de ciclo interno e externo de postura 3) estimar o peso de albúmen e de casca pela relação alometrica com a gema e o conteúdo do ovo, respetivamente.

O potencial do peso da gema pode ser calculado em relação a idade da ave pelo modelo de McMillan (MCMILLAN et al., 1970):

$$y = A \times (1 - e^{(-c \times (t-D))}) \times e^{(-R \times t)} \qquad \text{Eq [5]}$$

Onde, y é o potencial do peso da gema (g); t é a idade da ave (d); A é o máximo do peso da gema em função da taxa crescente, C é a taxa de crescimento da gema, D é o tempo inicial da primeira gema e R é a taxa de decréscimo do peso da gema. Outro modelo utilizado com o mesmo objetivo é o modelo Linear-by-linear function (JOHNSTON & GOUS, 2006):

$$y = A + C/(1 - R \times t) \qquad \text{Eq [6]}$$

Onde, y é o potencial do peso da gema (g); t é a idade da ave (d), A, C e R são os parâmetros.

A segunda caraterística para descrever o potencial da ave é a taxa de ovulação, a qual está influenciada pelo comprimento do ciclo interno (ICL) e o ciclo externo (EXCL). O comprimento do ciclo externo em geral é de 24h devido ao fornecimento de 16 horas de luz e 8 horas de escuro. O ICL pode ser determinado pela equação de Emmans & Fisher (1986):

$$\mathrm{ICL} = \mathrm{ICL_0} - \mathrm{L} + 1/[(1/\mathrm{L}) - \mathrm{K} \times \mathrm{t}] \qquad \text{Eq [7]}$$

em que, ICL_0 é o comprimento inicial do ciclo interno, K é a taxa de decréscimo, L é o intervalo entre cada ovulação e t é a idade ao primeiro ovo, em dias. Como esta equação não permite simular as pequenas sequencias no início da postura, Johnston (2004) descreveu o ICL pela seguinte equação:

$$\mathrm{ICL} = \mathrm{A} + \mathrm{B}/(1 + \mathrm{Dt}) + \mathrm{Ct} \qquad \text{Eq [8]}$$

em que A, B, D e C são os parâmetros da equação e t é a idade ao primeiro ovo, em dias. Adicionalmente, o ICL pode ser descrito pelo modelo Line- plus-exponential equation:

$ICL = A + B \times (R^T) + C \times T$ Eq [9]

em que A, B, C e R são constantes, t é o tempo a partir do primeiro ovo (d) (GOUS & NONIS, 2010), a soma dos parâmetros A+B indica o valor do ICL no início de postura.

Considerando o valor do ICL, Emmans & Fisher (1986) descreveram a taxa de ovulação (RL) da seguinte forma:

$\mathrm{RL} = 24/\mathrm{EXCL}$ se (EXCL≥ICL)

ou $\mathrm{RL} = l/[(\mathrm{ICL} - \mathrm{EXCL}) \times (1 + (\mathrm{L}/(\mathrm{ICL} - \mathrm{EXCL})))]$ se (EXCL<ICL).

Em condições não limitantes, o peso do albúmen e da casca pode ser estimado por relações alométricas com o peso da gema (EMMANS & FISHER, 1986). Mudanças no peso da gema influenciam o peso de albúmen e da casca. Os pesos do albúmen e casca podem ser preditos pela equação:

$Y = aX^b$ Eq [10]

Onde *Y* é a variável dependente, podendo representar tanto o peso do albúmen como da casca; *X* é a variável independente, podendo representar tanto o peso da gema e como o conteúdo (gema mais albúmen). Essa equação possui dois parâmetros importantes, o coeficiente de proporcionalidade "*a*" e o expoente alométrico "*b*". Esses dois parametros podem ser estimados por meio de uma análise de regressão não linear após a conversão dos valores para logaritmo. Assim, a equação pode ser representada da seguinte forma: $\ln(\mathrm{Y}) = \mathrm{a} + \mathrm{b} \cdot \ln(\mathrm{X})$.

Com o peso dos componentes dos ovos (gema, albúmen e casca) o peso do ovo pode ser obtido pela soma dos três componentes.

Métodos para determinar as exigências nutricionais

O método dose-resposta é o mais comum para determinar as exigências em aves, no qual tem como base a resposta do desempenho como ganho de peso, conversão alimentar, produção de ovos em função de níveis crescentes de um determinado nutriente (SAKOMURA & ROSTAGNO, 2007). Os resultados podem ser diferentes segundo o critério de resposta ou modelos de regressão utilizados.

De acordo com Sakomura & Rostagno (2007) a adição de um nutriente limitante numa ração, mantendo níveis adequados dos demais nutrientes, resulta no crescimento do animal até que sua exigência seja atendida. Esta resposta pode ser descrita em quatro fases: Inicial em que o acréscimo do nutriente garante a mantença do animal; fase de resposta onde o acréscimo do nível de nutriente acompanha o crescimento, até o nível em que se estabiliza a produção; fase estável onde a adição do nutriente não apresenta resposta ao desempenho e a fase tóxica**,** onde a adição do nutriente pode causar redução no desempenho.

Devido a sua fácil execução o método dose-resposta tem sido utilizado em vários experimentos. Contudo, muitas vezes é necessário repetir experimentos em diferentes condições devido a fatores como ambiente, clima e genética que afetam a determinação dos níveis nutricionais (SAKOMURA & ROSTAGNO, 2007).

Outro método utilizado para a determinação das exigências é o método fatorial com base no princípio de que as aves requerem determinada quantidade de nutrientes necessários para a manutenção dos processos vitais, crescimento e produção de ovos (SAKOMURA & ROSTAGNO, 2007). No modelo fatorial, a quantidade de um nutriente necessário para a produção de ovos (C_N) pode ser expressa em função da quantidade do nutriente necessário para mantença (N_m) e para produção da gema (N_y), albúmen (N_{alb}) e casca (N_{sh}) como descrito:

$$C_N = N_m + N_y + N_{alb} + N_{sh} \qquad \text{Eq [11]}$$

Determinação da exigência para mantença

A exigência de energia para mantença em animais adultos pode ser definida como a quantidade de energia para manter o balanço entre o catabolismo e o anabolismo. Entretanto para animais jovens torna-se necessária para manter o *turnover* de proteína e lipídio, a temperatura corporal e as atividades de locomoção.

Energia, proteína e aminoácidos são necessários para manter as funções de mantença da ave. Estas exigências estão relacionadas ao peso corporal e podem ser expressas em função do peso metabólico. Segundo Emmans & Fisher (1986) a exigência de mantença para energia e proteína podem ser calculadas pela equação 12 e a quantidade necessária de aminoácido é calculada pela equação 13.

$$N_m = m \times {Bp_m}^{0.73} \times \mu \qquad \text{Eq [12]}$$

$$AA_m = (a \times m \times Bp_m{}^{0.73} \times \mu)/e_m \qquad \text{Eq [13]}$$

Onde, m é o nutriente exigido por unidade de mantença (MJ/kg, g/kg ou mg/kg), BP_m é o peso proteico na maturidade (g/kg), $\mu = P/P_m$, a é o coeficiente do aminoácido para mantença (mg/kg) e e_m é a eficiência de utilização do aminoácido para mantença.

Determinação da exigência para produção de ovos

A energia de produção para animais em crescimento pode ser definida como a quantidade de energia necessária para a retenção de proteína e gordura. Para poedeiras, pode ser definida como a quantidade de energia necessária para produção de ovos.

A produção de ovos pode ser expressa em função da quantidade do nutriente necessário (proteína, energia ou aminoacidos) para a produção de cada componente do ovo (N_c) (EMMANS & FISHER, 1986).

A quantidade do nutriente necessário (proteína, energia e aminoacidos) para a produção de cada componente do ovo (N_c) é dada pela equação (EMMANS & FISHER, 1986):

$$N_c = QN_c \times CW/1000 \qquad \text{Eq.[14]}$$

Onde, QN_c é quantidade do nutriente no componente do ovo e CW é o peso do componente (gema, albúmen e casca).

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CAPÍTULO 2 - Desire feed intake based on the growth of body and reproductive organs in pre-laying hens

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Abstract

The feed cost can be optimised by manipulating the feed composition; therefore, it is necessary to accurately predict feed intake. The objective of this study was to describe the growth of reproductive organs and based on this information predict feed intake during the pre-laying phase of laying-type pullets and to evaluate the results of the models. Feed intake was calculated based on the deposition of protein and lipids into four compartments (body, feathers, ovary and oviduct). Two experiments were carried out. Ninety-six ISA-Brown pullets from 15 to 28 weeks of age were used in the first trial. Twice a week, four of these birds were slaughtered. The weights of the birds with and without feathers, ovaries and oviducts were measured, and samples were taken to analyse dry matter, gross energy and crude protein. Seventy-six ISA-Brown and seventy-six Hy-Line pullets from 15 to 24 weeks of age were used in the second trial. Feed intake was measured daily for each hen until the first egg was laid. The content of protein and lipid content in each compartment in the first experiment was fitted by the Gompertz function to estimate the parameters. The derivative of the Gompertz function was used to estimate protein deposition (DP), and an allometric function was used to calculate lipid deposition (DL) based on actual content protein. The energy for maintenance (EEM) was calculated based on actual content protein and protein weight at maturity. The effective energy (EE) requirement was calculated as EER=EEM+50DP+56DL. Feed intake was calculated by dividing the EE requirement and the EE content in the feed. The outputs from the simulation of feed intake for ISA-Browns and Hy-Lines were evaluated by regressing the residual values (observed minus predicted values) with the predicted values centred (predicted value minus the mean predicted value). Overall, the simulation of feed intake overestimated values of 0.41 g/day ($P>0.05$) and 2.65 g/day ($P<0.001$) for Hy-Lines and ISA-Browns, respectively. Significant linear bias was observed for Hy-Lines ($P<0.001$) but not for ISA-Browns ($P>0.05$). The assessment of the results indicated that the models for predicting feed intake were more accurate and less precise for Hy-Lines than for ISA-Browns. Thus, there was agreement between the calculated and measured values for feed intake, which shows that the models provide a true estimation of feed intake during the pre-laying phase.

Keywords: Accuracy, Assessment, Egg, Nutrition model, Pullets

Introduction

Feed intake in birds is largely influenced by the birds' genotypes, the environment and the composition of the given feed (Emmans, 1997). By manipulating feed composition, the cost of feeding can be optimised whilst providing the nutrients required by the birds to function optimally. To accomplish this, it is essential that feed intake is accurately predicted. In this context, predicts feed intake seems to be a strategic tool for the poultry industry, and this has led to the development of several models to predict feed intake by poultry (Fisher and Johnson, 1956, Emmans and Fisher, 1986, Fisher *et al.*, 1973, Gous *et al.*, 2006; Hauschild, 2014).

The accuracy of model for predicting feed intake depends on the model's successful description of the bird's growth potential as well as the effects of factors such as nutrient composition of the feed, environmental temperature, relative humidity, stocking density, etc. Much of this information has become available as a result of the publication of a plausible theory for predicting feed intake by Emmans (1981). Many of the more successful models, mentioned above, are based on this theory. Emmans (1981; 1987; 1997) based his theory on the principle that a bird will attempt to grow at its genetic potential, so it will attempt to consume a sufficient amount of the given feed to enable it to do so. This desired feed intake may not be achieved because of constraints such as gut capacity and the inability to lose sufficient heat to the environment.

The Gompertz growth equation has been shown to be useful in describing potential animal growth because only three parameters are necessary and all of them have biological significance (Emmans, 1981). By describing potential protein growth in this way and using allometric relationships between body protein and other chemical components (lipids, water and ash), the growth of these components can also be predicted. However, components of the body that do not mature at the same rate as body protein cannot be predicted in this way. Examples of such components are feathers and the reproductive organs, which grow considerably faster than body protein. The potential growth of these components must be predicted using separate Gompertz equations.

In this context, Bowmaker and Gous (1989) described the growth of the reproductive organs and determined the nutrient requirements for broiler breeder pullets. Similarly, Silva (2014) and Bonato (2014) developed models to predict daily amino acid intake prior to the birds reaching sexual maturity that accounted for the development of the reproductive organs (ovary and oviduct). However, the effect of the development of the reproductive organs on feed intake has not been described, and experimental evaluation is necessary to compare the predicted data with real data and determine the accuracy of these models. Thus, the objective of this study was to describe the growth of reproductive organs and based on this information predict feed intake during the pre-laying phase of laying-type pullets and to evaluate the results of the models.

Materials and methods

The desired feed intake in pre-laying hens based on the growth of reproductive organs and the body is described in three sections: a description of the models to predict feed intake, a growth description of pullets in pre-laying phase and a final section describing the model evaluation. The data used to estimate the parameters models for describe the growth of reproductive organs and for the evaluation of the results of feed intake provided by the models were obtained from two experimental conducted at the Laboratory of Poultry Science of the Faculty of Agriculture and Veterinary Sciences (FCAV), Universidade Estadual Paulista (UNESP), Jaboticabal, São Paulo, Brazil. This study was approved by the Ethics Committee on Animal Use of this university (protocol number 007125-08).

Calculating desired feed intake for the pre-laying phase

The average value of the desired feed intake was calculated for individual hens (in the pre-laying phase) based on the growth potential of the body, ovary and oviduct. The potential for protein growth was described by the Gompertz (1825) equation as follows:

$$P_t = P_m \times e^{-e^{(-b(t-t^*))}}, \qquad \text{Eq [1]}$$

Where P_t is the protein weight at age t (g); P_m is the protein weight at maturity (g); *b* is the growth rate (per day); t * is the age at maximum growth rate (days). Based on the Gompertz function, Emmans (1981) described the deposition of protein (*DP*, g/day) considering two state variables, P_t and P_m, as follows:

$$DP = b \times P_t \times ln\left(\frac{P_m}{P_t}\right) \qquad \text{Eq [2]}$$

The deposition of lipids (DL, g/day) was related to the body protein (P_t) as a lipid: protein ratio at maturity (LP_m) and could be estimated by the following equation:

$$DL = DP \times LP_m \times b_1 \times (Pt/Pm)^{b1-1}, \qquad \text{Eq [3]}$$

the b_1 value was estimated by: $b_1 = 1.46 \times LP_m{}^{0.23}$. Eq [4]

The effective energy requirement (EER, KJ/day) of the pullets was calculated for each day of the pre-laying phase using Eq. 5 (Emmans, 1989) as follows:

$$EER = EEM + 50\left(\frac{DP}{1000}\right) + 56\left(\frac{DL}{1000}\right), \qquad \text{Eq [5]}$$

where *EEM* is the energy for maintenance (KJ/day) and is calculated by Eq. 6 (Emmans and Fisher, 1986) as follows:

$$EEM = M_E \times P_t \times (P_m)^{-0.27}/1000, \qquad \text{Eq [6]}$$

where M_E is the effective energy needed per maintenance unit, which has a value of 1.63 MJ (Emmans, 1988).

The desired feed intake (DFI, g), which will meet the requirements for energy in a thermoneutral environment, is determined using Eq. 7 (Emmans, 1981) as follows:

$$DFI = {}^{EER}/_{EEC}, \qquad \text{Eq [7]}$$

where *EEC* is the effective energy content in the feed (KJ/g), and this value is estimated by equation Eq. 8 (Emmans, 1994):

$$EEC = 1.17 \times ME - 4.29 \times CP - 2.44, \qquad \text{Eq [8]}$$

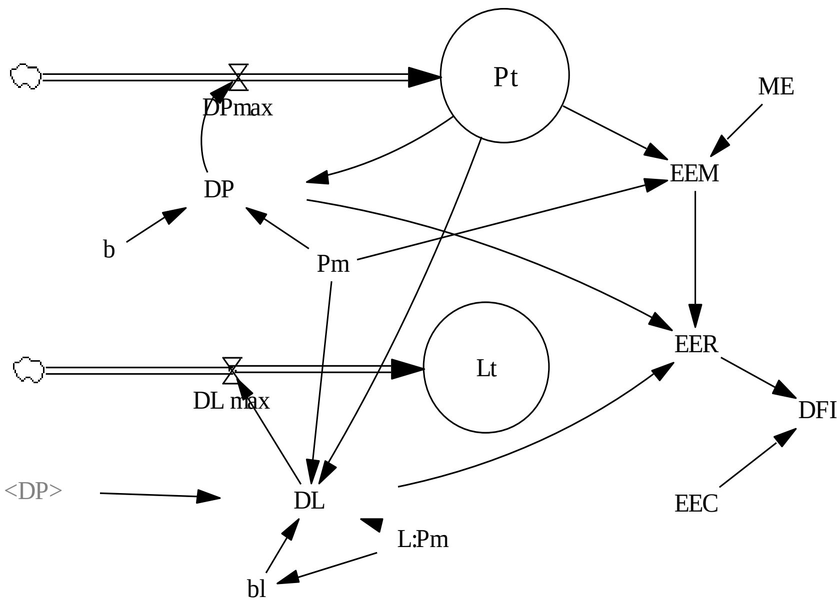
where *ME* is the metabolisable energy content of the feed (KJ/g) and *CP* is the crude protein content of the feed (g/g).

Growth description of pullets in pre-laying phase

An experiment was conducted to describe the growth of the body and reproductive organs in pullets during the pre-laying phase. Twice a week, four Isa-Brown pullets were slaughtered, totalling 96 pullets from 15 to 28 weeks of age. The pullets selected for slaughter were kept in a fasting state for 24 hours and were then slaughtered by CO_2 asphyxiation. The feathers, feather-free body, ovary and oviduct of each bird were weighed. These samples were taken and identified to analyse for dry matter, ash, gross energy and crude protein (N × 6.25) by Kjeldahl method (method No. 2001.11) according to AOAC (2005).

The protein content of each compartment (ovary and oviduct) was fitted by the Gompertz equation (Eq. 1) to estimate the parameters. Parameter values for the fitted equations for each variable were estimated using the Gauss-Newton method by means of the NLIN procedure of SAS (version 9.0). Alternatively, the protein contents of the body and feathers were not fitted by the Gompertz equation because the experimental period was insufficient to evaluate body development. For this reason, the parameters used to describe the body and feather protein contents of Isa-Browns and Hy-Lines were obtained from Silva (2014) and Bonato (2014), respectively. These researchers calculated the Gompertz parameters for different strain of pullets (Dekalb White).

The protein deposition in each compartment was calculated by Eq 2. As a result, daily protein weight in each compartment was calculated by integrating the daily protein deposition, considering the average weight of protein at 105 days as the initial value (Table 1). Based on protein weight, lipid deposition was calculated (Eq 3 and Eq 4). Particularly for lipid deposition in the body, the L_m value was considered from the literature (Bonato, 2014; Silva, 2014), which was necessary to estimate the lipid: protein ratio at maturity used in Eq. 3 and Eq. 4. The EER (estimated using Eq. 5) was calculated based on the EEM as well as protein (body, feather, ovary and oviduct) and lipid (body, ovary and oviduct) deposition. Taking into account the crude protein and metabolisable energy in the diet used in the experiment described in the following section, the EEC is 10.74.



Pt is the protein weight at time t, Pm maturity weight (g), b is the growth rate (daily), DP is the protein deposition and which has the same value that DPmax, DL is the desired lipid deposition, LPm is lipid: maturity protein ratio, b1= 1.46×LPm 0.23, ME is effective energy needed per maintenance unit, EEM is the effective energy for maintenance, EER is the effective energy requirement, EEC is the effective energy content and DFI is desire feed intake

Figure 1 Diagram of the model to estimate desire feed intake used in the Vensim simulation software. Circles represent a stock variable, arrows with simple line represent the relationship that allow to use the value variable in the equation and arrow with double line represent the rate which the stock variable increased.

The models described were integrated in the Vensim simulation software (Ventana Systems, 2003). The simulation was defined from 105 to 137 days of age as a result of the development of each compartment during this period. Figure 1 represents the model diagram, which considers the development of organs as a function of protein levels. The input values for the simulation model are P_m, b, b_1, LP_m, ME and EEC which is considered a constant. EER and DFI are the output values of the simulation model (Figure 1).

Evaluation of the predicted feed intake by the simulation model

To evaluate the results, the predicted feed intake for pre-laying hens were compared with the data obtained from the following experiment. Seventy-six Isa-Brown and seventy-six Hy-Line pullets, from 15 to 24 weeks of age, were used. The birds were housed in an experimental facility with a negative pressure system for controlling temperature according to recommendations in the strain guidelines (Isa-Brown, 2011), and all the birds were placed in individual cages. The diet based on corn and soybean meal was formulated according to recommendations of the Brazilian Tables for Poultry and Swine (Rostagno *et al*., 2011) with 0.1741 g/g of protein and 11.9 KJ/g of metabolisable energy in the diet. Feed and water were available *ad libitum*. Light stimulation was started at 5% of egg production by increasing light hours by one hour per week until sixteen light hours were reached (16L:8D). Feed intake was measured every day, and the day on which the first egg was laid was registered. This arrangement allowed the researchers to monitor the change in feed intake before and after the time point 14 days after the first egg for each bird.

The output of the simulation model of feed intake was evaluated by regressing residual (observed minus predicted) values with the predicted values centred on their mean value (St-Pierre, 2003); this was done using the PROC GLM procedure of the statistical software SAS (Statistical Analysis System, version 9.0), according to the following model:

$$e_i = \beta_0 + \beta_1 * cPFI + \varepsilon_i, \quad \text{Eq [9]}$$

where β_o is the intercept and indicates the overall prediction bias, β_1 is the slope and indicates the linear prediction bias, *cPFI* is the centred predicted value (predicted value of feed intake minus the mean of all predicted values of feed intake) and ε_i is the error of the regression of the residuals on the predicted values.

Results

Describing the growth and composition of the reproductive organs in the pre-laying phase.

Table 1 shows the mean weights and respective standard deviations of the body, ovary and oviduct for Isa-Brown pullets from 105 to 196 days of age.

Table 1 *Mean ± standard deviations of weight of body and reproductive organs for Isa Brown pullets*.

Age (days)	Body weight (kg)	Ovary	Oviduct
		------------------------------(g)---------------------------	
105	1.06 ± 0.02	0.68 ± 0.25	1.68 ± 1.80
112	1.11 ± 0.03	0.64 ± 0.24	0.90 ± 0.71
119	1.29 ± 0.02	1.43 ± 0.67	3.20 ± 3.00
126	1.40 ± 0.04	9.51 ± 17.0	12.5 ± 21.0
133	1.45 ± 0.07	7.17 ± 10.8	13.9 ± 16.5
140	1.48 ± 0.07	19.6 ± 13.5	33.3 ± 19.0
147	1.56 ± 0.13	19.4 ± 16.5	36.4 ± 19.5
154	1.49 ± 0.14	25.0 ± 10.6	40.4 ± 18.6
161	1.40 ± 0.10	33.2 ± 4.63	47.7 ± 5.80
168	1.41 ± 0.25	33.6 ± 17.8	42.4 ± 23.8
175	1.58 ± 0.30	30.6 ± 19.4	41.9 ± 19.3
182	1.44 ± 0.22	32.1 ± 11.3	42.2 ± 11.5
189	1.54 ± 0.32	29.5 ± 15.4	47.1 ± 21.6
196	1.51 ± 0.24	31.6 ± 13.2	42.2 ± 7.18

The weights of the body, ovary and oviduct increased as a function of age but at different rates, and the standard deviation increased as a function of age for the ovary and oviduct. The Gompertz parameters describing the growth of lipids and protein in the ovary and oviduct are presented in Table 2. The R^2 values were 0.80 and 0.85 for the weights of the ovary and oviduct, respectively. These higher R^2 values indicated that the Gompertz equation presented a proper fit for the weights of the ovary and oviduct. Higher W_m and b values were observed for the oviduct than for the ovary. Additionally, the age of maximum growth rate for the oviduct was estimated at 131 days, which is a value lower than that for the ovary.

Table 2 *Parameters ± standard error of gompertz model.*

Parameters	Ovary	Oviduct
	Weight	
W_m[1]	33.60 ± 3.21	44.20 ± 2.69
b[2]	0.07 ± 0.03	0.11 ± 0.04
t[3]	135.00 ± 3.44	131.00 ±2.70
	Protein	
P_m[4]	4.81 ± 0.59	6.96 ± 0.46
P_i[5]	0.07 ± 0.02	0.14 ± 0.14
b	0.18 ± 0.04	0.12 ± 2.76
	Lipids	
L_m[6]	6.68 ± 0.60	0.81 ± 0.07
L_i[7]	0.01 ± 0.003	0.03 ± 0.02
b	0.34 ± 0.05	0.09 ± 0.04

Gompertz equation to estimate the weight of ovary and oviduct: $W_t=P_m \times e^{-e(-b(t-t^*)}$, Where W_t is the weight at age t (g); W_m is the weight at maturity (g); *b* is the growth rate (per day); *t* * is the age at maximum growth rate (days).

Protein or lipid deposition for ovary and oviduct: $DP=b \times P_t \times \ln(P_m/P_t)$, Where P_t is the protein weight at age t (g); P_m is the protein weight at maturity (g); *b* is the growth rate (per day).

The value obtained for the maturity rate of protein (Table 2) in the ovary was 0.18, whereas the corresponding values for oviduct protein were 0.12. In contrast, the weight of protein in the ovary at maturity was lower (4.81 g) than the protein weights in the oviduct (6.96 g). Figure 2 shows the deposition of protein for the ovary and oviduct. The deposition of protein in the ovary and oviduct increased until 129 and 133 days, respectively, and then decreased after those times. The actual protein content in each compartment was calculated while accounting for the parameters described above, and the initial values for weight that were input to the Vensim simulation software were 10^{-6} and 10^{-9} g for the ovary and oviduct, respectively.

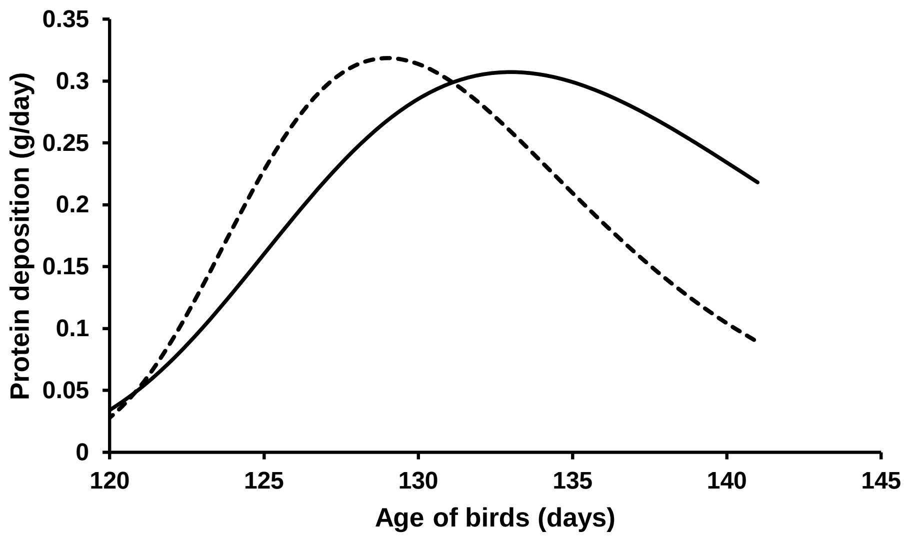


Figure 2 Deposition of protein (g/day) for ovary (- - -) and oviduct (—) for Isa-Brown in pre-laying phase.

The maturity rate of lipids was 0.34 for the ovary, whereas the values for the oviduct was 0.09. Additionally, the lipid weight at maturity for the ovary was higher (6.68 g) than the lipid weights at maturity for the oviduct (0.81 g), so the LP_m values for the ovary and oviduct were 1.38 and 0.18, respectively. Figure 3 shows the deposition of lipids for the ovary and oviduct. The deposition of lipids in the ovary and oviduct increased until 132 days of age, respectively, and then decreased after those times. The current lipid weight was calculated by integrating the desired lipid deposition and considering the initial lipid value weights that were input to the Vensim simulation software of 10^{-6} and 0.01 oviduct and ovary, respectively.

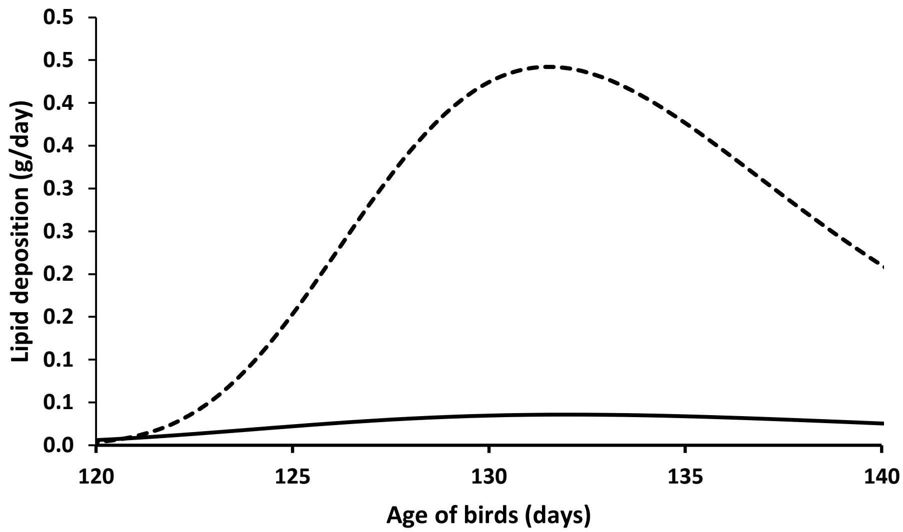


Figure 3 Lipid weight (g) for ovary (▬ ▬ ▬) and oviduct (▬) for Isa-Brown in pre-laying phase.

Estimating desired feed intake and the evaluation model

The EERs calculated by equation 5 were 718 and 832 KJ/day for Hy-Lines and Isa-Browns, respectively, at 105 days, accounting for the development of the body, feathers and reproductive organs and 710 and 823 KJ/day without the growth of reproductive organs (Table 3). In the same way, the EERs were 748 and 854 KJ/day for Hy-Lines and Isa-Browns, respectively, and 747 and 852 KJ/day without the growth of reproductive organs at 130 days of age; after that, the EER values decreased. The effective energy content in the feed that was calculated by Eq 8 was 10.74 KJ/g, considering 0.1741 g/g of protein and 11.9 KJ/g of metabolisable energy in the diet. These effective energy content values used by the simulation model were the same values used in the second experiment.

The measurements collected for individual birds within the fourteen days before the first egg was laid describe the same response regarding feed intake as was shown by the simulation models (Figure 4). Hy-Lines experimentally presented a similar response regarding feed intake predicted, and reached the maximum value seven days before the first egg. In contrast with this response, the feed intake increased during the experimental period for Isa-Brown pullets. The Hy-Line and Isa-Brown strains each presented a different response regarding feed intake before the first egg.

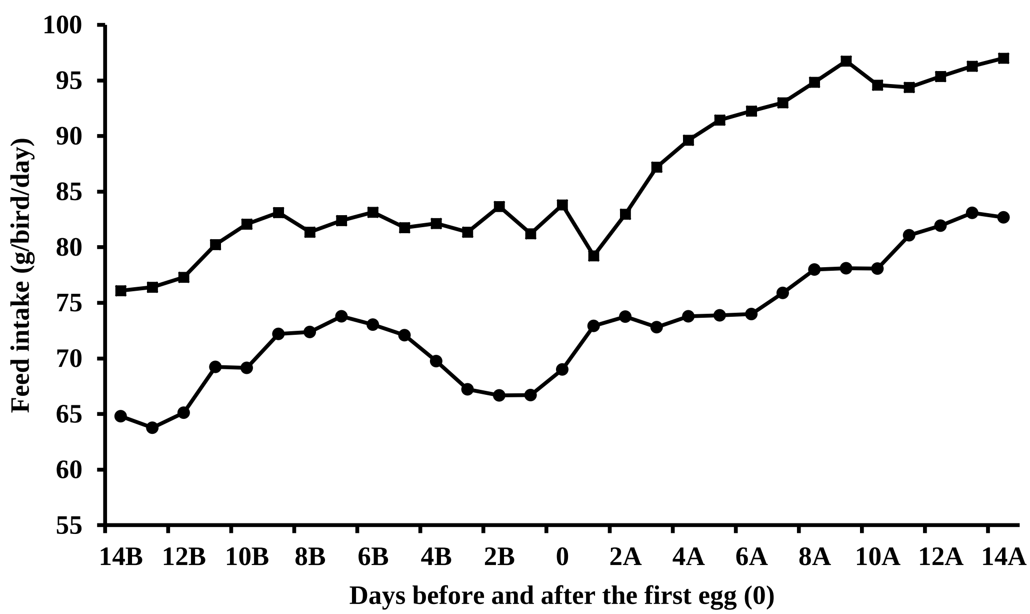


Figure 4 Feed intake (g/day) base on the first egg (0) for Isa-Brown (◆) and Hy-Line(●).

Figures 5 and 6 show the regression of residual values (observed minus predicted) on the centred predicted values for feed intake (DFI minus mean DFI) for Hy-lines and for Isa browns, respectively. The mean bias is not significant (intercept= 0.41 ± 0.43, P>0.05) for Hy-Lines and is significant (intercept=2.65 ± 0.52, P<0.001) for Isa-browns. Additionally, significant linear bias was observed for Hy-Lines (slope= 1.85 ± 0.45, P<0.001), but no significant linear bias was observed for Isa-Browns (slope= 0.76 ± 0.57, P>0.05).

Table 3 Observed (DFI) and p*redicted value of desire feed intake (g/bird/day) based on the growth of body with (DFI-1) and without reproductive organs (DFI-2) fourteen days before the first egg.*

Day	DFI		DFI-1		DFI-2	
	Isa-Brown	Hy-Line	Isa-Brown	Hy-Line	Isa-Brown	Hy-Line
0	83.8 ± 19.6	69.0 ± 19.6	77.32	67.71	73.43	63.76
1	81.2 ± 13.5	66.7 ± 13.5	77.78	68.14	73.54	63.83
2	83.7 ± 12.3	66.7 ± 12.3	78.24	68.55	73.65	63.90
3	81.4 ± 12.5	67.2 ± 12.5	78.66	68.93	73.76	63.97
4	82.1 ± 12.0	69.8 ± 12.0	79.02	69.26	73.87	64.04
5	81.8 ± 14.1	72.1 ± 14.1	79.3	69.50	73.99	64.11
6	83.2 ± 14.1	73.0 ± 14.1	79.48	69.63	74.10	64.18
7	82.4 ± 11.0	73.8 ± 11.1	79.52	69.64	74.21	64.26
8	81.4 ± 14.9	72.4 ± 14.9	79.40	69.49	74.33	64.33
9	83.1 ± 15.9	72.2 ± 15.9	79.14	69.18	74.44	64.41
10	82.1 ± 12.9	68.5 ± 12.9	78.74	68.74	74.55	64.48
11	80.2 ± 11.1	69.2 ± 11.1	78.23	68.20	74.67	64.56
12	77.3 ± 11.8	65.1 ± 11.8	77.68	67.61	74.78	64.63
13	76.4 ± 11.9	63.8 ± 11.9	77.14	67.04	74.89	64.71
14	76.1 ± 13.7	64.8 ± 13.7	76.67	66.53	75.00	64.79

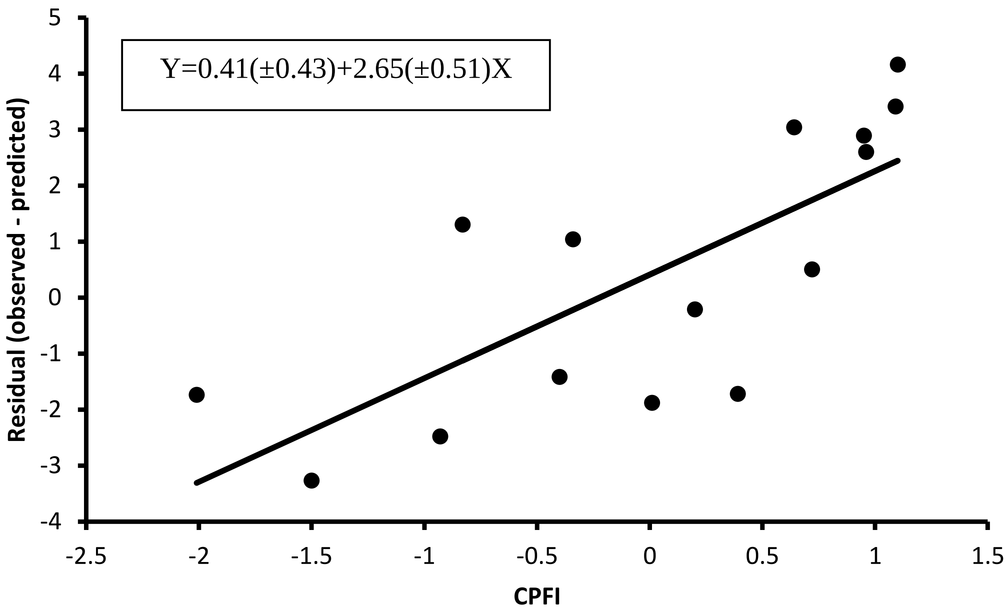


Figure 5 Plot of residual (mean of observed and predicted value for each day) vs. predicted value centered of fee intake for Hy-Line. The mean bias (0.41g/day) is not significant and the linear bias (1.85) is significant.

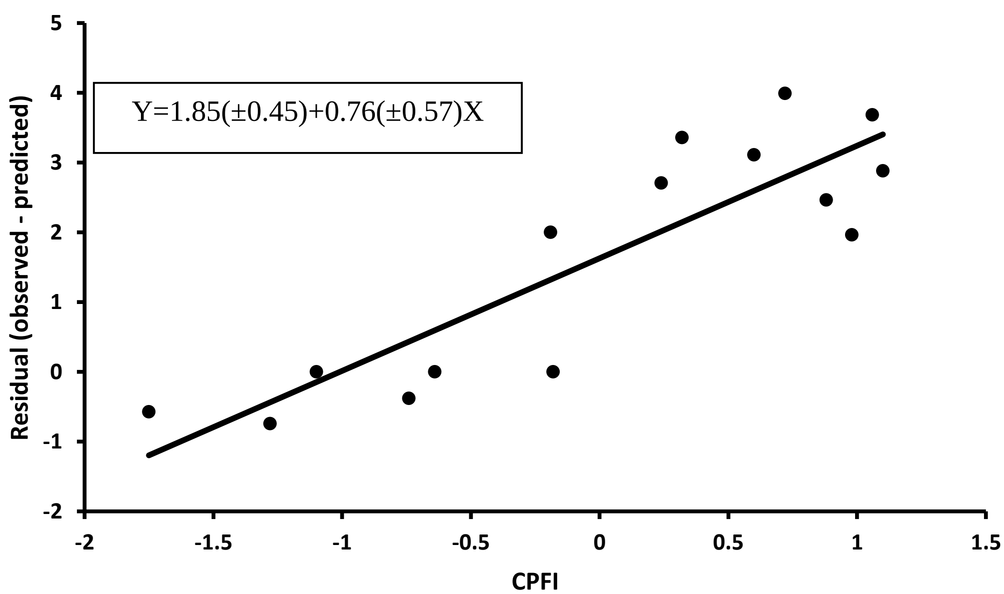


Figure 6 Plot of residual (mean of observed and predicted value for each day) vs. predicted value centered of fee intake for Isa Brown. The mean bias (2.65 g/day) is significant and the linear bias (0.76) is not significant.

Discussion

Experimental evaluation allows to contrast measured feed intake and calculated feed intake provided by the models, while considering the development of reproductive organs, which enables us to predict feed intake during the pre-laying phase. It is useful to predict feed intake as a function of the current state of several compartments (body, feather, ovary and oviduct) because this arrangement allows for predicting nutrient requirements based on the daily deposition of chemical components (Emmans, 1989). However, the accuracy of the results depends on the growth description used for each compartment. The data collected from the slaughtered birds (twice a week) was enough to describe changes in the weights of reproductive organs. Therefore, it was possible to properly fit a Gompertz function and estimate the parameters to describe the growth of the reproductive organs in the pre-laying phase.

The ovary and oviduct were shown to have greater development in the pre-laying phase, which is in agreement with the literature (Bowmaker and Gous, 1989). The oviduct reaches maturity earlier than the other organs because it presented higher W_m and b values than those for the ovary. These values were lower than the values observed by Silva (2014), and the contrasting results are probably due to the difference in the pullet strains used in the studies and the different lighting programmes adopted. Additionally, the predicted values of protein weight in the ovary and oviduct showed a higher protein gain over this period because the daily deposition of protein increased in the pre-laying phase. The value obtained for the maturity rate of protein in the ovary was higher than the corresponding values in the oviduct; for this reason, protein in the ovary reaches maturity earlier than protein in the oviduct.

Lipid deposition does not have a limit and depends on nutrition. In contrast, the lipid deposition was estimated as the desired lipid growth to quantify the relationship between protein and lipid levels (Emmans, 1981). This concept has the advantage of controlling the lipid growth based on the voluntary feed intake. The predicted values of lipid weight in the ovary increased in this period in contrast to the oviduct. Growth of the ovary in this period is mainly due to the fat that is stored in this compartment for follicle development and support yolk output throughout the laying period (Bowmaker and Gous, 1989). Similarly, the lipid weight in the oviduct increased but did so at a lower rate than in the ovary (Table 2).

All the parameters that describe the growth of the compartments were estimated with the data collected in the experiment, except those parameters that describe the body and feather growth. Body weight slightly increased in the pre-laying phase (Table 1) in contrast to the development of the reproductive organs. For this reason, the parameters that describe the body growth were obtained from the literature (Bonato, 2014; Silva, 2014). This alternative may reduce the accuracy of the results because these parameters were estimated from different strains.

The energy requirement for growth and maintenance was determined by the effective energy system (Emmans, 1994). The efficiencies of protein deposition and desired lipid deposition were 50 and 56 MJ/kg, respectively (Emmans, 1989). These values were taken for all compartments because there are not efficiency values for each compartment reported in the literature. The effective energy content in the feed of the experiment was 10.74 KJ/g, which is the same value used in the simulation model to compare the predicted with the observed feed intake value. The predicted value of feed intake by the simulation model is a desired feed intake because it does not account for other potentially limiting factors such as environment, health status or density. However, the predicted feed intake was still compared with the observed feed intake. The maximum predicted values of feed intake in this period were 79.5 and 69.6 g/day for Isa-Browns and Hy-Lines, respectively. This value is 0.5 grams less than that suggested by the Isa Brown guidelines at 17 weeks of age and 7 grams more than that suggested by the Hy-Line guidelines at the same age (Isa Brown, 2011; Hy-Line, 2013). Considering the nutritional specifications for pre-laying diets from the guidelines, the effective energy content for Isa Browns was 10.27 KJ/g (EM = 2750 kcal/kg; CP=17%), and the EER calculated by the simulation model resulted in a desired feed intake of 79.39 g/day, which is in agreement with the Isa-Brown guidelines (Isa Brown, 2011) at 17 weeks of age. For Hy-Lines, the effective energy content was 11.09 KJ/g (EM = 2911 kcal/kg; CP=17%), and the EER calculated by the simulation model resulted in a desired feed intake of 63.57 g/day, which is in agreement with the Hy-Line guidelines (Hy-Line, 2011) at 17 weeks of age. This result indicates slightly differences between the predicted feed intake by the simulation and the feed intake suggested by guidelines due to the feed energy content value.

The changes in feed intake as a function of laying the first egg were different for both strains. One week before the first egg was laid, Hy-Line pullets consumed 2 g more protein and 33 kcal more energy than birds at seven days before the first egg was laid. However, this response was not observed for Isa-Brown pullets, probably because this strain consumed more feed than the Hy-Lines at the start of the pre-laying phase. Additionally, the increasing feed intake over the pre-laying period was probably due to the lower rate of body maturation in Isa-Brown pullets compared to Hy-Line pullets (Silva, 2014).

The reproductive organs develop in a short time and reach mature weight quickly. Additionally, the time when the growth rate is maximal is almost equal for the ovary and the oviduct. Moreover, feed intake changes during the pre-laying phase, and greater changes were shown one week before the first egg, but the impact is higher among light pullets. For these reasons, the increase in feed intake was probably due, in large part, to the need for ovary and oviduct growth in the pre-laying phase. Nevertheless, there are different responses in each strain.

The simulation of feed intake overall overestimated values of 0.41 ($P>0.05$) and 2.65 g/day ($P<0.001$) for Hy-Lines and Isa-browns, respectively. Significant linear bias was observed for Hy-Lines ($P<0.001$) but was not observed for Isa-Browns ($P>0.05$). The assessment of the results indicates that the simulation models for predicting feed intake were more accurate and less precise for Hy-Line pullets than for Isa-Brown pullets.

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CAPÍTULO 3 - Modelling potential egg production in laying hens

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Abstract

A model of the changes that occur in the composition of egg components over time is an important tool for the nutritionists since it can provide information about the nutrients required by a laying hen to achieve her potential egg output. In this context, this study aimed to model the potential egg production of laying hens during the egg production period. One hundred and twenty Hy-Line W36 and ISA Brown layers were used from 18 to 60 weeks of age with each bird being an experimental unit. The birds were housed in individual cages during the experimental period. Egg production (%), egg weight (g/egg) and the weight of egg components were recorded for each bird. The data were used to calculate the parameters of equations for predicting the weights of yolk, albumen and shell, and for predicting internal cycle length. The result of egg weight and internal cycle length were evaluated by regressing residual (observed minus predicted) values on the predicted values centred on their mean value.The equations for predicting mean yolk weight with age are y_1 = 13.6×(1-$e^{(-0.0207\times(Age-81.46)))}$) $\times\, e^{0.00053\times Age}$ and y_2 = 15.3×(1-$e^{(-0.0207\times(Age-109.4)))}$) $\times\, e^{0.00011\times Age}$ for Hy-Line W36 (y_1) and ISA-Brown (y_2), respectively. Albumen and shell weights for Hy-Line W36 were described by the equations 15.07×(yolk weight)$^{0.37}$ and 0.70×(yolk + albumen weight)$^{0.50}$, respectively, and for ISA-Brown, 21.99×(yolk weight)$^{0.24}$ and 1.60×(yolk + albumen weight)$^{0.34}$, respectively. The mean internal cycle length over time for Hy-Line W36 (ICL_1) is described by the model $22.95 + 5.24 \times (0.962^T) + 0.02 \times T$ and for ISA-Brown, $24.01 + 10.29 \times (0.94^T) + 0.004 \times T$, where T is the age at first egg (d). The assessment of the results indicates that the equations for predicting egg weight were more accurate for Hy-Line W36 but less precise for both strains, the equation models for predicting the ICL were more accurate and precise for ISA-Browns. The models can be described the behavior of egg components weight, egg weight and the rate of lay associated with the ICL and based on this information is possible to improve the estimated the nutrient requirement.

Keywords: Egg production, Genetic, Laying hens, Nutrition model

Introduction

Considerable progress has been made over the years by poultry geneticists in increasing the egg output of laying hens. Twenty years ago a laying hen produced approximately 230 eggs in the period 20 to 60 weeks of age (Elliot, 2012) whilst today an average of 260 eggs per hen is expected during that 40-week laying period (Hy-Line, 2015). As a result the nutritional requirements of modern laying strains have increased.

Such genetic progress is likely to continue into the future, but to avoid having to conduct response experiments at regular intervals to keep up with these changes, equations have in the past been published designed to account for such changes when determining nutrient requirements of hens. Fisher *et al*. (1973) recognised the value of such an approach and published the so-called Reading Model that enabled the amino acid requirements of a flock of laying hens to be calculated from the mean body weight and maximum egg output (g/bird d) of the flock, as well as the prevailing marginal cost of each amino acid and the marginal revenue derived from the sale of the eggs. As the mean body weight and maximum egg output of the genotype is altered by selection, so these equations may be used to update the amino acid requirements of each new strain of laying hen. Although this approach has merit, the main criticism is that food intake needs to be predicted in order to utilise the concept fully.

Emmans (1987) pointed out that in order to predict food intake it is necessary to know what the bird or animal is attempting to achieve, i.e. in the case of a laying hen it is necessary to predict the age at sexual maturity, the potential rate of laying (the rate at which egg production rises to a peak and then decays over time), and the potential egg weight achievable over time. With such information it would be possible to determine the daily intakes of essential nutrients required to achieve that potential laying performance. Only once this has been successfully achieved is it possible to address the related issue of what the consequences in egg production would be if the hen were unable to consume sufficient of the limiting nutrient.

Several models have been developed to predict rate of laying, egg weight and egg mass output (Emmans and Fisher, 1986; Álvarez & Hocking, 2007; Johnston and Gous, 2007; Gous and Nonis, 2010). Emmans and Fisher (1986) described potential egg production in terms of changes in ovulation rate and in the weight of the egg components over time. Because each component of the egg has a different chemical composition, and because the proportions change over time (Ahn *et al*., 1997; Arafa *et al*., 1982; Hussein *et al.*, 1993) it is not sufficient to predict only the change in egg weight over time: changes in the proportions of yolk, albumen and shell need to be considered when determining the daily intake of nutrients required by a hen to express her potential.

Ovulation rate, or the interval between successive ovulations, is controlled through the synchronization between the release of LH and follicle maturation by FSH, androgens, progesterone, oestrogen and prostaglandin (Johnson, 2000). Each ovulation occurs 15 - 75 minutes after oviposition except for the first egg of a sequence (Johnson, 2000). The interval between successive ovulations differs between individuals and also changes over time, resulting in the egg laying curve characteristic of a flock of laying hens. The hen's internal cycle length (ICL) controls ovulation rate (Fraps, 1955; Etches & Schoch, 1984), and this mechanism, including the decay in ICL over time, has been successfully modelled by Johnson and Gous (2006). The model is applied to an individual and is made stochastic using appropriate means and standard deviations thereby simulating the potential egg output of a flock of laying hens. This information may then be used to determine the daily intake of essential nutrients required by the flock in order to achieve this potential performance.

The genetic improvements in egg laying potential that have taken place over the past two decades raise the issue of the extent to which the nutrient requirements of a laying flock would have changed in that time. In this context, the objective of this study was to measure the laying performance of two modern laying strains, one light and the other, semi-heavy, and thereby determine to what extent the values of parameters in the published models should be altered to account for these changes.

Materials and methods

Data used to estimate the model parameters in two modern laying strains were obtained from a trial conducted at the Laboratory of Poultry Science of the Faculty of Agriculture and Veterinary Sciences (FCAV), Universidade Estadual Paulista (UNESP), Jaboticabal, São Paulo, Brazil.

One hundred and twenty laying hens of ISA-Brown and Hy-Line W36 strain were used. The birds were housed in galvanized wire cages at 18 weeks of age in a climate-controlled facility with temperature and humidity according to the strain guidelines recommended by ISA-Brown (2013) and Hy-Line (2014). The cages were divided into four compartments measuring 25x40x40 cm, with one bird per compartment. The cages were equipped with galvanized feeders and nipple drinkers. The diet was formulated according to recommendations of the Brazilian Tables for Poultry and Swine (Rostagno *et al*., 2011) with 174 g protein and 11.9 MJ metabolisable energy/kg feed. Feed and water were available *ad libitum*. When egg production in the flock exceeded 5 eggs/ 100 hens, the photoperiod was increased from 14 h, by one hour per week, until a maximum of 16 h light was reached, whereafter this lighting programme was maintained to the end of the trial when the birds were 60 w of age. Feed intake (g/bird d) and body weight (kg/bird) were measured at the end of each week; egg production and egg weight (g) were recorded daily and the weight of the egg components was measured three times per week.

The assumptions of normality and homoscedasticity were tested by the Cramer-Von Mises and Levene tests, respectively. The parameters of equations to estimate the weight of yolk, albumen, shell and the internal cycle length (ICL) were calculated using the SAS PROC NLIN (Statistical Analysis System, version 9.0). Akaike's information criterion, AIC, (Akaike, 1981) was used for model selection for yolk weight and ICL. The equations for egg weight and ICL were evaluated by regressing residual (observed minus predicted) values on the predicted values centred on their mean value (St-Pierre, 2003); this was done using the PROC GLM procedure of the statistical software SAS (Statistical Analysis System, version 9.0), according to the following model:

$$e_i = \beta_0 + \beta_1 \times cP + \varepsilon_i \qquad \text{Eq [1]}$$

where β_0 is the intercept and indicates the overall prediction bias, β_1 is the slope and indicates the linear prediction bias, cP is the centred predicted value (predicted value of egg weight or ICL minus the mean of all predicted values) and ε_i is the error of the regression of the residuals on the predicted values.

Predicting potential egg weight

Egg weight was predicted from the sum of its components: yolk, albumen and shell. Two functions were used for calculating yolk weight (YW, g), both based on hen age. The first was a function suggested by McMillan *et al.* (1970).

$$YW = A \times (1 - e^{(-C\times(t-D))}) \times e^{(-R\times t)} \qquad \text{Eq [2]}$$

where *t* is the hen age; *A* is the maximum yolk weight, *C* is the rate of increase in yolk weight, *D* is the starting age and *R* is the rate of decrease in yolk weight.

The second function used was a linear-by-linear function

$$YW = A + C/(1 - R \times t) \qquad \text{Eq [3]}$$

where *A,C* and *R* are parameters.

The weights of albumen and shell were estimated by allometric functions (Emmans and Fisher, 1986). Albumen weight (Eq.4) was predicted as a function of yolk weight, and shell weight (Eq. 5) was predicted as a function of the sum of yolk and albumen weights.

$$AW = a \times YW^b \qquad \text{Eq [4]}$$

$$SH = a \times (AW + YW)^b \qquad \text{Eq [5],}$$

Predicting potential internal cycle length

Two equations were used to estimate the potential ICL of the hens in the study, namely, a line-plus-exponential equation (Eq [6]) suggested by Gous and Nonis (2010) and a quadratic-by-linear equation (Eq [7]) (Johnston and Gous, 2006). A mean weekly ICL for each hen was calculated from her weekly egg production (ICL = 2400/mean % rate of lay) and these were regressed against the days from first egg using the following functions:

$$ICL = A + B \times (R^t) + C \times t \qquad \text{Eq [6]}$$

$$ICL = A + \frac{B}{1 + D \times t} + C \times t \qquad \text{Eq [7]}$$

where *A*, *B*, *C, D* and *R* are constants, and *t* is the time from first egg, in days. The parameter A+B in Eq [6] indicates the ICL at the start of the laying period.

Results

Hens started laying from 18 w so all the equations were fitted to data collected from 18 to 60 w. Parameter values (± standard error) for the McMillan and the linear-by-linear models fitted to yolk weight for Hy-Line W36 and ISA-Brown laying hens are given in Table 1. A reasonably good fit (R^2 adj.) was obtained with both the McMillan (0.99) and linear-by-linear models (0.98). As the AIC values were lower with the McMillan model (Eq. 2) this model was chosen to describe the changes in yolk weight in the Hy-Line W36 (YW_1) and ISA-Brown (YW_2) strains:

$$YW_1 = 13.66\ (\pm 0.24) \times (1 - e^{(-0.02(\pm 0.001) \times (t - 81.45(\pm 2.74))}) \times e^{(0.0005(\pm 0.00004) \times t)}$$

$$YW_2 = 15.55\ (\pm 0.39) \times (1 - e^{(-0.02(\pm 0.001) \times (t - 106.9(\pm 2.98))}) \times e^{(0.00008(\pm 0.00006) \times t)}.$$

The above equations demonstrate that the maximum yolk weight (A) was higher in ISA-Brown hens, whereas the age at which the first yolk was laid (D) was earlier for Hy-Line W36 hens. The rate of increase in yolk weight (R) was similar for both strains whereas the rate of decrease in yolk weight (C) was higher for ISA-Brown hens.

Table 1 *Parameters ± standard error of McMillan and linear-by-linear functions to estimate yolk weight.*

Strain	Parameters				AIC
	A	C	D	R	
		----------McMillan function----------			
Hy-Line W36	13.7 ± 0.24	0.02 ± 0.001	81.5 ± 2.75	-0.0005 ± 0.00004	2612
ISA-Brown	15.6 ± 0.39	0.02 ± 0.001	107 ±2.98	-0.00008 ± 0.00006	2110
		----------Linear-by-linear equation----------			
Hy-Line W36	19.1 ± 0.11	15.5 ± 1.73	-	0.0199 ± 0.0013	2618
ISA-Brown	17.3 ± 0.07	3.06 ± 0.20	-	0.008 ± 0.00017	2131

McMillan function: $YW = A \times (1 - e^{(-c \times (t - D))}) \times e^{(-R \times t)}$

Linear-by-linear equation: $YW = A + C/(1 - R \times t)$

Table 2 *Parameters ± standard error of allometric functions to estimate albumen and shell weight.*

Strain	----------------Albumen----------------		------------------Shell-------------	
	a	b	a	b
Hy-Line W36	2.713 ± 0.368	0.368 ± 0.005	-0.351 ± 0.004	0.506 ± 0.004
ISA-Brown	3.091 ± 0.029	0.245 ± 0.011	0.471 ± 0.008	0.336 ± 0.021

Allometric function to estimate albumen weight (AW) based on yolk weight (YW):

$ln(AW) = ln(a) + b \times ln(YW)$

Allometric function to estimate shell weight (SH) based on egg content weight (AW + YW)

$ln(SH) = ln(a) + b \times ln(AW + YW)$

The egg component weights were used to test if the albumen weight and shell weight were directly proportional to yolk weight. The regression of albumen weight on yolk weight had a higher coefficient of determination than that between shell weight and yolk+albumen weight, the R^2 for the former being 0.96 for Hy-Line W36 and 0.83 for ISA-Brown, respectively whereas, the R^2 for the latter was 0.84 for Hy-Line W36 and 0.71 for ISA-Brown hens. Thus an acceptable relationship existed between the egg components such that albumen weight could be predicted from yolk weight, and shell weight from yolk plus albumen weight. The parameters values (± standard error) of allometric equation for albumen and shell weight for Hy-Line W36 and ISA-Brown hens are given in Table 1. The weights of albumen and shell for Hy-Line W36 and ISA-Brown hens were best described using the following equations: $AW = 15.07 \times YW^{0.37}$ and $SH = 0.70 \times (AW + YW)^{0.50}$ for Hy-Line W36 hens; and $AW = 21.99 \times YW^{0.24}$ and $SH = 1.60 \times (AW + YW)^{0.34}$ for ISA-Brown hens.

Whereas the weights of yolk, albumen and shell increased with age in both strains, the albumen and shell components, as a proportion of the whole, decreased. The changes that took place in these component proportions over time are illustrated in Fig's

1 and 2 for Hy-Line W36 and ISA-Brown, respectively, the patterns being the same for both strains.

Egg weight was calculated by summing the predicted weights of yolk, albumen and shell. Fig. 3 illustrated the lower overall egg weight for the Hy-Line W36 strain compared with ISA-Brown in spite of the eggs from this strain being heavier initially. The relationship between residual values (observed minus predicted) and the centred predicted values for egg weight was analysed using linear regression. The mean bias was not significant for Hy-Line W36 hens (intercept= -0.098 ± 0.09, P=0.28) but was for ISA-Brown (intercept= -0.37 ± 0.18, P=0.04). Additionally, significant linear bias was observed for Hy-Line W36 (slope= 0.06 ± 0.02, P=0.0002) and ISA-Brown (slope= 0.41 ± 0.05, P<0.0001).

Parameters values (± standard error) for predicting ICL in Hy-Line W36 and ISA-Brown hens, using the line-plus-exponential and quadratic-by-linear equations, are given in Table 3. The line-plus-exponential model (Eq. 6) had the highest R^2 adj and lowest AIC values and was therefore the favoured equation to calculate the ICL (h) for Hy-Line W36 (ICL_1) and ISA-Brown (ICL_2) laying hens:

$$ICL_1 = 22.95(\pm 0.24) + 5.24(\pm 0.48) \times [0.96(\pm 0.006)]^t + 0.02(\pm 0.001) \times t$$

$$ICL_2 = 24.01(\pm 0.21) + 10.29(\pm 2.74) \times [0.94(\pm 0.009)]^t + 0.004(\pm 0.001) \times t$$

where t is the time (d) from the start of laying.

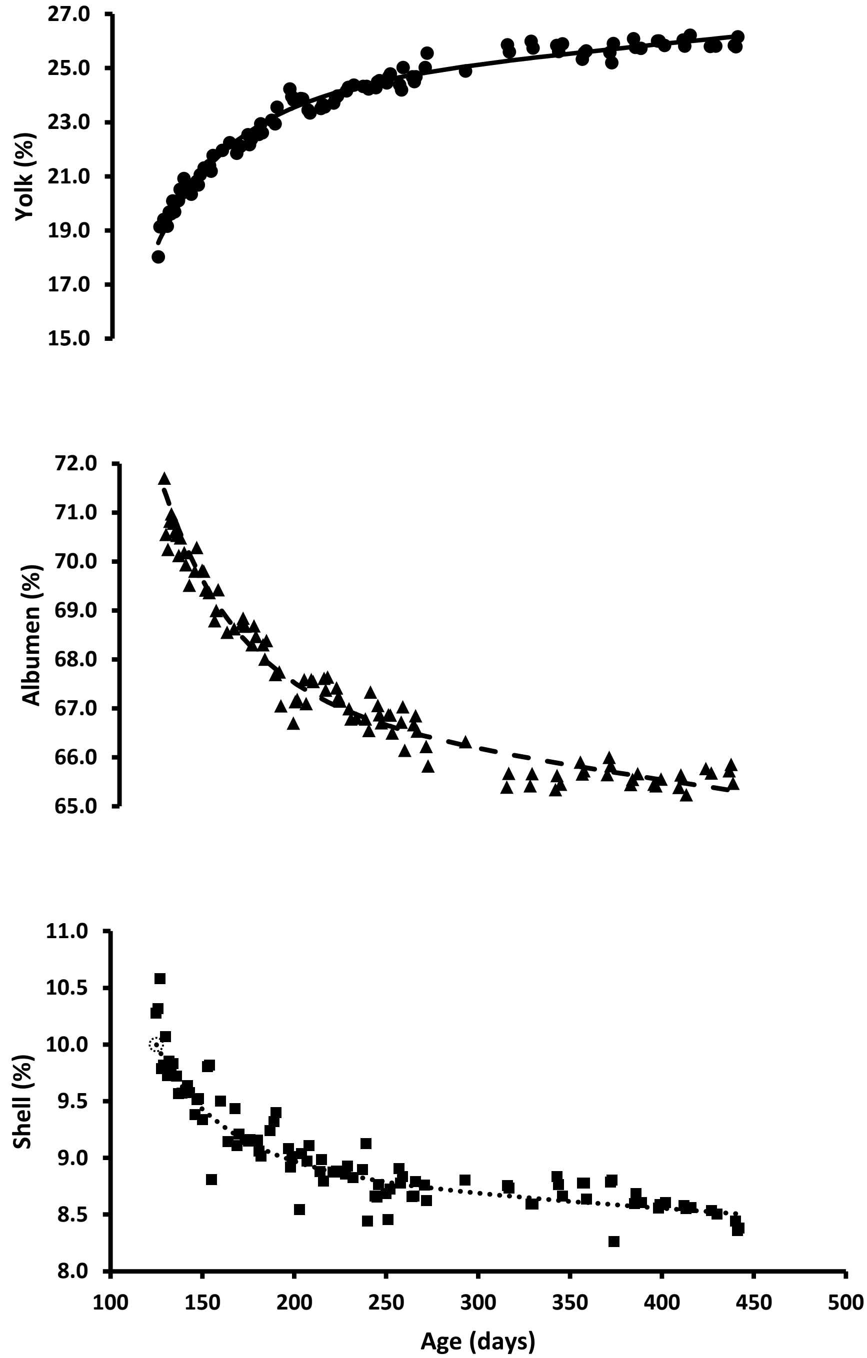

Figure 1. Relationship between the observed proportions of yolk (●), albumen (▲) and shell (■) in the egg with age for Hy-Line W36 hens from 18 to 60 w, and those predicted (▬▬), (▬ ▬ ▬), (……): yolk weight by the McMillan model; albumen and shell weights using allometric equations on the predicted yolk weight.

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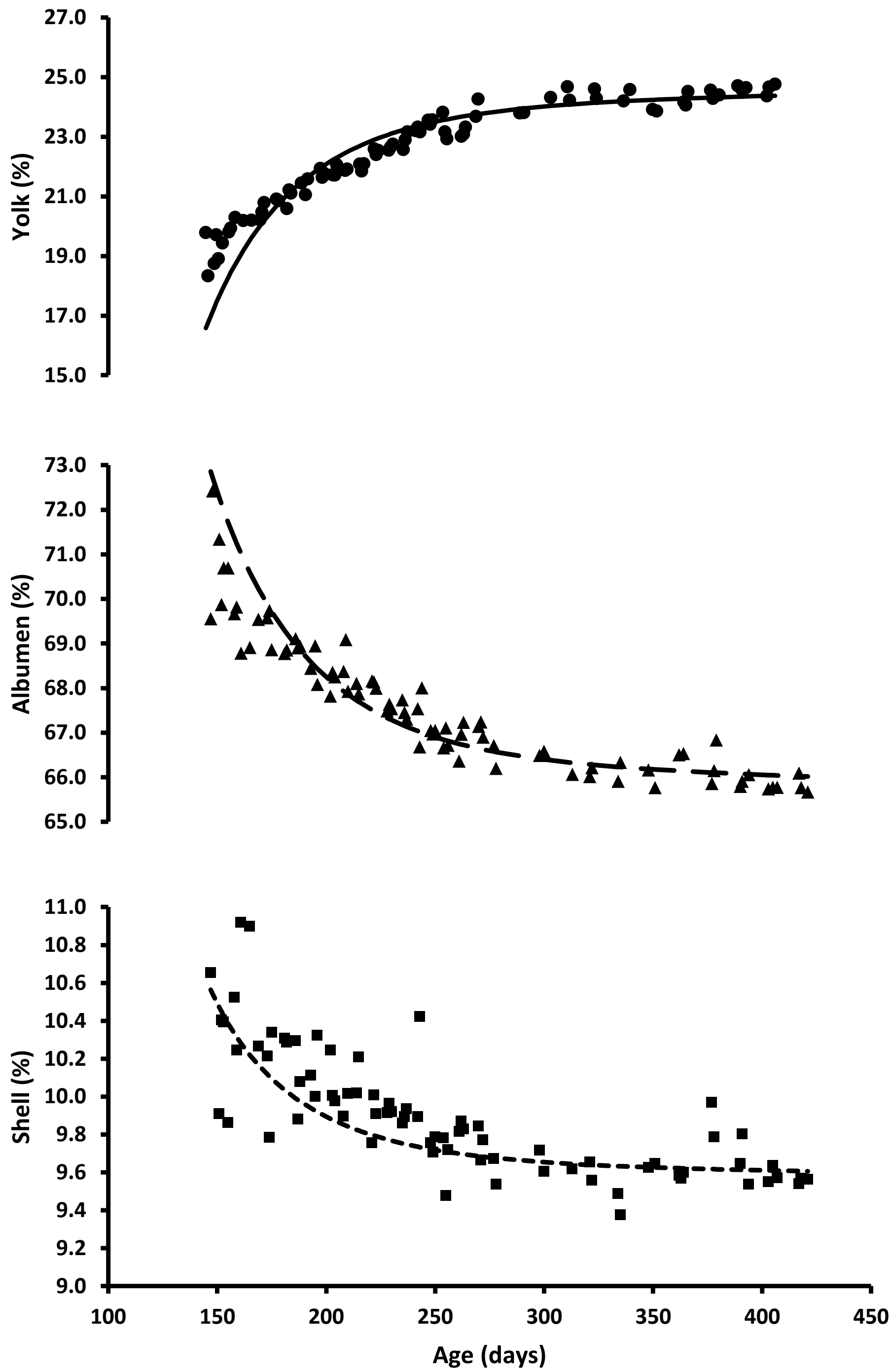

Figure 2. Relationship between the observed proportions of yolk (●), albumen (▲) and shell (■) in the egg with age for ISA Brown hens from 18 – 60 w, and those predicted (▬▬), (▬ ▬ ▬) and (......): yolk weight by the McMillan model; albumen and shell weights using allometric equations on the predicted yolk weight

Table 3 *Parameters ± standard error of linear-plus-exponential and quadratic-by-linear equations to estimate internal cycle length*.

Strain	Parameter					AIC
	A	B	C	D	R	
--Line-plus-exponential equation-----------------------------						
Hy-Line W36	22.95 ± 0.24	5.24 ± 0.48	0.02 ± 0.001	-	0.96 ± 0.006	-569
ISA-Brown	24.01 ± 0.21	10.29 ± 2.74	0.004 ± 0.001	-	0.94 ± 0.009	1293
--Quadratic-by-linear equation-------------------------------------						
Hy-Line W36	21.40 ± 0.57	7.64 ± 0.71	0.02 ± 0.001	0.05 ± 0.02	-	-538
ISA-Brown	22.32 ± 0.44	16.70 ± 5.49	0.009 ± 0.001	0.13 ± 0.06	-	1473

The ICL at the start of the laying period was predicted to be 28 h for Hy-line W36 hens and 33.7 h for ISA-Brown (Fig 4), with the shortest ICL, 24 h, being achieved by the Hy-line W36 strain 58 d after sexual maturity. The lowest ICL achieved by ISA-Brown hens (24.8 h) occurred 60 d after starting to lay. By the end of the laying period (300 d) the ICL of ISA-Brown hens was 28.9 and of Hy-line W36, 27 h. The relationship between residual values (observed minus predicted) and the centred predicted values for ICL was analysed using linear regression for both strains. The mean bias was not significant for either strain (for Hy-Line W36 the intercept = -0.13 ± 0.18, P=0.36 and for ISA-Brown the intercept = -0.06 ± 0.18, P=0.73). Significant linear bias was observed for Hy-Line W36 (slope = -0.26 ± 0.05, P<0.0001) but not for ISA-Brown (slope = -0.085 ± 0.05, P=0.09).

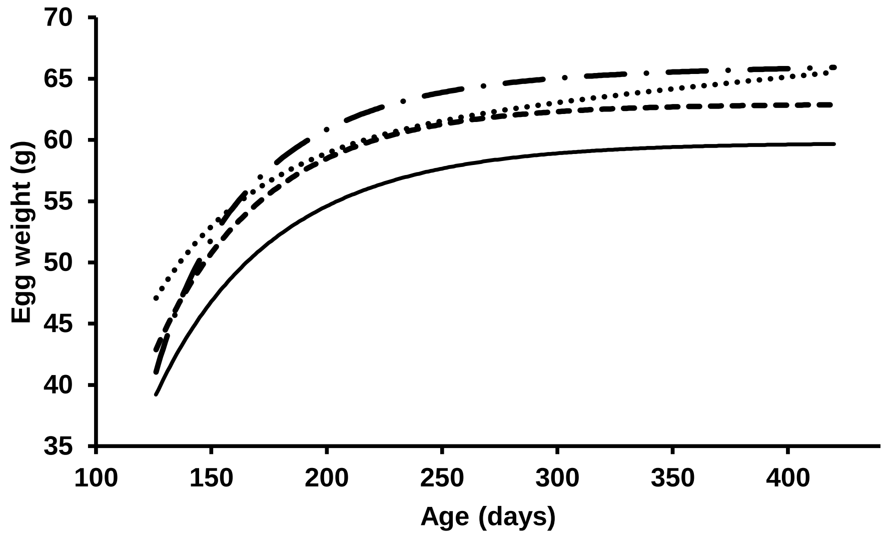

Figure 3. Predicted egg weights with age for ISA-Brown (▬ ▪ ╷), Hy-Line W36 (▪▪▪▪▪▪), Hy-Line Silver (▬▬) and Hy-Line Brown (▬ ▬ ▪).The egg weight for the last two strains was predicted using the model proposed by Johnston and Gous (2007).

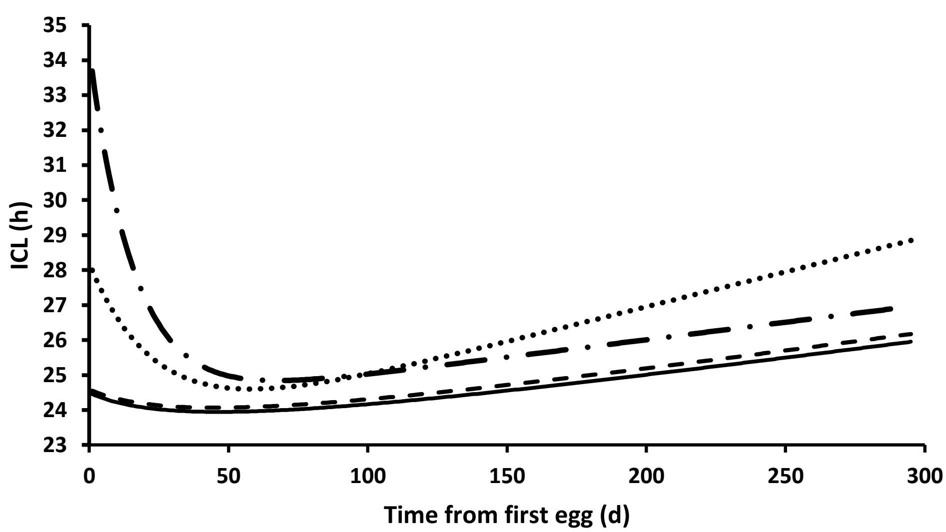

Figure 4. Predicted internal cycle length (ICL, h) with the time from first egg (d) for ISA-Brown (▬ ▪ ╷), Hy-Line W36(▪▪▪▪▪▪), Hy-Line Silver (▬▬) and Hy-Line Brown (▬ ▬ ▪).The ICL for the last two strains was predicted using the model proposed by Johnston and Gous (2007).

Discussion

Rate of laying and egg weight have both been considerably improved in commercial laying flocks due to genetic selection. These changes have been of great advantage to the poultry industry because highly productive birds with different characteristics are available to suit different market demands for egg size. The present study was designed to describe the potential rate of laying and egg weight of two modern commercial laying strains having different characteristic laying patterns and egg weights. The two characteristics measured here, of changes in the proportion of the egg components and the changes in ICL during the laying period, are of particular relevance when attempting to calculate the daily nutrient intake that will support the potential reproductive performance of a laying hen throughout the laying period. Because different equations have been published that describe these changes in egg component weights and ICL, the opportunity arose to compare these equations to determine which predicted performance most accurately.

Despite differences in egg weight between the two strains used in this trial, both exhibited consistent patterns of change in these egg components over time. Whereas all three components of the egg increase in weight, the yolk takes up a greater proportion of the egg with time, which is consistent with the literature (Emmans and Fisher, 1986; Hussein *et al*., 1993; Di Masso *et al.,* 1998; Johnston and Gous, 2007; Gous and Nonis, 2010).

The statistical analysis (AIC) conducted on these data indicated that the McMillan model is more accurate than the linear-by-linear model for predicting changes in egg yolk over time. By the end of the laying period, the heaviest yolks were those produced by the

Hy-Line W36 hens (17.1 g) compared with yolks of the ISA-Brown strain (16.1 g). These weights differ from those published by Johnston and Gous (2007), who registered lower yolk weight for Hy-Line Silver (15.9 g) and Hy-Line Brown (14.8) are lower than the values predicted by Nonis and Gous (2010), (23.2, g) or by Ferreira *et al*. (2015) (27, g). The latter dissimilarities are due to the large difference in egg weight between laying hens and broiler breeders.

Commercial egg producers have to cater for different markets depending on the demands of their customers so there is an advantage in being able to choose between strains of laying hens on the basis of the size of the eggs they lay, as well as the extent to which egg size changes over the laying period. The two strains used in this trial exhibited different patterns of yolk weight change over time (Table 1 and Fig's 1 and 2) suggesting that geneticists have used different selection goals for the two strains.

The high coefficient of determination between the three components of the egg confirm that albumen and shell weight can be expressed as simple power functions of yolk weight, which is in agreement with the literature (Emmans and Fisher, 1986; Johnston and Gous, 2007; Gous and Nonis, 2010). Interesting differences were again apparent between the two strains (Table 4) with the constant term for predicting albumen and shell weight from yolk weight being higher for ISA-Brown hens but with a lower slope than for Hy-Line W36 hens, which indicates that the rate of increase in albumen and shell weight is higher for Hy-Line W36 hens, but from a lower starting weight.

Table 4. Predicted four-weekly means for rate of lay, egg weight, yolk, albumen and shell weight for Hy-Line (H) and ISA-Brown (I)

Age	Rate of lay		Egg weight		Yolk weight		Albumen weight		Shell weight	
	H	I	H	I	H	I	H	I	H	I
20	91.6	83.0	50.9	48.4	10.3	7.3	35.7	35.8	4.9	5.2
24	97.1	93.0	55.8	56.4	12.4	11.0	38.2	39.6	5.1	5.7
28	97.8	96.2	58.6	60.4	13.7	13.1	39.6	41.4	5.3	6.0
32	96.8	97.8	60.4	62.7	14.6	14.3	40.5	42.3	5.4	6.1
36	95.2	96.3	61.6	63.9	15.6	15.0	41.1	42.8	5.4	6.2
40	93.5	93.4	62.5	64.7	15.6	15.4	41.5	43.0	5.5	6.3
44	91.8	91.7	63.2	65.1	15.9	15.6	41.8	43.2	5.5	6.3
48	90.1	90.0	63.9	65.4	16.2	15.8	42.1	43.3	5.5	6.3
52	88.5	88.5	64.4	65.6	16.5	15.9	42.4	43.4	5.5	6.3
56	86.9	87.0	65.0	65.8	16.8	16.0	42.6	43.5	5.6	6.3
60	85.4	85.5	65.5	65.9	17.1	16.1	42.9	43.5	5.6	6.3

The proportion of yolk in the egg increased with age and was similar for both strains during the laying period. In contrast the proportions of albumen and shell decreased during the same period (Fig.'s 1 and 2). These changes justify the prediction of each component of the egg over time when calculating the daily amino acid and energy requirements of a laying hen. Nevertheless, this approach for predicting egg weight underestimated the overall egg weight by 0.098 (P=0.28) and 0.37 g/d (P=0.04) for Hy-

Line W36 and ISA-Brown hens, respectively. A significant linear bias was observed for both Hy-Line W36 (slope= 0.06 ± 0.02, $P<0.0002$) and ISA-Brown hens (slope= 0.41 ± 0.05, $P<0.0001$).

The models for predicting egg weight were more accurate for Hy-Line W36 hens even though the residual error was higher at the start of laying period for both strains. Compared with the Hy-Line W36 manual guidelines overall egg weight was overestimated by less than 4% except at the start of the laying period where egg weight was overestimated by 10%. In the case of the ISA-Brown strain the predicted weights were slightly more accurate with the equivalent numbers being 3% overall, with an overestimate of 8 % at the start. The McMillan model appears not to predict yolk weight accurately at the start of the laying period (Ferreira *et al*., 2015).

The change in ICL over time was similar for both strains. At the start and at the end of the laying period the ICL was longer than daylength (24h) probably due to poor synchronization between LH release and follicle maturation initially and then later due to an increase in the number of atretic follicles (Johnson, 2000). As a result, the laying sequence is short initially; it then increases to reach a peak (prime sequence) before becoming shorter once more (Robinson *et al.,* 1990).

Whereas the overall pattern of ICL over time is similar between strains the extent to which these cycle lengths change over time differ both between and within strains. Large differences existed between the two strains measured in this trial and those used by Johnston and Gous (2007). At the start of the laying period, Johnston and Gous (2007) predicted an ICL of 24.4 h for Hy-Line Silver and 24.5 h for Hy-Line Brown, the shortest ICL (24 h) being achieved 50 d after sexual maturity in both strains. In the present study the ISA-Brown strain had an ICL of 33.8 h at the start, and the HyLine W36 strain an ICL of 28h (Fig. 4). At no point did the ICL of the two strains in the present study drop below 24 h, and their prime sequences occurred considerably later than did the two strains reported by Johnston and Gous (2007). These substantial differences between the strains must result in differences in the nutrient intakes required to achieve potential performance.

The AIC method used to compare different models identified the linear-plus-exponential model as being more accurate than the quadratic-by-linear model. Johnston and Gous (2007), Gous and Nonis (2010) and Ferreira et al. (2015) also favoured the linear-plus-exponential model for predicting ICL over time. The two latter papers referred to broiler breeders where the sequence length is considerably shorter than in commercial laying hens.

The process of recording egg production data from individually-caged hens over the entire laying period enables the variation in laying performance within a strain to be calculated. The best strategy to use when modelling a population of hens is to model each hen separately and then to determine the mean performance of the population. Each individual needs to be described, and it is from the variation observed in a sample population of hens that it is possible to describe the potential performance of each individual in terms of means and standard errors of the mean. These need to be applied to all the characteristics that describe an individual, including among many others, body protein content, age at sexual maturity, initial yolk weight, the allometric relationship between yolk and albumen weight, and the ICL over time. Based on the means and standard errors in Tables 1 to 3 the potential weight of the egg components and potential laying performance of each individual making up a given population may be generated, from which it would be possible to determine the daily intake of nutrients required to sustain that potential performance.

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CAPÍTULO 4 - Nutrient intake for laying hens based on the stochastic model

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Abstract

Poultry nutritionists should constantly evaluate their feeds and feeding programs in accordance with the potential egg production in laying hens. In this context, this study aimed to develop a simulation with stochastic model to predict daily nutrient intake for flock of light and semi-heavy laying hens based on the potential laying performance. The rate of lay was predicted by the ratio between the external (ECL) and internal cycle length (ICL). The ECL value was 24 hours and the ICL value was predicted by Linear-plus-exponential model for Hy-Line and ISA-Brown. McMillar model predicted the yolk weight and the other egg components were predicted by allometric functions. Based on these informations, daily effective energy and amino acid intake were predicted. The effective energy intake was calculated by the sum of energy for maintenance (EE_m) and energy for egg production (EE_c). The EE_m was calculated based on protein weight at maturity and the EE_c was calculated taking into account the weight of egg components and their energy content. At the same way, the digestible amino acid intake (AA) was calculated. The simulation was made for population of 50 laying hens from 18 to 70 weeks of age and include random normal distribution. The average egg weight were 55.1 g and 59.7 g at peak of egg production for Hy-Line and ISA-Brown. At this period, the average of effective energy and digestible lysine intake were 1067 kJ/d and 723 mg/d for Hy-Line and 1075 kJ/d and 744 mg/d for ISA-Brown. The simulation modelling could be estimated the daily intake of effective energy and digestible amino acid for laying hens under different genetic and population circumstances.

Keywords: Egg, Nutrition model, Population, Strains

Introduction

Large number of information about nutrient requirements was published in the last two decades. The first publication about nutrient requirement was registered in 1944 by National Research Council (Applegate & Angel, 2014). At the same way, others studies were conducted to estimated nutrient requirement take into account the different environmental conditions, much of this information has been available and it is so essential to feed formulation for the poultry industry. The optimization of feed can be result in huge benefits cost of feeding so it is essential to accurately predict nutrient requirement. In this context, the incorporation of models that consider the characteristics of potential of the laying hens could be a useful tool for the nutritionist in taking decisions.

A model can represent biological phenomena such as growth, egg production, absorption of nutrients, etc. (Rondón et al., 2002). This method allow us to estimate nutrient requirements in different environmental conditions and it is possible include the variation inherent to body weight, egg production and egg weight (Hurwitz & Bornstein, 1973). Therefore, modelling the nutrient requirement by stochastic or factorial models helps to predict the consequence of management changes and reduce the number of potential experiments (Álvarez & Hocking, 2007).

The stochastic model predict range of possible outcomes because this model include random elements (Rondón et al., 2002; Thornley and France, 2007). The range of the output variation depends on the individual variation so it is possible to incorporate this characteristic to optimize feeding program for the flock of laying birds and improve the profitability in poultry industry (Gous and Berhe, 2006). However, model building requires a satisfactory theory to describe the behavior of the biological system (Emmans and Fisher, 1986), as a result, many studies were conducted to provide concise information.

Fraps (1955) described physiological process that involving the ovulation, since then numerous studies have been developed to improve the knowledge on this process. Based on Fraps's theory, Etches and Schoch (1984) describe mathematically the ovulatory process for maximum nine eggs per sequence. However, the number of egg in the sequence change over the laying period. For this reason, Johnston and Gous (2006) developed a model to describe a large range of egg number in the sequence. Whereas, sequence length change between individuals and between genotype (Gous, 2014).

Genetic progress for improve egg production of laying hens has result in substantially different hens population. Nowadays, Laying birds are efficient and exigent with higher potential egg production so nutritional requirements changed for modern laying strains. Thus, this study aimed to develop a simulation with stochastic model to predict daily nutrient intake for flock of light and semi-heavy laying hens base on the potential laying performance.

Materials and methods

The simulation of the daily nutrient intake for laying hens based on the potential egg production was built in four sections: describing the laying hens, predicting the energy and amino acids intake, the assumption of the simulation modelling, and generating a population of laying hens.

Describing the laying hens

The simulation modelling based on data inputs in the Table 1 and 2 provide the following information for Hy-Line and ISA-Brown: rate of lay, egg weight, the weight of the egg components (yolk, albumen and shell).

Table 1. Inputs in the simulation modelling

Strains	Hy-Line	ISA-Brown
Average body weight (kg)	1.5[a]	1.8[b]
CV of body weight (%)	10	10
Body protein (%)	17	17
CV of body protein (%)	1	1
age at change in photoperiod (days)	49	49
Initial photoperiod - during rearing (hours)	12	12
Final photoperiod - during rearing (hours)	14	14
Daylength (hours)	24	24

[a]Hy-Line (2013), [b]ISA-Brown (2011)

General information for Hy-Line and ISA-Brown was obtained from manual guideline (Table 1). Data used to estimate the model parameters to describe the egg weight and the internal cycle length in two modern laying strains were obtained from a trial conducted at the Laboratory of Poultry Science of the Faculty of Agriculture and Veterinary Sciences (FCAV), Universidade Estadual Paulista (UNESP), Jaboticabal, São Paulo, Brazil.

Table 2. Parameters values to describe the internal cycle length (ICL), yolk, albumen and shell weight for Hy-Line and ISA-Brown

Strain	Hy-Line	ISA-Brown
Internal cycle length	ICL=A+B×(R^T)+C×T	
A	22.95	24.01
B	5.24	10.29
C	0.02	0.004
R	0.96	0.94
yolk weight	y=A×(1-e^((-c×(t-D))))×e^((-R×t))	
A	13.66	15.55
C	0.02	0.02
D	81.46	106.9
R	0.0005	0.00008
Albumen weight	AW=a×y^b	
a	15.07	21.99
b	0.37	0.24
Shell weight	SH=a×(AW+y)^b	
a	0.7	1.6
b	0.5	0.34

T = time from first egg, t = age in days of laying hen

One hundred and twenty laying hens of ISA-Brown and Hy-Line W36 strain were used. The birds were housed in galvanized wire cages at 18 weeks of age in a climate-controlled facility with temperature according to the strain guidelines recommended by ISA-Brown (2013) and Hy-Line (2014). Feed and water were available *ad libitum*. When egg production in the flock exceeded 5 eggs/ 100 hens, the photoperiod was increased from 14 hours, by one hour per week, until a maximum of 16 h light was reached, whereafter this lighting programme was maintained to the end of the trial when the birds were 60 weeks of age. Feed intake (g/bird d) and body weight (kg/bird) were measured at the end of each week; egg production and egg weight (g) were recorded daily and the weight of the egg components was measured three times per week. These data were used to calculate the parameters of McMillan, allometric and line-plus-exponential models (Table 2) for predicting the weights of yolk, albumen and shell, internal cycle length, respectively, using the SAS PROC NLIN (Statistical Analysis System, version 9.0).

All the information described above was used to describe laying hens for the simulation modelling. Additionally, the age at sexual maturity (AFE) and the standard deviation was predict by the following model: 63.3+0.619X, where X is age (days) at change in the photoperiod (Gous et al., 2000). In the simulation, hen lay based on the value of ICL, external cycle length (ECL) and time of egg output (TEO). The value of TEO was eight hours at the start egg production period or after the pause days and the standard variation of this value was two hours. The following TEO for the next day was calculated by the sum of the initial value of TEO (8 h) and the value of the difference between the internal and the external cycle length. Therefore, hen lay when sum of lag and the time of egg output in hours was lower than 16 hours.

Predicting the energy and the amino acids intake

The nutrient requirements are calculated by the sum of nutrient required for maintenance, yolk, albumen and shell production. Effective energy intake for maintenance was predicted by the following equation (Emmans and Fisher, 1986):

$$EE_m = m \times Bp_m{}^{0.73} \times \mu \qquad \text{Eq [1]}$$

where, *m* is the energy requirement per maintenance unit (MJ/kg) and the value of this parameter for energy is 1.63 MJ/$P_m^{0.73}$, BP_m is maturity body protein weight (g/kg), μ is the degree of maturity in body protein, and the value is one in the simulation modelling. At the same way, amino acid requirement for maintenance was predicted:

$$AA_m = (a \times m \times Bp_m{}^{0.73} \times \mu)/e_m \qquad \text{Eq [2]}$$

where, *a* is the amino acid in the body protein (Table 1), *m* is coefficient of amino acid for maintenance (mg/kg) and the value of this parameter is 0.008 kg/$P_m^{0.73}$, e_m is the efficiency of amino acid utilization for maintenance and the value is one in the simulation modelling.

The energy requirement for yolk, albumen and shell was predicted by the following equation (Emmans and Fisher, 1986):

$$EE_C = CN \times Y \qquad \text{Eq [3]}$$

where, EE_c is the energy (MJ) requirement to produce yolk, albumen or shell output. *CN* is the energy contained in the yolk, albumen and shell and the value of this parameter was 25, 3.6 and 1.2 MJ/kg, respectively.

The digestible amino acid requirement for yolk, albumen and shell were predicted by the following equation (Emmans and Fisher, 1986):

$$AA_c = NC \times CAA/e_p \qquad \text{Eq [4]}$$

where, *AA* is the digestible amino acid requirement to produce yolk, albumen or shell output, *NC* is the nitrogen contained in the yolk and albumen, the value of this parameter was obtained to multiplied the yolk and albumen weight per 0.027 and 0.017 N/g, respectively. *CAA* is the amino acid content (mg/g N) in the yolk and albumen (Table 3), e_p is the efficiency of amino acid utilization for egg production and the value is 0.8 for all the amino acids in the simulation modelling.

Table 3. Amino acid composition (mg/g nitrogen)

Amino acids*	Body protein (g/kg protein)	Yolk (mg/g nitrogen)	Albumen (mg/g nitrogen)
Arginine	68	434	330
Histidine	26	148	132
Isoleucine	40	348	331
Leucine	71	548	521
Lysine	75	477	378
Methionine	25	175	240
Phenilalanine	40	261	368
Threonine	42	313	272
Valine	44	378	429
Methionine+Cystine	36	338	418
Phenilalanine+Tyrosine	71	514	625
Tryptophano	10	121	116

*From Lumven et al. (1973) and Fisher (1998)

Assumptions of the simulation modelling

It was supposed that the egg production of laying hens was simulated in a thermoneutral environment because under this condition the actual egg production will be the potential egg production (Emmans and Kyriazakis, 1999). The growth of body birds after the first egg was not consider, consequently the nutrient intake were calculated taking into account the nutrient for maintenance and potential of egg production. Additionally, the simulation modelling does not take into account the variation in the composition of feed and it is assumed that vitamins, minerals and essential fatty acids are not limiting the egg production and it is constant over the laying period.

Generating a population of laying hens

The models (Table 2) and all the information described above were integrated in the Microsoft Excel 2013 for population of fifty laying hens from 18 to 70 weeks of age. The simulation of population was created by include random normal distribution to describe the performance in the population of laying birds using the following generalised equation:

$$V = ((SQRT(-2 \times LN(RAND(\,))) \times SIN(2 \times PI(\,) * RAND(\,))) \times SD) + MEAN$$

Where, V is a standardized normally distributed value for each bird. RAND() is a command to generate a random number (range 0 - 1), SQRT is square root, LN is natural logarithm, SIN is sine and PI is mathematical constant, SD is the standard deviation.

Results

The egg production simulation of 50 individuals hens for both strains made it possible to describe the potential egg production over the laying period and gave the knowledge about the daily egg production and egg components weight for flock of Hy-Line and ISA-Brown laying hens. Additionally, simulation modelling for flock of laying hens predicted the daily intake of effective energy and digestible amino acids and described the variation.

Table 4. Predicted mean weight of yolk, albumen, shell, egg and percentage of lay from Hy-Line (H) and ISA-Brown (I)

Age	Yolk (g)		Albumen (g)		Shell (g)		Egg weight (g)		Lay (%)	
	H	I	H	I	H	I	H	I	H	I
20	10.5	7.9	35.4	36.2	4.8	5.2	50.8	49.3	40.0	33.1
24	12.3	11.2	37.4	38.4	5.0	5.6	54.7	55.9	92.3	86.9
28	12.7	12.7	36.1	39.1	4.8	5.5	53.5	55.3	97.4	95.4
32	13.5	13.9	36.9	40.5	4.9	5.8	55.1	59.7	97.4	94.3
36	14.5	14.9	38.8	40.3	5.1	5.8	58.3	58.9	95.4	93.1
40	15.2	15.1	40.2	41.5	5.3	6.0	60.6	64.1	92.9	92.3
44	15.6	15.4	41.1	41.5	5.4	6.2	62.1	63.3	90.0	91.7
48	16.0	15.4	41.5	43.2	5.4	6.3	62.8	64.1	86.9	89.7
52	16.3	15.5	41.8	41.8	5.5	6.2	63.6	65.1	84.0	88.3
56	16.8	16.0	42.7	43.0	5.6	6.3	65.1	65.5	83.4	85.1
60	17.1	16.0	42.7	43.4	5.6	6.3	65.3	65.4	80.0	86.0
64	17.2	16.1	43.0	43.4	5.6	6.3	65.9	65.5	78.6	84.0
68	17.6	16.1	43.3	43.6	5.6	6.3	66.5	65.6	74.6	81.1

Table 4 shows the mean weights of egg components and the percentage of lay for Hy-Line and ISA-Brown laying hens at four weekly intervals. The average weight of yolk, albumen and shell increased over the laying period for both laying hen strains but with different rates. The ratio of yolk:egg weight at the start of laying period was 20 % and 16 % for Hy-Line and ISA-Brown, these values increased in 4% and 7% at peak of egg production (32 weeks of age) and in 2 % and 1 %from 32 to 68 weeks of age for Hy-Line and ISA-Brown, respectively. At the same way, the ratio of albumen:egg weight decreased in 2.8 % and 5.5 % from 20 to 32 weeks of age and in 1.8 % and 1.4 % from 32 to 68 weeks of age for Hy-Line and ISA-Brown. Additionally, the ratio of shell:egg weight decreased in 0.7 % and 0.9 % from 20 to 32 weeks of age and in 0.3 % and 0.1 % from 32 to 68 weeks of age for Hy-Line and ISA-Brown.

The average of egg weight increased with age for both laying hen. At the start of laying period the egg weight was 50.8 g and 49.3 g for Hy-Line and ISA-Brown, these values increased in 8 % (55.1 g) and 21 % (59.7 g) at peak of egg production (32 weeks of age) and in 20 % (66.5 g) and 9 % (65.6) from 32 to 68 weeks of ages for Hy-Line and ISA-Brown, respectively. Additionally, the average egg weight for Hy-Line was lower than ISA-Brown over the laying period except at the start and at the end of egg production. In contrast, percentage of lay increase for both strains until reach the peak production at 32 weeks of ages; follow this time the lay decreased and reach 75% and 81% for Hy-Line and ISA-Brown at the end of the simulation (68 week of ages).

Daily intake of energy, lysine and methionine+cystine of simulation with fifty individual's hens for both strains are presented in Table 4. The simulation modelling provided a range of outcomes taking into account the individual variation. Lower difference between the average and the minimum nutrient requirement was presented at the start of egg production. In contrast, the average and the maximum nutrient requirement presented lower difference at peak of egg production. At the start of laying period, the average of effective energy requirement was 764 kJ/d and 753 kJ/d for Hy-Line and ISA-Brown, respectively. These values increased in 40% (1067 kJ/d) and 42% (1075 kJ/d) at peak of egg production (32 weeks of age) for Hy-Line and ISA-Brown, respectively. The Higher value of effective energy was 1098 kJ/ d and 1099 kJ/ d at 40 and 48 weeks of age for Hy-Line and ISA-Brown, respectively. Since this age, the daily energy intake decrease and reach 1063 kJ/ d and 1068 kJ/ d at 68 weeks of age

Similar to effective energy, the simulation modelling provided a range of outcomes of digestible lysine intake. Difference at start of egg production between the average and the minimum digestible lysine intake was 205 mg/d and 196 mg/ d and at peak production was 477 mg/ d and 482 mg/ d for Hy-Line and ISA-Brown, respectively. At the start of laying period, the average of digestible lysine intake was 406 and 282 mg/ d for Hy-Line and ISA-Brown, respectively. These values increased their initial value in 317 mg and 334 mg at peak of egg production (32 weeks of age) for Hy-Line and ISA-Brown, respectively. Like the effective energy, the higher value of digestible lysine intake was 740 mg/ d and 595 mg/ d at 40 weeks of age and it for Hy-Line and ISA-Brown, respectively. At the same way, difference between the average and the minimum digestible methionine+cystine intake was 186 mg/d and 189 mg/ d at start of egg production and this difference was 450 mg/ d and 467 mg/ d at peak production for Hy-Line W36 and ISA-Brown, respectively. At the start of laying period, the average of digestible methionine+cystine intake was 282 and 292 mg/ d for Hy-Line W36 and ISA-Brown, respectively. These values increased their initial value in 294 mg and 308 mg at peak of egg production (32 weeks of age) for Hy-Line W36 and ISA-Brown, respectively. Like lysine, highest value of methionine+cystine was 600 mg/ d and 610 mg/ d at 40 and 48 weeks of age for Hy-Line W36 and ISA-Brown, respectively.

Table 5. Predicted minimum, mean and maximum daily intake of energy (kJ/d), lysine (mg/d) and methionine + cysteine (mg/d) intakes for theoretical population of 50 laying hens of Hy-Line and ISA-Brown, using the data shown in Table 1

Age	----------Energy----------			------------Lysine----------			-----------Met+Cys-------		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
---Hy-Line---									
20	550	764	900	201	406	581	96	282	454
24	610	1019	1120	240	684	759	122	544	617

28	590	1045	1240	233	704	848	119	561	678
32	630	1067	1240	246	723	853	126	576	684
36	630	1090	1280	246	744	880	126	595	704
40	640	1098	1280	249	750	877	127	600	714
44	610	1097	1340	238	748	916	122	598	730
48	580	1090	1310	227	738	886	116	587	714
52	580	1083	1290	227	728	918	116	578	746
56	580	1095	1290	227	739	907	116	586	735
60	600	1081	1290	233	722	910	119	570	736
64	570	1078	1300	223	718	895	115	566	717
68	580	1063	1290	228	700	923	117	549	751
ISA-Brown									
20	590	753	820	215	411	300	103	292	144
24	610	978	1140	226	661	778	108	530	625
28	710	1009	1250	277	679	844	140	541	672
32	680	1075	1270	262	744	854	133	600	681
36	690	1078	1300	269	741	878	136	596	708
40	650	1070	1370	253	730	927	129	584	738
44	690	1088	1390	267	748	933	136	600	740
48	690	1099	1380	270	759	948	137	610	759
52	630	1080	1370	247	737	959	126	589	771
56	620	1090	1380	242	748	924	123	599	731
60	700	1085	1300	254	742	897	129	594	722
64	690	1079	1360	269	733	916	137	585	727
68	660	1068	1370	258	722	919	131	575	729

Discussion

The simulation of fifty hens allows us to describe the potential egg production based on the egg production and egg components weight for individual hen, by this way show how the individual variation of the performance of laying hen affected the predicted energy and the amino acid (lysine and methionine+cystine) intake for flock of light and semi-heavy laying hens. The main advantage of this method is predicted the daily intake of effective energy and amino acid for any population of laying hens because this arrangement predict the nutrient intake as a function of the given potential laying performance and considering the inherent variation in egg production, egg weight and body weight.

the simulation of potential egg production show that the predicted egg weight increase over the laying period, as well as the egg components. In fact, egg components have greater development due to the effect of age (Emmans and Fisher, 1986; Hussein et al., 1993; Di Masso et al., 1998; Johnston and Gous, 2007; Gous and Nonis, 2010). This effect was considered by the simulation for each egg components, since the McMillan model predict the yolk weight include the age of laying hens, consequently the weight of albumen and shell are predicted taking into account the effect of age by alometric function.

The lowest ratio of yolk:egg weight at the start of laying period was related with the low yolk weight for both strains of laying hens and the lowest value was presented for ISA-Brown laying hen. Consequently, the albumen and shell weight also was affected by the interrelationship between yolk weight and albumen weight. However, the growth rate of yolk for ISA-Brown was higher than Hy-Line for this reason the yolk weight increased in 76% and 28% and reach 13.5 g and 13.9 g at peak of egg production (32 weeks of age) for Hy-Line and ISA-Brown hens, respectively. On the other hand, the albumen and shell weight increase over the laying period but the ratio of albumen:egg weight and shell:egg weight decreased because the growth of yolk was higher than the growth of the other egg components. In all cases, the predicted yolk weight is quite similar for both strains, although, the predicted weight of albumen and shell for ISA-Brown was higher than Hy-Line hens and this result is according to manual guidelines.

The average of egg weight increased due to the effect of age on the egg components for both strains of laying hens (Johnston and Gous, 2007; Ferreira *et al*., 2015). The simulation modelling for predicted egg weight overestimated in less 3 g the recorded by the Hy-Line manual guideline, except at the start of laying period, in which cases the predicted value of egg weight overestimated in 5 g. In contrast, the simulation for predicted egg weight underestimated in less 5 g the recorded by ISA-Brown manual guideline. The difference at the start of the laying period was due to the McMillan model is less accurate to predict the yolk weight at the start of laying period (Ferreira *et al*., 2015).

The simulation of flock of light and semi-heavy laying hens allows us widely description the daily intake of effective energy and amino acids for maintenance and for yolk and albumen synthesis over the laying period. The body protein weight are constant over the time in the simulation of egg production, for this reason the difference in energy and amino acid intake due to the egg output (egg weight X egg production). The rate of lay of ISA-Brown was lower than Hy-Line W36 because the initial value of ICL was higher at the start of the laying period (Figure 1 and 2). However, the rate of lay for Hy-Line W36 decrease is faster than ISA-Brown so the egg number is quite similar for both strains.

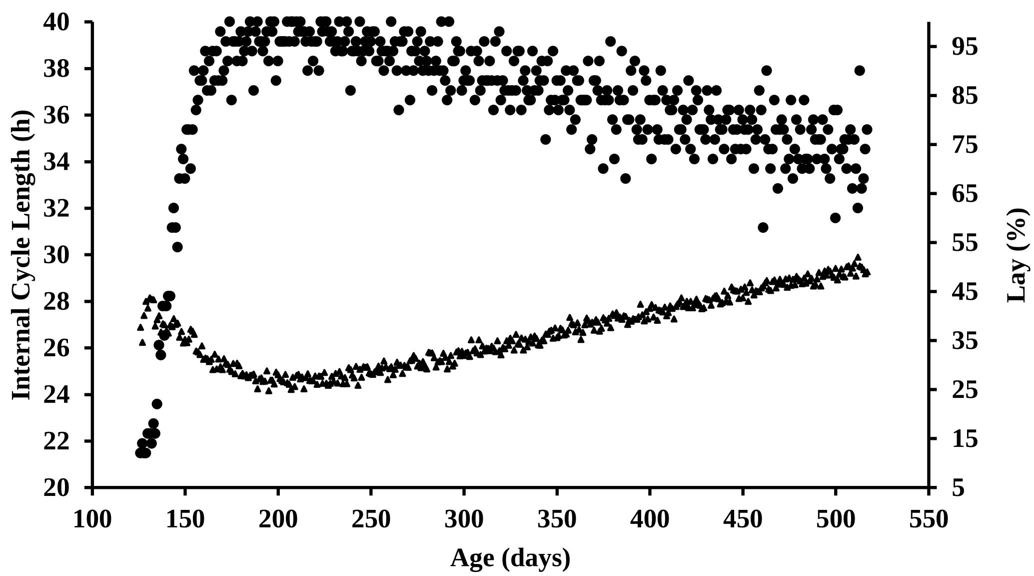

Figure 1. Internal cycle length (▲) and percentage of lay (●) for theoretical population of 50 laying hens of Hy-Line, using the data shown in Table 1.

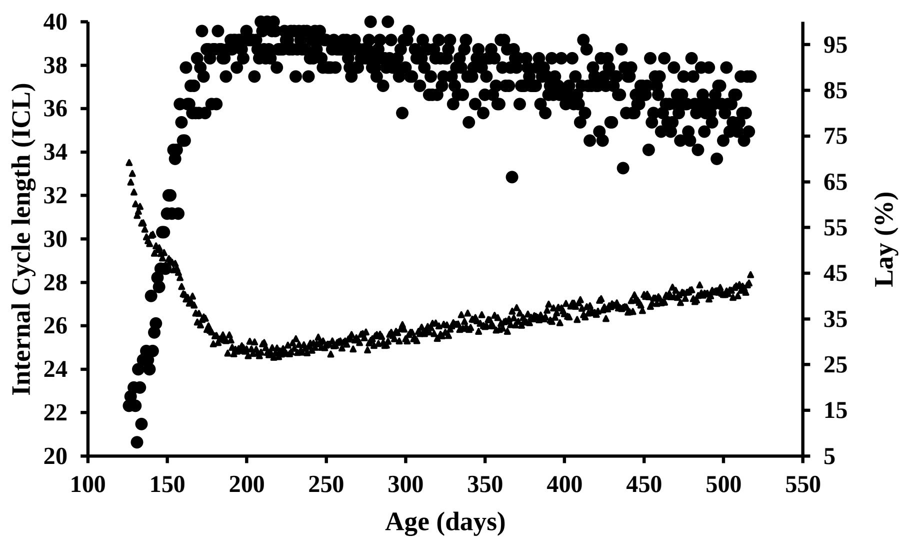

Figure 2. Internal cycle length (▲) and percentage of lay (●) for theoretical population of 50 laying hens of ISA-Brown, using the data shown in Table 1.

Braziliam table for poultry and swine (Rostagno et al., 2011) and commercial management guide for Hy-Line W36 and ISA-Brown provide nutritional recommendations for energy and digestible amino acids. The models used in the simulation allow us to predict a range outcome of digestible amino acids intake for flock of laying hens and this range included the recommendation proposed by Rostagno et al. (2011). In contrast, the digestible amino acid intake proposed by commercial management guide are higher than the recommended by the simulation modelling.

The average predicted value represents the requirement for average individual and the maximum predicted value represent the requirement for the most demanding individual. The difference between the average predicted value and the maximum predicted value was around 15 % for all the cases. In general, the simulation modelling predicted greater range of requirements for amino acid intake to population. Compared to the nutritional recommendation for manual guidelines at 32 weeks of age, the maximum digestible lysine intake were 8 % and 1% higher than the guidelines for Hy-Line W36 and ISA-Brown, respectively. As well as, the maximum digestible methionine+cystine intake were 6 % and 4% higher than the guidelines for Hy-Line W36 and ISA-Brown, respectively.

The predicted range of lysine and methionine+cystine intake by the simulation modelling were close to those of Bendezu et al. (2015), who found the optimum intakes of these amino acids by Reading model (Fisher et al., 1973) in different economic circumstance. The optimum economic intake of the amino acids depends not only the potential laying performance of the flock but also the relationship between the marginal cost of the amino acids and the marginal revenue for eggs. In conclusion, the simulation could be estimated the effective energy and digestible amino acid intake for laying hens under different genetic and population circumstances. Additionally, the values of the parameters used by the simulation reported a further evidence that can be applied to predict energy and amino acid intake considering the effect of age on egg output and egg components.

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CAPÍTULO 5 - The effect of feed protein content on the uniformity of production in laying hens

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ABSTRACT

The objective of this research was to describe the effect of dietary protein content on the uniformity of egg production in ISA-Brown and Hy-Line laying strains. Six dietary protein levels (120 to 220 g protein/kg feed) were each fed to sixteen individually-caged hens, per treatment and strain, during the first six weeks of the trial from 28 weeks of age. During the second phase, from 35 weeks, only one feed was offered, this containing 175 g protein/kg. Egg production, feed intake, egg weight, egg output and changes in body weight were measured. Some birds were sampled before the trial began, after six- and again after ten-weeks for carcass analysis.

Maximum egg output differed between strains but the marginal response to dietary protein was the same in both strains, the coefficients of response being 220 mg protein/g egg output and 9.0 g per kg body weight.

The coefficient of variation (CV) in egg output was low in both strains fed the highest protein feed but increased as the dietary protein level dropped, with the biggest increase occurring in outputs between birds fed 140 and 120 g protein/kg. These increases were particularly marked in the ISA strain, being almost twice as high as those of the Hy-Line strain. Similarly the lowest CV's in daily food intake were on the highest protein feeds, with a two- to three-fold increase on the lowest dietary protein levels, but with both strains in this case showing similar degrees of uniformity. Variation in body lipid content was higher in the ISA strain between dietary treatments.

Uniformity in egg output is increased at the highest intakes of dietary protein because the amino acid requirements of an increasing proportion of the population are met by these higher protein contents. As the protein supply becomes marginal and then deficient uniformity is decreased not only because the most demanding individuals cannot consume sufficient to achieve their potential, but also because birds differ in their ability to deposit excess energy as body lipid when attempting to consume sufficient of a feed limiting in protein. This ability to fatten differs not only between individuals within a population but between strains, as shown in the differences between the two strains used in this trial.

Introduction

Uniformity is an important measure of performance when optimising the feed and feeding programme of broilers and laying hens as it relates to the spread of product yield available for sale. Poor uniformity reduces revenue and increases waste so poultry producers need to take account of any factors that may influence this.

There is strong evidence that uniformity is increased by feeding higher levels of a limiting amino acid or protein (Duncan, 1988; Lemme, 2003; Berhe & Gous, 2008). Lemme (2003) described how the coefficient of variation (CV %) in liveweight at 42 d was reduced by 0.40 and breast meat yield by 0.47 through the supplementation of DL Methionine to a basal feed. Supplemental vitamins too have been reported to improve uniformity in a broiler flock. McNaughton (1995) applied different levels of stress to broilers and reported continuing economic responses in several characteristics up to the highest level of vitamins tested. There was little convincing evidence in his trial that the response to vitamin level depended on the level of stress applied, as performance improved with increasing vitamin doses even when no stress was applied.

The reason for the improved uniformity is that the requirements of a greater proportion of the population will be met as the concentration of the limiting feed resource is increased. Fisher *et al*. (1973) showed that the response of an individual laying hen to an increasing supply of an amino acid differs markedly from that of the population from which the individual is drawn. Whereas the response of each hen can be assumed to be linear, up to a point where output plateaus (the genetic potential), the population response is a continuous, asymptotic curve with no abrupt threshold. This population response curve, the mean response of a group of individuals at a time, is the result of the variation that exists in both body weight (maintenance requirement) and the potential egg output of the population. This so-called Reading Model (Fisher *et al*., 1973) may be used to determine the optimum economic intake of the limiting amino acid for a flock of hens. The increased egg output of those birds with above-average requirements for maintenance and above-average maximum potential egg outputs justifies the cost of increasing the amino acid intake by all birds.

The theory of food intake proposed by Emmans (1981; 1987) suggests that a bird will attempt to consume sufficient of a given food to enable it to grow or reproduce at its potential, thus overconsuming energy if the feed is marginally deficient in an essential nutrient such as an amino acid. It is apparent that strains of broilers and individuals within a strain overconsume energy to different extents when faced with a marginally deficient feed (Gous *et al*., 1990; Corzo *et al*., 2004; Kemp *et al*., 2005; Berhe & Gous, 2008). It is likely therefore that such feeds will reduce uniformity, as some birds will be capable of consuming more than others and would thus benefit from the extra feed intake. The ability to overconsume energy when faced with a marginal deficiency of an essential nutrient in the feed will depend on the extent to which the bird is capable of depositing lipid: modern pig genotypes, for example, are incapable of depositing as much body lipid as a Meishan pig, and would therefore not be capable of surviving on the poor quality feeds conventionally fed to the Meishan strain**.** Two issues are therefore involved in determining the uniformity of performance in a flock of laying hens: the potential performance differs between individuals as does their ability to overcome a marginal deficiency by consuming more and depositing the excess energy consumed as body lipid.

In this trial two strains that differ in their egg production potential were housed and monitored individually so as to determine the extent to which their egg laying performance and daily food intake were influenced by feeds marginally deficient in protein.

Material and Methods

The study was conducted at the Laboratory of Poultry Science, Faculty of Agriculture and Veterinary Sciences (FCAV) of the São Paulo State University “Júlio de Mesquita Filho” (UNESP), Jaboticabal, SP, Brazil, from April 2014 to July 2014.

Isa-Brown and Hy-Line W-36 laying hens, 28 weeks of age, were used in the trial, with 96 hens of each strain being housed individually in galvanized wire cages in a climate-controlled facility with temperature and humidity according to the strain guidelines (Isa-Brown, 2011; Hy-Line, 2013). The cages were divided into four compartments measuring 25 x 40 x 40 cm, each with one bird per compartment and with 16 birds per replication. Each cage was equipped with a galvanized feeder and nipple drinker. The management and light program followed the recommendations of the strain guidelines, using 16 h of continuous light per d.

The birds were sorted according to body weight and egg production to provide the same conditions for all treatments at the beginning of the trial. The experiment was divided in two phases. The first phase started when the hens were 28 w of age and continued for 6 weeks. The dietary treatments used during this phase consisted of six levels of protein, ranging from 120 to 220 g/kg prepared using a dilution technique (Fisher and Morris, 1970) in which a high protein summit diet is blended with a low protein diet (100:0, 80:20, 60:40, 40:60, 20:80, 0:100) to produce the desired range of protein levels. The second phase started at 35 weeks of age and for the next four weeks only one level of protein (175 g/kg) was fed (Table 1).

Table 1. Composition of the experimental diets used in the first (28 to 34 weeks) and second (35 to 38 weeks of age) phases of the trial

Ingredients	First phase		Second phase
	Summit diet	Dilution diet	
Maize	417	533	585
Wheat bran	-	148	-
Soybean meal (46%)	400	111	275
Limestone	93.5	95.2	91.4
Dicalcium phosphate	18.9	19.1	19.5
Soybean oil	56.9	80.0	19.3
DL-Methionine (98%)	4.00	1.32	2.81
Salt	2.64	1.01	1.85
Sodium bicarbonate	2.50	5.20	1.50
Mineral/Vitamin supplement[1]	1.00	1.00	1.00
Potassium chloride (98.5%)	-	1.21	-
Choline chloride (60%)	0.50	2.15	0.89
L-Threonine (98.5%)	1.15	0.50	0.68
L-Valine (98%)	1.00	0.30	0.52
Antoxidant[2]	0.10	0.10	0.10
L-Lysine (78.5%)	-	0.81	-
Calculated nutrient content			
Crude protein	220 (224)	120 (122)	174 (172)
ME (MJ/kg)	11.9	11.9	11.9
Lysine	10.5	5.01	7.79
Methionine+Cysteine	9.25	4.56	7.28
Methionine	6.63	2.87	5.03
Threonine	7.79	3.81	6.08
Tryptophan	2.49	1.18	1.89
Valine	9.75	4.76	7.60
Isoleucine	8.60	3.91	6.60
Calcium	42.0	42.0	42.0
Av. Phosphorus	4.60	4.60	4.60
Sodium	2.13	2.09	1.50
Chloride	1.90	1.90	1.50

(1)Content/kg. vit A=7,000,000UI, vit E=5,000UI, vit B_2=3,000mg, vit D_3=2000000UI, vit B_{12}=8,000mcg, pantothenic acid = 5000mg, vit B_3=20g, vit K_3=1600mg, selenium=200 mg, manganese = 70 g, iron =50g, zinc = 50g, copper = 8000 mg, iodine = 1200 mg, (2)Butylhyidroxy toluene, (2) The numbers in parentheses refer to the composition analyzed (N*6.25).

Egg production was recorded daily and egg weight (g) was measured three times each week. These data were used to calculate egg mass output (g/bird d). Feed intake (g/bird d) was measured at the same time each day as the difference between the feed offered and left-over, these intakes being averaged to obtain a weekly mean intake per bird.

At the start of the experiment 40 laying hens from the same populations of Isa-Brown and Hy-Line W-36 strains were slaughtered. Additionally, four birds were slaughtered per treatment during the sixth and tenth weeks of the experiment. The birds selected for sampling were fasted for 24 hours and then killed by CO_2 asphyxiation. The feathers and the feather-free body were separated, weighed and then freeze dried to determine the water content. Dried carcass samples were analysed for ether extract (Soxhlet equipment) and nitrogen content (Kjeldahl method, crude protein=nitrogen x 6.25). Feather samples were chopped with a cutter mill and protein was then determined also by the Kjeldahl method. The protein weight of each bird was calculated as the sum of protein content in the carcass and in the feathers. AOAC methods were followed in all analyses.

The Reading Model (Fisher *et al*., 1973) was fitted to the response data for each strain and for the two strains combined using their mean body weights at the end of week 6, the mean dietary protein intakes and egg outputs during weeks 4 to 6 of the trial period, standard deviations of 0.1 for body weight and 0.15 for mean maximum egg output, and with a correlation of zero between body weight and egg output.

Coefficients of variation (CV) were calculated as SE/mean for egg outputs and food intakes of each treatment and strain and the means over weeks 4 – 6 were calculated.

Table 2. Mean food intake, rate of laying, egg weight and change in body weight of Hy-Line and ISA laying hens fed six levels of dietary protein over the last three weeks of a six-week trial period

Dietary protein, g/kg	Food intake, g/bird d			Rate of laying /100 birds			Egg weight, g			Change in weight, g/bird d		
	Hy-Line	ISA	Mean	Hy-Line	ISA	Mean	Hy-Line	ISA	Mean	Hy-Line	ISA	Mean
120	78.3	80.1	79.2	67.3	61.0	64.1	56.3	55.8	56.1	-0.71	-0.12	-0.42
140	91.9	99.4	95.6	87.5	95.2	91.4	58.9	59.0	58.9	-1.94	2.41	0.23
160	92.7	104.6	98.6	92.3	98.8	95.5	59.2	63.5	61.3	0.85	4.19	2.52
180	92.3	94.0	93.1	94.1	91.8	92.9	60.2	60.6	60.4	1.59	2.24	1.91
200	89.1	101.8	95.5	95.2	99.7	97.5	59.9	65.2	62.5	2.09	2.91	2.50
220	94.2	102.3	98.3	96.4	96.4	96.4	60.5	64.0	62.2	2.10	1.93	2.01
	89.7	97.0		88.8	90.5		59.2	61.3		0.66	2.26	
RSD	140 (178 d.f.)			160 (178 d.f.)			18.9 (177 d.f.)			8.12 (176 d.f.)		

The mean performance of the hens in the final two weeks of the ten-week trial was determined to ascertain to what extent the birds on the lowest protein feeds during the first six weeks would return to normal when placed on a feed adequate in dietary protein.

Results

To measure the response of the two strains of laying hen to dietary protein the performance during the three week period from week 4 to 6 of the experimental period was averaged, and these are given in Table 2. In both strains mean food intake, rate of laying, egg weight and change in body weight were all lower on the lowest dietary protein level but essentially similar on the three or four highest protein levels. The ISA strain consumed more food, had a higher rate of laying and egg weight and grew at a faster rate than the Hy-Line strain.

Table 3. Mean protein intake (g/d), observed and predicted[1] egg output (g/bird d) of Hy-Line and ISA laying hens fed six levels of dietary protein over the last three weeks of a six-week trial period

Dietary protein, g/kg	Protein intake, g/d			Egg output, g/bird d			Predicted[1] egg output		
	Hy-Line	ISA	Mean	Hy-Line	ISA	Mean	Hy-Line	ISA	Mean
120	9.4	9.6	9.5	38.9	37.3	38.1	36.9	36.9	36.9
140	12.9	13.9	13.4	51.3	56.3	53.8	52.6	56.4	52.5
160	14.8	16.7	15.8	54.6	62.7	58.7	56.7	61.5	59.1
180	16.6	16.9	16.8	57.3	56.4	56.9	56.8	61.5	59.2
200	17.8	20.4	19.1	57.0	65.0	61.0	56.8	61.5	59.2
220	20.7	22.5	21.6	58.2	61.7	60.0	56.8	61.5	59.2
	15.4	16.7		52.9	56.6		52.8	56.6	
RSD	3.20 (178 d.f.)			56.7 (177 d.f.)					

[1] Predicted using the Reading Model of Fisher *et al*.(1973). For parameter estimates see text

In fitting the Reading Model to response data the mean dietary protein intakes and egg outputs on the various dietary treatments are required. These are given in Table 3 for both strains of laying hen. The dietary treatments imposed resulted in a continual increase in dietary protein intake whereas egg output reached a plateau after the third or fourth level of dietary protein. Whereas the maximum egg output differed between strains the marginal response to dietary protein was the same, the coefficients of response for both strains being 220 mg protein/g egg output and 9.0 g per kg body weight. Using these coefficients the egg outputs predicted for the different protein intakes measured are given in Table 3. The SS deviations when fitting the model to these data was 7.80.

Table 4. Mean body plus feather protein and body lipid weights after 6 and 10 weeks of the start[1] of the trial

Dietary protein, g/kg	Protein weight				Body lipid weight			
	Week 6		Week 10		Week 6		Week 10	
	Hy-Line	ISA	Hy-Line	ISA	Hy-Line	ISA	Hy-Line	ISA
120	300	301	291	332	235	257	240	314
140	279	354	289	323	206	276	286	240
160	283	326	289	325	247	242	280	277
180	270	364	280	344	227	375	222	365
200	279	339	277	332	252	332	215	254
220	244	324	305	336	205	273	262	231
Mean	276	335	288	332	229	293	251	280

[1] Initial conditions: Body + feather weight, Hy-Line = 280 g, CV = 4.4%
ISA = 358 g, CV = 18.5%
Body lipid weight, Hy-Line = 194 g, CV = 12.5
ISA = 240 g, CV = 19.6

Mean body plus feather protein weights at the start of the experiment, and after 6 and 10 weeks of the trial are given in Table 4. Initially the ISA strain had 78 g more protein and a lower uniformity (18.5 *vs.* 4.4 % CV) than the Hy-Line strain, and 46 g more body lipid with a slightly lower uniformity (19.6 vs. 12.5 % CV). After six weeks on the experimental diets the differences were similar between strains, with ISA having 59 g more protein and 64 g more lipid than the Hy-Line strain. Body and feather protein weights on the different dietary treatments were similar in both strains with a range of only 63 (ISA) and 56 g (Hy-Line) respectively. Although there were no consistent trends in body lipid content between treatments the range in lipid weights was considerably greater (133 g) with the ISA than with the Hy-Line (42 g) strain. These differences were still evident after ten weeks of the trial.

Table 5. Coefficients of variation of mean egg output over three periods during the trial resulting from feeding six levels of dietary protein to Hy-Line and ISA strains

Protein	Mean weeks 1 -3		Mean weeks 4 - 6		Mean weeks 7 - 10	
content	Hy-Line	ISA	Hy-Line	ISA	Hy-Line	ISA
120	12.7	25.1	25.5	40.9	14.3	30.1
140	8.8	18.4	10.9	19.2	12.3	20.7
160	11.0	9.5	11.6	11.8	11.5	12.9
180	9.2	16.8	10.1	9.3	15.2	7.7
200	7.0	9.7	10.2	11.1	8.8	10.7
220	7.0	8.7	8.1	9.6	8.8	9.0

The CV in egg output was low (about 9 %) in both strains fed the highest protein feed (Table 5) but increased as the dietary protein level dropped, with the biggest increase occurring in outputs between birds fed 140 and 120 g protein/kg. These increases were particularly marked in the ISA strain, becoming almost twice as high as those of the Hy-

Line strain (25.1 *vs*. 12.7 from week 1 – 3; 40.9 *vs*. 25.5 from week 4 – 6 and 30.1 *vs*. 14.3 for the final four weeks of the trial).

The similar exercise conducted on the CV's for food intake (Table 6) yielded similar results to those of egg output. The lowest CV's were on the highest protein feeds, with a two- to three-fold increase on the lowest dietary protein levels. In this case the difference between the two strains was not as great as was the case with egg output.

Table 6. Coefficients of variation of mean daily food intake over three periods during the trial resulting from feeding six levels of dietary protein to Hy-Line and ISA strains

Protein content	Mean weeks 1 -3		Mean weeks 4 - 6		Mean weeks 7 - 10	
	Hy-Line	ISA	Hy-Line	ISA	Hy-Line	ISA
120	16.9	24.7	20.5	33.9	16.3	25.6
140	12.1	12.3	14.0	14.3	15.1	16.2
160	11.4	10.2	12.4	11.6	10.7	30.4
180	12.1	16.1	11.2	11.1	12.7	10.9
200	7.7	10.2	9.1	7.9	6.6	6.5
220	7.9	9.3	6.2	9.2	6.2	9.1

The mean performance of hens during the final four weeks of the trial is given in Table 7. No significant trends were evident in any of the variables measured, although in the final two weeks the Hy-Line hens previously fed the lowest protein feed consumed 10 g more feed /d than the hens previously on the other treatments and this resulted in these hens laying heavier eggs (62.2 *vs*. 60.9 g) in the final two weeks and gaining more weight (3.8 *vs*. 0.5 g/d). ISA hens previously on the lowest protein treatment did not show an increase in food intake once they had been returned to an adequate feed, although they gained considerably more body weight (5.5 vs. 0.7 g/d) than birds on the other treatments. Although mean rate of lay over the final four weeks was lower in birds previously on the

Table 7. Mean food intake, rate of laying, egg weight and change in body weight of Hy-Line and ISA laying hens fed six levels of dietary protein over the last four weeks of the ten-week trial period

Dietary protein,	Food intake, g/bird d			Rate of laying /100 birds			Egg weight, g			Change in weight, g/bird d		
g/kg	Hy-Line	ISA	Mean	Hy-Line	ISA	Mean	Hy-Line	ISA	Mean	Hy-Line	ISA	Mean
120	97.6	89.6	93.6	85.9	75.0	80.5	61.1	60.1	60.6	3.83	5.51	4.67
140	93.0	101	97.0	89.8	94.2	92.0	60.7	61.5	61.1	1.15	-0.32	0.41
160	93.0	102	97.6	93.7	99.9	96.6	59.8	63.9	61.8	0.99	0.44	0.71
180	92.3	88.7	90.5	91.0	86.1	88.5	61.0	59.8	60.4	-0.04	-0.16	-0.10
200	93.8	104	99.0	97.3	100	98.7	59.6	65.7	62.7	0.12	1.31	0.72
220	95.6	108	102	96.4	96.4	96.4	60.5	64.1	62.3	0.34	2.29	1.31
	94.2	98.9		92.4	91.9		60.4	62.5		1.06	1.51	
RSD[1]	171 (116 d.f.)			119 (115 d.f.)			18.4 (115 d.f.)			6.19 (120 d.f.)		

[1] Residual standard deviation

lowest protein feed, this returned to the same level as the other treatments in both strains by the end of the four-week recovery period.

Discussion

The potential performance of a population of broilers and laying hens depends largely on the inherent genotype of the population and the extent to which this varies between individuals (Emmans & Fisher, 1986), but many nutritional and environmental factors conspire to constrain this potential performance resulting in a wider spread of egg outputs than would be the case if all birds performed at their potential (Gous & Berhe, 2006). Fisher *et al.* (1973) predicted that the uniformity in egg output of a population of laying hens would increase as the protein supply was increased, as this would ensure that an increasing proportion of the population would have its requirements met. The results of this trial confirmed this prediction.

The examples given in the Introduction of reports in which evidence is led that uniformity is increased by feeding higher levels of a limiting amino acid or protein (Duncan, 1988; McNaughton, 1995; Lemme, 2003; Berhe & Gous, 2008) all dealt with broiler chickens. The principle remains the same for laying hens. But uniformity is not only influenced by ensuring that the most productive birds are allowed to achieve this potential by increasing the feed nutrient supply, as suggested by Fisher et al. (1973); at low nutrient levels the ability of birds to overconsume energy contributes substantially to the uniformity of the flock. It is apparent that strains of broilers and individuals within a strain overconsume energy to different extents when faced with a marginally deficient feed (Gous *et al*., 1990; Corzo *et al*., 2004; Kemp *et al*., 2005; Berhe & Gous, 2008). On feeds with a marginal or low nutrient supply, therefore, some birds will be capable of consuming more than others and would thus benefit from the extra feed intake resulting in a decrease in uniformity. The results in Table 5 and 6 illustrate this point very clearly.

The variation between individuals in food intake, and hence in egg output, is highest on the lowest protein levels and decreases almost linearly as the protein supply is increased. On low protein feeds the ability to overconsume energy is all-important in governing the amount of food the bird can consume. The ISA strain has a greater ability to fatten than does the Hy-Line strain, as is evident in Table 4 where the variation in lipid content was three-fold greater in ISA than in Hy-Line hens after six weeks of the trial. This increased ability to fatten resulted in a greater range of food intakes (Table 6), changes in body weight (Table 2) and egg outputs (Table 5) in the ISA strain on the lowest dietary protein levels. At the highest protein levels the CV was similar between strains, indicating that the variation in potential egg output is similar in the two strains. The hen has no need on the highest dietary protein contents to overconsume energy in an attempt to consume sufficient protein to meet the amino acid requirements for potential production. Indeed, if the hen has surplus reserves of body lipid it is possible that these reserves will be used as an energy source when high protein feeds are offered (Gous *et al*., 1990; Nonis & Gous, 2015), the hen thereby avoiding having to overconsume protein in some cases.

Body protein content remained relatively constant throughout the trial in both strains, irrespective of the feed protein treatment applied. At the start of the trial the mean protein weight in the Hy-Line strain was 280 g/bird and after six weeks the mean was 276 g and after ten weeks, 288 g. In the ISA strain the equivalent weights were 358, 335 and 332 g/bird. This provides further evidence that laying hens do not deposit body protein once they reach sexual maturity (Nonis & Gous, 2015). Body lipid, on the other hand, increased markedly over the first six-week trial period, in the Hy-Line strain from 194 to 229 g/bird and then to 251 g after ten weeks, whilst body lipid content of the ISA strain increased from 240 to 293 g before falling in the final four weeks to 280 g/bird. Changes in body weight in laying hens are likely to be due almost entirely to changes in body lipid content (Nonis & Gous, 2015).

The protein content of the feed given in the last four weeks of the trial was similar to the 180 g/kg treatment applied to hens in the first six weeks. Those hens previously given 180 g protein/kg consumed less feed during the final four weeks of the trial than did those on any of the other treatments. In the final four weeks the range in feed intakes between treatments among the Hy-Line strain was only 5.3 g/bird d, whereas among the ISA strain there was a 19.3 g difference between the highest and lowest intakes, again demonstrating that because these birds have the capacity to deposit more lipid in the body than Hy-Line hens, the variation in food intake and hence reproductive performance is likely to be greater in this strain. By the final week of the recovery period there were no differences in rate of lay, egg weight or egg output between treatments although food intakes remained higher and more variable among the ISA than the Hi-Line hens.

In conclusion, uniformity in egg output is increased at the highest intakes of dietary protein because the amino acid requirements of an increasing proportion of the population are met by these higher protein contents. As the protein supply becomes marginal and then deficient uniformity is decreased not only because the most demanding individuals cannot consume sufficient to achieve their potential, but also because birds differ in their ability to deposit excess energy as body lipid when attempting to consume sufficient of a feed limiting in protein. This enables some hens to consume more feed, and hence protein, than others and this contributes to an increase in the variability in egg output between individuals in the population. This ability to fatten differs not only between individuals within a population but between strains, as was demonstrated in this trial where the ISA strain exhibited greater variation in weight gain, lipid gain, food intake and egg output than the Hy-Line strain.

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CAPÍTULO 6 - Considerações finais

A presente tese mostrou de forma sequencial o processo na determinação do consumo diário de nutrientes com base no crescimento (fase pre-postura) e no potencial de produção de ovos. A revisão de literatura no capitulo 1 mostra as diferentes metodologias utilizadas para determinar o consumo de nutrientes, com ênfase na diferença entre o método dose-resposta e o método fatorial. Adicionalmente, foram apresentados diversos modelos utilizados para descrever o crescimento e o potencial de produção de ovos, informações necessárias para predizer o consumo diário de nutrientes. Desta forma, o capitulo fornece as informações para modelar o potencial de produção de ovo das novas linhagens de poedeiras.

Predizer o consumo de ração é uma ferramenta de grande utilidade na indústria avícola. Contudo o consumo varia ao longo do crescimento e produção. Assim, no capitulo 2, foi descrito o crescimento do corpo dividido em quatro compartimentos (corpo, pena, ovário e oviduto) e com base nesta informação foi calculado o consumo diário na fase de pre-postura. Apresentou-se diferenças entre o consumo calculado considerando o desenvolvimento do corpo com e sem o desenvolvimento dos órgãos reprodutivos. Desta forma, o consumo predito considerando o desenvolvimento dos órgãos reprodutivos sobrestimou em média 0.41 e 2.65 g/dia para a linhagem Hy-Line e ISA-Brown, respetivamente, mostrando que os modelos foram mais acurados para a linhagem Hy-Line.

Da mesma forma, para predizer o consumo durante a fase de produção é necessário conhecer o potencial de produção da ave. Assim o capitulo 3, mostra os diferentes modelos presentes na literatura e com base nesta informação foram determinados os paramentos para descrever o comprimento do ciclo interno e o peso dos componentes do ovo das linhagens atuais (Hy-Line e ISA-Brown). Informações requeridas para descrever o potencial genético das galinhas poedeiras.

O capitulo 4 foi desenvolvido com base no capitulo 3. Os modelos para descrever o comprimento do ciclo interno e o peso do ovo ao longo da idade da ave de cada linhagem, são utilizados para simular a ingestão diária de nutrientes. De esta forma, foi possível predizer a ingestão diária de nutrientes para duas populações ao considerar o potencial de produção das duas linhagens e ao introduzir elemento aleatório no modelo com base nas condições do lote.

Formular mantendo a restrição mínima de proteína bruta com inclusão de aminoácidos sintéticos é uma estratégia comum para reduzir a produção de nitrogênio e os custos de produção. O capitulo 5 mostra a resposta de poedeiras submetidas a mudanças no conteúdo proteico na dieta e o efeito na uniformidade da população em duas linhagens. Foi observado que a Isa Brown tem maior capacidade para depositar gordura, porem esta linhagem pode aumentar a ingestão em dietas com deficiência em proteína. No entanto a uniformidade do lote diminui em dietas com conteúdo proteico baixo.

Neste estudo, se fundamenta a utilização da modelagem como ferramenta para predizer o potencial de produção de ovos e consumo de nutrientes. Constituindo informação valiosa para o desenvolvimento do software capaz de simular respostas para diferentes condições, além de fornecer conhecimento do sistema envolvido na produção.