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MODELAGEM DO CRESCIMENTO, COMPOSIÇÃO DO CORPO
E DAS PENAS EM FRANGOS DE CORTE

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PENAS EM FRANGOS DE CORTE

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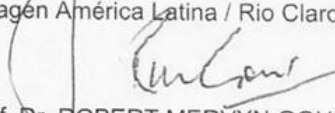
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CAMILA ANGELICA GONÇALVES – nasceu dia 02 de agosto de 1984, no município de Ourinhos, São Paulo. Seus pais são aposentados, Reinaldo Gonçalves Filho, coordenador de vendas e Neusa Maria Cabral Gonçalves, assistente social e também auxiliar de enfermagem. Ingressou no curso de Zootecnia na Escola Superior de Agronomia de Paraguaçu Paulista (ESAPP), em agosto de 2002. Em agosto de 2007 obteve o título de Zootecnista. Em agosto 2009, iniciou seus estudos com nutrição de aves como aluna especial do curso de mestrado e no ano de 2010 colaborando pela primeira vez em um projeto de pesquisa envolvendo frangos de corte. Entrou na pós-graduação em 2011, quando foi aprovada no curso de mestrado na Faculdade de Medicina Veterinária de Araçatuba da Universidade Estadual Paulista “Júlio de Mesquita Filho” (FMVA/UNESP). Obteve o título de Mestre em Ciência Animal em fevereiro de 2013. Em junho de 2013 participou de uma seleção de bolsista de treinamento técnico da FAPESP, para auxiliar na execução de análises químicas bromatológicas do Laboratório de Ciências Avícolas da UNESP – Jaboticabal, sendo concedida em setembro de 2013 a fevereiro de 2014. Durante esse tempo, foi aprovada no curso de Doutorado em Zootecnia, na Faculdade de Ciências Agrárias e Veterinárias de Jaboticabal da Universidade Estadual Paulista “Júlio de Mesquita Filho” (FCAV/UNESP), iniciando em março de 2014. Em junho de 2017, submeteu-se a defesa da tese e foi aprovada para receber o título de Doutora em Zootecnia.

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ABREVIATURAS

α - intercepto; intercept.

AMEn – energia metabolizável aparente; apparent metabolizable energy.

ANOVA – análise de variância; analysis of variance.

B – taxa de crescimento; growth rate.

b – coeficiente alométrico, a relação em percentagem da mudança do Y para o X ; allometric coefficient, the ratio of percentage change in Y to the X .

BAsh – cinzas do corpo; body ash.

BC – composição corporal; body composition.

BC_{DXA} – composição corporal estimada pelo DXA; body composition estimated by DXA.

BL – lipídeos do corpo; body lipid.

BMC – conteúdo mineral ósseo; bone mineral content.

BP – proteína corporal; body protein.

BW – peso corporal; body weight.

BWater – água corporal; body water.

Cci – concentração do componente ao nascimento; concentration of the componente at birth.

Ccm – concentração do componente à maturidade; concentration of the componente at maturity.

CHEM – análises químicas; chemical analyses.

CV – coeficiente de variação; coefficient of variation.

DF – grau de liberdade; degree of freedom.

Dp/Dt - deposição diária do peso ou do componente químico; daily deposition of the weight or chemical component.

DIC – delineamento inteiramente casualizado; completely randomized design.

DXA – absorciometria de raios-X de dupla energia; dual energy X-ray absorptiometry.

e – base natural dos logaritmos naturais 2,718; natural basis of natural logarithms 2,718.

FFB – corpo livre de penas; feather free body.

FFBW – peso do corpo livre de penas; feather free body weight.

FM – massa gorda; fat mass.

HP – dieta com nível de proteína alto; high protein level of diet.

LP – dieta com nível de proteína baixo; low protein level of diet.

LM – massa magra; lean mass.

\ln – logaritmo neperiano; logarithm neperian.

SE – erro padrão; standard error.

SD – desvio padrão da média; standard deviation.

SP – dieta com nível de proteína padrão; standard crude protein level of diet.

t – idade; age.

t^* – idade da máxima taxa de crescimento é alcançada; age of maximum growth rate.

TM – massa total; total mass.

U – grau de maturidade; maturity degree.

W_i – peso ao nascimento; birth weight.

W_m – peso na maturidade; maturity weight.

W_t – peso no tempo; weight at time.

X – variável dependente; dependent variable.

Y – variável independente, independent variable.

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MODELAGEM DO CRESCIMENTO, COMPOSIÇÃO DO CORPO E DAS PENAS EM FRANGOS DE CORTE

RESUMO - O escâner absorciometria de raios-X de dupla energia (DXA) consiste em uma técnica não invasiva para obter informações sobre a composição corporal dos animais, que permite avaliar a dinâmica de crescimento dos mesmos sem que haja a necessidade de abate. Foram conduzidos três experimentos com frangos de corte, realizados com os objetivos de determinar equações que predizem a composição corporal *in vivo* das aves no equipamento DXA (experimento I), e estimar o potencial genético de três linhagens comerciais (experimentos II e III). No experimento I foram utilizados 720 frangos de corte Cobb (360 machos e 360 fêmeas) distribuídos em delineamento inteiramente casualizado (DIC), dividido em esquema de parcelas subdivididas 3×2×2 (três níveis de proteína bruta nas dietas, dois sexos e duas técnicas nas sub-parcelas) com seis repetições de 20 aves cada. As dietas foram formuladas com o objetivo de alterar a composição corporal das aves, variando a proteína bruta em 70, 100, e 130% da exigência de cada fase avaliada, mas mantendo a relação entre os aminoácidos. Ao todo 216 aves foram digitalizadas no DXA para quantificação dos dados fornecidos pelo equipamento: massa magra, massa gorda, conteúdo mineral ósseo e massa total. Em seguida, as mesmas aves foram mantidas em jejum alimentar de 24h e depois, abatidas e depenadas. Foi realizada a análise química do corpo livre de penas (FFB) das aves para os conteúdos de proteína, água, lipídeos e matéria mineral. Os dados foram submetidos à análise de variância (ANOVA), sendo constatadas diferenças na quantificação da composição corporal pelas diferentes técnicas. Devido à essas diferenças, foram ajustadas regressões para cada componente químico do corpo. Todas as equações estabelecidas apresentaram alta correlação e podem ser utilizadas na avaliação da composição corporal por DXA, de forma direta, em ensaios futuros envolvendo diferenças entre grupos de frangos de corte e de indivíduos ao longo da vida. Através da condução dos experimentos II e III as equações DXA foram validadas e objetivou-se estimar os parâmetros da função Gompertz para

avaliar o potencial genético de crescimento do peso vivo, dos constituintes químicos do FFB e das penas para as linhagens comerciais de frangos de corte Cobb, Hubbard e Ross, machos e fêmeas. Em ambos os ensaios, 336 frangos de corte de cada linhagem e sexo foram distribuídos em delineamento inteiramente casualizado, distribuído em esquema fatorial de 3 linhagens \times 2 sexos, com quatro repetições (totalizando 24 unidades experimentais). As aves foram alojadas em ambiente termoneutro de 1 a 105 dias de idade e alimentadas com dieta única para machos e fêmeas divididas em quatro fases, contendo 3100 kcal EMAn/kg, formuladas acima das outras exigências nutricionais. As avaliações envolveram 12 aves por linhagem e sexo ao longo do crescimento para obtenção dos dados de composição do corpo livre de penas determinados *in vivo* por DXA (experimento II) e abate comparativo realizado em 48 aves por linhagem e por sexo ao longo de todo período experimental para a composição química das penas (experimento III). Os dados foram ajustados à curva de crescimento Gompertz e as taxas de deposição calculadas pela equação derivada. Relações alométricas entre os pesos dos componentes químicos do corpo livre de penas e das penas com o peso proteico dos mesmos foram determinadas para descrever as taxas de crescimento dos componentes nos diferentes genótipos. Os resultados evidenciaram o potencial dos machos em atingir maior peso na maturidade, maior crescimento e deposição proteica em comparação às fêmeas. Constatou-se que as linhagens comerciais atuais apresentam maior peso corporal na maturidade e conseqüentemente taxas de deposição dos componentes em relação a estudos prévios encontrados na literatura. Por alometria, observou que a gordura corporal foi depositada a uma taxa de 22% e 15% superior nas fêmeas e nos machos, respectivamente, em relação à deposição proteica no corpo. Esses resultados mostram as diferenças no potencial de crescimento das linhagens envolvidas e atualizam as curvas de crescimento para cada linhagem de frangos de corte.

Palavras-chave: alometria, análises químicas, linhagens, peso proteico, taxa de crescimento

GROWTH MODELING, BODY AND FEATHER COMPOSITION IN BROILER CHICKENS

ABSTRACT – The dual-energy X-ray absorptiometry (DXA) consists of a non-invasive technique to obtain information about the body composition of the animals, which allows evaluating the growth dynamics of the animals without the need for slaughter. Three experiments were carried out with broilers, with the objective of determining predictive equations for the *in vivo* body composition of birds in the DXA equipment (experiment I), and to estimate the genetic potential of three commercial strains (experiments II and III). In the experiment I, 720 Cobb broilers (360 males and 360 females) were distributed in a completely randomized design (DIC), divided into split plot design $3 \times 2 \times 2$ (three crude protein levels in the diets, two sexes and two methods of body evaluation at sub parcels) with six replicates of 20 birds each. The diets were formulated with the objective of altering the body composition of the birds, varying the crude protein in 70, 100, and 130% of the requirement of each evaluated phase, but maintaining the relation between the amino acids. A total of 216 birds were digitized in the DXA to quantify the data provided by the equipment: lean mass, fat mass, bone mineral content and total mass. Then, the same birds were kept in a 24-hour fasting meal, slaughtered and plucked. The chemical analysis of the feather free body (FFB) of birds was carried out for protein, water, lipids and mineral matter content. The data were submitted to analysis of variance (ANOVA), being observed differences between diets, sexes and in the quantification of body composition by the different techniques. Due to the differences between the techniques, regressions were adjusted for each chemical component of the body and for each sex. All the established equations presented an $R^2 < 0.96$ and allow the evaluation of body composition by DXA to be determined directly and rapidly in future scans involving broiler chickens. Through the conduction of experiments II and III we aimed to estimate the parameters of the Gompertz function to evaluate the genetic potential of growth of live weight, chemical constituents of FFB and feathers for the commercial lines of broilers Cobb, Hubbard and Ross, males and females. In both trials,

336 broilers of each lineage and sex were distributed in a completely randomized design, distributed in a factorial arrangement of 3 lines × 2 sexes, with four replications (totaling 24 experimental units). The birds were housed in a thermoneutral environment from 1 to 105 days of age and fed a single diet for males and females divided into four phases, containing 3100 kcal ME/kg, and formulated above nutritional requirements. The evaluations involved 12 birds per strain and sex throughout the growth to obtain feather free body composition data determined *in vivo* by DXA (experiment II) and a comparative slaughter performed in 48 birds per strain and sex throughout experimental period for the chemical composition of feathers (experiment III). The data were adjusted to the Gompertz growth curve and the deposition rates calculated by the derived equation. Allometric relationships between the weights of the chemical components of the FFB and the feathers with their protein weight were determined to describe the growth rates of the different strains. Numerically, the results evidenced the potential of males to reach higher weight at maturity, higher growth and protein deposition compared to females. It was observed that the current commercial lines present higher body weight at maturity and consequently deposition rates of the components in relation to previous studies found in the literature. In general, body fat was deposited at a rate of 22% and 15% higher in females and males, respectively, in relation to protein deposition in the body. The proportion of water and minerals deposited in the body has decreased relative to the protein. These results show the differences in the growth potential of the strains involved and update the growth curves of modern broiler chickens.

Keywords: allometry, chemical analysis, growth rate, protein weight, strains

CAPÍTULO 1 – CONSIDERAÇÕES GERAIS

Introdução

Na avicultura de corte, o melhoramento genético aplicado nas linhas puras resultou em mudanças no padrão de crescimento e na produtividade das linhagens modernas de frangos de corte, que atualmente apresentam maior crescimento muscular e ganho de peso em curto período de criação.

O peso corporal e a conversão alimentar geralmente são utilizados para caracterizar o desempenho das aves na granja. No entanto, apenas uma mensuração do peso do corpo é insuficiente para se descrever as diferenças do crescimento das linhagens atuais, visto que cada linhagem possui especificidade no que tange suas taxas de deposição de proteína, água, gordura e minerais, as quais não são informadas pelas empresas que fornecem os híbridos comerciais.

Baseado no método proposto por Emmans (1981), a função Gompertz (1825) tem sido utilizada para descrever e comparar o potencial de crescimento das linhagens de frangos de corte (HANCOCK et al., 1995; GOUS et al., 1999; SANTOS et al., 2005; MARCATO et al., 2010; SAKOMURA et al., 2011). Contudo, trata-se de um tipo de pesquisa que deve ser realizada periodicamente, a fim de atualizar os parâmetros de crescimento dos componentes químicos, que auxiliam na determinação dos níveis nutricionais das dietas, que irão refletir sobre a qualidade do produto final e na rentabilidade da produção (MARTIN; BRADFORD; GOUS, 1994; ZELENKA et al., 2011; RIVERA-TORRES; NOBLET; van MILGEN, 2011).

O abate comparativo é o método mais tradicional na avaliação do crescimento corporal, consistindo na amostragem, abate e análise química corporal de animais semelhantes em diferentes estádios de crescimento.

Atualmente, a questão da ética, bem-estar e uso de animais em experimentos tem gerado discussões importantes no meio científico e na sociedade, onde existe uma demanda pelo uso de métodos não invasivos, para a avaliação da composição corporal dos animais. Frente a tais pressões, o desenvolvimento de novos métodos e tecnologias que reduzam a necessidade do abate animal caracteriza-se como tendência apoiada por novos regulamentos, como por exemplo, a Resolução Normativa n. 17, de 2014 do CONCEA, que estabeleceu

o processo de reconhecimento de métodos alternativos no Brasil como qualquer método que possa ser utilizado para substituir, reduzir ou refinar o uso de animais em atividades de pesquisa (BRASIL, 2016).

O método Absorciometria de Raios-X de dupla energia (DXA) tem demonstrado ser uma ferramenta útil para a substituição do método do abate em animais. A técnica foi desenvolvida para o uso em humanos e já foi utilizada em animais de produção para quantificar a composição química do corpo ou da carcaça em tempo real, com estudos envolvendo suínos (MITCHELL; SCHOLZ; PURSEL, 2003; SUSTER et al., 2004; SILVA, 2015), poedeiras (SCHREIWEIS et al., 2005), frangos de corte (MITCHELL; ROSEBROUGH; CONWAY, 1997; BUYSE et al. 2003; SWENNEN et al., 2004; SALAS et al., 2012) e peixes (WOOD, 2004; JOHNSON et al., 2017). Além disso, estudos comparativos com a análise química da carcaça são necessários como medida de padronização de erros e correção dos valores determinados em cada equipamento DXA.

Dessa forma, a partir de três ensaios experimentais, foram estruturados cinco capítulos, com o primeiro contemplando a introdução e revisão de literatura. O capítulo 2 apresenta o foco de investigação como a DXA pode ser utilizada na determinação da composição corporal em frangos de corte.

O capítulo 3 constituiu-se na descrição do potencial genético de crescimento das linhagens Cobb, Ross e Hubbard de 1 a 105 dias, machos e fêmeas por meio da estimativa dos parâmetros da função Gompertz.

No capítulo 4, foi abordado o crescimento do corpo livre de penas e das penas das linhagens através de relações alométricas entre os pesos dos componentes químicos e o peso da proteína.

No capítulo 5, estão presentes as implicações do estudo, onde são discutidas as expectativas futuras para o uso da técnica DXA na avaliação da composição corporal de aves.

Revisão de literatura

Avaliação da composição corporal por DXA

A padronização e utilização de técnicas não invasivas para estudar a composição química corporal em animais têm aumentado, devido à necessidade de aplicação de conceitos de bem estar animal e também para o avanço com a pesquisa científica sobre a informação do indivíduo em tempo real com procedimentos mais simplificados. Neste contexto, a técnica de absorciometria por dupla energia de raios-X (DXA) pode ser uma alternativa ao abate de carcaças para avaliação da composição animal.

Os equipamentos DXA (também denominados como DEXA em algumas publicações) são aparelhos de densitometria óssea, introduzidos comercialmente no final da década de 80 com o objetivo de investigar a perda de massa óssea e diagnosticar osteoporose em humanos (KOHRT, 1995; ANN LASKEY; PHIL, 1996).

Atualmente, vem sendo utilizado por pesquisadores ao redor do mundo para mensurar a composição corporal dos animais de forma não invasiva, rápida e sem causar desconforto no animal (MITCHELL; ROSEBROUGH; CONWAY, 1997; MITCHELL; SCHOLZ; PURSEL, 2003; SPEAKMAN; BOOLES; BUTTERWICK, 2001; BROMMAGE, 2003).

O princípio da técnica DXA é a mensuração da transmissão de raios-X com dupla energia (dois níveis de energia, baixo e alto) que atravessam o corpo e são atenuados de acordo com a composição, densidade e espessura dos tecidos corporais (MITCHELL; SCHOLZ; CONWAY, 1998; SILVA, 2015). A atenuação dos raios-X, gera o contraste para a formação dos pixels da imagem capturada e separa a composição corporal em três compartimentos: conteúdo mineral ósseo, massa gorda e massa magra (PIETROBELLI et al., 1996).

Ao longo do tempo, a tecnologia do DXA foi aprimorada (Figura 1). Originalmente, os equipamentos transmitiam e captavam um feixe de radiação “retilíneo e estreito” na forma de lápis (pencil beam) que saíam da fonte emissora de raios-X na forma de um orifício e detectores simples determinando a quantidade de fótons que atravessavam o corpo. Esse sistema foi substituído por feixes de raios-X tipo leque (fan beam) e detectores múltiplos, resultando em uma maior faixa do

corpo exposta à passagem do laser e possibilitando imagens com processamento mais rápido com melhores resoluções (ANN LASKEY; PHIL, 1996).

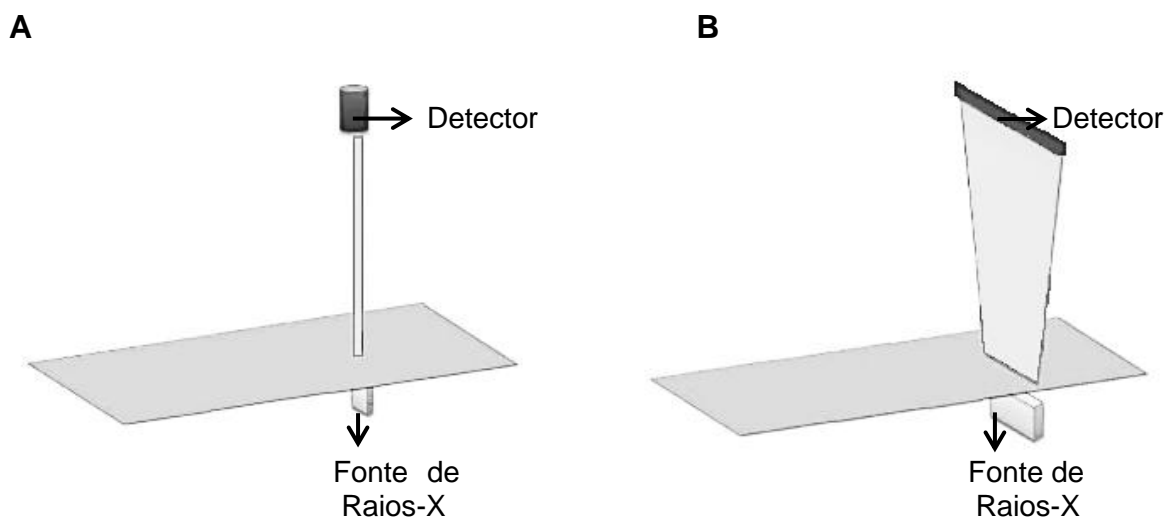


Figura 1 - Representação do sistema fonte-detector do DXA, sendo: A) feixe tipo lápis, utilizado antigamente e B) feixe tipo leque, utilizado nos dias atuais.

Três empresas fabricam o DXA utilizado em humanos: GE Lunar, Hologic e Norland. Estes fabricantes possuem equipamentos que são exclusivos na geração dos feixes de raios-X de alta e baixa energia, nos detectores de raios-X, nos algoritmos para geração das imagens, na definição de análise regional para avaliar membros corporais (cabeça, tronco, pernas e braços), tamanho do pixel e na metodologia de calibração do sistema – realizada pelo uso de peças artificiais (“Phantoms”) com composição conhecida, para o controle de qualidade e monitoramento da máquina (GENTON et al., 2002; LÖSEL et al., 2010; SILVA, 2015).

Desta forma, estudos comparativos envolvendo equipamentos e software diferentes e até mesmo entre equipamentos do mesmo fabricante DXA podem apresentar resultados inconsistentes e que contribuem para a dúvida sobre a validade da técnica (KOHRT, 1995). Scholz et al. (2007) avaliaram a composição corporal em suínos utilizando dois modelos diferentes de scanners DXA em dois locais diferentes, e os resultados indicaram cautela na comparação de mensurações entre equipamentos, pois todos os procedimentos e ajustes devem ser idênticos.

No entanto, de acordo com SUSTER et al (2004) a comparação entre equipamentos DXA pode ser dificultada por outros fatores relativos aos animais como sexo, variação de genótipos, e hidratação do corpo. Swennen et al. (2004) avaliando a precisão das mensurações DXA em frangos de corte, não encontrou diferenças significativas no modo de escaneamento e posicionamento das aves. Contudo, os fabricantes de DXA não revelam as causas dessas variações, como também não divulgam as informações sobre os algoritmos utilizados para calcular a composição corporal, mas que, apesar dessas variações, operam de forma semelhante para a aquisição dos resultados, conforme a descrição a seguir.

Na avaliação da composição do corpo pelo equipamento DXA (figura 2), o animal deve ser posicionado sobre a mesa de escaneamento. Na parte de baixo existe uma fonte de raios-X e acima da mesa, um detector, formando um braço em C. Este sistema caminha todo junto, em movimentos lineares, longitudinal e lateral, que acompanham uma varredura ao longo do corpo. Os dados contendo os valores da atenuação são transmitidos para um software de computador e um algoritmo interpreta cada pixel, criando a imagem bidimensional junto com as medidas quantitativas da composição corporal (NHANES, 2012).

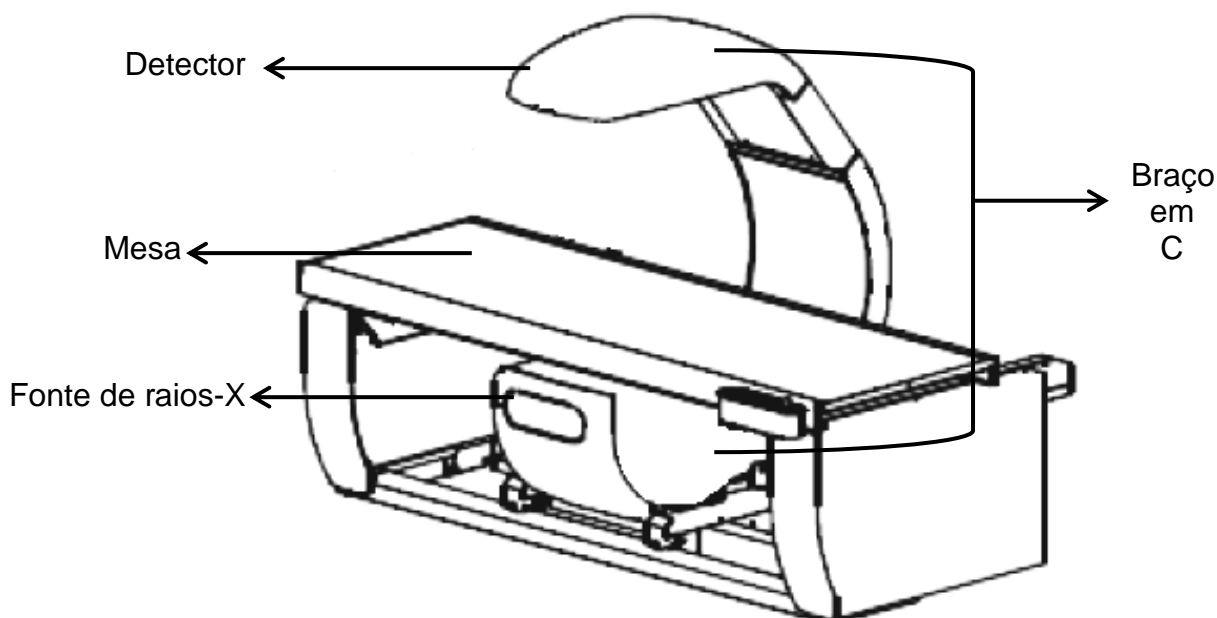


Figura 2 – Representação do sistema DXA para obtenção dos resultados de composição corporal.

No entanto, para a validação da avaliação da composição corporal dos animais pela técnica DXA, um ajuste dos resultados é necessário e realizado através da comparação com um método de referência (MITCHELL; ROSEBROUGH; CONWAY, 1997). Este procedimento é muito importante porque o equipamento DXA utiliza padronizações inerentes ao uso em humanos e os valores obtidos nos animais não condizem exatamente com o quimicamente determinado, isto é, podem ser diferentes em situações que dependem do tamanho da espécie animal, do seu posicionamento perante as digitalizações, do componente corporal avaliado e como citado anteriormente, das características de modelo comercial e software de escaneamento do DXA (SCHOLZ et al., 2007).

A configuração do software dos equipamentos DXA inclui versões de módulos projetadas para uso humano (adulto e infantil) e pequenos animais, recomendadas a uma faixa de peso para cada módulo. A adequação do sistema ao tamanho animal vem sendo estudada, sendo utilizado em animais maiores, tais como cães, suínos e ovelhas o módulo adultos (com limite de peso de cerca de 200 kg).

O módulo “pequenos animais” foi utilizado por Mitchell; Rosebrough e Conway (1997), onde foram encontradas diferenças significativas entre as medições do DXA em aves acima de 2 kg de peso vivo. A causa dessa variação seria, portanto, a inadequação do módulo para a aplicação em aves, pois conforme as especificações dos fabricantes o uso deste módulo é indicado em animais com peso corporal inferior ao de frangos, como por exemplo, camundongos (JEBB et al., 1996).

Desta forma, os protocolos de estudo devem ser adaptados e bem embasados em medida de precisão para o tamanho do animal, tipo de software e posicionamento do corpo, para posteriormente, realizar ensaios com o intuito de obter uma regressão entre os resultados DXA com o método de referência de avaliação da composição corporal (mais tradicionais são as técnicas de análises químicas do corpo todo ou componentes dissecados). As equações ajustadas relacionam as técnicas e corrigem os valores para predizer a composição corporal verdadeira dos animais, levando em consideração o viés dos métodos (SCHREIWEIS et al., 2005; SALAS et al., 2012; SILVA, 2015; JOHNSON et al., 2017).

A técnica DXA estima a composição corporal de forma peculiar. O DXA não fornece uma medida separada de proteína e água, mas sim a estimativa de “massa magra”, que compreende os valores de proteína, água, carboidratos e minerais não ósseos (PIETROBELLI et al., 1996). Já nas análises químicas, carboidratos corporais apresentam baixos valores e por isso não são mensurados, e a proteína (valor do nitrogênio total $\times 6.25$) mais a água somadas correspondem com a massa magra dos valores encontrados pelo DXA.

O conteúdo mineral ósseo do DXA é referente somente aos ossos. Na determinação química a matéria mineral representam conteúdos minerais ósseos e não ósseos, que não são separados entre si (SUSTER et al., 2004).

Por fim, o percentual de gordura do DXA é a única medida que relaciona com os lipídeos do corpo determinados quimicamente, porque ambos não mensuram somente a quantidade de tecido adiposo e sim, a gordura de todas as partes do corpo, incluindo membranas (JEBB et al., 1996).

Outro possível desafio associado ao uso do equipamento em animais *in vivo* é a necessidade de anestésiar os animais para mantê-los imóveis durante o escaneamento. Contudo, essa decisão deve ter como base o uso de um anestésico que não comprometa a recuperação dos animais (como no consumo de alimentos) e que seja de fácil administração, como é o caso do isoflurano inalatório, onde os animais acordam minutos após a interrupção do fornecimento desse anestésico.

Uma das vantagens do método (DXA) é a possibilidade de diminuir as fontes de variação individual da ave em diferentes idades para a interpretação estatística dos dados coletados. Alguns autores reportaram que no abate comparativo, a interpretação dos resultados depende de um somatório de informações de animais diferentes, abatidos ao longo do crescimento, que pode levar a interpretações errôneas (SCHREIWEIS et al., 2005; SILVA et al., 2016).

Contudo, o padrão aceito para a análise da composição corporal é a análise química de carcaça, portanto, nenhuma técnica *in vivo* pode ser considerada mais exata. Também é improvável que uma única técnica seja adequada em todas as circunstâncias, pois mesmo que a magnitude de erros varie entre técnicas, erros metodológicos na coleta de dados e erros nos pressupostos pelos quais os dados brutos são convertidos em valores finais são comuns.

No entanto, até agora, existem dados limitados disponíveis sobre a composição corporal das aves em relação à técnica DXA *in vivo*, até porque, no campo da pesquisa animal o número de escâneres DXA é limitado a poucos centros de pesquisa ao redor do mundo.

Curva Gompertz para crescimento em frangos

O crescimento corporal é representado pelo aumento do tamanho do animal no peso corporal, como também no seu tamanho em função da idade, do nascimento até a maturidade. Em função do peso vivo, o crescimento caracteriza a idade fisiológica das aves através de mudanças nas taxas de deposição de proteína, gordura, água e matéria mineral, pré-determinados pelo potencial genético de crescimento e cessa o crescimento quando atinge o seu tamanho a maturidade (EMMANS, 1981; EMMANS, 1987).

Com a pressão de seleção das empresas de genética, os genótipos podem diferir entre si em vários aspectos como velocidade de crescimento, peso na maturidade, composição corporal e taxa de deposição dos nutrientes corporais (HANCOCK et al., 1995; GOUS et al., 1999; MARCATO et al., 2008; HENN et al., 2014).

As curvas de crescimento são funções matemáticas não lineares que simulam o crescimento do peso vivo e dos componentes corporais em função do tempo. Há diversas funções conhecidas, sendo que a decisão em se optar por um modelo depende da espécie animal, sexo e objetivos de estudo. No entanto, deve-se basear em algumas premissas como de possibilidade de interpretação biológica, facilidade de elaboração e qualidade do ajuste dos parâmetros (FIALHO, 1999).

O método proposto por Emmans (1981) descreve o potencial genético de crescimento de aves utilizando a função de Gompertz (1825). Os parâmetros ajustados aos dados de composição de carcaça, mensurados ao longo do crescimento devem ser obtidos criando os animais em condições ideais de temperatura, densidade e fornecimento *ad libitum* de ração, que atendam às exigências nutricionais, para não interferir sobre as aves em manifestar o seu máximo potencial genético (EMMANS; OLDHAM, 1988; GOUS et al., 1999). Se essas condições não forem atendidas, tanto a taxa de crescimento potencial quanto

a quantidade de adiposidade, não serão valores referentes ao potencial genético da ave e sim, serão equações que representam o desempenho e que estarão abaixo do potencial (EMMANS, 1987).

A função Gompertz consiste em três parâmetros: peso na maturidade (W_m , kg), taxa de crescimento (B , kg por dia) e idade em que a máxima taxa de crescimento é alcançada (t^* , dia). A equação é dada pela seguinte expressão apresentada por Winsor (1932):

$$W_t = W_m \times e(-e(-B \times (t - t^*)))$$

Sendo: W_t é o peso no tempo (kg); W_m é o peso na maturidade (kg); e é a base dos logaritmos naturais 2,718; B é a taxa de maturidade (kg por dia); t é a idade (dias) e t^* é a idade em que a taxa de crescimento é máxima (em dias após o nascimento).

De acordo com Emmans (1987), existem dois caminhos com que os genótipos variam: o primeiro é o que eles se tornam quando estão maduros e o segundo é o caminho percorrido para chegar à maturidade. Dessa forma, o crescimento se inicia após o nascimento e segue ao longo do tempo até encontrar um estado de equilíbrio final: a maturidade, onde por ocasião é a fase que marca uma taxa zero nas alterações do crescimento (EMMANS; OLDHAM, 1988).

Uma forma adicional a essa equação de Gompertz, segundo Emmans (1981) consiste em substituir t^* por W_i (peso ao nascimento):

$$W_t = W_m \times e \left[-e \left(\left(\ln(-\ln(W_i/W_m)) - (B \times t) \right) \right) \right]$$

Onde: W_t é o peso no tempo (kg); e é a base natural dos logaritmos naturais 2,718; \ln é o logaritmo neperiano; W_i é o peso ao nascimento (kg); W_m é o peso na maturidade (kg); B é a taxa de crescimento (kg/dia) e t é a idade (dias).

Os parâmetros W_m e B já são suficientes para descrever o padrão de crescimento de determinado genótipo. A estimativa da taxa potencial de crescimento do ganho de peso e/ou de deposição dos componentes químicos é calculada conforme a equação:

$$Dp/Dt = B \times W_t \times \ln(W_m/W_t)$$

Onde: Dp/Dt é a deposição diária do peso ou do componente químico (kg/dia); B é a taxa de crescimento (kg/dia); W_t é o peso no tempo (kg); \ln é o logaritmo neperiano e W_m é o peso do componente na maturidade (kg).

Utilizando essas formas da função Gompertz, é possível uma descrição do potencial genético das linhagens para cada componente químico do corpo. Além disso, a função Gompertz tem sido amplamente utilizada em ensaios envolvendo frangos de corte, e como esses parâmetros ajustados já são bem conhecidos, pode-se comparar o avanço genético dado um determinado genótipo com trabalhos anteriores (HANCOCK et al., 1995; GOUS et al., 1999; MARCATO et al., 2008).

Crescimento e composição das penas em frangos

Um tópico importante na caracterização das linhagens e modelagem do crescimento das aves é a quantificação das penas (STILBORN, 1994), que crescem continuamente até um tamanho máximo, caem, regeneram-se (DESCHUTTER; LEESON, 1986) e em função da idade representam aproximadamente 3% a 8% do peso vivo da ave.

As penas possuem duas funções principais no corpo dos frangos de corte: isolamento térmico e proteção ao meio externo. Desenvolvem-se a partir de folículos encontrados na pele e crescem ativamente para atender tais funções e ao atingirem o tamanho máximo permanecem no folículo até serem substituídas (LEESON; WALSH, 2004). Em frangos de corte, as penugens da primeira geração de pintos recém-nascidos são substituídas num processo que leva geralmente 2 a 4 semanas. Aos 42 dias de idade, podem ser observadas penugens aderidas às penas de 2º geração, e penas de 3º geração desenvolvendo (PRADO, 2017, comunicado pessoal).

Por isso, durante o crescimento, as aves estão sempre trocando as penas do corpo naturalmente, e assim, o peso da pena mensurado nas idades que as aves são abatidas, apresentam considerável variabilidade, mesmo quando expressos em relação à massa corporal e não representam um crescimento acumulado das penas (EMMANS, 1989; HANCOCK et al., 1995; LEESON; WALSH, 2004).

Fisher et al. (1981) determinaram as perdas das penas em frangos de corte e concluíram que fêmeas perdem de 3 a 5 vezes mais penas do que aves machos em relação a idade, estando portanto, relacionado a taxa de empenamento diferencial entre sexos.

A sucessão de plumagem e taxa de empenamento possuem padrões específicos entre as linhagens, sexo e idade das aves (MARTIN; BRADFORD; GOUS, 1994; HANCOCK et al., 1995; LEESON; SUMMERS, 2009). Hancock et al. (1995) com o objetivo de descrever o potencial genético de crescimento das penas em seis linhagens de frangos de corte, encontraram diferenças significativas no peso das penas, para a proporção de água e proteína entre os sexos, mas não entre as linhagens.

A taxa de empenamento das aves relacionada ao sexo é controlada pela genética há diversos anos, desde que foram introduzidos no mercado linhagens auto-sexáveis pelas penas das asas, como por exemplo, nas linhagens Cobb, Hubbard e Ross, visando condições para alojamento de lotes separados por sexo, fornecendo rações mais condizentes com as exigências nutricionais para cada sexo, com o intuito de maximizar o ganho de peso e reduzir os custos com alimentação.

Genes para o empenamento lento (K) e empenamento rápido (k), caracterizam a taxa de empenamento do frango de corte comercial e auxiliam na diferenciação sexual no primeiro dia de vida (MOREIRA et al., 2006). Quando os pais possuem os genótipos k^+k^+ para os machos e a K para as galinhas, os descendentes resultantes do cruzamento terão pintinhas k^+ com empenamento rápido e os pintinhos machos Kk^+ com um atraso no empenamento (LEESON; WALSH, 2004; KHOSRAVINIA, 2008).

Por isso, em tais linhagens comerciais, os pintinhos recém-nascidos fêmeas apresentam as penas primárias mais compridas (fileira inferior das penas vista de cima da ave) que as penas de cobertura (fileira superior) e nos machos as penas primárias são menores ou do mesmo tamanho que as de cobertura, enquanto que em ambos os sexos, o resto do corpo é coberto por uma penugem (Figura 3).

Assim, devido esse dimorfismo sexual em aves jovens, o gene ligado para o empenamento rápido nas fêmeas como critério de sexagem promove uma maior taxa de empenamento (tamanho e peso de penas) em relação aos machos em outras regiões do corpo, tal como dorso, asas (remiges) e cauda (retrices). Para os machos uma maior definição do empenamento ocorre após 21 dias de idade (SAKOMURA et al., 2005) e portanto, quando as aves tornam-se adultas as

características genéticas de empenamento lento vs. rápido exerce pouca influencia na massa das penas (LEESON; WALSH, 2004).

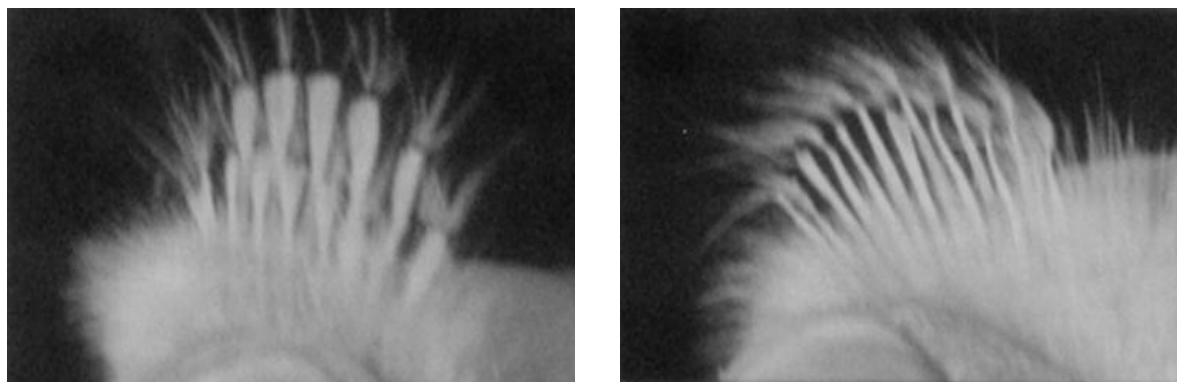


Figura 3 - Sexagem de aves pelas penas das asas no primeiro dia de vida (A) fêmeas; (B) machos.

Fonte: <http://atividaderural.com.br/artigos/4e599d9110b15.pdf>. Acessado em: 30 de julho de 2017.

Ao longo do crescimento e estágios de desenvolvimento das penas (através da síntese de pulpa e penas), a sua estrutura (cálamo, raquis e barbas) varia. Assim, as penas apresentam uma variação na composição, através do aumento do teor de proteína e decréscimo na quantidade de água na maturidade (HANCOCK et al., 1995; RIVERA-TORRES; NOBLET; van MILGEN, 2011; SILVA et al., 2016).

Uma vez que a proteína é o principal componente das penas, cerca de 89% a 97% (FISHER et al., 1981), diversas pesquisas tem focado em avaliar as exigências de aminoácidos das aves para a síntese de penas (DESCHUTTER; LEESON, 1986). Segundo Rivera-Torres; Noblet e van Milgen (2011) o perfil dos aminoácidos que compõem a proteína das penas, além de diferir dos aminoácidos que constitui o corpo, apresenta também variação em função da região (ou estrutura) da pena. A taxa de maturação proteica é mais acelerada em relação ao crescimento do corpo e para formação das penas, os nutrientes são exigidos em maior concentração no início da vida das aves (EMMANS, 1989).

Neste contexto, as estimativas do crescimento potencial das penas em função do peso na maturidade e taxa de crescimento devem ser separadas do corpo livre de penas, para o ajuste de modelos fatoriais de predição das exigências nutricionais,

através da soma das quantidades necessárias do nutriente para o crescimento do corpo depenado e das penas (EMMANS, 1989; MARTIN; BRADFORD; GOUS, 1994), pois levando em conta a variação na taxa de empenamento, a avaliação das exigências de aminoácidos é mais acurada, junto com a demanda por uniformidade das (DESCHUTTER; LEESON, 1986).

O método do abate comparativo é utilizado nos estudos para determinar o crescimento das penas. No entanto, o peso das penas é subestimado, ante as dificuldades em mensurar as perdas de penas e mudanças de empenamento das aves em crescimento (EMMANS, 1989) apontadas acima. Mesmo com estas características, até agora o abate comparativo se mostra indispensável para mensurar a quantidade de penas e para a realização de análises químicas na pesquisa com aves de produção, e se obter as estimativas de como essas características podem diferir entre as linhagens.

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CAPÍTULO 2 – Dual Energy X-Ray Absorptiometry is a valid tool for assessing *in vivo* body composition of broilers

Abstract: The determination of body composition (BC) of birds has many applications for investigation about genetic, nutritional status as well as growth evaluation. This study was conducted to adjust models that predict the *in vivo* body composition of broilers for the Dual energy X-Ray absorptiometry (DXA) device. A total of 720 Cobb broilers (360 males and 360 females) was randomly assigned in a completely randomized design in split plot arrangement 3 (protein levels) × 2 (sexes) × 2 (methods of BC evaluation) with six replicates of 20 birds each. Experimental diets were formulated to produce a wide range of body weights and compositions, consisting in three different crude protein levels in each phase. At 7, 14, 28, 42, 56 and 77 days of age, it was selected one bird per replicate to be alive scanned on Hologic Discovery® Wi DXA to determine bone mineral content (BMC), fat mass (FM), lean mass (LM) and total mass (TM). Then, the same birds were slaughtered, defeathered, ground, frozen and stored for further chemical analysis (water, protein, ether extract and ash). The effects of methods were analyzed as one-way ANOVA and statistical significance were considered for $p < 0.05$. Chemical analysis and DXA method provided different estimates of broiler body composition ($p < 0.05$). In order to adjust the broiler body composition data obtained through chemical analysis to those determined by DXA method, the following regression equations were obtained to determine the body feather-free components directly as follows: Protein (g) = $e^{[-2.57623 + 1.09710 \times (\ln LM)]} \pm 0.10$ g, $R^2 = 0.9950$; Water = $e^{[-0.21858 + 0.98152 \times (\ln LM)]} \pm 0.06$ g, $R^2 = 0.9977$; Ash = $e^{[0.65487 + 0.96626 \times (\ln BMC)]} \pm 0.16$ g, $R^2 = 0.9859$ and Lipids = $e^{[-2.78590 + 0.44774 \times (\ln FM) + 0.79215 \times (\ln BWater)]} \pm 0.38$ g, $R^2 = 0.9457$. All equations had significant parameters (intercept and independent variables) ($P < 0.01$). In conclusion, the correction of data obtained from DXA method by the regression equations aforementioned showed to be an alternative method to assess broiler *in vivo* body composition.

Keywords: carcass, chemical analysis, prediction equations, sex

Introduction

The accuracy of determining body composition is a primary focus in many scientific studies, particularly for those involving growth and nutrition. The knowledge of body composition is fundamental in animal research because it provides useful information about genetic growth pattern, nutritional status and changes in terms of lean meat yields and fat of the body, which are factors related directly by diets, environmental conditions and sanitary challenges.

Several methods, which vary in complexity and invasiveness, are used to estimate the chemical composition of animals (TOPEL, 1988; HEDRICK, 1983; BROMMAGE, 2003). Among such methods, the comparative slaughter is widely used and involves the animal sacrifice to establish the body content of nutrients such as protein, fat, water and minerals. Although comparative slaughter reproduces reliable estimates, it does not allow obtaining repeated measurements of the same animal throughout its growth.

Alternative methods, which allow the *in vivo* estimate of chemical composition of the body, offer several advantages to animal research. Beyond providing more precise information about animal growth rates, the *in vivo* measurements could also serve as tool to reduce costs related to chemical analysis and meet the current demands of some groups of society for more ethical animal care and use of animals, by preventing the slaughter of many individuals.

The Dual energy X-ray absorptiometry (DXA) is an advanced imaging tool for human diagnosis, which has shown to be effective in estimating body composition of birds (MITCHELL et al., 1997; SWENNEN, et al., 2004; SALAS et al., 2012) as well as in other farm animal species as pigs (MITCHELL; SCHOLZ; CONWAY, 1998; SUSTER et al., 2003; SILVA, 2015) and fish (JOHNSON et al., 2017). However, to use the device in animals, it is necessary to standardize the technique through the development of validation models that, in almost cases, are regressions between the data of DXA and of chemical analysis of carcasses.

The development of models to use DXA in birds must be done for a particular device model and software (SWENNEN et al., 2004). This affirmation is due to the fact of different models of DXA and software applied can present differences in the determined body composition (SCHOLZ et al., 2007). Anyway, whenever a new a

software model, scan mode and positioning of the individual are used, it is necessary to calibrate models that correct the results for the new situation.

Therefore, the purpose of this study was to compare broilers body composition measurements (body weight, lean mass, fat mass and bone mineral content) taken by DXA and on the chemical analysis methods to adjust a model to predict *in vivo* body composition of broilers.

Material e methods

The experiment was conducted at the Universidade Estadual Paulista, Jaboticabal Campus, SP, Brazil (Bone Densitometry Laboratory and Poultry Science Laboratory). All procedures followed in the trial were according to the ethical guidelines adopted by the Brazilian College of Animal Experimentation (COBEA) and were approved by the “Ethics Committee on Animal Use” of the Faculty of Agricultural and Veterinary Sciences, UNESP (Protocol No. 9999/14).

Experimental design and Management

A total of 720 day-old Cobb broiler chicks (360 males and 360 females) were housed in environmentally controlled room, which provided the temperature recommended by genetic strain management guide (Cobb-Vantress, 2013). Broiler chicks were randomly assigned to 36 floor pens (20 chicks/pen) with split-plot arrangement of treatments (three crude protein levels diets × two sexes × two methods at sub plots: DXA and chemical analysis). Each treatment was replicated six times. Throughout the feeding trial, broilers had free access to water and feed (mash form). Lighting program consisted of the daily supply of 24 hours of light.

Experimental diets

A four-phase feeding program was used: 1 to 14 days, 15 to 28 days, 29 to 42 days and 43 to 77 days. At all period the diets contained 3100 Kcal ME/kg and three different levels of crude protein levels, to obtain 70, 100, and 130% of CP and amino acids specifications of each phase for obtaining light, standard and heavy body weights and different body compositions (DANISMAN and GOUS, 2011). Diets (Table 1) were formulated according to Brazilian Tables (ROSTAGNO et al., 2011).

Table 1 - Ingredients and nutritional composition of diets according to crude protein levels: high (HP), standard (SP) and low (LP) and the feed phase program

Ingredients (%)	1-14 days			15-28 days			29-42 days			43-77 days		
	HP	SP	LP	HP	SP	LP	HP	SP	LP	HP	SP	LP
Corn	33.06	51.52	60.10	38.15	57.20	62.84	43.27	60.69	62.94	47.20	66.32	60.11
Soyben meal	46.27	39.78	18.54	41.05	34.56	15.73	35.81	32.82	15.64	31.72	28.65	18.52
Corn gluten meal 60%	9.01	-----	1.65	7.63	1.71	0.91	6.24	----	0.88	5.17	----	1.65
Rice husk	1.09	-----	9.21	2.62	-----	10.04	4.15	----	10.06	5.33	----	9.21
Soybean oil	5.64	4.65	5.93	5.69	3.31	5.96	5.73	3.39	5.96	5.77	2.28	5.93
Dicalcium phosphate	1.85	1.49	2.12	1.90	1.33	2.15	1.95	1.14	2.15	1.99	0.90	2.12
Limestone	0.88	1.17	0.68	0.84	1.13	0.65	0.80	0.98	0.65	0.77	0.85	0.68
L-Lysine (54,6%)	0.74	0.29	0.37	0.67	-----	0.33	0.60	0.07	0.33	0.54	0.13	0.37
DL- Methionine (98%)	0.39	0.29	0.13	0.34	0.11	0.10	0.29	0.20	0.10	0.26	0.19	0.13
L-Treonine	0.16	0.07	0.05	0.14	-----	0.04	0.12	----	0.04	0.10	----	0.05
Salt	0.52	0.52	0.50	0.51	0.50	0.50	0.51	0.46	0.50	0.51	0.43	0.50
Potassium chloride	0.04	-----	0.36	0.10	-----	0.39	0.16	----	0.39	0.21	-----	0.36
L-Valine (98 %)	0.07	0.01	0.01	0.06	-----	0.01	0.05	----	0.01	0.04	-----	0.01
Arginine	0.11	-----	0.04	0.10	-----	0.03	0.09	----	0.03	0.08	-----	0.04
Choline chloride	0.02	0.04	0.14	0.04	-----	0.15	0.06	----	0.15	0.08	----	0.17
Min/Vit. supplement ¹	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.20	0.10	0.10	0.20	0.10
Anticoccidiostatic ²	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Calculated composition												
Crude protein,%	29.90	22.40	16.10	27.30	21.20	14.70	24.70	19.8	13.30	22.10	18.40	11.90
AMEn (Kcal/kg)	3100	3100	3100	3100	3100	3100	3100	3100	3100	3100	3100	3100
Calcium,%	0.92	0.92	0.92	0.92	0.85	0.92	0.92	0.75	0.92	0.92	0.63	0.92
Non-phytate phosphorous,%	0.47	0.40	0.47	0.47	0.36	0.47	0.47	0.32	0.47	0.47	0.27	0.47
Potassium,%	0.97	0.84	0.66	0.91	0.75	0.62	0.85	0.78	0.62	0.80	0.72	0.59
Sodium,%	0.22	0.22	0.22	0.22	0.21	0.22	0.22	0.20	0.22	0.22	0.19	0.22
Chloride,%	0.36	0.36	0.41	0,37	0.34	0.42	0,38	0.33	0.47	0.46	0.31	0.56
Lysine Dig.,%	1.64	1.22	0.78	1.48	0.97	0.69	1.31	1.02	0.69	1.19	0.96	0.60
Methionine Dig.,%	0.81	0.59	0.33	0.72	0.41	0.29	0.63	0.47	0.30	0.57	0.44	0.25
Met + cysteine Dig.,%	1.18	0.88	0.56	1.06	0.70	0.50	0.95	0.74	0.50	0.86	0.70	0.43
Tryptophan Dig.,%	0.29	0.24	0.15	0.26	0.22	0.14	0.23	0.22	0.12	0.20	0.20	0.10
Threonine Dig.,%	1.07	0.79	0.52	0.96	0.68	0.47	0.86	0.68	0.46	0.77	0.63	0.39
Arginine Dig.,%	1.78	1.37	0.91	1.61	1.26	0.82	1.45	1.25	0.73	1.28	1.13	0.65
Valine Dig.,%	1.27	0.94	0.67	1.16	0.89	0.61	1.04	0.85	0.56	0.92	0.78	0.48
Isoleucine Dig.,%	1.10	0.85	0.58	1.01	0.81	0.53	0.91	0.78	0.47	0.80	0.71	0.41
Leucine Dig.,%	2.49	1.70	1.37	2.28	1.74	1.26	2.06	1.59	1.15	1.86	1.51	1.05
Histidine Dig.,%	0.69	0.55	0.39	0.63	0.53	0.36	0.58	0.50	0.33	0.52	0.46	0.29
Phenylalanine. Dig.,%	1.36	1.01	0.72	1.24	0.98	0.65	1.12	0.92	0.60	0.99	0.85	0.52
Phenyl + tyrosine Dig.,%	2.56	1.89	1.26	2.32	1.83	1.13	2.07	1.58	1.02	1.91	1.45	0.90

¹Composition/kg of diet: Mn = 150,000 mg, Fe = 100,000 mg, Zn = 100,000 mg, Cu= 16,000 mg, I = 1,500 mg, ²Content/kg of product: Folic acid = 1000 mg, pantothenic acid = 15,000 mg, Niacin = 40,000 mg, Biotin = 60 mg, vit B1 = 1,800 mg, vit, B12 = 12,000 mg, vit, B2 = 6,000 mg, vit, B6 = 2,800 mg, vit D3 = 2,000,000 UI, vit E = 15,000 mg, vit, K3 = 1,800 mg, Se = 300 mg. ² Coxistac 12%with salinomycin sodium.

The DXA scan procedures and chemical analysis (CHEM)

A Discovery Wi™ DXA device (Hologic, Bedford, MA) was used to scan the birds individually in different ages (total of 216 birds). The instrument was calibrated by a spine phantom using the infant whole body mode (QDR Software for Windows). At each examination, input data such as body weight and bird length (that limits the scanned area) was requested by the software.

One bird per plot was randomly selected to determine the whole body composition on DXA at 7, 14, 28, 42, 56 and 77 days of age. Prior to the measurements, birds were subjected to 2 hours withdrawal of feed. After that, they were manually contained for induction via facial mask with isoflurane diluted in 100% of oxygen. Afterwards, they were maintained in the general inhalation anesthesia, immobile to perform the scanning.

Birds were scanned in dorsal position, with legs and wings flexed, in the cranial to caudal direction (Figure 1). In order to diminish the variation between scans, prior to the conduction of the current study we performed tests to determine the position of broilers into the scan. After approximately 3 minutes of scanning it was obtained the measurements in grams of bone mineral content (BMC), fat mass (FM), lean mass (LM) and total mass (TM) which is the sum of LM, FM and BMC.



Figure 1– In vivo positioning of broilers on DXA for whole body analysis.

Posteriorly the DXA measurements, birds were fasted for 24 hours, weighed and then euthanized with CO₂ inhalation. All feathers were removed, by scalding (70°C) and using an automatic plucking machine. The feather-free body (FFB) was rinsed, drained and weighed. After that they were frozen at - 20°C in bags.

Subsequently FFB was cut in pieces and minced twice in a meat grinder to obtain a homogenous sample. Aliquot samples of FFB of this last process were collected in petri dish, frozen at - 80°C and freeze-dried under vacuum for 72 hours at - 50 °C (Edwards Super Modulyo, Thermo Fisher Scientific, Waltham, MA). Dried samples were ground in a ball mill to precede chemicals analysis.

Chemical analyses of the body feather-free samples were determined according to standard methods of AOAC (2005). The moisture was determined by the water lost in the pre-drying plus oven drying at 105 °C for 16 hours (method 920.39). The mineral content was determined by ashing in a muffle furnace at 500 °C for 4 hours (method 942.05). The crude protein was obtained by Kjeldahl method (Kjeltec 8400, Foss, Sweden) (method 2001.11). Fat was determined by Ankom^{XT15} Extractor (ANKOM Technology, Macedon, NY) with petroleum ether solvent (method 920.39).

Variables calculation to analysis of variance

In vivo total mass (TM) data obtained from DXA were compared with live body weight (g) of the same bird. Data of body composition obtained by DXA in grams were transformed in relative basis, % as follows:

$$Y\% = (BC_{DXA}/TM) \times 100$$

Where: BC_{DXA} is the body composition of DXA (i.e. fat mass, lean mass and bone mineral content in grams); TM is the total mass in grams.

The body composition chemically determined (% of natural matter) were transformed in relative basis, % of the feather-free body weight (FFBW):

$$Y\% = (BC_{CHEM}/FFBW) \times 100$$

Where: Y% is the percentage of the chemical component; BC_{CHEM} is the body composition determined by chemical analysis (CHEM) (i.e. protein+water to correspond to the lean, ash and fat content in grams); FFBW is the feather-free body weight in grams.

Data were subjected to analysis of variance for calculation of treatment means. To homogenize the variance, the body components of chemical and DXA were logarithmically transformed. Square root calculation was used for ash. The Box-Cox test was used to check the variance and the Crame von-Maises to test the errors

normality, and the F test was applied at 5% significance using the PROC GLM of statistical software SAS (SAS Institute; Cary, NC) version 9.4.

Regression analysis for predictive equations of DXA

All body components in grams were transformed to \ln (natural logarithm) before the application of the regression analysis. The regression was fitted in order to associate *in vivo* DXA measurements with the chemical feather-free body (FFB) data using PROC REG of SAS software (SAS Institute; Cary, NC) version 9.4. Simple and multiple linear equations were used to adjust the relationship between $\ln Y$, component by CHEM, and $\ln X$, component by DXA.

$$\text{Simple regression: } \ln Y = \beta_0 + \beta_1 \times \ln X_1 + \varepsilon$$

Where: Y is the component in grams (body weight, protein, water or ash); β_0 is the intercept; β_1 is the regression coefficient; X_1 is the input variable (g) and ε is the error term.

For fat mass (FM, g) a multiple linear was used, with the introduction of two input variables to obtain better correlation. It was adopted the Akaike (AIC) criteria to selection the parameters of the model, according to BEAL (2005).

$$\text{Multiple regression: } \ln Y = \beta_0 + \beta_1 \times \ln X_1 + \beta_2 \times \ln X_2 + \varepsilon$$

Where: β_0 , β_1 , β_2 are regression coefficients; X_1 and X_2 are input variables (g); \ln is natural log and ε is the error.

Results

Comparisons of DXA and chemical analyzes (CHEM)

The effects of dietary crude protein levels, sex and the different methods used to estimate broiler body chemical composition are detailed in tables 2 (body weight), 3 (fat percentage), 4 (lean percentage) and 5 (ash percentage).

There were differences by the sex, dietary crude protein levels and method, and also interactions between factors evaluated. However, only differences on estimates of body composition provided by the DXA and chemical analysis methods were objective of interest. The mean values presented here demonstrated that the factors used, namely, sex and protein levels, allowed to modify and to obtain greater variation on the chemical composition of the birds.

Table 2 - Mean total mass (g) and body weight (g) (\pm SD) of broilers according to sex, dietary crude protein level and methods for body composition estimate: DXA and chemical analysis (CHEM)

Diet ¹	Sex	7d	14d	28d	42d	56d and 63d ²	77d
Total mass (g) – DXA							
HP	Male	169.0 \pm 29.7	472.6 \pm 34.1	1580.8 \pm 85.0	3271.5 \pm 198.4	4932.1 \pm 96.0	6665.7 \pm 397.1
SP	Male	166.8 \pm 19.3	501.5 \pm 29.8	1668.1 \pm 181.0	3107.3 \pm 208.6	4647.7 \pm 209.9	6596.9 \pm 126.3
LP	Male	138.4 \pm 14.1	379.5 \pm 79.3	1405.5 \pm 163.4	3005.6 \pm 210.3	4557.8 \pm 280.4	6274.3 \pm 893.6
HP	Female	174.3 \pm 17.4	505.2 \pm 34.0	1521.5 \pm 127.2	2902.6 \pm 171.1	3907.4 \pm 276.4	5532.2 \pm 254.8
SP	Female	147.6 \pm 20.9	482.8 \pm 43.8	1471.7 \pm 41.2	2833.1 \pm 105.3	3879.6 \pm 254.0	5035.1 \pm 144.3
LP	Female	140.5 \pm 19.7	394.4 \pm 48.2	1348.8 \pm 130.4	2678.4 \pm 318.2	3746.0 \pm 520.5	5124.7 \pm 203.8
General mean		156.1	456.0	1499.4	2966.4	4278.4	5871.5
Body weight (g) – CHEM							
HP	Male	166.7 \pm 22.1	495.0 \pm 30.3	1560.0 \pm 88.6	3188.3 \pm 206.2	4743.3 \pm 148.5	6436.7 \pm 304.4
SP	Male	164.2 \pm 13.2	485.0 \pm 26.4	1656.7 \pm 180.4	3015.0 \pm 203.1	4504.2 \pm 210.0	6351.7 \pm 121.0
LP	Male	140.0 \pm 13.8	385.8 \pm 50.1	1392.5 \pm 159.0	2915.8 \pm 220.8	4445.0 \pm 273.0	6075.0 \pm 848.7
HP	Female	167.5 \pm 17.2	460.8 \pm 30.6	1507.5 \pm 120.2	2809.2 \pm 167.4	3839.2 \pm 355.2	5401.7 \pm 296.1
SP	Female	144.2 \pm 16.6	478.3 \pm 54.7	1477.5 \pm 64.1	2759.2 \pm 92.5	3869.2 \pm 278.9	4915.0 \pm 140.6
LP	Female	139.2 \pm 12.4	393.3 \pm 41.1	1329.1 \pm 124.7	2569.2 \pm 293.4	3652.5 \pm 487.8	4965.0 \pm 216.7
General mean		153.6	449.7	1487.2	2876.1	4175.6	5690.9
Sources of variation		-----Probability-----					
Sex		0.0016	ns	0.0016	<0.0001	<0.0001	<0.0001
Diet		<0.0001	<0.0001	<0.0001	0.0005	0.0203	ns
Method		ns	ns	ns	ns	ns	ns
Sex x Diet		ns	ns	ns	ns	ns	ns
Sex x Method		ns	ns	ns	ns	ns	ns
Diet x Method		ns	ns	ns	ns	ns	ns
Sex x Diet x Method		ns	ns	ns	ns	ns	ns
CV%		8.67	9.81	8.67	7.15	7.25	7.01

¹Diet = HP (High protein), LP (Low protein), SP (Standard protein).

² Birds evaluated at 56 days for males and 63 days for females.

Table 3 - Mean fat percentage (\pm SD) of broilers according to sex, dietary crude protein level and methods for body composition estimate: DXA and chemical analysis (CHEM)

Diet ¹	Sex	7d	14d	28d	42d	56d and 63d ²	77d
Fat (%) – DXA							
HP	Male	12.0 \pm 2.07	12.08 \pm 1.10	8.31 \pm 0.01	10.75 \pm 1.28	10.9 \pm 1.22	10.57 \pm 1.17
SP	Male	12.0 \pm 2.76	12.12 \pm 1.74	8.50 \pm 0.09	13.03 \pm 1.62	11.1 \pm 1.27	10.19 \pm 0.27
LP	Male	14.7 \pm 1.34	18.07 \pm 1.09	9.00 \pm 0.17	12.61 \pm 2.30	11.7 \pm 1.35	11.27 \pm 0.96
HP	Female	14.7 \pm 2.56	10.25 \pm 1.19	8.33 \pm 0.03	15.15 \pm 1.55	12.8 \pm 1.54	14.80 \pm 1.51
SP	Female	13.8 \pm 1.84	10.83 \pm 1.76	8.39 \pm 0.06	11.91 \pm 1.51	15.9 \pm 1.74	12.70 \pm 1.02
LP	Female	12.9 \pm 1.60	12.36 \pm 1.70	9.37 \pm 0.23	21.05 \pm 0.89	17.1 \pm 3.09	14.34 \pm 1.27
General mean		13.4	12.6	8.7	14.1	13.3	12.3
Fat (%) – CHEM							
HP	Male	3.7 \pm 0.21	6.05 \pm 0.41	6.27 \pm 0.92	7.86 \pm 0.63	7.9 \pm 0.84	9.24 \pm 1.53
SP	Male	5.5 \pm 0.32	7.40 \pm 0.59	10.91 \pm 0.43	10.83 \pm 0.79	10.3 \pm 0.77	11.96 \pm 0.93
LP	Male	9.0 \pm 0.56	13.56 \pm 0.39	17.38 \pm 1.24	16.46 \pm 0.81	15.3 \pm 1.19	14.74 \pm 3.32
HP	Female	5.1 \pm 0.50	5.47 \pm 0.59	8.71 \pm 0.59	10.56 \pm 1.24	13.2 \pm 1.52	16.63 \pm 0.45
SP	Female	5.8 \pm 0.39	8.21 \pm 0.43	10.68 \pm 0.86	12.63 \pm 0.81	13.0 \pm 0.76	20.75 \pm 1.66
LP	Female	9.5 \pm 0.80	14.33 \pm 0.43	16.85 \pm 0.84	17.21 \pm 0.66	18.8 \pm 0.91	19.64 \pm 1.31
General mean		6.4	9.2	11.8	12.6	13.1	15.5
Sources of variation		-----Probability-----					
Sex		ns	ns	ns	0.0005	<0.0001	<0.0001
Diet		<0.0001	<0.0001	<0.0001	<0.0001	0.0003	ns
Method		<0.0001	<0.0001	<0.0001	ns	ns	0.0021
Sex x Diet		ns	ns	ns	ns	ns	ns
Sex x Method		ns	0.0286	ns	ns	ns	ns
Diet x Method		0.0006	0.0002	<0.0001	0.0250	0.0410	0.0490
Sex x Diet x Method		ns	ns	0.0397	0.0334	ns	ns
CV%		13.39	10.18	7.23	10.02	10.87	6.68

¹Diet = HP (High protein), LP (Low protein), SP (Standard protein).

² Birds evaluated at 56 days for males and 63 days for females.

Table 4 - Mean lean percentage (\pm SD) of broilers according to sex, dietary crude protein level and methods for body composition estimate: DXA and chemical analysis (CHEM)

Diet ¹	Sex	7d	14d	28d	42d	56d and 63d ²	77d
Lean (%) – DXA							
HP	Male	87.06 \pm 2.11	86.79 \pm 1.13	90.36 \pm 0.07	88.41 \pm 1.44	87.61 \pm 1.19	87.91 \pm 1.12
SP	Male	89.69 \pm 1.08	86.84 \pm 1.76	90.12 \pm 0.06	85.63 \pm 1.61	87.49 \pm 1.26	88.33 \pm 0.24
LP	Male	84.29 \pm 1.26	81.07 \pm 1.31	89.65 \pm 0.18	85.34 \pm 2.74	86.75 \pm 1.38	87.27 \pm 0.94
HP	Female	84.28 \pm 2.66	89.01 \pm 1.36	90.33 \pm 0.06	81.82 \pm 0.72	85.88 \pm 1.52	83.92 \pm 1.55
SP	Female	85.23 \pm 1.82	88.06 \pm 1.78	90.34 \pm 0.06	86.88 \pm 1.54	82.82 \pm 1.75	86.07 \pm 1.02
LP	Female	86.17 \pm 1.60	87.40 \pm 1.83	89.30 \pm 0.25	77.67 \pm 0.90	81.54 \pm 3.09	84.44 \pm 1.31
General mean		86.12	86.53	90.02	84.29	85.35	86.32
Protein+Water (%) – CHEM							
HP	Male	91.48 \pm 1.01	88.68 \pm 0.79	90.36 \pm 0.07	87.85 \pm 1.05	87.19 \pm 0.72	84.87 \pm 0.73
SP	Male	89.57 \pm 0.82	87.66 \pm 0.49	84.48 \pm 0.43	85.53 \pm 1.09	85.51 \pm 1.18	82.85 \pm 0.61
LP	Male	87.30 \pm 0.62	82.44 \pm 0.24	78.96 \pm 1.25	79.55 \pm 0.69	80.35 \pm 1.30	79.99 \pm 2.12
HP	Female	90.50 \pm 0.65	89.92 \pm 0.97	87.18 \pm 1.28	85.40 \pm 1.22	83.44 \pm 1.83	79.34 \pm 1.63
SP	Female	88.54 \pm 0.91	87.44 \pm 0.80	85.29 \pm 1.28	82.65 \pm 0.59	81.97 \pm 0.97	75.75 \pm 1.64
LP	Female	85.16 \pm 0.73	81.38 \pm 0.46	80.16 \pm 1.11	78.78 \pm 0.67	77.05 \pm 1.22	77.86 \pm 0.71
General mean		88.76	86.25	84.41	83.29	82.59	80.11
Sources of variation		-----Probability-----					
Sex		0.0499	0.0207	ns	<0.0001	0.0001	<0.0001
Diet		0.0156	<0.0001	<0.0001	<0.0001	0.0003	ns
Method		0.0014	ns	<0.0001	ns	0.0038	<0.0001
Sex x Diet		ns	ns	ns	ns	ns	ns
Sex x Method		ns	0.0168	ns	ns	ns	ns
Diet x Method		ns	ns	<0.0001	ns	ns	ns
Sex x Diet x Method		ns	ns	ns	0.0075	ns	ns
CV%		0.86	0.73	0.54	0.81	1.04	0.60

¹Diet = HP (High protein), LP (Low protein), SP (Standard protein).

² Birds evaluated at 56 days for males and 63 days for females.

Table 5 - Mean bone mineral percentage and ash percentage (\pm SD) of broilers according to sex, dietary crude protein level and methods for body composition estimate: DXA and chemical analysis (CHEM)

Diet ¹	Sex	7d	14d	28d	42d	56d and 63d ²	77d
Bone mineral (%) – DXA							
HP	Male	0.96 \pm 0.04	1.12 \pm 0.04	1.33 \pm 0.07	1.29 \pm 0.04	1.49 \pm 0.06	1.51 \pm 0.05
SP	Male	0.94 \pm 0.03	1.03 \pm 0.05	1.38 \pm 0.05	1.34 \pm 0.04	1.41 \pm 0.03	1.47 \pm 0.03
LP	Male	1.03 \pm 0.09	1.13 \pm 0.06	1.34 \pm 0.05	1.38 \pm 0.05	1.51 \pm 0.05	1.45 \pm 0.04
HP	Female	1.07 \pm 0.12	1.03 \pm 0.03	1.33 \pm 0.04	1.27 \pm 0.02	1.29 \pm 0.06	1.27 \pm 0.07
SP	Female	0.94 \pm 0.08	1.11 \pm 0.05	1.27 \pm 0.02	1.20 \pm 0.04	1.31 \pm 0.07	1.22 \pm 0.03
LP	Female	0.97 \pm 0.08	1.08 \pm 0.04	1.32 \pm 0.03	1.27 \pm 0.02	1.35 \pm 0.02	1.21 \pm 0.05
General mean		0.99	1.08	1.33	1.29	1.39	1.36
Ash (%) – CHEM							
HP	Male	2.08 \pm 0.08	2.51 \pm 0.13	2.43 \pm 0.17	2.64 \pm 0.16	2.48 \pm 0.15	3.07 \pm 0.05
SP	Male	2.06 \pm 0.04	2.28 \pm 0.12	2.45 \pm 0.12	2.66 \pm 0.10	2.75 \pm 0.11	2.64 \pm 0.12
LP	Male	1.99 \pm 0.07	2.30 \pm 0.08	2.79 \pm 0.22	2.85 \pm 0.21	2.88 \pm 0.27	3.06 \pm 0.60
HP	Female	2.26 \pm 0.08	2.26 \pm 0.10	2.55 \pm 0.14	2.41 \pm 0.11	2.48 \pm 0.07	2.19 \pm 0.25
SP	Female	2.02 \pm 0.07	2.38 \pm 0.14	2.47 \pm 0.10	2.73 \pm 0.23	2.64 \pm 0.17	2.71 \pm 0.16
LP	Female	2.00 \pm 0.11	2.79 \pm 0.27	2.64 \pm 0.17	2.29 \pm 0.11	2.51 \pm 0.12	2.21 \pm 0.45
General mean		2.07	2.42	2.56	2.60	2.62	2.65
Sources of variation		-----Probability-----					
Sex		ns	ns	ns	0.0110	0.0166	0.0002
Diet		ns	ns	ns	ns	ns	ns
Method		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Sex x Diet		ns	ns	ns	ns	ns	ns
Sex x Method		ns	ns	ns	ns	ns	ns
Diet x Method		ns	ns	ns	ns	ns	ns
Sex x Diet x Method		ns	ns	ns	ns	ns	ns
CV%		6.36	6.74	6.68	6.60	6.85	6.65

¹Diet = HP (High protein), LP (Low protein), SP (Standard protein).

² Birds evaluated at 56 days for males and 63 days for females.

There was no significance difference on the methods between the body weight (g) and DXA total mass (g) at the ages evaluated (Table 2). However, there was significant difference for sex and diets.

At 7, 14, 28, and 77 days of age, fat content (table 3) in broiler carcasses varied according to the method employed for body composition measurements ($p < 0.01$). It could be also observed that there was a discrepancy in the DXA values read at 28 days of age, where the overall mean was lower than the other evaluated ages. The difference between DXA and CHEM in the fat composition at 7, 14, 28 and 77 days were 51,8%, 27,3%, 26.7% and 20.5%, respectively.

Also, there was a significant interaction for diet and method in percentage of fat at all ages evaluated. According to factorial analysis, the interaction between sex \times diet \times method was significant, only lean percentage ($p = 0.0075$) at 42 days of age (Table 4). There was also significant interaction for diet and method at 28 days of age and significant interaction for sex and method at 14 days of age ($p = 0.0168$). Although the presence of these interactions, it was chosen not to investigate them due they were mostly punctual and difficult for explanation.

The methods used to determine body composition provided different estimates for ash content in broiler bodies in all ages evaluated ($P < 0.001$). Such differences ranged from 44.3% to 54.4%.

Predictive equations for *in vivo* body composition measurements on DXA

Based on the differences observed by methods the following regression equations (\pm SE) were elaborated to calculate the body composition directly by DXA inputs: the feather free body weight (FFBW) and its contents of protein (BP), water (BWater), ash (BAsh) and lipids (BL) as follows:

Feather- free body compositions in females:

$$\text{FFBW} = \exp[-0.30299 + 1.02326 \times (\ln \text{ Total Mass})] \pm 1.03 \text{ g}, R^2 = 0.9994;$$

$$\text{BP} = \exp[-2.60837 + 1.10137 \times (\ln \text{ Lean Mass})] \pm 1.11 \text{ g}, R^2 = 0.9940;$$

$$\text{BWater} = \exp[-0.22907 + 0.98247 \times (\ln \text{ Lean Mass})] \pm 1.07 \text{ g}, R^2 = 0.9971;$$

BAsh = $\exp[0.67199+0.96387 \times (\ln \text{ Bone Mineral Content})] \pm 1.18 \text{ g}$, $R^2 = 0.9839$;

BL = $\exp[-3.03573+0.35802 \times (\ln \text{ Fat Mass})+0.91155 \times (\ln \text{ BWater})] \pm 1.50 \text{ g}$,
 $R^2 = 0.9569$

Feather- free body compositions in males:

FFBW = $\exp[-0.26714+1.01939 \times (\ln \text{ Total Mass})] \pm 1.05 \text{ g}$, $R^2 = 0.9988$;

BP = $\exp[-2.54693+1.0932 \times (\ln \text{ Lean Mass})] \pm 1.10 \text{ g}$, $R^2 = 0.9959$;

BWater = $\exp[-0.20794+0.98056 \times (\ln \text{ Lean Mass})] \pm 1.06 \text{ g}$, $R^2 = 0.9981$;

BAsh = $\exp[0.63735+0.96876 \times (\ln \text{ Bone Mineral Content})] \pm 1.17 \text{ g}$, $R^2 = 0.9874$;

BL = $\exp[-2.73978+0.45512 \times (\ln \text{ Fat Mass})+0.76642 \times (\ln \text{ BWater})] \pm 1.50 \text{ g}$, $R^2 = 0.9400$

However, it is limiting to have to use different equations for males and females. Data for both genders were compared using simple linear regression with groups in Genstat software (2002), to test whether a common equation could be used for both sexes and though there were some statistically significant differences, the relationships were very near between two sexes. For this reason, we encourage to use the regression of both sexes below.

Feather- free body compositions in both sexes:

FFBW = $\exp[-0.28473+1.02128 \times (\ln \text{ Total Mass})] \pm 0.04 \text{ g}$, $R^2 = 0.9991$;

Body protein = $\exp[-2.57623+1.09710 \times (\ln \text{ Lean Mass})] \pm 0.10 \text{ g}$, $R^2 = 0.9950$;

Body water = $\exp[-0.21858+0.98152 \times (\ln \text{ Lean Mass})] \pm 0.06 \text{ g}$, $R^2 = 0.9977$;

Body ash = $\exp[0.65487+0.96626 \times (\ln \text{ Bone Mineral Content})] \pm 0.16 \text{ g}$, $R^2 = 0.9859$;

Body Lipids = $\exp[-2.78590+0.44774 \times (\ln \text{ Fat Mass})+0.79215 \times (\ln \text{ Body Water})] \pm 0.38 \text{ g}$, $R^2 = 0.9457$.

Discussion

The usage of DXA as a tool to determine broiler body composition has already been reported in literature. The method basis generally consists of the attenuation of the X-ray energies. Despite its advantages published data demonstrate a trend of DXA method in overestimating broiler (SWENNEN et al., 2004; SALAS et al., 2012) and rats (JEBB et al. 1996) total mass.

In a previous study involving broiler body composition determination by DXA and chemical analysis, Mitchell et al. (1997) observed differences in bird total mass (TM) and body weight. The aforementioned authors noticed that these differences became higher in broilers with body weight lower than 2 kg. Contrary to such findings, our results demonstrate that the methods herein evaluated did not differ in estimating body weight and total mass. Although the average values from TM compared to weighing in the scale of the body weight were up to 3% higher, this difference was not enough to be detected by analysis of variance. In fact this was the only variable which corresponded with the value of reference determined.

Total mass obtained through DXA method represents lean, fat mass and total bone mineral content of the body. Our results indicated a correspondence between chemical analysis and DXA method for the weight of birds. However these results do not provide evidences which allow extrapolating that such behavior of response may be also applied to bird whole body composition, because DXA can over or sub estimate some components (MITCHELL et al., 1998).

Fat mass estimates are associated with a high variation due to the existing individual variation among animals (MITCHELL et al., 1997). BROMMAGE, (2003) observed that DXA method overestimated fat mass in rats. Our results support these findings for broilers at 7 and 14 days of age, which had a higher fat mass percentage according to DXA method comparing with chemical analysis. However, at 28 and 77 days of age, we noticed an opposite response in broiler fat mass percentage, which were underestimated by DXA device. Indeed, the reason for this discrepancy is not clear.

The DXA predicts the body composition separating the components in a 3-compartment model (fat mass, lean and BMC), in which protein and water are primarily determined as lean mass. According to PIETROBELLI et al. (1998), the

water content of lean mass may interfere on body fat determination. The aforementioned authors observed systematic errors in fat mass estimates in response to changes in fluid balance.

The errors in DXA measurements of body composition was classified by BAZZOCHI et al. (2016) as: (1) technical errors generated by the machine or incorrect positioning on the scanning bed and (2) biological variations, which include changes in hydration status, by food and fluid intake. The second statement can be a problem when comparing different types of body composition as those classically occur between males and females broilers, where fat-free mass hydration can vary during growth.

Mitchell et al. (1997) using chickens ranging from 400 to 3290 g of weight found low correlation between fat percentage by DXA and chemical measurements ($R^2= 0.33$ to 0.47). In the present research, it was used birds ranging from 140g to 6500g and through the multiple linear association between fat and lean in the model allowed better fit ($R^2=0.9569$ for females and 0.9387 for males).

Percentage of DXA lean was compared to chemical lean based on the determination of protein and water content and apparently very small differences between the methods can be noticed (table 4).

The DXA method underestimated ash content. The differences between bone mineral content (BMC) and ash content may be attributed to the fact that DXA only takes mineral content of bones in account, whereas chemical analysis consider ashes of bones and non-bone tissues, which include organs, muscles and liver, which have considerable mineral content (SPEAKMAN et al., 2001).

The BMC measured by DXA in human investigations has been reported to be very well-established accurate method and became a clinical standard for the assessment of bone mineral mass. It is important to consider that fact of not providing accurate estimates about total mineral content of body do not become DXA method not applicable. On the contrary, the method allows evaluating some relevant variables related to bone integrity, without involving animal slaughter.

SCHREIWEIS et al. (2005) found positive correlations between laying hen bone mineral content obtained through DXA device and bone breaking force and

bone ash content, which indicate that DXA may be a potential tool for noninvasive analysis of bird skeletal integrity.

The development of different equations for males and females broilers are an important point, to eliminate discrepancies caused by gender and also innovative compared to previous studies in birds (MITCHEL et al., 1997; SALAS et al, 2012) that not attempted to correct the differences on growth and composition of weight gain by gender, and now can be assumed by the predictive models to diminish bias on DXA scans.

WILLIAMS (2006) pointed that the accuracy of DXA was different due to age, sex, size, fatness and disease states, when scanned the human body composition on healthy non-obese, obese and ill patients. This statement appears in others reports in clinical studies of humans (BAZZOCHI et al., 2016). The variances between bodies composition in humans can be larger as compared to a uniform chicken population. However, dietary protein levels applied in this research promoted means of increasing the amplitude of body weights and particularly, fat depositions in the animals, varying in sex and age. Once, most of the researches conducted in this laboratory involving broilers nutrition and diverse body composition, the information provided from this research - regarding DXA standardization and equations elaborated - will make its use in future researches a possibility.

In general, our findings indicated that each method evaluates the body composition of broilers differently and caution is required in the application of DXA in the measurement of broiler body composition, because it can not provide a direct measurement without the use of the predictive equations established here.

Based on the above-mentioned it would be worth expanding this noninvasive method into procedures of broilers and consequently, DXA could be an important tool for studies investigating factors that influence body composition in scientific

Conclusion

The results presented show the potential of using DXA tool to assess body composition of *in vivo* broilers.

The correlations between the results of DXA measurements and chemical analysis were highly significant. The main advantage of the equations established to

determine body composition by DXA is that it allows serial measurements of the same animal at various stages of life, offering assess the results almost instantly.

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CAPÍTULO 3 – THE DXA BODY COMPOSITION SUPPORTS *in vivo* ASSESMENT OF THE POTENTIAL GROWTH OF BROILER STRAINS

Abstract: Genetic improvements in modern strains have led to continuous increments in broiler growth rates, which as a consequence have resulted in higher economic returns for broiler producers over the last decades. This study was conducted to characterize the potential growth of the body and feathers of Cobb, Hubbard and Ross male and female broilers, as well as to assess the changes in chemical composition that occur up to 15 weeks of age. Birds were fed isoenergetic diets, divided in four phases, and formulated to exceed marginally the nutritional requirements of the strains throughout the growing period. They were maintained in a controlled environment so as not to limit growth. A dual energy X-ray absorptiometry (DXA) scanner was used to follow the *in vivo* body composition of 12 broilers of each strain and sex whilst the feather weight and composition was determined in birds selected at intervals during the growing period (in total 48 broilers of each strain and sex) through comparative slaughter with later chemical analysis. Parameters of Gompertz growth curve to describe the strains were estimated for body and feather weight as well as for the growth of their chemical components. Differences were evident in the growth rates between males and females, and between strains indicating the possible differences in selection methods used by geneticists in the different breeding companies. These results confirm that differences exist in the growth potential of three commercial broilers strains, and that the DXA technology may successfully be used to measure the growth potential of broilers. The main advantage of DXA technology is to decrease the variation resulting from the use of the serial slaughter technique for measuring the chemical composition of the body. However, it is unsuitable for measuring the growth of feathers.

Keywords: comparative slaughter, chemical composition, feathers, fat, genetics, Gompertz function; protein

Introduction

Over the last decades geneticists have continually improved the growth potential and body composition of broilers, with changes in nutrition having less influence on these observed improvements (HAVENSTEIN et al., 2003; SCHMIDT et al., 2009; ZUIDHOF et al., 2014). In response to intensive genetic selection, modern strains of broilers now exhibit elevated growth rates in a short period of time, associated with improvements in feed conversion.

In general, animal growth can be described as the successive accretion of protein, fat, water and ash, which is the result of biological processes encoded by animal genotype (MARTIN et al., 1994). Several factors, which include genetic strain, gender, feeding program, bird development stage and environmental conditions are widely recognized to influence broiler growth pattern. Inevitably, as a direct consequence of changes in bird growth, changes in body chemical composition are expected. Knowledge of the potential rates at which the chemical components of the body are deposited over time is essential, for example, to manipulate feeding programs in order to ensure maximum conversion of dietary protein into muscle protein. This is becoming increasingly important since consumers are now demanding specific characteristics in broilers carcasses such as a lower percentage of fat.

The potential of a broiler strain growth can be predicted when birds are raised under non-limiting conditions (dietary and environmentally) (GOUS et al., 1999). Of the many mathematical models that describe the genetic potential of broiler growth the Gompertz model (1825) is the most frequently used due to its simplicity in predicting growth responses based on only three parameters: initial body weight (W_i), mature size (W_m) and the rate parameter, B (LEWIS et al., 2002).

In order to calculate the growth rates of the chemical components of the body, Emmans (1986) proposed the successive sampling of birds at intervals from hatch through to maturity for chemical analysis of their carcasses (MARTIN et al., 1994; HANCOCK et al., 1995). Although chemical analyses traditionally represent a reliable method to investigate body chemical composition, it is also limited since it does not allow the measurements to be taken of the same animal during its different phases of growth.

As an alternative, technologies have been adopted to collect such data. The dual energy X-ray absorptiometry (DXA) is a diagnostics imaging tool used in human medicine that has been demonstrated to be an acceptable method to assess the body composition of broilers *in vivo* (MITCHELL; ROSEBROUGH; CONWAY, 1997; SWENNEN et al., 2004). The application of DXA method to determine broiler chemical composition could provide precise data to establish a curve of nutrient deposition accounting for individual variation of birds.

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In a previous study, equations were established in order to correlate the DXA measurements with body protein, ash and lipid weight of the feather free body (FFB) (CHAPTER 2). The dayold variables were taken by comparative slaughter method due to the lack accurate values provided by the software DXA using the infant whole body module of scan. However, with regard to the feather growth and composition, to the best of our knowledge, it is poorly measured by DXA (MITCHELL et al., 2011) and to avoid bias due feathers the interpretation still needs to be done by comparative slaughter.

Therefore, this study was conducted: 1) to determine the parameters of the growth potential of three broilers strains: Cobb, Ross and Hubbard (males and females), by means of a Gompertz function using DXA method to obtain *in vivo* growth potential and body composition; 2) define feather growth by Gompertz function in order to compare the rates of feather growth between strains.

Material and methods

Ethics Statement

All procedures herein adopted were previously approved by the Ethics Committee of Animal Care and Use (protocol number, 999) of the Faculdade de Ciências Agrárias e Veterinárias de Jaboticabal, UNESP.

Bird husbandry and experimental design

One day-old male and female broilers chicks of three genetic strains (Cobb, Hubbard and Ross) were obtained from a local commercial hatchery, from broiler breeders with approximate ages, Cobb 42 w, Hubbard 40 w and Ross 41 w and housed in an environmentally controlled room with a negative pressure system controlled by thermostats and timers to promote minimum ventilation, air movement and thermal comfort. Up to two weeks of age chicks were heated with infrared lamps.

Broilers chicks were reared from 1 to 105 days of age. A factorial arrangement was used with three strains (Cobb, Hubbard and Ross) x two gender (males and females). A total of 384 day-old broiler chicks (128 birds/strain) was randomly assigned to one of the six treatments, with four replicates of 16 birds in order to determine the potential broiler growth rates and chemical composition using the DXA method. A further 624 day-old broiler chicks (208 birds/strain) were randomly assigned to one of six treatments, with four replicates of 26 birds in order to determine the behavior of feather growth. These latter birds were sacrificed at intervals throughout the growing period.

Birds were allocated to pens covered with wood-shavings. Throughout the feeding trials birds had free access to water and feed (mash form), provided by nipple drinkers and tubular-feeders, respectively. Lighting program was set at 24L during the first week post hatch and 20L:4D from 7 d post hatch to the end of the experiment. The stocking density at the end of the trial was kept at 24 kg/m².

Experimental diets

A four-phase nutrition program was formulated: 1 to 14 days, 15 to 28 days, 29 to 42 days and 43 to 105 days. Experimental diets (Table 1) were formulated to

contain 3105 kcal of AMEn/kg and meet or exceed broiler nutritional requirements according to EFG broiler growth model (EFG Software, 2006). Feedstuffs and experimental diets were analyzed for dry matter, crude protein, and gross energy (AOAC, 2005).

Measurements

Body growth and composition of the strains by DXA

Body composition was determined in the initial group (six birds of each strain and sex, n= 36, were sampled at dayold for chemical analysis) and thereafter in birds individually scanned *in vivo* using the DXA device (n= 12 birds of each sex and strain).

At 7 d post-hatch, three birds per replicate (12 birds of each sex and strain) were randomly selected, identified by a microchip implant under tight skin and scanned on a Discovery Wi DXA device (Hologic QDR series) using infant whole body scan configuration. The same birds were scanned weekly until 8 w of age and thereafter every two weeks until achieving 15 w. Due to logistics problems DXA measurements on males and females were made on alternate days (males measured one day prior to females). Logistical problems at 8 w resulted in only males being measured then, with females being analyzed a week later at 9 weeks.

Prior to live scanning, broilers were anesthetized after 2 h of feed withdrawal. Anesthesia was induced with isoflurane dissolved in 100% oxygen via face mask. The birds were placed on the DXA and scanned. Afterwards, birds were immediately returned to their respective floor pens to receive feed thereby not compromising growth.

Measurements of body chemical composition reported by DXA were total mass (TM, g), fat mass (FM, g), lean mass (LM, g) and bone mineral content (BMC, g). These values were corrected by the prediction equations described by (CHAPTER 2) to adjust the raw DXA data outputs into chemical contents in grams of water, protein, ash and fat of the feather-free body weight (FFBW):

$$\text{FFBW} = \exp[-0.28473 + 1.02128 \times (\ln \text{Total Mass})];$$

$$\text{Body protein} = \exp[-2.57623 + 1.09710 \times (\ln \text{Lean Mass})];$$

$$\text{Body water} = \exp[-0.21858 + 0.98152 \times (\ln \text{Lean Mass})];$$

Body ash = $\exp[0.65487+0.96626 \times (\ln \text{ Bone Mineral Content})]$;

Body Lipids = $\exp[-2.78590+0.44774 \times (\ln \text{ Fat Mass})+0.79215 \times (\ln \text{ Body Water})]$.

Table 1- Ingredients and nutritional composition of experimental diets, as-fed basis

Ingredients (%)	Phases			
	1-14 days	15-28 days	29-42 days	43-105 days
Corn	53.83	61.29	69.50	68.00
Soyben meal (45%)	32.11	25.83	20.82	18.16
Corn gluten meal (60%)	5.65	6.61	4.88	---
Wheat bran	---	---	---	7.64
Soybean oil	3.26	1.79	0.66	2.53
Dicalcium phosphate	2.02	1.82	1.62	1.43
Limestone	0.95	0.87	0.80	0.81
L-lysine (54,6%)	1.06	0.90	0.78	0.56
DL- methionine (98%)	0.22	0.15	0.12	0.12
L-arginine (99%)	0.17	0.15	0.16	0.09
L-treonine (98.5%)	0.15	0.11	0.11	0.10
L-valine (96.5 %)	0.09	0.00	0.07	0.08
Salt	0.36	0.36	0.36	0.35
Vitamin and Mineral Supplement ¹	0.10	0.10	0.10	0.10
Anticoccidiostatic ²	0.02	0.02	0.02	0.02
Calculated composition				
AMEn, Kcal/kg	3105	3105	3105	3105
Crude Protein,%	24.00	22.00	19.00	15.00
Lysine Dig.,%	1.56	1.33	1.14	0.94
Methionine Dig. ,%	0.55	0.47	0.40	0.33
Methionine + cystine Dig.,%	0.86	0.76	0.66	0.55
Tryptophan Dig. ,%	0.23	0.20	0.17	0.15
Threonine Dig. ,%	0.90	0.80	0.71	0.59
Arginine Dig. ,%	1.48	1.31	1.15	0.97
Valine,%	1.05	0.89	0.84	0.70
Isoleucine,%	0.89	0.80	0.68	0.54
Leucine,%	1.51	1.38	1.29	1.25
Phenylalanine + tyrosine,%	1.90	1.77	1.51	1.13
Calcium,%	0.96	0.87	0.78	0.74
Sodium,%	0.16	0.16	0.16	0.16
Non-phytate phosphorus,%	0.48	0.43	0.39	0.37
Potassium,%	0.75	0.65	0.58	0.60
Glycine+serine,%	1.83	1.67	1.44	1.13
Histidine,%	0.54	0.49	0.43	0.37

¹Content/kg of diet: Mn = 150.000 mg. Fe = 100.000 mg. Zn = 100.000 mg. Cu= 16.000 mg. I = 1.500 mg. ²Content/kg of product: Folic acid = 1000 mg. pantothenic acid = 15.000 mg. Niacin = 40.000 mg. Biotin = 60 mg. vit B1 = 1.800 mg. vit. B12 = 12.000 mg. vit. B2 = 6.000 mg. vit. B6 = 2.800 mg. vit D3 = 2.000.000 UI. vit E = 15.000 mg. vit. K3 = 1.800 mg. Se = 300 mg. ² Coxistac 12% with salinomycin sodium.

Feather growth and composition of the genotypes

At 1, 6, 13, 20, 27, 34, 41, 55, 69, 83, 97 and 104 d of age, one bird per pen (total of 4 birds per strain and sex) was randomly selected, weighed and fasted for 24 h. These birds were euthanized by CO₂ inhalation and individual feather samples from different parts of the body were collected and stored in weighed paper bags. After scalding at 65°C, the remaining feathers were mechanically removed from the bodies. Feather weight was calculated as the difference between live weight and defeathered weight.

Feather samples were dried in forced-air ventilation (55°C for 72 h), ground in a multi-purpose mill (Tecnal, TE 631/4) and analyzed for dry matter, ash and nitrogen content according to AOAC (2005). The dry matter was determined by drying a constant weight in a convection oven in 105°C per 16 h (method 920.39); nitrogen was determined by Kjeldahl procedure (Foss Kjelttec 8400, method 2001.11) and ash by furnace at 550°C per 4 hours (method 942.05). Crude protein was calculated by multiplying nitrogen content by 6.25.

Body and feather growth analysis and statistical models

The Gompertz growth function (1825) was utilized to estimate the potential growth rates of feather- free body and feathers and their chemical components for each strain described by Emmans (1981):

$$Wt = Wm \times e [- e ((\ln (-\ln (Wi/Wm)) - (B \times t)))] \quad [\text{Eq. 1}]$$

Where: Wt is the weight of the component (g) at time t , Wm is the weight of the component at maturity (g); Wi is the weight of the component at birth (g), B is the growth rate (daily), and t is the age in days.

The hatching weight of the body and feather components was used as the parameter Wi , using the birds slaughtered at the start of the experiment, for each strain and sex according to Silva (2016). Once the parameter Wm was estimated, the value was set in the Gompertz function described by Winsor (1932), to estimate the inflection point of the growth curve (t^*):

$$Wt = Wm \times e (-e (-B \times (t - t^*))) \quad [\text{Eq. 2}]$$

Where: Wt (grams) = weight of the component at time t ; Wm (grams) = weight of the component at maturity; B = growth rate (grams per day); t^* = time that growth rate is maximum (days).

The estimate of the absolute growth rate for body and feathers (g/day) expressed as a function of the weight at the time (dW/dt) was obtained using the derivative of Gompertz function:

$$\frac{dW}{dt} = B \times Wt \times \ln\left(\frac{Wm}{Wt}\right) \quad [\text{Eq.3}]$$

All estimates for Gompertz parameters values were performed using the proc NLIN of SAS statistical package version 9.2 (SAS Institute, Cary, NC, USA)

Results

Growth of the body by DXA

The mean body weights measured throughout the experiment is summarized in Table 2, and the mean chemical composition at different ages is presented in Tables 3 and 4.

Table 2 - Average body weight (g) of broilers at different ages according to strains

Age ¹		Strain/sex					
		Cobb		Hubbard		Ross	
Male	Female	Male	Female	Male	Female	Male	Female
0	0	42.0	45.2	41.0	38.0	44.0	42.0
7	8	182.2	212.0	139.6	159.4	155.0	193.2
14	15	495.4	544.2	400.8	434.2	436.3	484.2
21	22	1000.8	1027.5	844.6	869.2	908.3	922.1
28	29	1687.1	1625.8	1468.3	1428.8	1561.3	1470.0
35	36	2477.1	2282.9	2172.5	2022.9	2290.8	2081.3
42	43	3237.3	2888.0	2897.9	2587.6	3029.6	2681.5
49	50	3924.0	3537.9	3722.5	3225.3	3922.5	3301.7
56	63*	4824.2	4546.3	4619.6	4191.8	4803.2	4386.3
70	71	6187.7	5021.3	6251.8	4816.3	6245.6	4872.1
84	85	7035.5	5716.7	7486.4	5830.0	7415.7	5557.9
105	106	7659.3	6309.2	8111.9	6375.5	7608.8	6429.2

¹ Values correspond to the average of 12 individual measurements per sex and strain.

* Females corresponded with the body weight measured at 63d.

As detailed in Table 2, it was not until 28 d of age that males of Cobb and Hubbard strain exhibited a higher body weight compared with females. Hubbard males were heavier at the end of the trial period than males of the other two strains, although the females at that age were all similar in weight.

In Table 3, it was observed that body protein on day 1 was higher than the week following, at 7th and 8th day. Also, there was a variation in the pattern of protein deposition, with a decrease in the composition of body protein at 63 to 106 days for females and also in males around the same age, which thereafter increased. In relation to lipids (Table 3), males and females continued to deposited fat in the body over time.

Table 3 - Protein and lipids content of broiler body at different ages according to strains

Age ¹		Strain/sex					
Male	Female	Cobb		Hubbard		Ross	
		Male	Female	Male	Female	Male	Female
Body protein (g/kg)							
1	1	134.8	138.2	130.1	131.9	130.2	135.0
7	8	131.8	134.0	127.6	130.2	130.5	133.3
14	15	142.1	144.0	140.5	141.3	140.9	143.0
21	22	145.5	150.8	146.1	150.1	146.9	150.6
28	29	152.7	149.4	151.2	147.9	151.9	152.0
35	36	160.2	156.9	158.0	157.2	154.4	151.8
42	43	162.6	158.9	160.4	157.3	161.7	163.1
49	50	167.4	156.6	164.5	160.6	160.3	152.6
56	63*	164.8	137.0	161.4	136.2	155.3	130.0
70	71	153.6	149.2	149.2	148.8	137.9	146.2
84	85	167.6	145.7	166.9	151.5	158.8	149.4
105	106	175.3	151.8	170.0	148.7	164.9	142.4
Lipids (g/kg)							
1	1	46.5	49.3	39.1	44.8	53.3	59.2
7	8	66.7	68.4	64.3	65.7	63.8	66.9
14	15	81.1	81.2	76.4	78.0	78.7	79.1
21	22	98.7	90.8	91.2	86.2	93.0	87.0
28	29	105.6	111.8	101.2	107.9	106.7	103.3
35	36	112.5	114.4	108.2	107.4	117.1	118.9
42	43	118.3	120.5	112.2	117.0	130.8	109.3
49	50	125.9	131.3	122.1	120.8	140.5	133.8
56	63*	133.3	157.5	135.9	156.1	148.9	162.9
70	71	136.9	155.4	137.0	154.3	141.4	160.1
84	85	152.3	165.0	152.7	160.2	165.6	160.4
105	106	144.9	162.1	153.0	167.6	153.4	172.9

¹ Values correspond to the average of 12 individual measurements per sex and strain. *Females 63 d.

In Table 4 it can be noticed that the water content of the body tended to decrease gradually with the advancement of age. The ash content decreased only from the first measurement and then it stabilized.

Estimates of Gompertz growth curve parameters for males and females of each strain for body weight (BW) are presented in Table 5 and chemical components in Table 6. There was convergence ($p > 0.0001$) by the Gauss-Newton iterative method in all the evaluated characteristics.

Table 4 - Water and mineral content of broiler body at different ages according to strains

Age ¹		Strain/Sex					
		Cobb		Hubbard		Ross	
Male	Female	Male	Female	Male	Female	Male	Female
Water (g/kg)							
1	1	787.4	775.6	800.2	795.4	788.9	774.4
7	8	768.7	766.1	768.6	769.8	774.9	769.8
14	15	738.9	740.3	749.5	745.8	743.9	744.8
21	22	701.1	722.7	717.7	732.0	715.1	730.9
28	29	692.5	681.4	696.7	685.1	694.6	699.6
35	36	693.1	685.7	694.3	695.7	675.7	671.8
42	43	682.8	676.2	682.5	678.5	684.5	698.7
49	50	686.8	653.8	677.8	675.3	660.3	643.3
56	63*	662.2	563.7	651.1	565.7	628.5	539.9
70	71	604.5	602.4	588.6	604.2	548.6	593.4
84	85	644.9	581.6	638.2	601.6	611.9	596.7
105	106	665.7	596.7	643.7	585.8	630.1	562.6
Mineral matter (g/kg)							
1	1	44.9	43.8	32.5	31.3	32.6	36.8
7	8	23.5	22.9	27.0	23.3	26.4	22.7
14	15	25.6	24.9	24.6	25.0	24.3	24.2
21	22	27.2	25.3	28.9	27.0	26.1	26.2
28	29	26.8	25.0	30.4	27.3	25.5	25.8
35	36	26.0	23.9	30.2	28.2	26.3	24.9
42	43	25.8	23.6	29.1	28.5	27.4	25.1
49	50	26.1	22.9	29.5	27.2	25.9	24.6
56	63*	26.2	22.2	28.4	26.6	26.3	23.1
70	71	25.3	22.4	28.6	26.0	25.5	23.2
84	85	27.5	22.7	29.0	26.0	27.2	23.3
105	106	31.4	25.5	31.9	28.6	32.0	25.6

¹ Values correspond to the average of 12 individual measurements per sex and strain.

* Females corresponded with the body weight measured at 63d.

Table 5 - Estimates of Gompertz function parameters (\pm SD) for live body weight in both sex according to strains from 1 to 105 days

Parameters	Cobb		Hubbard				Ross					
	Male \pm σ	Female \pm σ	Male \pm σ	Female \pm σ	Male \pm σ	Female \pm σ						
<i>Wi</i> (g)	41.6 \pm 8.8	45.3 \pm 1.4	40.6 \pm 1.6	37.9 \pm 4.3	43.7 \pm 1.9	41.9 \pm 1.8						
<i>Wm</i> (g)	8110.7 \pm 134.1	6565.0 \pm 53.1	9186.3 \pm 154.9	6874.4 \pm 138.9	8375.5 \pm 134.9	6754.8 \pm 99.5						
<i>B</i> (g/day)	0.042 \pm 0.001	0.042 \pm 0.001	0.037 \pm 0.001	0.039 \pm 0.001	0.040 \pm 0.001	0.040 \pm 0.001						
<i>t*</i> (days)	40 \pm 0.4	38 \pm 0.2	45 \pm 0.4	42 \pm 0.5	41 \pm 0.3	41 \pm 0.4						
DF	71	71	68	71	71	71						
Limits of confidence interval estimation at $\alpha = 95\%$												
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
<i>Wm</i> (g)	7845.3	8376.1	6460.3	6670.5	8879.6	9492.9	6599.6	7149.3	8108.3	8642.8	6557.9	6951.7
<i>B</i> (g/day)	0.040	0.043	0.041	0.043	0.036	0.039	0.037	0.040	0.039	0.041	0.038	0.041
<i>t*</i> (days)	39	40	37	38	44	46	41	43	41	42	40	41

Abbreviations: *Wi* initial weight, *Wm* mature weight, *B* rate of maturing, *t** inflection point, DF degree of freedom

Table 6 - Estimates of parameters of the Gompertz function for body protein, fat, mineral matter and water (\pm SD) according to strains, determined in vivo by DXA

Parameter	Cobb		Hubbard		Ross	
	Male \pm σ	Female \pm σ	Male \pm σ	Female \pm σ	Male \pm σ	Female \pm σ
Protein						
Cci	139.5	137.0	131.3	135.9	131.9	133.3
Ccm	168.0	146.3	169.5	145.2	158.2	140.4
Wi (g)	5.6 \pm 0.8	6.0 \pm 0.6	5.2 \pm 0.5	5.0 \pm 0.4	5.5 \pm 0.3	5.4 \pm 0.5
Wm (g)	1296.4 \pm 30.3	909.9 \pm 18.4	1477.4 \pm 35.6	949.8 \pm 21.7	1265.6 \pm 25.5	900.5 \pm 20.3
b (g/day)	0.040 \pm 0.001	0.043 \pm 0.001	0.036 \pm 0.001	0.040 \pm 0.001	0.039 \pm 0.001	0.041 \pm 0.001
<i>t</i> * (days)	42	40	48	42	43	40
Fat						
Cci	48.6	43.4	39.4	45.5	54.0	55.8
Ccm	151.7	172.0	154.2	181.1	167.9	184.1
Wi (g)	2.0 \pm 0.6	1.9 \pm 0.4	1.6 \pm 0.2	1.7 \pm 0.4	2.3 \pm 0.3	2.2 \pm 0.2
Wm (g)	1170.3 \pm 35.3	1069.5 \pm 18.3	1344.1 \pm 45.9	1184.7 \pm 42.5	1343.4 \pm 46.5	1180.9 \pm 28.3
B (g/day)	0.041 \pm 0.001	0.040 \pm 0.001	0.039 \pm 0.001	0.036 \pm 0.001	0.039 \pm 0.001	0.036 \pm 0.001
<i>t</i> * (days)	45	46	50	52	48	51
Mineral matter						
Cci	38.9	42.3	33.0	32.3	31.4	35.4
Ccm	31.9	25.4	31.9	27.7	30.5	25.1
Wi (g)	1.6 \pm 0.4	1.8 \pm 0.2	1.3 \pm 0.2	1.2 \pm 0.1	1.3 \pm 0.5	1.4 \pm 0.1
Wm (g)	246.2 \pm 5.3	157.9 \pm 3.2	277.9 \pm 5.2	181.3 \pm 4.4	244.3 \pm 5.7	160.9 \pm 4.1
B (g/day)	0.034 \pm 0.001	0.036 \pm 0.001	0.034 \pm 0.001	0.037 \pm 0.001	0.035 \pm 0.001	0.036 \pm 0.001
<i>t</i> * (days)	47	41	49	44	48	43
Water						
Cci	779.0	783.9	798.1	790.1	786.2	779.7
Ccm	626.8	567.6	625.1	559.4	594.2	544.9
Wi (g)	31.3 \pm 5.3	34.1 \pm 1.6	31.4 \pm 1.8	28.8 \pm 3.5	33.0 \pm 2.2	31.3 \pm 2.0
Wm (g)	4837.2 \pm 100.1	3529.4 \pm 62.7	5449.3 \pm 115.4	3659.1 \pm 73.9	4752.8 \pm 86.5	3494.2 \pm 68.6
B (g/day)	0.042	0.044	0.037	0.041	0.040	0.042
<i>t</i> * (days)	39	34	44	38	40	36

Abbreviations: Cci (g/kg) concentration of the component at birth (Cci=initial weight of the component/initial body weight), Ccm (g/kg) concentration of the component at maturity (Ccm= mature weight of the component/mature body weight), Wi initial weight of the component, Wm mature weight of the component, B rate of maturing, *t** inflection point.

Males were heavier than females in both maturity weights (Table 5) and rate of protein deposition (Table 6). Females, however, exhibited higher body fat values at maturity than males. The values for Wm of live weight estimated for Hubbard males was higher (9186g) and with a lower rate of maturing 0.037 g/d, therefore, being later, followed by Ross (Wm=8375g and b=0.040g/d) and Cobb (Wm=8110g and

$b=0.042$ g/d). Between females, the Cobb was also earlier, with a growth rate of 0.042g and the inflection point at 38 d. The point of inflection in the growth curve (t^*) for males and females for the body weight was different for

Figure 1, shows the growth curves for BW and the components of the feather-free body of broilers strains.

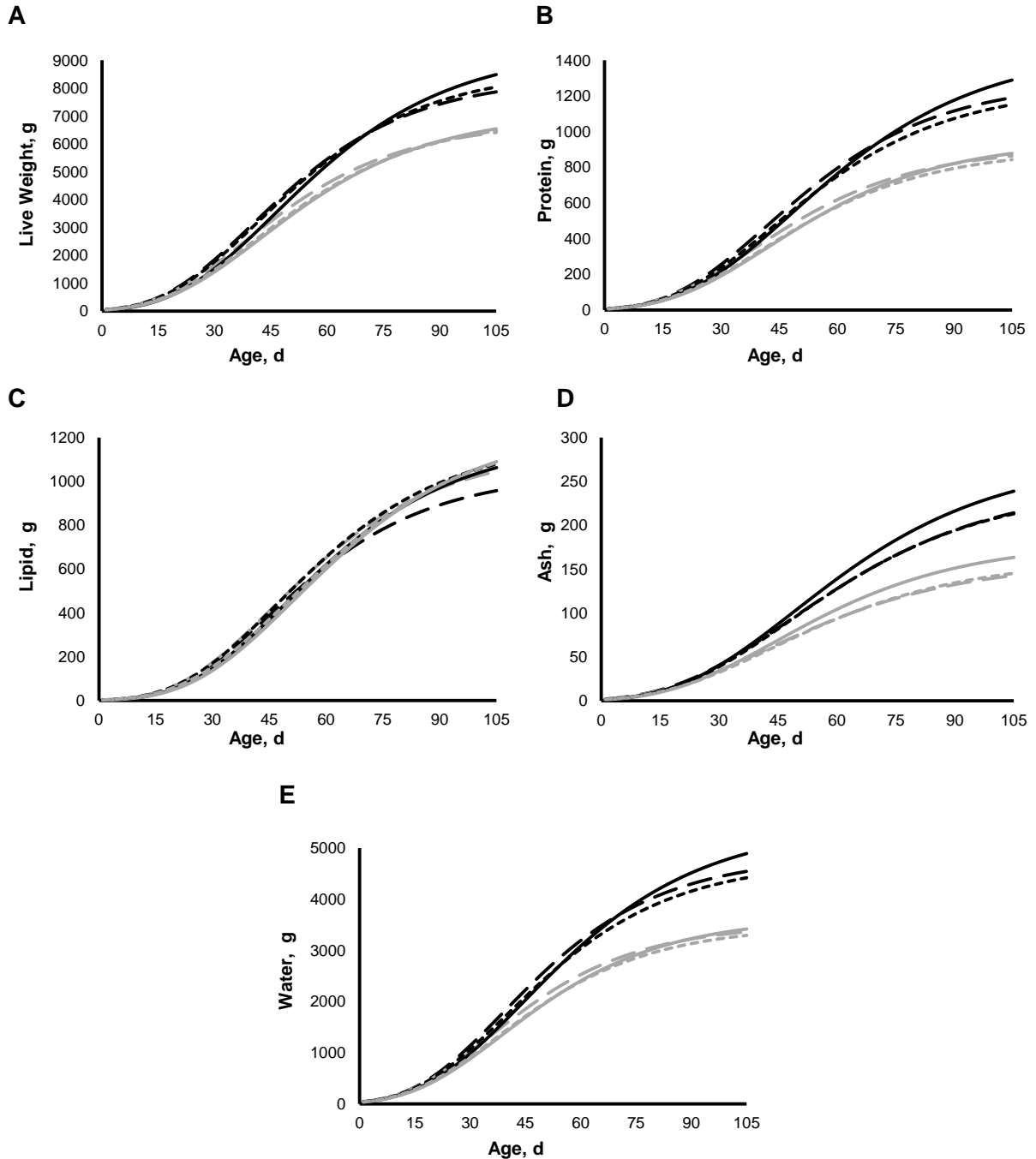


Figure 1- Growth curve for weight (A), Protein (B); Fat (C); Ash (D) and Water (E) of the feather-free body: Cobb Male, ---; Cobb Female, - - -; Hubbard Male, ——; Hubbard Female, ——; Ross Male, - - - - -; Ross Female, - - - - -.

Figure 2 shows the relationship between the gain (g) and degree maturity ($U=W/Wm$, which is the weight of the body or the component divided by its weight at maturity). The shape of the curve shows that the growth rate increases to a maximum and then declines to zero at maturity.

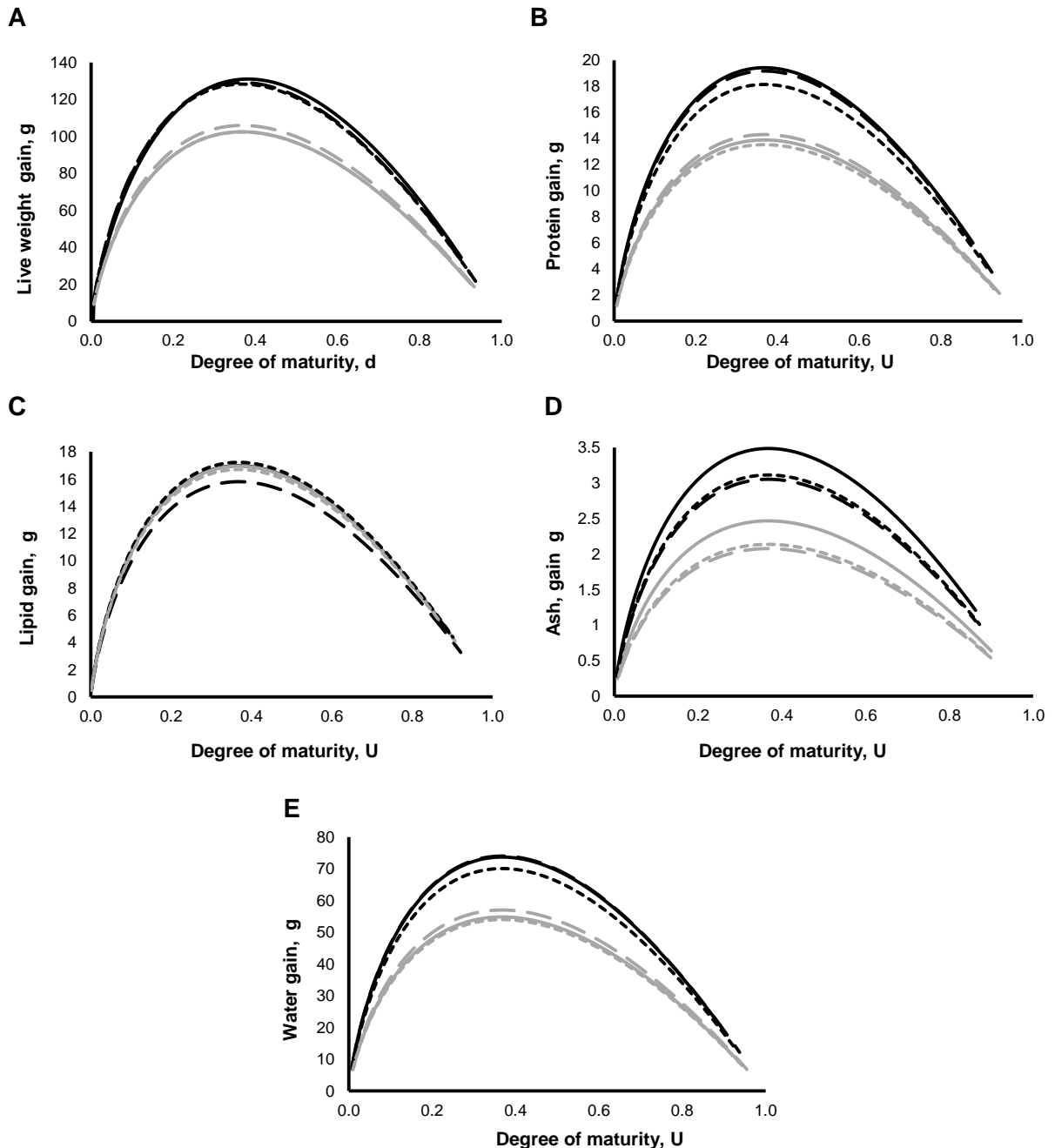


Figure 2 -Body weight gain (A); Protein gain (B); Lipid gain (C); Ash gain (D) and water gain (E) in relation to degree of maturity (U): Cobb Male, - - -; Cobb Female, - · - ·; Hubbard Male, —; Hubbard Female, — — —; Ross Male, - - - - -; Ross Female, - - - - -.

Feathers Growth

The mean feather weights (g) with age are given in Table 7. Females exhibited higher feather weights than males up to 4 w of age.

Table 7 - Feather weight (g) of broilers at different ages according to strains

Age (days) ¹	Cobb		Hubbard		Ross	
	Male	Female	Male	Female	Male	Female
0	1.50	1.75	1.50	1.63	1.75	1.75
6	2.57	3.86	2.42	3.29	3.26	3.34
13	10.00	10.00	10.00	10.00	7.50	10.00
20	36.25	36.25	20.00	30.00	26.25	37.50
27	40.00	48.75	41.25	42.50	32.50	43.75
34	71.25	62.50	58.75	61.25	62.50	58.75
41	78.75	101.25	81.67	116.67	72.50	81.67
47	133.75	118.75	82.50	115.63	120.00	87.50
55	152.00	126.67	127.33	142.67	131.00	131.00
69	158.50	188.67	169.00	210.67	192.67	169.00
83	171.67	188.75	211.67	163.75	195.00	181.25
98	175.00	170.00	170.00	168.33	211.25	165.00
104	233.33	181.25	156.25	171.25	215.00	195.00

¹Mean of 4 birds of each genotype per week

The mean composition of protein, ash and water in feathers with time are presented in Table 8.

Feather protein content showed little variation in the phases assessed, whereas ash content decreased throughout the growing period. Water content in feathers showed no particular trend as the birds aged.

The estimates of feather growth and its chemical constituents obtained through Gompertz function are detailed in Table 9.

Through Table 9, during the growing period it can be noticed by the concentration of the component at birth (C_{ci}) and by the concentration of the component at maturity (C_{cm}) that feathers maintained the same amount of protein content and the water and ash decreased steadily.

The estimated parameters for feathers indicate that the growth rate (B) differ from that of the body components. Females have higher B for feathers weight and its components. Also, the age at which feathers and their components reach their maximum growth rate (t^*) varied considerably, with water and mineral matter attaining their maximum growth rates earlier than protein.

Table 8 - Feather chemical composition (protein, mineral matter and water) of broilers at different ages according to strains

Age	Cobb		Hubbard		Ross	
	Male	Female	Male	Female	Male	Female
Days	Protein (g/kg)					
0	913.13	890.78	911.72	913.91	904.84	896.95
6	860.63	839.90	849.45	841.88	856.25	845.42
13	818.44	826.68	823.20	822.50	835.31	826.64
20	861.56	876.99	857.34	864.58	852.27	864.45
27	886.25	875.73	877.66	878.91	878.44	884.27
34	862.11	846.72	862.42	862.66	857.27	865.00
41	856.41	855.31	858.91	857.03	852.27	865.47
47	907.50	913.83	915.08	909.45	905.78	908.98
55	910.00	903.13	917.89	923.13	922.11	911.64
69	899.30	901.56	896.48	908.98	909.22	902.97
83	894.14	874.53	881.17	889.38	896.72	881.80
98	932.11	928.44	939.45	924.22	921.95	918.20
104	872.71	875.31	882.58	881.01	881.48	880.55
	Mineral matter (g/kg)					
0	10.79	12.92	10.79	14.74	11.34	11.24
6	23.79	23.23	23.87	24.16	22.88	24.04
13	27.19	22.32	23.52	25.15	28.33	23.35
20	20.32	18.56	24.94	17.77	24.63	17.58
27	14.05	13.37	17.01	13.41	15.51	11.86
34	11.91	9.47	11.24	10.70	10.17	9.88
41	8.51	8.51	10.56	8.78	11.81	7.99
47	8.28	7.24	9.61	8.28	8.82	8.17
55	7.41	7.13	6.99	6.45	8.92	7.31
69	7.24	6.68	6.12	6.16	7.20	5.34
83	7.30	4.92	7.02	8.48	7.43	6.41
98	8.16	7.40	7.57	7.15	8.60	7.22
104	9.14	7.11	7.55	7.31	9.96	7.14
	Water (g/kg)					
0	94.89	88.61	75.97	82.84	101.01	86.91
6	103.22	104.62	102.72	102.91	99.03	103.63
13	85.19	86.93	85.08	85.91	89.42	84.24
20	107.78	107.56	112.51	107.54	109.44	108.63
27	113.04	113.83	113.87	111.92	113.63	113.20
34	153.72	156.42	146.70	151.10	153.40	149.32
41	135.90	133.92	139.05	137.26	140.30	138.78
47	87.39	88.34	86.58	89.20	85.93	87.58
55	116.97	117.82	115.78	116.78	116.30	117.30
69	87.36	85.52	85.62	85.42	86.45	85.12
83	95.01	95.06	93.67	93.22	93.04	91.15
98	52.52	51.13	52.13	53.06	52.19	50.65
104	102.09	102.61	102.21	101.95	103.40	98.84

Table 9 - Estimates of parameters of the Gompertz function for broiler feather weight, protein, water and mineral matter according to strains

Parameters	Cobb		Hubbard		Ross	
	Male	Female	Male	Female	Male	Female
Feather weight						
<i>Wi</i> (g)	1.50	1.75	1.50	1.63	1.75	1.75
<i>Wm</i> (g)	210.5	194.9	195.5	187.7	239.9	201.2
<i>B</i> (g/day)	0.045	0.047	0.043	0.051	0.039	0.042
<i>t*</i> (days)	36	34	38	33	42	38
Protein						
<i>Cci</i>	913.3	891.4	913.3	914.1	902.9	897.1
<i>Ccm</i>	901.2	898.9	906.9	905.7	905.0	896.6
<i>Wi</i> (g)	1.37	1.56	1.37	1.49	1.58	1.57
<i>Wm</i> (g)	189.7	175.2	177.3	170.0	217.1	180.4
<i>B</i> (g/day)	0.044	0.047	0.042	0.050	0.039	0.042
<i>t*</i> (days)	36	34	39	33	42	38
Water						
<i>Cci</i>	93.3	85.7	73.3	79.8	102.9	85.7
<i>Ccm</i>	80.2	80.9	78.5	83.3	76.0	75.8
<i>Wi</i> (g)	0.14	0.15	0.11	0.13	0.18	0.15
<i>Wm</i> (g)	16.9	15.8	15.3	15.6	18.2	15.2
<i>B</i> (g/day)	0.060	0.064	0.058	0.068	0.050	0.058
<i>t*</i> (days)	27	26	29	27	31	27
Mineral matter						
<i>Cci</i>	13.3	11.4	13.3	12.3	11.4	11.4
<i>Ccm</i>	7.7	5.9	6.4	6.8	8.2	6.0
<i>Wi</i> (g)	0.02	0.02	0.02	0.02	0.02	0.02
<i>Wm</i> (g)	1.61	1.15	1.26	1.27	1.96	1.21
<i>B</i> (g/day)	0.049	0.066	0.057	0.062	0.042	0.052
<i>t*</i> (days)	27	19	23	22	34	24

Abbreviations: *Cci* (g/kg) concentration of the component at birth (*Cci*=initial weight of the component/initial feather weight), *Ccm* (g/kg) concentration of the component at maturity (*Ccm*= mature weight of the component/mature feather weight), *Wi* initial weight of the component, *Wm* mature weight of the component, *B* rate of maturing, *t** inflection point.

The feathers growth curve for weight and its contents estimated by Gompertz are illustrated in Figure 3.

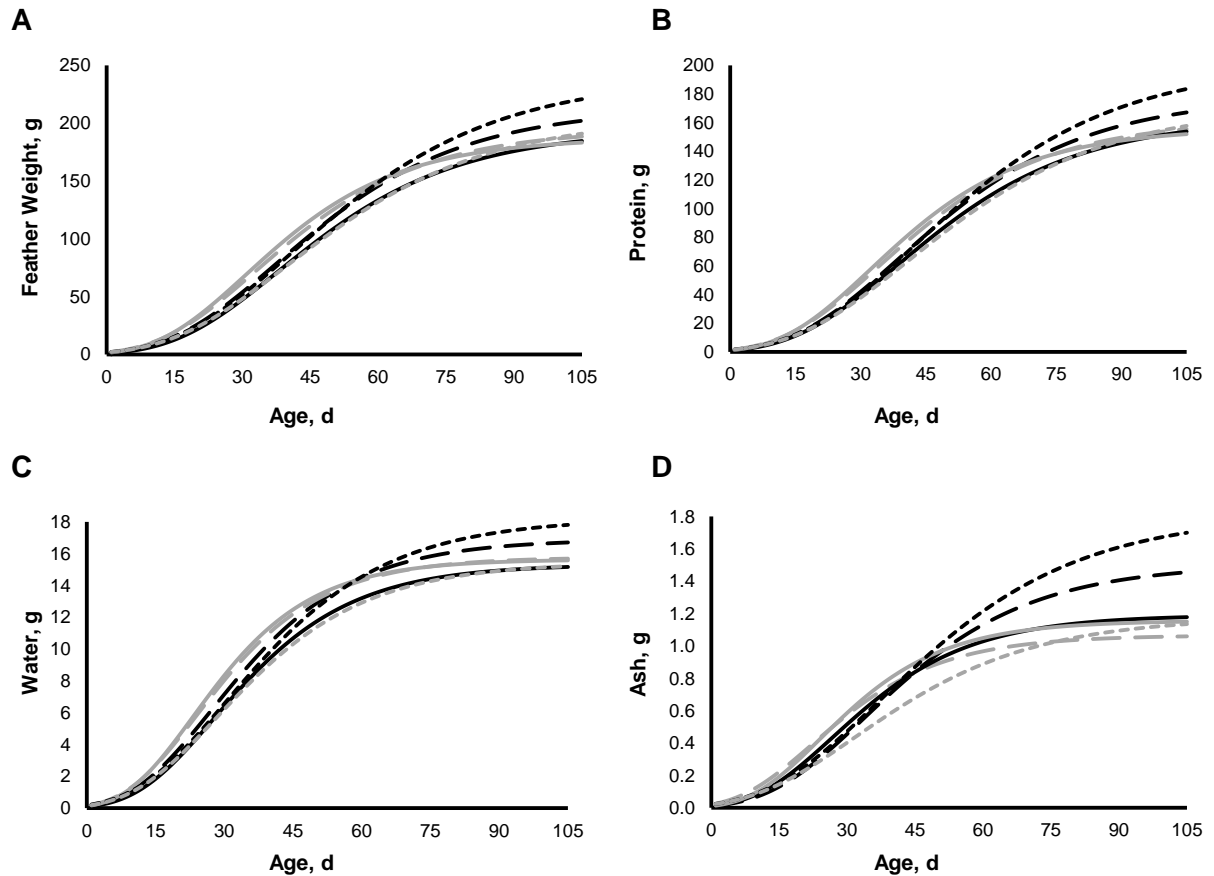


Figure 3 - Growth curves of feather weight (A); protein (B); water (C) and ash (D) of the strains: Cobb Male, - - -; Cobb Female, - . - .; Hubbard Male, ———; Hubbard Female, ————; Ross Male, - - - - -; Ross Female, - - - - - .

Figure 4, depicts the deposition of the components (g/d) of feathers in function of the degree at maturity U , assuming the maximum deposition until declining to zero at maturity.

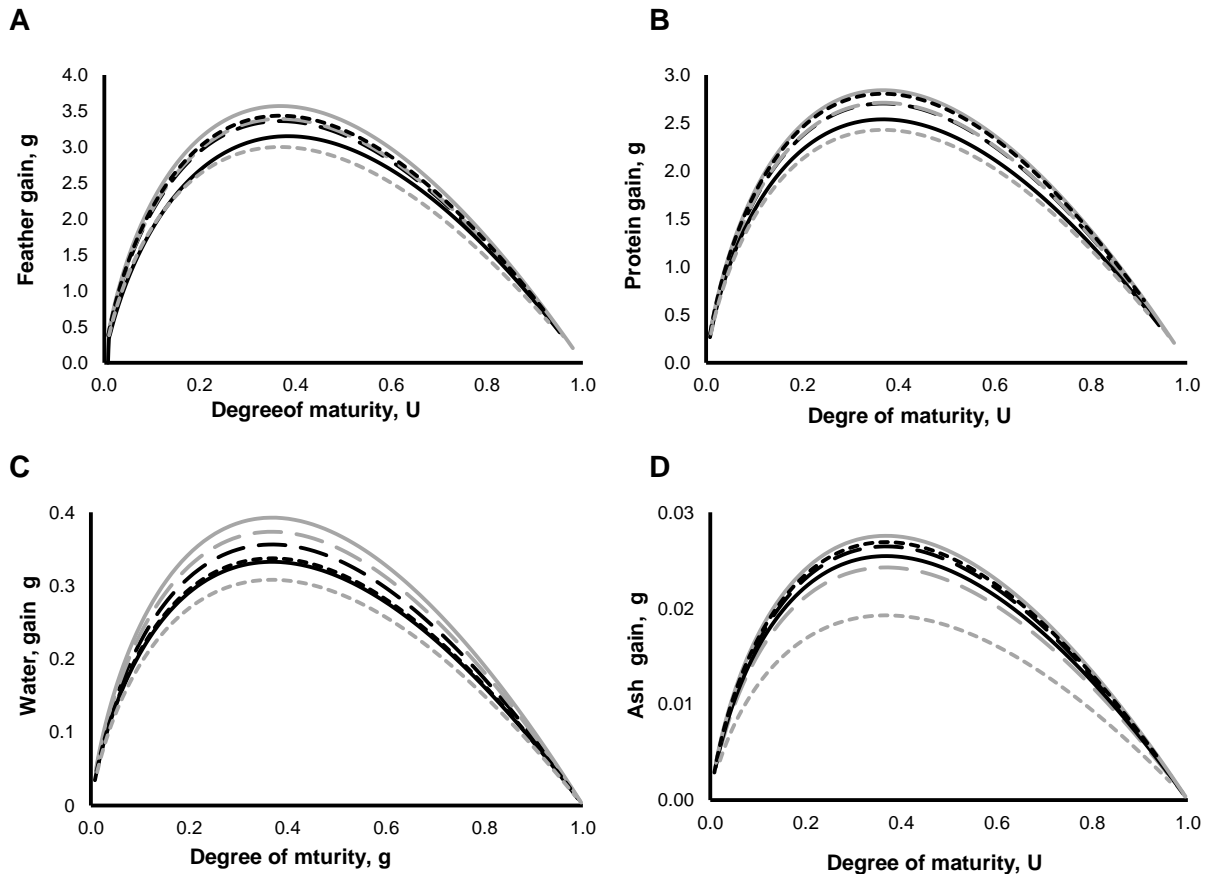


Figure 4 - Deposition curves of feathers in relation to degree of maturity (U) for weight of feathers (A); protein (B); water (C) and ash (D) of the strains: Cobb Male, ----; Cobb Female, -.-.-; Hubbard Male, ———; Hubbard Female, ———; Ross Male,; Ross Female,

Discussion

Growth of body

Numerous trials have been conducted to evaluate the growth of broiler genotypes using the Gompertz curve (1825) based on the theories of Emmans (1981; 1987) and using the comparative slaughter technique (HANCOCK et al., 1995; GOUS et al., 1999; MARCATO et al., 2008; HENN et al., 2014). Since there has been a considerable gap between these studies, the focus of this study was to evaluate the growth curves of three current commercial broiler strains to describe the changes that have been made in the last years. According to Gous (2014) as the values of parameters of Gompertz are better known, an estimate of how these values might change with time are possible.

The Hubbard birds of both sexes had heavier mature weights estimated (Tables 11 and 12) and Cobb presented the highest rates of maturing (B). Thus, the pattern of growth of males was different, implying that the nutritional requirements for males and females is different and that the feeds and feeding programmes used for the two sexes should also be different (EMMANS, 1987; MARCATO et al., 2008).

Genetic selection for growth rate has resulted in early maturing birds with a rapid growth rate (RIVERA-TORRES et al., 2011). In comparison between species, the selection for a higher body weight at a specific age will tend to increase both Wm and B (EMMANS & OLDHAM, 1988). Higher values of B imply that growth is more concentrated around the inflection point of the curve thereby reaching the highest growth rate (g/d) at an earlier age, and not necessarily means that they will have greater weight (TAYLOR, 1980; FIALHO, 1999). A lower value of B makes the growth more distributed through time.

In a previous study, MARCATO et al. (2008) found growth rate of the live body weight of 0.042 g/d for males of Cobb and Ross strains and 0.047 and 0.051 g/d for Cobb and Ross females, respectively. These results are higher than our findings. However, the maximum age utilized by these authors was 56 d only, which is equivalent to about 0.35 of the mature weight, thus introducing a high degree of error when extrapolating to obtain the mature weight. When we restricted our body weight data to 56 d the estimated rate of maturing increased to 0.045 for Cobb, 0.043 for Hubbard and Ross females; in males the values for B , were 0.045, 0.040 and 0.041 for Cobb, Hubbard and Ross respectively.

These differences could presumably be attributed to the different physiological states of the birds, but even so, the values of Marcato et al. (2008) were higher for the aforementioned strains, leading to the conclusion that the growth rates of the referred strains are increased because the mature weight is also higher over the years.

Emmans and Fisher (1986) stated that the growth potential should be defined as the upper limit to the rate of protein production, and the desired level of fatness of the animal, rather than an output of weight. Although differences among strains were demonstrated, an important but already well known aspect observed in the present

study was the differences between sex. Females have lower Wm and greater B , as a result, they reach the maximum growth rate at lower ages compared to males.

A large variation is observed when a comparison is made between our results with those described in literature. These discrepancies may be due to pressures of breeders changing the mature size and rate of maturing of the different components within genotypes and also be associated with factors like the genetic strain used and the stage of maturity of birds. In general, our results presented a low error associated with the estimates of the rate of parameter, B , due to the method DXA which evaluates the growth of the same bird over its entire life, diminishing the individual variation of broilers.

The lipid content of broilers during growth can be affected by the genotype, composition of the feed and environmental conditions. In the present study broilers strains were reared under non-limiting conditions, and reached the average 170g of fat/kg live weight at maturity for females and 150 g/kg in males. This response would be indicative of the genetic influence on fattening as females approach sexual maturity (EMMANS, 1981). The differences in the inherent fatness of strains and sexes are more difficult to measure than any other chemical components of the body; because lipid stores are used to assist a bird to overcome deficiencies as well as oversupply of essential nutrients in a given feed (FISHER, 1984).

The accurate quantification of body growth of the chemical components of broiler is important for the assessment of the development of the genetics and nutritional status. Attempts to determine body composition have as basis the gross estimates from different animals in successive slaughters. Indeed, comparative slaughter is a reliable method to determine whole body composition, methods, which take the individual growth of the animal in account by non-invasive techniques (e.g. DXA method), allow isolating the individual variation in growth models, beyond becoming easier the investigations on genetic strain growth pattern.

Growth of feathers

Broilers differ genetically in the rate of feathering, with either fast or slow feathering influencing early feather weight and size. Chick sexing is commonly used

in commercial strains for distinguishing the sex, so, females can be differentiated from males by length of their primary feathers (LEESON; WALSH, 2004).

As a result, females reach the inflection point (t^*) for the weight of feather and protein earlier than males. Hancock et al. (1995) verified the difference between sexes in the age at which t^* is reached as 2 days approximately.

Nevertheless, feathering differences between strains are likely to be small due to competitive pressures on the breeding companies. As the market age of broilers continues to decline the precocity on feathering becomes important for skin protection. The Hubbard strain pointed out to be later in weight of feathers.

Broiler chickens will have about 50 to 60 g of feathers by market age of 35 d (Table 7), although some feathers will have been lost at this age (LEESON; WALSH 2004). The weight of feathers in males close to maturity is greater than in females (Table 9), although there is little difference when data are expressed as a proportion of body weight. The mature weight of feathers differed between strains. This result corroborates the results of HANCOCK et al. (1995) where differences in feather weight were evident between sexes but not between strains.

The parameters estimated for feather weight shows lower B in Ross males, 0.039 g/d and 0.042 g/d in females. In order to investigate feather growth of Ross females, Sakomura et al. (2005) found values for B of 0.058g/d but these measurements were made to 56 d of age and, as mentioned above, extrapolation to predict the mature weight would result in considerable inaccuracy in this case. The rates of growth in the present study are likely to reflect the mature weight more accurately, suggesting that this is higher, and B lower than estimated by Sakomura et al. (2005).

Feather protein growth is not a simple power function of body protein growth and follows a different growth curve to that of body protein (EMMANS, 1989; MARTIN; BRADFORD; GOUS, 1994). Feather protein content appears to increase throughout the growth period (HANCOCK et al., 1995). The difference in the rate of maturing of feather protein (Table 9) and body protein (Table 5) emphasizes the impossibility of a common allometric relationship between these two tissues and obviously, as feather presented a greater rate of maturing, justifies the use of separate equations to predict the growth of body and feathers.

Conclusion

The three broiler strains evaluated here displayed differences in their potential growth rates and body composition and appear to have heavier mature weights and higher rates of maturing than the strains evaluated previously.

Measuring body and feather weights and composition of these birds up to 15 weeks of age improved the accuracy of estimation of the mature composition of the broilers strains compared with trials in which growth was measured only to 56 d of age.

The use of DXA in measuring the body composition of the same individuals over time would have reduced the error in evaluating the potential growth rates of the chemical components of the body in the broiler strains evaluated here, compared with a serial slaughter technique..

It is not possible to measure the composition of feathers using DXA, which is a limitation when evaluating the growth of individuals over time.

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CAPÍTULO 4 – GROWTH PATTERN OF BODY BY ALLOMETRIC RELATIONSHIPS IN BROILER CHICKEN STRAINS

Abstract: The growth rate of body components is important information that reflects the dynamics of growth necessary to determine the nutritional requirements and to verify changes that genetic selection has made in poultry. This study was conducted to describe the changes in the chemical composition of three commercial strains, sex separated, by allometric relationships. Two trials, each one with a 3 strains × 2 sex factorial design and four replicates, were conducted using Cobb, Hubbard and Ross strains. The evaluation of the feather free body composition (FFB) of water, protein, lipid and ash was determined by *in vivo* DXA imaging tool (trial 1) and feather composition of water, protein and ash by serial comparative slaughter followed of chemical analysis (trial 2). A total of 1008 birds were reared from 1 to 105 days of age in an environmentally controlled room under *ad libitum* consumption of balanced diets. The measurements were carried out at weekly intervals until 56 days of age and thereafter every 15 days. For the required measurements of body composition it was utilized 12 broilers of each sex and strain throughout life and for chemical feathers measurements it was utilized four broilers of each strain and sex slaughtered at the established periods, and totalizing 48 broilers of each strain and sex at the end of data collection. Allometric relationships were used to describe changes in body composition of the strains male and females. It was found that the body fat deposition was higher than the protein deposition in an average of 20% in females and 15% in males. Water and ash presented earlier maturity compared with protein, which is presumably explained by the genetic selection improvements for increases protein deposition. As feathers are mostly composed by protein, allometric equations of this component to the weight of feathers presented an isogonic scale $b=1$. In conclusion the allometric relationships provide means to understand and compare the depositions of components of the different broilers genotypes. The broilers strains have own characteristics values for protein, water, ash and fat depositions in the body and the feathers it was determined lower variation on protein and water content deposited across genotypes.

Keywords: allometry, body composition, feathers, protein weight

Introduction

Over the last decades, genetic selection of broiler breeder hens reflected on improvements on offspring growth potential, whose expression is represented by the fast growth rates, increased body weight and breast meat yield (ZUIDHOF, et al. 2014). Concurrently with the growth of body, chemical components have their deposition also increased. Animal growth can be defined as the result of the growth of carcass components such as meat, bone and skin. According to Emmans (1988) the empty body of an animal could be represented by the lipid-free content (protein, ash and carbohydrates), water and lipids.

In order to describe the rate with which chemical components such as ash, protein and water are deposited in broiler bodies, growth models have been using the Gompertz function (1825). Emmans and Fisher (1986) described chemical component growth of different genotypes based on the relationship of body components with protein by non-isometric scaling. The usage of allometric relationships is well established within animal species and can be used to reflect the dynamics of growth of the different components of the body and the physical components of the body, since they share the same rates of maturing (GOUS, et al., 1999; ZELENKA et al., 2011).

Published data involving such approach for broiler chickens has already reported for body chemical components by Emmans and Fisher (1986), Gous et al. (1999), Zelenka et al. (2011), parts of the body by Sakomura et al. (2011), Danisman and Gous (2011), in laying-type pullets by Martin; Bradford; Gous (1994) and in turkeys by Emmans (1989) and Rivera-Torres et al. (2011).

To better understand the effects of intensive selection on broilers; more information is required on how increasing body growth rate of components has been occurred in different strains in the last years. All this literature was based to describe this paper, to better understand the effects of intensive selection on broilers; more information is required on how increasing body growth rate of components has been occurred in different strains in the last years.

Therefore, this study was conducted to describe the change in body composition in male and female broilers of three strains as a function of body weight, body protein weight and feathers.

Material and methods

All the procedures were approved by the Ethics Committee on Animal Use (CEUA) n°. 9999/14 of Univ Estadual Paulista (UNESP), campus of Jaboticabal.

Birds and housing

One day-old male and female broiler chicks, vaccinated for Marek, Newcastle and Gumboro disease, were obtained from local commercial hatcheries. Offspring were obtained from breeders of different genetic strains (Cobb, Hubbard and Ross), but with similar ages (42-wk-old Cobb, 39-wk-old Hubbard and 41-wk-old Ross breeders).

From 1 to 105 d of age, a total of 1008 broiler chicks were housed in an environmentally controlled room equipped with a negative pressure system and randomly assigned to a factorial arrangement of 3 strains x 2 sexes with 4 replicates of 16 birds (experiment I) and 26 birds (experiment II).

In both experiments, diets (mash form) were formulated to contain 3105 kcal of AMEn/kg (Table 1). All the other nutrients were supplied to meet or exceed EFG Broiler Growth Model (EFG Software, 2007) recommendations. A four-phase feeding program was used: 1 to 14 days, 15 to 28 days, 29 to 42 days and 43 to 105 days (table 1).

At 10th day post-hatch, all birds were vaccinated for Newcastle and Gumboro disease. Birds had free access to water and diets throughout the 15-week feeding trials. All pens were covered with wood-shavings and equipped with nipple drinkers and a tubular feeder. Lighting program was set 24 hours until 7 days of age and 20L:4D until the end of the trials.

Measurements

At one day of age, thirty-six birds (6 birds per strain and 6 birds per sex) were slaughtered in order to measure body and feather weight and chemical composition. Thereafter, all evaluations were determined separately by two different methods, feather-free body composition by DXA (trial I) and feather chemical analysis (trial II).

Trial I: At 7, 14, 21, 28, 35, 42, 56, 70, 84, 98 and 105 days of age for males and at 8, 15, 22, 29, 36, 43, 57, 71, 85, 99 and 106 days of age for females, a group

of birds of each pen was randomly selected for body composition determination by Discovery Wi DXA device (Hologic QDR series). The selected birds

Procedures for the scanning in DXA are described in the chapter 2. The measurements of body composition taken at DXA were: fat mass (FM, g); lean mass (LM, g) and bone mineral content (BMC, g). These values were then corrected by the predictive equations for feather free body weight (FFBW), body protein (BP), water (BWater), ash (BAsh) and lipids (BL) determined on chapter 2, for both sex, to estimate directly the body feather-free composition of broilers as the following:

$$\text{FFBW} = \exp[-0.26714 + 1.01939 \times (\ln \text{ Total Mass})];$$

$$\text{BP} = \exp[-2.54693 + 1.0932 \times (\ln \text{ Lean Mass})];$$

$$\text{BWater} = \exp[-0.20794 + 0.98056 \times (\ln \text{ Lean Mass})];$$

$$\text{BAsh} = \exp[0.63735 + 0.96876 \times (\ln \text{ Bone Mineral Content})];$$

$$\text{BL} = \exp[-2.73978 + 0.45512 \times (\ln \text{ Fat Mass}) + 0.76642 \times (\ln \text{ BWater})].$$

Trial II: At 1, 6, 13, 20, 27, 34, 41, 55, 69, 83, 97 and 104 days of age, one bird per plot (totaling 24 birds at time) was selected, and after 24h of feed withdrawal were killed by CO₂ asphyxiation. Samples of feathers in different parts of the body were collected in paper bags to represent the body feathering throughout the ages. The feather weight was calculated by the difference of the fasten body weight and the plucked body. The feathers collected were pre-dried in a forced-draft oven at 55 °C for 72 hours. After that, they were ground in a multi-purpose mill (Tecnal, TE 631/4) to determine the chemical composition of water (method 920.39), protein (method 2001.11) and ash (method 942.05), according to standards of AOAC (2005).

Table 1 - Ingredients and nutritional composition of experimental diets, as-fed basis

Ingredients (%)	Phases			
	1-14 days	15-28 days	29-42 days	43-105 days
Corn	53.83	61.29	69.50	68.00
Soyben meal (45%)	32.11	25.83	20.82	18.16
Corn gluten meal (60%)	5.65	6.61	4.88	---
Wheat bran	---	---	---	7.64
Soybean oil	3.26	1.79	0.66	2.53
Dicalcium phosphate	2.02	1.82	1.62	1.43
Limestone	0.95	0.87	0.80	0.81
L-lysine (54,6%)	1.06	0.90	0.78	0.56
DL- methionine (98%)	0.22	0.15	0.12	0.12
L-arginine (99%)	0.17	0.15	0.16	0.09
L-treonine (98.5%)	0.15	0.11	0.11	0.10
L-valine (96.5 %)	0.09	0.00	0.07	0.08
Salt	0.36	0.36	0.36	0.35
Vitamin/mineral supplement ¹	0.10	0.10	0.10	0.10
Anticoccidiostatic ²	0.02	0.02	0.02	0.02
Calculated composition				
AMEn, Kcal/kg	3105	3105	3105	3105
Crude Protein,%	24.00	22.00	19.00	15.00
Lysine Dig.,%	1.56	1.33	1.14	0.94
Methionine Dig.,%	0.55	0.47	0.40	0.33
Methionine + cystine Dig.,%	0.86	0.76	0.66	0.55
Tryptophan Dig.,%	0.23	0.20	0.17	0.15
Threonine Dig.,%	0.90	0.80	0.71	0.59
Arginine Dig.,%	1.48	1.31	1.15	0.97
Valine,%	1.05	0.89	0.84	0.70
Isoleucine,%	0.89	0.80	0.68	0.54
Leucine,%	1.51	1.38	1.29	1.25
Phenylalanine + tyrosine,%	1.90	1.77	1.51	1.13
Calcium,%	0.96	0.87	0.78	0.74
Sodium,%	0.16	0.16	0.16	0.16
Non-phytate phosphorus,%	0.48	0.43	0.39	0.37
Potassium,%	0.75	0.65	0.58	0.60
Glycine+serine,%	1.83	1.67	1.44	1.13
Histidine,%	0.54	0.49	0.43	0.37

¹Amount/kg of diet: Mn = 150.000 mg. Fe = 100.000 mg. Zn = 100.000 mg. Cu= 16.000 mg. I = 1.500 mg. ²Content/kg of product: Folic acid = 1000 mg. pantothenic acid = 15.000 mg. Niacin = 40.000 mg. Biotin = 60 mg. vit B1 = 1.800 mg. vit. B12 = 12.000 mg. vit. B2 = 6.000 mg. vit. B6 = 2.800 mg. vit D3 = 2.000.000 UI. vit E = 15.000 mg. vit. K3 = 1.800 mg. Se = 300 mg. ² Coxistac 12% with salinomycin sodium.

Calculations and statistical analysis

Allometric relationships were estimated for each strain and sex to predict the weight of chemical components relative to a reference compartment (e.g. body protein, body weight and feather protein), according to Emmans and Fisher (1986).

Taking logarithms gives a linear equation to establish the relationship of the natural log scales \ln chemical components weight (X , dependent variable, which may be ash, lipid or water) with \ln protein weight (Y , independent variable):

$$\ln Y = a + b \times \ln X$$

Where: Y is the component weight (g); a is the intercept; X is the protein weight (g); and b is the allometric coefficient, the ratio of percentage change in Y to the X .

The growth of the component is classified by the allometric coefficients being: $b = 1$ indicates a similar rate of deposition from X to Y ; $b > 1$ indicates that the deposition of a component is later and $b < 1$ the growth of the component is early.

The effect of strains of each sex on the linear regression parameters: constant terms (a) and the allometric regressions slopes (b) were performed by PROC GLM at 5% of significance level according to Kaps and Lamberson (2004). Estimates of strains and statistics were performed separated by sex from 1 to 105 days of age using the SAS statistical software version 9.2 (SAS Institute, Cary, NC, USA).

Results

The means of body weight and feather-free body chemical composition of the male and female broiler of the strains studied according to age are detailed in table 2. There was an increase of fat percentage in the body of males and females within 15 weeks post hatch. Overall females were on average 18% fatty than males. However, water content decreased as birds aged and protein and ash contents were markedly constants in the same period.

Table 3 shows the allometric relationships between the different body components and body weight. The protein deposition related to the body weight increased in 4.5%, 3.9% and 4.9% for Cobb, Ross and Hubbard males. Body fat content increased, whereas water and ash exhibited a decrease. The estimates of a and b of allometric relationships of body components to body weight in females did not presented any similarity (table 3). In another way, males presented equality on the allometric coefficients for water ($b = 0.945$) between Cobb and Ross; and for fat deposition of 22.7% in Ross and Hubbard.

Table 2 – Live body weight and percentage of feather free body chemical composition of broilers strains male and female at different ages

Days	Weight g	Protein %	Fat %	Water %	Ash %	Weight g	Protein %	Fat %	Water %	Ash %	Weight g	Protein %	Fat %	Water %	Ash %
	Cobb Female					Hubbard Female					Ross Female				
1	45.2	13.8	4.9	77.5	4.4	38.0	13.2	4.5	79.5	3.1	42.0	13.5	5.9	77.4	3.7
8	212.0	13.4	6.8	76.6	2.3	159.4	13.0	6.6	77.0	2.3	193.2	13.3	6.7	77.0	2.3
15	544.2	14.4	8.1	74.0	2.5	434.2	14.1	7.8	74.6	2.5	484.2	14.3	7.9	74.5	2.4
22	1027.5	15.1	9.1	72.3	2.5	869.2	15.0	8.6	73.2	2.7	922.1	15.1	8.7	73.1	2.6
29	1625.8	14.9	11.2	68.1	2.5	1428.8	14.8	10.8	68.5	2.7	1470.0	15.2	10.3	70.0	2.6
36	2282.9	15.7	11.4	68.6	2.4	2022.9	15.7	10.7	69.6	2.8	2081.3	15.2	11.9	67.2	2.5
43	2888.0	15.9	12.1	67.6	2.4	2587.6	15.7	11.7	67.8	2.9	2681.5	16.3	10.9	69.9	2.5
50	3537.9	15.7	13.1	65.4	2.3	3225.3	16.1	12.1	67.5	2.7	3301.7	15.3	13.4	64.3	2.5
63	4546.3	13.7	15.8	56.4	2.2	4191.8	13.6	15.6	56.6	2.7	4386.3	13.0	16.3	54.0	2.3
71	5021.3	14.9	15.5	60.2	2.2	4816.3	14.9	15.4	60.4	2.6	4872.1	14.6	16.0	59.3	2.3
85	5716.7	14.6	16.5	58.2	2.3	5830.0	15.1	16.0	60.2	2.6	5557.9	14.9	16.0	59.7	2.3
106	6309.2	15.2	16.2	59.7	2.6	6375.5	14.9	16.8	58.6	2.9	6429.2	14.2	17.3	56.3	2.6
	Cobb Male					Hubbard Male					Ross Male				
1	42.0	13.5	4.6	78.7	4.5	41.0	13.0	3.9	80.0	3.2	44.0	13.0	5.3	78.8	3.2
7	182.2	13.2	6.7	76.9	2.4	139.6	12.8	6.4	76.9	2.7	155.0	13.0	6.4	77.5	2.6
14	495.4	14.2	8.1	73.9	2.6	400.8	14.0	7.6	74.9	2.5	436.3	14.1	7.9	74.4	2.4
21	1000.8	14.5	9.9	70.1	2.7	844.6	14.6	9.1	71.8	2.9	908.3	14.7	9.3	71.5	2.6
28	1687.1	15.3	10.6	69.2	2.7	1468.3	15.1	10.1	69.7	3.0	1561.3	15.2	10.7	69.5	2.6
35	2477.1	16.0	11.3	69.3	2.6	2172.5	15.8	10.8	69.4	3.0	2290.8	15.4	11.7	67.6	2.6
42	3237.3	16.3	11.8	68.3	2.6	2897.9	16.0	11.2	68.2	2.9	3029.6	16.2	13.1	68.5	2.7
49	3924.0	16.7	12.6	68.7	2.6	3722.5	16.4	12.2	67.8	2.9	3922.5	16.0	14.0	66.0	2.6
56	4824.2	16.5	13.3	66.2	2.6	4619.6	16.1	13.6	65.1	2.8	4803.2	15.5	14.9	62.9	2.6
70	6187.7	15.4	13.7	60.4	2.5	6251.8	14.9	13.7	58.9	2.9	6245.6	13.8	14.1	54.9	2.6
84	7035.5	16.8	15.2	64.5	2.7	7486.4	16.7	15.3	63.8	2.9	7415.7	15.9	16.6	61.2	2.7
105	7659.3	17.5	14.5	66.6	3.1	8111.9	17.0	15.3	64.4	3.2	7608.8	16.5	15.3	63.0	3.2

Table 3 - Constant term (a) and allometric coefficients (b) between the different body components and body weight ($\ln Y = a + b \ln X$)¹ according to female and male strains

Component	Cobb	Ross	Hubbard	Cobb	Ross	Hubbard	R ²
	Constant term (a)			Allometric coefficient (b)			
Females							
Protein	-2.161±0.054	-2.152±0.051	-2.190±0.050	1.032±0.007	1.030±0.007	1.033±0.007	99.8
Water	-0.068±0.033	-0.044±0.032	-0.009±0.031	0.949±0.004	0.944±0.004	0.940±0.004	99.9
Fat	-4.172±0.160	-4.095±0.154	-4.420±0.150	1.267±0.022	1.262±0.021	1.301±0.021	98.7
Ash	-3.041±0.186	-3.153±0.179	-3.576±0.173	0.927±0.025	0.948±0.024	1.010±0.024	97.1
Males							
Protein	-2.328±0.032	-2.305±0.032	-2.368±0.030	1.045±0.004	1.039±0.004	1.049±0.004	99.8
Water	-0.156±0.025	-0.097±0.025	-0.131±0.024	0.945±0.003		0.951±0.003	99.8
Fat	-3.912±0.046	-4.156±0.044		1.196±0.006	1.227±0.005		99.6
Ash	-3.594±0.065		-3.681±0.062	0.979±0.009	1.002±0.008		99.0

¹Linear regressions are sex separated. Where significant differences ($p < 0.05$) exist in parameter between strains the difference (\pm SE) is shown, where not present, a general value is given on the constant term and/or regression coefficient.

Table 4 - Constant term (a) and allometric coefficients (b) between the different body components and protein weight ($\ln Y = a + b \ln X$)¹ according to female and male strains

Component	Cobb	Ross	Hubbard	Cobb	Ross	Hubbard	R ²
	Constant term (a)			Allometric coefficient (b)			
Females							
Water	1.967±0.009		2.002±0.009	0.914±0.002		0.908±0.002	99.9
Fat	-1.446±0.048	-1.288±0.047	-1.414±0.045	1.208±0.008			99.3
Ash	-1.168±0.045	-1.351±0.044	-1.500±0.042	0.888±0.008	0.925±0.008	0.965±0.008	99.0
Males							
Water	1.975±0.007	2.001±0.007		0.913±0.001	0.909±0.001		99.9
Fat	-1.225±0.051	-1.247±0.051	-1.357±0.049	1.157±0.009			99.2
Ash	-1.217±0.040	-1.419±0.040		0.906±0.007	0.942±0.007		99.2

¹Linear regressions are sex separated. Where significant differences ($p < 0.05$) exist in parameter between strains the difference (\pm SE) is shown, where not present, a general value is given on the constant term and/or regression coefficient.

Parameters a (index of correlation) and b (allometric coefficient or maturation rate) estimated in the feather free body (FFB) for water, fat and ash weights and the protein weight, according to strain and sex are presented in Table 4.

For water vs. protein and ash vs. protein, for males and females, the allometric slope was below than unity ($b < 1$). This means that the amount of water and ash per unit of protein decreased and their growth rates are earlier than protein. For fat vs. protein the allometric coefficients ($b > 1$) was greater than unity, meaning that as protein increased the fat also increased in higher rates. The growth rate of fat was higher than the protein in the body in an average of 20.8% in females and 15.7 % in males, and also fat presented later maturing rate ($b > 1$).

The differences among allometric slopes for the body components by each sex are presented in (table 4). Where no differences exist between the allometric regressions only one general value is given for the constant term and/or regression coefficient. Using the statistic approach of Kaps and Lamberson (2004), it was evident that males and females strains used Ross strain as reference to calculate the difference on the body components of each sex and the three strains evaluated.

The water content in females, Cobb and Ross presented the same constant term (1.967) and allometric coefficient (0.914). Hubbard strain was different from the other strains. Between males Ross and Hubbard the constant term and the allometric coefficient were the same for these strains, being Cobb the different strain.

There were differences on strains on constant terms on females' fat, but no differences on the regressions being 1.208 for Ross a general coefficient between strains. For males, the fat presented differences in the slope and they were all equals on the allometric coefficients.

Estimates for ash in relation to feather-free body protein shown differences between female strains. However, parameters of b were lower for Cobb (0.888), followed by Ross (0.925) and Hubbard (0.965). Males presented equalities on the constant term and allometric coefficients (0.942) for Ross and Hubbard strains.

Table 5 - Feather weight (g) and proportion (%) of the chemical components of the feather of males and females in Cobb, Ross and Hubbard strains

Week	Weight g	Protein %	Water %	Ash %	Weight g	Protein %	Water %	Ash %	Weight g	Protein %	Water %	Ash %
	Cobb Female				Hubbard Female				Ross Female			
0	1.8	89.1	8.9	1.3	1.6	91.4	8.3	1.5	1.8	89.7	8.7	1.1
1	3.9	84.0	10.5	2.3	3.3	84.2	10.3	2.4	3.3	84.5	10.4	2.4
2	10.0	82.7	8.7	2.2	10.0	82.3	8.6	2.5	10.0	82.7	8.4	2.3
3	36.3	87.7	10.8	1.9	30.0	86.5	10.8	1.8	37.5	86.4	10.9	1.8
4	48.8	87.6	11.4	1.3	42.5	87.9	11.2	1.3	43.8	88.4	11.3	1.2
5	62.5	84.7	15.6	0.9	61.3	86.3	15.1	1.1	58.8	86.5	14.9	1.0
6	101.3	85.5	13.4	0.9	116.7	85.7	13.7	0.9	81.7	86.5	13.9	0.8
7	118.8	91.4	8.8	0.7	115.6	90.9	8.9	0.8	87.5	90.9	8.8	0.8
8	126.7	90.3	11.8	0.7	142.7	92.3	11.7	0.6	131.0	91.2	11.7	0.7
10	188.7	90.2	8.6	0.7	210.7	90.9	8.5	0.6	169.0	90.3	8.5	0.5
12	188.8	87.5	9.5	0.5	163.8	88.9	9.3	0.8	181.3	88.2	9.1	0.6
14	170.0	92.8	5.1	0.7	168.3	92.4	5.3	0.7	165.0	91.8	5.1	0.7
15	181.3	87.5	10.3	0.7	171.3	88.1	10.2	0.7	195.0	88.1	9.9	0.7
	Cobb Male				Hubbard Male				Ross Male			
0	1.50	91.3	9.5	1.1	1.5	91.2	7.6	1.1	1.8	90.5	10.1	1.1
1	2.57	86.1	10.3	2.4	2.4	84.9	10.3	2.4	3.3	85.6	9.9	2.3
2	10.00	81.8	8.5	2.7	10.0	82.3	8.5	2.4	7.5	83.5	8.9	2.8
3	36.25	86.2	10.8	2.0	20.0	85.7	11.3	2.5	26.3	85.2	10.9	2.5
4	40.00	88.6	11.3	1.4	41.3	87.8	11.4	1.7	32.5	87.8	11.4	1.6
5	71.25	86.2	15.4	1.2	58.8	86.2	14.7	1.1	62.5	85.7	15.3	1.0
6	78.75	85.6	13.6	0.9	81.7	85.9	13.9	1.1	72.5	85.2	14.0	1.2
7	133.75	90.8	8.7	0.8	82.5	91.5	8.7	1.0	120.0	90.6	8.6	0.9
8	152.00	91.0	11.7	0.7	127.3	91.8	11.6	0.7	131.0	92.2	11.6	0.9
10	158.50	89.9	8.7	0.7	169.0	89.6	8.6	0.6	192.7	90.9	8.6	0.7
12	171.67	89.4	9.5	0.7	211.7	88.1	9.4	0.7	195.0	89.7	9.3	0.7
14	175.00	93.2	5.3	0.8	170.0	93.9	5.2	0.8	211.3	92.2	5.2	0.9
15	233.33	87.3	10.2	0.9	156.3	88.3	10.2	0.8	215.0	88.1	10.3	1.0

In table 5 are presented the mean weights (g) of feather and the proportion (in %) of ash, protein and water by each strain and sex. Average feather weight (g) showed that until 6 weeks of age females had higher feather weights. The proportions of protein, water and ash in feathers were altered throughout the trial.

Parameters a (index of correlation) and b (allometric coefficient) estimated for the feathers for water and ash weights in relation to the feather protein weight are summarized in table 6.

Table 6 - Constant term (a) and allometric coefficients (b) between the feather components and feather protein weight ($\ln Y = a + b \ln X$)¹ according to female and male strains

Component	Cobb	Ross	Hubbard	Cobb	Ross	Hubbard	R ²
	constant term (a)			allometric coefficient (b)			
Females							
Water	-0.333±0.115			0.903±0.029			95.1
Ash	-3.617±0.125			0.760±0.032			91.8
Males							
Water	-0.433±0.116			0.935±0.029			95.2
Ash	-3.635±0.138			0.814±0.035			91.1
<i>Feather protein to feather weight – males and females</i>							
	-0.272±0.020			1.009±0.005			99.8

¹Linear regressions are sex separated. Where significant differences ($p < 0.05$) exist in parameter between strains the difference (\pm SE) is shown, where not present, a general value is given on the constant term and/or regression coefficient.

As detailed in table 6, the value of allometric coefficient indicate that when compared with protein, water and ash growth reduced, which indicates that both nutrients grow earlier than protein. Also, the b for ash was lower than b of water indicating that ash content decreases more rapidly.

However, in the comparison between strains, the estimated allometric parameters (a and b) for the same sex and for each component showed none significant differences ($p < 0.05$). Thus, a generalization of the parameters required to describe the components deposition in function of protein weight are the same for strains of each sex.

The respective allometric coefficients of 1.0 describing the relationships feather protein with feather weight (table 6) was the same for males and females, and it represents that as feathers content is higher in protein (88%), at the level the weight of feather increases the protein increases at the same rate.

Discussion

The major effect of broiler chickens selection has been an increase in overall protein mass (g) of the body of the chickens. This is particularly higher in males compared to females (table 3). The overall metabolism of the modern broiler has evolved birds that are highly efficient at converting feed to body mass along with increased protein and resulting from early maturation.

The allometric coefficients of water and ash content declined when they were related to the body weight. According to Emmans (1989) the relationships between water and ash to protein are relatively constant across genotypes. In the present study, a very slow difference was found between estimates of water between strains (table 3 and 4), leading to agree with the hypotheses of Emmans.

Gous et al. (1999) reported different equations for males and females to calculate the water contents from the body protein weight. The authors found values of the allometric coefficients (b) in an average of 0.917 for males and 0.902 for females, and pointed that the relationship between water does not vary much between sexes or among genotypes. Also, in the present study there were no differences on the allometric coefficients for water between sex ($p= 0.0667$, not shown) and the mean values for males and females was $b=0.911$.

The values of ash estimated amply varied between strains females and between males, the Cobb varied from Ross and Hubbard. These results indicate that the female strains and Cobb male strain has a different growth pattern of ash in comparison to other strains. This result corroborates with those by Gous et al. (1999) where it was found that the ratio of ash to protein was essentially constant.

Zelenka et al. (2011) who worked with slow and fast growth cockerels until 22 days post hatch found allometric coefficients describing the relationships of ash with protein in the fast strains of 1.097 and 1.186 in slow strains and concluded that high allometric coefficients for ash indicates the rapid growth of skeletal tissues.

Discrepancies in results of studies are probably related to differences among animal characteristics, nutritional treatments and data analysis. For example, differences in genotype, length of the experimental period and age at the beginning of this period may explain these differences on estimated values (EITS, 2002).

The fat deposition weights increased more quickly relative to protein and also the body weight in females than males. Zelenka et al. (2011) found an allometric coefficient describing the relationships of fat with protein of 0.910, again, because the age those birds were grown. As reported by Gous et al. (1999) female broilers chickens increased faster the lipid weights after 56 d of age than predicted from their protein weights, so different equations would be required for males and females to calculate the lipid contents from the body protein weight. The same tendency was confirmed by ours results, with females increasing the fat deposition than males.

However, females did not vary on allometric coefficient between lipid and protein of the body across strains. This result indicates a similar degree of fatness between female strains, as was also evident for Martin; Bradford; Gous (1994) studying these relationships in laying breeds.

The body composition of a bird grown under non limiting conditions would reflect the genotypic composition (EMMANS and FISHER, 1986). This is particularly important in respect of the lipid content deposited on the body, because it is significantly influenced by deviations from feed and environment. Due to these interactions, it is preferable to obtain the relative growth of body feather-free components expressed as a function of body protein weight, and thus the problem of confounding effect of fatness of the genotype can be avoided (DANISMAN; GOUS, 2011; ZELENKA et al., 2011).

Also, the regressions shown to describe the body composition from allometric relationships in the present study cannot be expected to have a general value to be used as growth model, they represent only means to demonstrate the relative growth of the body components of the broilers strains can vary. As commented by GOUS et al. (1999) only when the estimated values of the growth rate parameters of the Gompertz function are essentially the same the assumption of a simple allometry is justified to develop growth models (EMMANS, 1988).

According to Emmans (1989) feather growth and rates of feather protein deposition of genotypes may differ due the presence of genes for fast or slow feathering and feather weight is not a simple function of the body weight. In order to predict feather growth using allometric relationships between the chemical components of the feathers and the protein gain is necessary to determine the relationships between water and ash to compound all weight of the feather (MARTIN; BRADFORD; GOUS, 1994).

No significant difference was found in feather protein related to feather weight between the genotypes. Based on the results it was obtained the same relationship for water and ash for males and females feathers for all strains.

Based on these results, it can be noticed that the knowledge of these relationships helps predicting the weights of the components of broilers, as it means that only the weight of body protein needs to be determined for all the remaining chemical components of the body or feather (EMMANS, 1989). However, the theory that the body weight of the bird can be built by from these relationships was not evaluated in this paper.

Conclusion

The allometric regressions provide adequately information that would allow describing the deposition of body feather-free components in growing broilers appropriate for each genotype.

Differences do exist in the relative growth rates of chemical components of the body of commercial broiler strains.

In the feathers, there were no significant differences concerning the ash and water between broilers strains when it was described in terms feather protein.

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CAPÍTULO 5 – IMPLICAÇÕES

A análise de composição corporal é um procedimento utilizado na pesquisa animal para avaliação do desempenho animal e também requisito essencial na obtenção de dados de diferentes componentes do corpo para determinar curvas de crescimento e deposição dos constituintes corporais correspondentes ao potencial genético de diferentes linhagens e sexos.

O intervalo de tempo entre a seleção e exploração comercial de frangos de corte em granjas é dinâmico, levando cerca de quatro anos. A cada ano, as empresas de genética realizam um programa de seleção visando um produto que chega ao mercado. Por isso, é relevante realizar avaliações periódicas sobre as características da curva de crescimento das aves, que contribuem como variáveis de entradas em modelos que estimam as exigências e ingestão de nutrientes dos animais cada vez mais condizentes com as reais necessidades das aves.

Classicamente a avaliação da composição corporal em frangos é realizada por abates comparativos em diversas idades e procedimentos laboratoriais de análises químicas. No entanto, são procedimentos destrutivos, demorados e trabalhosos. Em alternativa a esta prática, o uso do DXA apresentou vantagens, tal como não necessitar abates, além de simplicidade e rapidez de obtenção dos valores químicos do corpo, quase imediato.

No experimento para avaliar o potencial genético de crescimento das linhagens, o uso do DXA indicou ser um instrumento importante para a avaliação animal, com informações obtidas ao longo da vida do indivíduo, de sustentável, racional e eficiente. Houve a redução do número de animais em experimento e com as mensurações repetidas no mesmo animal, pode-se reduzir o erro devido à menor variabilidade de indivíduos utilizados para o ajuste da curva de crescimento.

As informações de peso a maturidade e taxas de crescimento dos componentes do corpo e das penas referentes a cada linhagem e sexo avaliados, são importantes para simular o crescimento em diferentes especificações de dietas e de condições ambientais. Há no mercado, diversos softwares para a simulação do crescimento em frangos de corte, destacando-se EFG[®], Omnipro II, AVINESP, entre outros que utilizam como base curvas de crescimento e de deposição dos

componentes corporais. Dentre esses, o software AVINESP desenvolvido pelo grupo de pesquisa em avicultura da FCAV- Jaboticabal permite a predição do crescimento e das exigências nutricionais para frangos de corte das linhagens Cobb e Ross. Produtos novos e específicos a linhagem Hubbard (que já foi líder de mercado anos atrás), estão se consolidando na avicultura brasileira, porém, o software AVINESP ainda não conta com dados de crescimento relativos a esta linhagem. Portanto, os resultados obtidos sobre potencial genético de crescimento das linhagens no presente trabalho serão importantes para a atualização do software.

Em tempos que a exploração de métodos alternativos ao uso de animais em atividades de pesquisa beneficia a sociedade e a comunidade científica pelo uso de recursos da produção animal, a nossa esperança é influenciar pesquisas futuras a utilizarem a técnica DXA e os modelos estabelecidos nesta tese em termos de composição do corpo livre de penas em frangos de corte.

Na nutrição de frangos de corte, experimentos que avaliam a composição do corpo das aves demandam altos recursos financeiros, devido alimentação das aves que por fim são abatidas em diversos estágios de crescimento, além dos custos com as análises químicas. Se ampliada para esse fim, a técnica DXA pode ser realizada em qualquer momento de vida da ave, sem interferir sobre o desempenho e obter inferências sobre dietas na deposição de proteína, gordura, matéria mineral e água, que são os componentes básicos do corpo das aves.