UNIVERSIDADE ESTADUAL PAULISTA – UNESP

CÂMPUS DE JABOTICABAL

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

Larissa Vargas

Zootecnista

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CERTIFICADO DE APROVAÇÃO

TÍTULO DA DISSERTAÇÃO: MODELAGEM DO CRESCIMENTO DAS PENAS E DO CORPO EM FRANGOS DE CORTE

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Jaboticabal, 11 de junho de 2019

DADOS CURRICULARES DO AUTOR

LARISSA VARGAS, filha de Cleyton Vargas e Márcia Fátima Paula Rodrigues Vargas, nascida no dia 11 de fevereiro de 1992 em Jaboticabal, São Paulo. Ingressou no curso de Zootecnia na Universidade Estadual Paulista “Júlio de Mesquita Filho” (UNESP) – Faculdade de Ciências Agrárias e Veterinárias, Campus de Jaboticabal, em março de 2012. Em janeiro de 2017 obteve o título de Zootecnista. Em março de 2017 ingressou no Programa de Pós-Graduação em Zootecnia da Universidade Estadual Paulista “Júlio de Mesquita Filho” (UNESP) – Faculdade de Ciências Agrárias e Veterinárias, Campus de Jaboticabal, onde obteve bolsa pelo CNPq, sob orientação da Profª Drª Nilva Kazue Sakomura, submetendo-se à defesa da dissertação em junho de 2019.

"A persistência é o caminho do êxito".

Charles Chaplin

Dedico

Aos meus pais Cleyton e Márcia, por todo amor, carinho e dedicação que sempre tiveram por mim, pelos esforços e incentivo durante toda minha trajetória. Amo cada um de vocês incondicionalmente.

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Sumário

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"JÚLIO DE MESQUITA FILHO"
Câmpus de Jaboticabal

CERTIFICADO

Certificamos que o projeto intitulado **"Crescimento e composição das penas em frangos de corte"**, protocolo nº 015111/17, sob a responsabilidade da Profª. Drª. Nilva Kazue Sakomura, que envolve a produção, manutenção e/ou utilização de animais pertencentes ao Filo Chordata, subfilo Vertebrata (exceto o homem), para fins de pesquisa científica (ou ensino) - encontra-se de acordo com os preceitos da lei nº 11.794, de 08 de outubro de 2008, no decreto 6.899, de 15 de julho de 2009, e com as normas editadas pelo Conselho Nacional de Controle de Experimentação Animal (CONCEA), e foi aprovado pela COMISSÃO DE ÉTICA NO USO DE ANIMAIS (CEUA), da FACULDADE DE CIÊNCIAS AGRÁRIAS E VETERINÁRIAS, UNESP - CÂMPUS DE JABOTICABAL-SP, em reunião ordinária de 05 de outubro de 2017.

Vigência do Projeto	12/10/2017 a 02/02/2018
Espécie / Linhagem	*Gallus gallus* / Cobb 500, Ross 308
Nº de animais	800
Peso / Idade	45 g / 1 dia de vida
Sexo	Ambos os sexos
Origem	Pluma Agroavícola – Descalvado - SP

Jaboticabal, 05 de outubro de 2017.

Profª Drª Lizandra Amoroso
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MODELAGEM DO CRESCIMENTO DAS PENAS E DO CORPO EM FRANGOS DE CORTE

RESUMO – O crescimento do corpo e das penas constituem características importantes para a indústria avícola. Contudo, visto que o crescimento das penas não foi avaliado como o do corpo e que nenhum estudo científico foi realizado para descrever o potencial de desempenho de genótipos de frangos de corte nas últimas décadas, torna-se necessário que novas pesquisas sejam conduzidas. Neste contexto, esta dissertação foi realizada com três principais propósitos: 1) descrever detalhadamente o crescimento das penas nos vários tratos do corpo; 2) descrever as perdas diárias das penas em uma amostra de aves para fornecer informações adicionais sobre os padrões de muda e 3) descrever o potencial crescimento das penas e do corpo livre de penas e seus componentes químicos. Para avaliar o crescimento das penas e o potencial crescimento do corpo sem penas, um ensaio foi conduzido durante 16 semanas utilizando um total de 800 frangos de corte alojados em 40 boxes e distribuídos aleatoriamente de acordo com duas linhagens (Cobb 500 MX e Ross 308 AP (AP95)), dois sexos (machos e fêmeas) com 20 aves por box. As aves foram alimentadas com quantidades adequadas de proteína dietética usando um programa de alimentação de quatro fases. Uma ave por box (10 aves por linhagem) foi amostrada e eutanasiada aos 14, 28, 42, 56, 70, 84, 98 e 112 dias de idade. As aves amostradas foram pesadas antes e depois de serem depenadas para determinar o peso das penas, e o corpo sem penas foi então processado e analisado quanto ao teor de água, proteína e lipídios. Todas as penas foram arrancadas de acordo com os tratos: capital, cervical, dorsopélvico, interescapular, peitoral e femoral. Três rectrices do trato dorsocaudal e três primárias e secundárias do trato alar da asa direita também foram avaliadas. O comprimento das penas selecionadas foi medido, o peso das penas de cada trato foi determinado, e o peso total das penas foi calculado como a diferença de peso entre a ave viva e a depenada. Os tratos capital e cervical foram agrupados ao mensurar o peso das penas, bem como os tratos humeral e alar. Para descrever as perdas de penas, um sub-ensaio foi conduzido utilizando 20 aves de cada um dos genótipos avaliados, as aves foram alojadas individualmente em gaiolas cercadas por telas e as perdas diárias de penas foram medidas. As penas foram coletadas de cada gaiola diariamente usando pinças, e estas foram armazenadas em sacos de papel identificados. Após a coleta, todas as bandejas foram limpas para evitar que as penas fossem sujas pelas excretas. As penas de cada gaiola foram separadas em penugens, penas de contorno, rêmiges e retrices e depois pesadas, pesando-se a penugem em uma balança de precisão de 1 µg e o restante com uma precisão de 0,1 mg. Foi evidenciado uma grande variação na taxa de maturidade (0,0329 / d) e no peso a maturidade (36,8 g) entre os diferentes tratos. Os tratos de crescimento mais lento foram os tratos capital e cervical, dorsocaudal e peitoral, com taxas de maturidade de quase metade dos tratos femoral e interescapular. O peso a maturidade dos tratos humeral e alar e femoral maiores do que os demais tratos. O peso das penas não se mostrou como um bom indicador da muda de penas em comparação com a medição das perdas de penas. A muda foi evidente apenas nos tratos alar e dorsocaudal, enquanto que, quando as perdas diárias foram medidas, a

maior proporção que ocorreu durante o período experimental de 112 dias (>0,70) foi a das penas de contorno. O peso corporal e a composição química dos machos das duas linhagens foram semelhantes durante todo o ensaio. As fêmeas das duas linhagens diferiram apenas no conteúdo lipídico corporal na maturidade, na qual as fêmeas Cobb atingiram valores maiores do que as fêmeas Ross (1371 vs. 1210 g). O peso do corpo a maturidade de machos e fêmeas de ambas as linhagens foi em média de 8420 e 6650 g; os pesos proteicos a maturidade foram em média de 1555 e 1030 g; e conteúdo lipídico do corpo a maturidade em média de 908 e 1290 g, respectivamente. As taxas de maturidade (/d) dos pesos corporais de machos e fêmeas de ambas as linhagens foram em média de 0,0385 e 0,0368; do conteúdo proteico corporal livre de penas, 0,0316 e 0,0348; e de lipídios corporais, 0,0503 e 0,0375, respectivamente. Estas taxas diferiram entre as fêmeas de Cobb e Ross (0,0352 vs. 0,0397 / d). Equações separadas foram necessárias para descrever a relação alométrica entre lipídios e proteínas no corpo livre de penas em machos e fêmeas, devido a diferenças genéticas na capacidade de depositar lipídios no corpo dos dois sexos. A taxa de maturidade das penas nas fêmeas foi maior que nos machos (0,0526 vs. 0,0398 / d) e o peso adulto foi menor (205 vs. 266 g). O peso das penas estava alometricamente relacionado ao peso da proteína corporal, mas equações separadas foram necessárias para machos e fêmeas. As duas linhagens não diferiram nesta relação. As penas de contorno, rêmiges e retrices juntos compõem a maior parte das penas em um frango, contribuindo substancialmente para os requisitos de aminoácidos para o crescimento de penas. A taxa de muda das penas dos tratos apresentados neste estudo será útil no cálculo das quantidades adicionais de aminoácidos necessárias para o crescimento da segunda fase do empenamento. A descrição do potencial de crescimento das linhagens atuais auxiliará na atualização dos modelos de crescimento de frangos de corte para predizer com maior precisão o crescimento do corpo e das penas, assim como a composição química e física do crescimento desses frangos e no cálculo das estimativas para as necessidades nutricionais nas diferentes idades.

Palavras-chave: alometria**,** curva de crescimento, muda das penas, tratos das penas, rêmiges, retrices

MODELING FEATHERS AND BODY GROWTH IN BROILER CHICKENS

ABSTRACT - Body and feather growth represents an important economic trait for broiler industry. However, given that feather growth has not been as well researched as that of the whole body and no scientific study has been conducted to describe the potential performance of these broiler genotypes over the past decades, it is necessary that further research be conducted. In this sense, this dissertation was conducted with three main purposes: 1) to describe in detail the growth of feathers in the various tracts on the body; 2) to describe daily feather losses in a sample of birds to provide additional information about moulting patterns and 3) to describe the potential growth of feathers and feather-free body and its chemical components. To evaluate feather growth and the potential growth of feather-free body, one trial was conducted for 16 weeks using a total of 800 sex separate day old chicks placed in 40 pens and assigned randomly according to two strains (Cobb 500 MX and Ross 308 AP (AP95)), two sex (male and female) with 20 chicks per pen. The birds were fed adequate amounts of dietary protein using a four-phase feeding programme. One bird per pen (10 birds per genotype) was sampled and euthanized at 14, 28, 42, 56, 70, 84, 98 and 112 d of age. Sampled birds were weighed before and after being dry-plucked to determine the weight of feathers, and the feather-free body was then minced and analysed for water, protein and lipid. All feathers were dry-plucked according to the capital and cervical, dorsopelvic, interscapular, pectoral and femoral tracts being randomly selected during plucking. Three rectrices of the dorsocaudal tract and three primaries and secondaries of the alar tract of the right wing were also evaluated. The length of the selected feathers was measured, the weight of the feathers from each tract was determined, and the total weight of feathers was calculated as the difference in weight between the live and defeathered bird. The capital and cervical tracts were grouped when the feather weight was measured, as well as the humeral and alar tracts. To describe feather losses, a sub-trial was conducted using 20 broilers of each of the genotypes evaluated, birds were placed in individual mini-pens surrounded by with a plastic net, and the daily losses of feathers was measured. Feathers were collected from each mini pen daily using tweezers, and these were stored in identified paper bags. After collection, all trays were cleaned to prevent feathers from being soiled by excreta. The feathers from each mini pen were separated into natal down, contour feathers, remiges and rectrices and then weighed, with natal down being weighed on an analytical balance of 1 µg and the remainder at a precision of 0.1 mg. A wide range of rates of maturing (0.0329 /d) and mature weights (36.8 g) were evident between tracts. The slowest-growing tracts were the dorsocaudal, capital and cervical and pectoral tracts with rates of maturing almost half of those of the femoral and interscapular tracts. The mature weights of the humeral and alar and femoral tracts were heavier than those in any other tracts. Using feather weight as an indicator of moulting was inaccurate compared with measuring feather losses. Moulting was evident only in the alar and dorsocaudal tracts, whereas when daily losses were measured, the greatest proportion that occurred over the 112-d trial period (>0.70) were contour feathers. Body weights and chemical composition of males of the two strains were similar throughout the trial. Females of the two strains differed only in their body lipid contents, with that of Cobb females at maturity being higher than Ross (1371 *vs*. 1210 g). Mature body weights of males and females of both strains averaged 8420 and 6650 g; mature body protein

weights averaged 1555 and 1030 g; and mature body lipid contents averaged 908 and 1290 g, respectively. Rates of maturing (/d) of body weights of males and females of both strains averaged 0.0385 and 0.0368; of feather-free body protein content, 0.0316 and 0.0348; and of body lipid, 0.0503 and 0.0375, respectively. These rates differed between Cobb and Ross females (0.0352 vs. 0.0397 /d). Separate equations were required to describe the allometric relationship between lipid and protein in the feather-free body in males and females due to genetic differences in the ability to deposit body lipid in the two sexes. The rate of maturing of feathers in females was higher than in males (0.0526 vs. 0,0398 /d) and the mature weight was lower (205 vs. 266 g). Feather weight was allometrically related to body protein weight, but separate equations were needed for males and females. The two strains did not differ in this relationship. The contour feathers, remiges and rectrices together make up the bulk of feathers in a broiler thus contributing substantially to the amino acid requirements for feather growth. The rate of moulting of feathers from these tracts, presented here, will be useful in calculating the additional amounts of amino acids required for the growth of the second phase of feathering. The description of the potential growth of current strains will enable broiler growth models to predict more accurately the growth of the body and feathers, as well the chemical and physical composition of broiler growth and to calculate estimates for nutritional requirements at different ages.

Key words: allometry, feather tracts, growth curve, molting, remiges, rectrices

CAPÍTULO 1 - Considerações gerais

Introdução

A avicultura de corte tem se destacado como uma das atividades mais desenvolvidas no Brasil. Associado a melhorias nas áreas de nutrição e genética, o setor avícola passou a ter caráter industrial, impulsionado pelo aumento na produção. Concomitantemente, mudanças no padrão de crescimento e na produtividade das linhagens comerciais ocorreram de forma intensiva, favorecendo a deposição proteica. Um tópico relevante, porém pouco estudado na caracterização deste crescimento, é o crescimento das penas. Em função das diferenças nas taxas de deposição de nutrientes e na composição química, sobretudo no que tange a composição aminoacídica, o crescimento do corpo e das penas deve ser avaliado separadamente.

As penas correspondem a aproximadamente 4 a 8% do peso vivo, porém a velocidade de empenamento varia entre as linhagens, sexo e idade (North e Bell, 1993). O crescimento das penas representa uma importante característica econômica para a indústria de frangos de corte. Em primeiro lugar, porque o mau empenamento aumenta a condenação de carcaça no abate, reduzindo assim a receita da produção de carne de frango. Segundo, porque o desenvolvimento das penas durante o crescimento das aves requer uma demanda de nutrientes, principalmente aminoácidos, que devem ser fornecidos por dietas em quantidades adequadas para suportar taxas de crescimento adequadas (Gous et al., 1999).

O crescimento do corpo deve ser compreendido como a soma dos componentes químicos proteínas, água, cinzas e lipídios, cujas taxas de deposições no corpo variam em função da idade da ave até sua maturidade, momento no qual a mesma se encontra em equilíbrio e as taxas de deposição são nulas (Ferguson, 2006). Tendo em vista o sucesso dos geneticistas em aumentar a taxa de crescimento e eficiência alimentar das aves, novos estudos devem ser conduzidos uma vez que ocorreram mudanças ao longo dos últimos anos nos genótipos utilizados e na nutrição de frangos de corte.

A descrição do crescimento do corpo e das penas pode ser contemplada a partir da utilização de funções matemáticas. A função Gompertz (Gompertz, 1825) é, dentre as funções matemáticas descritas na literatura, a mais adequada para descrever o crescimento (Wellock et al., 2004). No entanto, apesar de suas

vantagens em cumprir o propósito de caracterizar o crescimento das penas, algumas falhas na maneira como os dados são coletados e ajustados à função podem influenciar a precisão da descrição do crescimento. Ao contrário do corpo, as penas não crescem indefinidamente até que as aves alcancem seu estado final de equilíbrio, dado que gerações de penas crescem e caem continuamente. Em adição, penas de diferentes tratos de frangos apresentam um padrão distinto de crescimento e maturação (Stillborn et al., 1997).

Alguns modelos fatoriais adotam, utilizam ou levam em consideração o peso de proteína corporal e das penas exclusivamente para predizer a necessidade de aminoácidos essenciais para frangos de corte (Martin et al., 1994; Sakomura et al., 2015). Assim, explorar as peculiaridades do processo de empenamento através da partição do crescimento nos diferentes tratos do corpo, permitiria obter parâmetros de crescimento de tais tratos, o que poderia tornar mais acurada a predição de modelos. Diante de tal cenário, tem-se como objetivo no presente trabalho determinar o potencial de crescimento do corpo e das penas e as perdas diárias de penas em diferentes idades e linhagens.

Revisão de literatura

Estrutura e morfogênese das penas

A pena consiste em um apêndice epidérmico altamente especializado, que se desenvolve ao longo de “tratos” específicos denominados de pterilas, intercalados por aptérios, regiões ausentes ou parcialmente cobertas por penas (Lucas e Stettenheim, 1972). Em aves de produção, existem tradicionalmente de sete a dez tratos principais, entre eles: (1) capital: cobre a crista até a base do bico e a região posterior do crânio; (2) espinhal ou dorsal: corre ao longo do dorso a partir do pescoço até à base da cauda, podendo ser dividido em dorso escapular, dorso pélvico e dorso caudal; (3) caudal: correspondem às rêtrices e a porção do uropígio; (4) humeral: reveste a borda das asas e ombros; (5) alar: correspondem às rêmiges e sua cobertura; (6) peitoral: estende-se desde a região dorsal cervical até o ventre; (7) femural: reveste a região das coxas (Figura 1) (Macari e Maiorka, 2017).

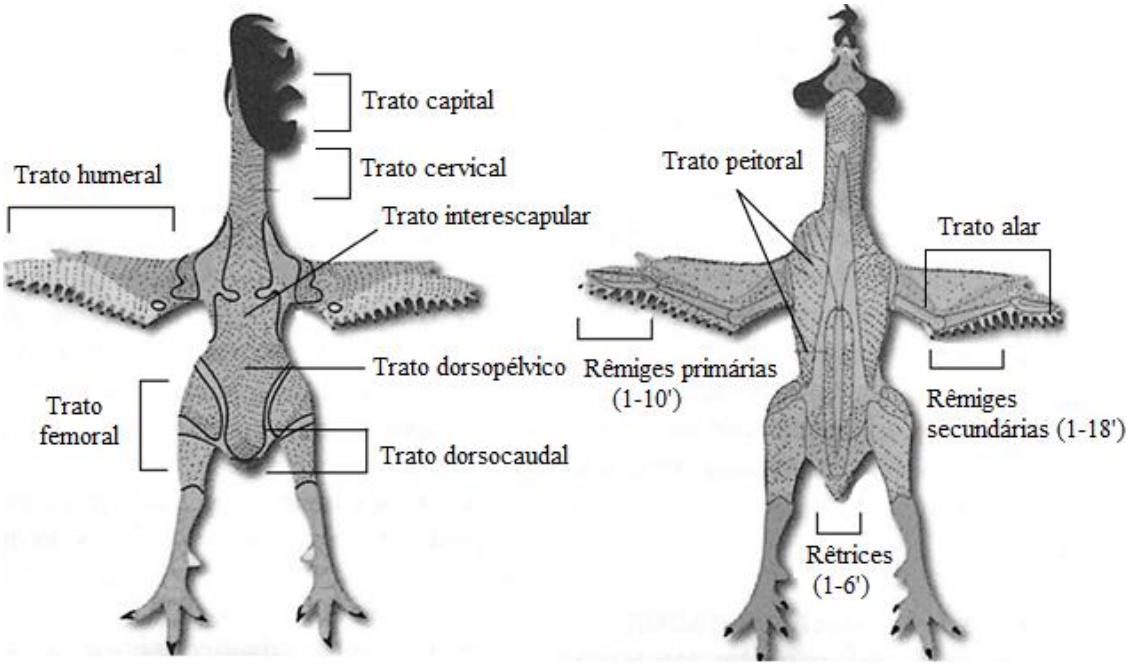

Figura 1. Diagrama das regiões de desenvolvimento das penas (Adaptado de Lucas e Stettenheim, 1972).

A estrutura das penas é composta por dois principais segmentos dispostos em seu eixo longitudinal, denominados de cálamo e ráquis. O cálamo é representado por uma base curta e tubular inserida no folículo das penas, composto por uma abertura localizada na porção inferior. Enquanto a ráquis compreende o eixo central acima da pele. No eixo central, existem ramificações primárias chamadas de barbas, as quais são conhecidas coletivamente por vexilo. As barbas apresentam ramificações secundárias suportadas por um ramo, nomeadas de bárbulas que possuem ramificações ainda menores denominadas de barbículas (Figura 2) (Prum e Williamson, 2001; Macari e Maiorka, 2017).

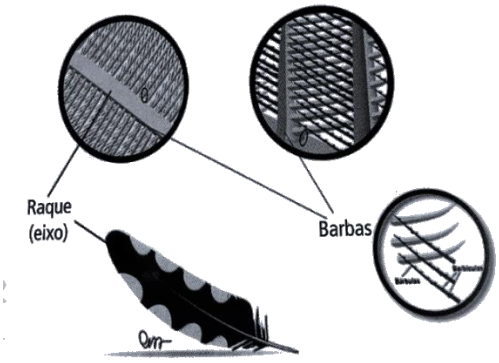

Figura 2. Estrutura das penas (Dahike et al. 2017)

Em virtude da diversidade de funções e características específicas, as penas podem ser classificadas em penas de contorno, semiplumas, filoplumas, penugens e cerdas. As penas de contorno são aquelas externamente visíveis, sendo que o tamanho pode variar desde as maiores até as menores, presentes na pálpebra. São penas com eixo bem desenvolvido e podem possuir uma porção plumácea (Macari e Maiorka, 2017).

As semiplumas apresentam ráquis longa e barba fofa distribuídas nas margens dos tratos das penas de contorno e auxiliam no isolamento necessário para reter calor corporal. As filoplumas estão situadas ao lado de outras penas, geralmente acompanhando as penas de contorno e semiplumas. Sugere-se que sua função está relacionada com a postura das penas, funcionando como um mecanorreceptor que permite o correto posicionamento das penas as quais estão associadas à filopluma (Lucas e Stettenheim, 1972; Macari e Maiorka, 2017).

As penugens são penas macias presentes abaixo das penas de contorno, responsáveis por proporcionar isolamento térmico adicional (Meng, 2014). As cerdas são penas geralmente caracterizadas por uma ráquis rígida e com ausência de barbas, exceto na extremidade proximal. São comuns na pálpebra e em outras regiões da cabeça e possuem função tátil (Lucas & Stettenheim, 1972).

Apesar da variedade, as penas de contorno são responsáveis pela maior cobertura da superfície do corpo das aves. Nesta categoria, estão inseridas as rêtrices (penas da cauda) e as rêmiges (penas das asas). Na maioria das aves, as rêtrices são constituídas por 6 pares, totalizando 12 penas (Figura 3). Já as rêmiges são classificadas em três diferentes grupos: penas primárias, penas secundárias e penas terciárias. As primárias encontram-se localizadas na extremidade distal da asa, normalmente apresentam-se em número de 10 nas aves de produção, numeradas a partir da região proximal da asa. As secundárias estão presentes na região da ulna e formam um grupo de 10 a 14 unidades. Já as terciárias representam o conjunto de penas mais próximas ao corpo das aves (Figura 4) (Macari e Maiorka, 2017).

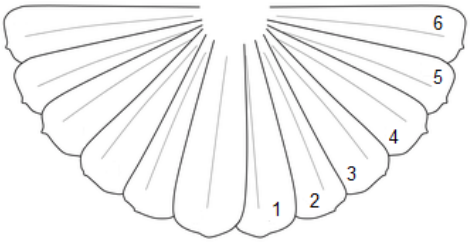

Figura 3. Diagramas das rêtrices da cauda (Domínio público)

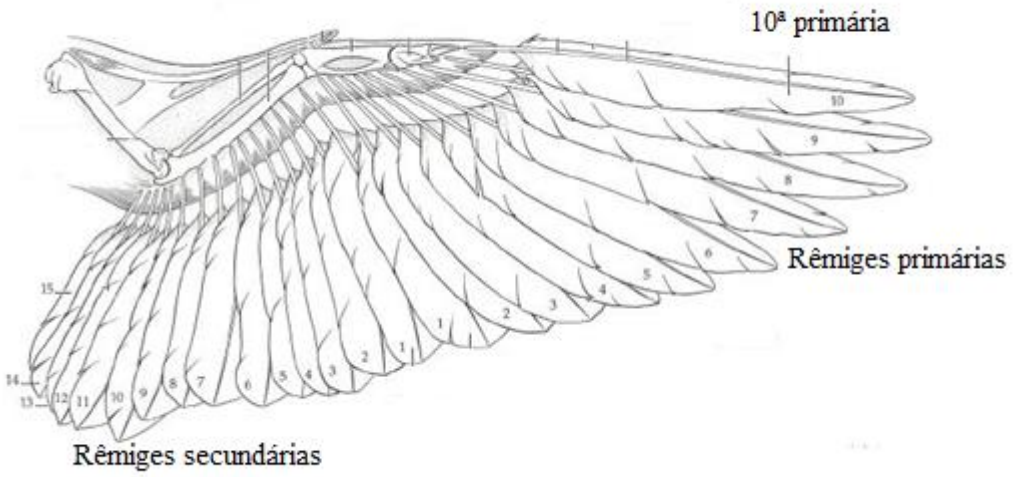

Figura 4. Diagrama das penas primárias e secundárias (Adaptado de Proctor e Lynch, 1993).

Crescimento das penas

O crescimento das penas, denominado de anagênese, abrange uma série de mecanismos morfológicos e fisiológicos influenciados por fatores nutricionais, genéticos, ambientais e hormonais, como no caso dos hormônios tireoidianos e das gonadotrofinas (Leeson e Walsh, 2004). O empenamento é estabelecido durante os primeiros 12 dias de vida do embrião, uma vez que tem-se o surgimento da papila, célula germinativa dos folículos. A papila dérmica compreende uma rica rede de capilares sanguíneos que se difundem de uma única artéria axial central, sendo responsável pela nutrição das penas (Lucas e Stettenheim, 1972; Macari e Maiorka, 2017).

Em resumo, o processo de formação das penas tem início com a condensação de células da derme, dispostas em linhas bem definidas. As células

germinativas das penas dos tratos femural, peitoral, espinhal, humeral, alar e capital, respectivamente, são formadas e projetam-se acima da pele. Posteriormente, ocorre a proliferação da epiderme em torno da base da papila criando uma invaginação cilíndrica para dentro da derme, tendo assim, o aparecimento dos folículos. A camada externa da epiderme forma as paredes dos folículos, enquanto que a camada interna o colarinho (Prum e Williamson, 2001; Macari e Maiorka, 2017).

Eventualmente, durante o crescimento das penas, toda divisão celular é realizada no colarinho do folículo (Lucas e Stettenheim, 1972). Desta forma, as penas se desenvolvem por proliferação e diferenciação dos queratinócitos que produzem a queratina. À medida que ocorre a multiplicação das células mais jovens, os queratinócitos mais velhos morrem e são deslocados para fora do colarinho, deixando para trás uma matriz de queratina depositada que constitui a pena madura. No centro de cada folículo tem-se ainda a polpa dérmica, responsável por fornecer os nutrientes para o crescimento das penas (Prum e Williamson, 2001).

A partir do momento em que os folículos ficam mais distintos, as penas tornam-se rudimentares e projetam-se acima da superfície corporal das aves, com uma parte já queratinizada. Assim, as diversas estruturas que compõe as penas são formadas por diferenciação e morfogênese no colarinho do folículo e, após a eclosão, a bainha protetora que reveste as penas seca e cai, deixando a pena livre e com aspecto de macia (Prum e Williamson, 2001; Macari e Maiorka, 2017) (Figura 5).

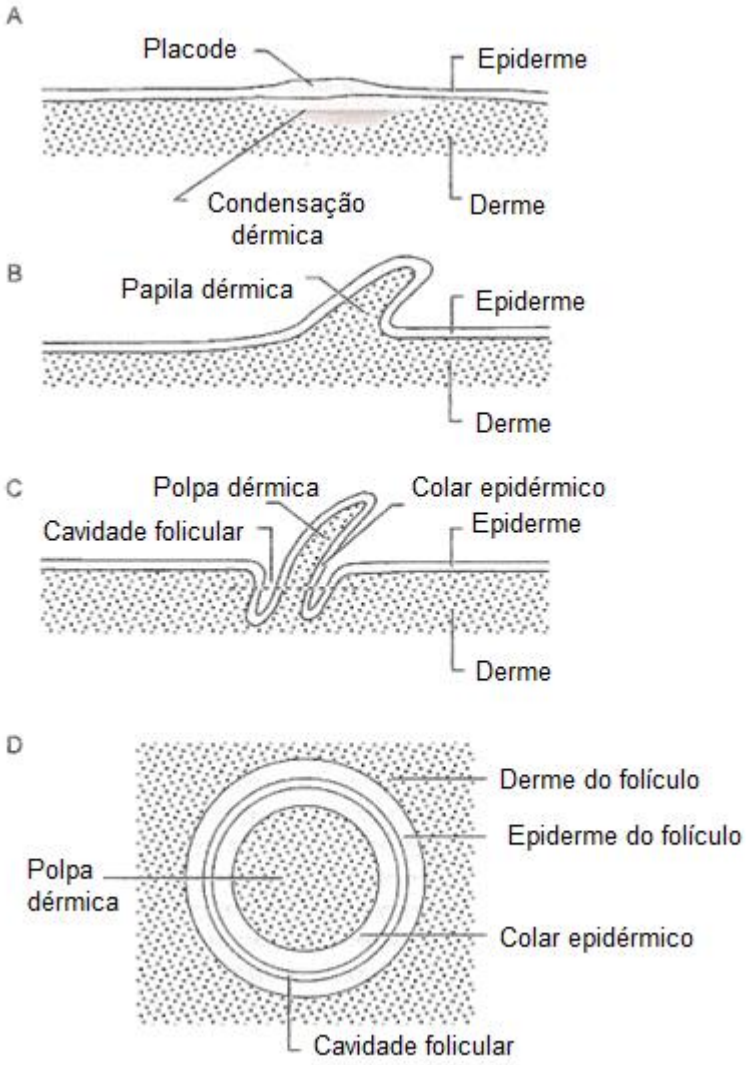

Figura 5. Diagrama do desenvolvimento de um folículo da pena. (A) Desenvolvimento do placode da pena epidérmica e condensação dérmica. (B) Desenvolvimento de uma papila de penas através da proliferação de células dérmicas. (C) Formação do folículo da pena pela invaginação de um cilindro de tecido epidérmico em torno da base da papila. (D) Corte transversal do folículo da pena (Adaptado de Prum e Williamson, 2001).

O crescimento da pena é considerado um processo dinâmico, pois a maturação da mesma em cada região do corpo da ave varia, colocando em evidência as diferentes gerações de penas, com menor destaque em frangos de corte devido ao período curto de criação. A plumagem completa ocorre em torno dos 50 dias de idade, embora para algumas linhagens o crescimento total possa ser mais tardio (Emmans, 1989; Edens, 2000).

Balanço hormonal e empenamento

Em diversas espécies avícolas, o crescimento e a muda das penas ocorrem de forma ordenada e sob a liberação de determinados hormônios (Voitkevich, 1966). Este crescimento é ditado por hormônios da tireoide (T3 e T4), estrogênio e testosterona (Leeson e Walsh, 2004) (Tabela 2).

O crescimento celular dos folículos sofre ação direta dos hormônios tireoidianos (T3 e T4), com exceção das penas primárias das asas que são pouco afetadas. Outro conjunto de penas que se desenvolvem sem a interferência do metabolismo da tireoide são as penugens, o que não acontece com as gerações subsequentes. Níveis de tiroxina (T4) são elevados durante a ocorrência da muda, contudo diminuem na regeneração das penas (Leeson e Walsh, 2004). Por outro lado, os níveis de triiodotironina (T3) são baixos durante o início da muda e altos à medida que as penas começam a crescer (Pethes, 1982).

Estudos endócrinos apontam para a importância de um segundo grupo de hormônios que atuam no controle ou indução da muda, os sexuais (Macari e Maiorka, 2017). Níveis altos de estrogênio, por exemplo, podem atrasar o crescimento das penas. Em uma série de espécies avícolas, a muda também está associada a níveis de progesterona plasmática. Os níveis de progesterona diminuem à medida que novas penas emergem (Leeson e Walsh, 2004). O mesmo ocorre no caso da testosterona, em que a presença de altos níveis desse hormônio retarda, impede ou interrompe a muda (Schleussner et al., 1985; Nolan et al., 1992).

Tabela 2. Ação dos hormônios tireoideanos e sexuais sobre o desenvolvimento das penas

Hormônios	**Ação**
Tiroxina (T4) e Progesterona	Estimulam o crescimento das penas
Testosterona e Estrógeno	Retardam o crescimento das penas

Adaptado de Macari et al., 2002

Genética e empenamento

Em programas de melhoramento genético, o gene k ligado ao cromossomo sexual Z tem sido responsável por garantir diferentes taxas de crescimento das penas em machos e fêmeas (Macari e Maiorka, 2017). O empenamento lento (K) é caracterizado por ser dominante em relação ao empenamento rápido (k). Os machos

carregam dois conjuntos de cromossomos sexuais KK (lento) ou kk (rápido), enquanto as fêmeas somente um conjunto de cromossomos sexuais (K- ou k-) (Leeson e Walsh, 2004). Ao cruzar machos homozigotos para o empenamento rápido (kk) com matrizes fêmeas de empenamento lento (K-), por exemplo, o resultado são pintainhos machos de empenamento lento (Kk) e fêmeas de empenamento rápido (k-) (Dunnington et al., 1986).

Na avicultura industrial, a introdução do gene k em linhagens comerciais de frangos de corte facilitou a identificação do sexo das aves, em virtude da diferença existente no comprimento das rêmiges primárias, entre machos e fêmeas, permitindo ao produtor a criação de lotes de sexo separado (Sakomura et al., 2005; Macari e Maiorka, 2017).

Muda e perda das penas

O crescimento das penas apresenta ciclos naturais e periódicos. Após atingir o máximo crescimento, a pena permanece no folículo como uma estrutura queratinizada (Hancock et al., 1995; Leeson e Walsh, 2004; Macari e Maiorka, 2017). Quando a mesma cai naturalmente ou acidentalmente, uma nova pena cresce no mesmo folículo em um período de duas semanas (Yu et al., 2004).

Segundo Lucas e Stettenheim (1972), as aves apresentam 3 gerações de penas, em frangos de corte comerciais, o processo de substituição da primeira geração (penugens) ocorre de 2 a 4 semanas, com exceção das asas, uma vez que as aves já nascem com penas de segunda geração nessa região. A primeira geração de penas formada é denominada de penugem. Já as penas da segunda geração são chamadas de penas juvenis, formadas no folículo ao final da fase embrionária, próximo à eclosão do pintainho. À medida que as penas desta geração crescem elas empurram as penugens para fora dos folículos (Yu et al., 2004). Normalmente, após o amadurecimento das penas juvenis, inicia-se o crescimento da terceira geração de penas, as penas de base. As penas da terceira geração são caracterizadas por exibirem textura e cor no padrão de uma ave adulta (Deschutter e Leeson, 1986).

Nos diferentes tratos de penas presentes no corpo das aves, o tempo e a ordem de muda podem variar (Tabela 3). Contudo, este fenômeno ocorre de forma coordenada garantindo uma boa cobertura de penas nas aves. Geralmente, as penas são substituídas em intervalos regulares e na mesma sequência encontrada

de seu desenvolvimento, como no caso das rêmiges primárias, onde a muda decorre das penas internas para as externas presentes na porção distal da asa, evidenciando a existência de um gradiente de maturação (Yu et al., 2004).

Tabela 3. Muda das penas de acordo com a idade

Idade (dias)	Geração das penas
0	Presença de penugens (primeira geração) em todo corpo da ave exceto nas rêmiges e rêtrices, por já apresentarem penas da segunda geração.
8	A maioria das rêmiges e rêtrices encontram-se na segunda geração de penas. O restante das penas são da primeira geração.
19	Todas as rêmiges e rêtrices são de segunda geração. Presença de penas imaturas da segunda geração nos tratos espinhal, humeral, capital ventral, peitoral, crural e caudal.
35	Penas imaturas da segunda geração prevalecem e as penugens seguem aderidas as penas da face, pescoço, dorso, peito e asas.
55	Surgimento de penas da terceira geração. Algumas penugens permanecem aderidas a penas dos tratos capital, dorsal e ao redor dos olhos.
77	Penas da terceira geração cresceram totalmente nos tratos humeral e alar. Algumas penas da segunda geração permanecem crescendo. Penugens ocorrem somente nos tratos capital e cervical.
103	Penas da terceira geração prevalecem na maioria dos tratos. Penas maduras da segunda geração estão presentes nos tratos capital, alar e abdominal lateral. Ausência de penugens.

Adaptado de Lucas e Stettenheim (1972)

A sucessão das penas, a taxa de crescimento e perda de penas possuem padrões específicos entre espécies, sexo e idade das aves (Hancock et al., 1995; Leeson & Summers, 2009; Martin et al., 1994). Fisher et al. (1981) ao avaliarem o crescimento das penas em frangos de corte observaram que as fêmeas perdiam cerca de 3,5 vezes mais penas que os machos conforme o avanço da idade da ave, o que pode ser explicado pela diferença na taxa de empenamento em relação ao sexo. Emmans (1989), ao mensurar a perda de penas diária em perus, observou uma perda de 0,01 g/ de penas/dia. Tendo em vista que tais valores tenham sido determinados com linhagens genéticas antigas, novos estudos sobre perda de penas são necessários visando atualizar as informações a partir da utilização de linhagens genéticas modernas.

Crescimento e composição do corpo

Com a pressão de seleção das empresas de genética, a taxa de crescimento relativo e a eficiência alimentar de frangos de corte diferiram nos últimos anos, tendo como resultado a diminuição na idade de abate para o mesmo peso vivo. Tal comportamento tem sido evidenciado por diversos estudos (Gous, 1986; Havenstein et al, 1994; McKay et al., 2000; Tallentire et al., 2016; Tavárez & de los Santos, 2016). Entretanto, até o momento, nenhum estudo científico foi realizado visando descrever o potencial de crescimento das linhagens comerciais modernas ao longo das últimas décadas.

As características de composição (proteína, água e lipídios) também são influenciadas pela seleção das aves. Fleming et al. (2007) observaram que o conteúdo de lipídio corporal sofreu uma redução de 269 g/kg na década de 1970 para 153 g/kg em linhagens comerciais. Hancock et al. (1995) ao avaliar os parâmetros de crescimento em linhagens comerciais de frangos de corte verificou um peso proteico a maturidade de 835 g/kg para machos e 746 g/kg para fêmeas. Em contrapartida, Marcato (2007) observou, para a mesma variável, valores de 1308,61 g/kg e 865,70 g/kg para machos e fêmeas, respectivamente. Tais comparações ilustram o sucesso dos geneticistas avícolas em melhorar a taxa de crescimento dos frangos de corte.

Modelagem do crescimento das penas e do corpo

Na avicultura, o desenvolvimento de modelos matemáticos são de suma importância para estimar o crescimento corporal e a deposição de nutrientes em função da idade da ave, padronizando o crescimento para seleção de novas linhagens (Freitas et al., 1983). A descrição do crescimento da ave ou dos componentes corporais tornou-se o primeiro passo para a elaboração de modelos simulação capazes de predizer as exigências nutricionais e determinar os efeitos do programa nutricional ou condições ambientais sobre o desempenho (Gous et al., 1999).

Diversos modelos não lineares têm sido empregados para descrever o crescimento e a deposição de nutrientes nas penas, porém a mais utilizada tem sido a função de Gompertz (1825), descrita por Winsor (1932). Esta equação possui parâmetros com significado biológico para explicar o crescimento das aves e

estabelecer taxas de crescimento para os componentes corporais (Talpaz et al., 1986; Marcato, 2007).

Ao descrever a taxa de crescimento potencial das linhagens utilizando a função de Gompertz, os parâmetros ajustados aos dados de composição mensurados durante o crescimento do animal devem ser obtidos em condições ideais de temperatura e densidade, ração balanceada e consumo *ad libitum*, sendo esta formulada para atender as exigências nutricionais (Emmans, 1988; Gous et al., 1999).

Segundo Fialho (1999), a equação de Gompertz possui propriedades desejáveis numa curva de crescimento. Este modelo consiste nos parâmetros: peso na maturidade (*A*, g), taxa de maturidade (*B*, /dia) e a idade em que a máxima taxa de crescimento é alcançada (*t**, dias). A equação pode ser expressa da seguinte forma:

$$Wt = A \times e^{(-e^{(-B \times (X-t^*))})}$$

Em que:

Wt = peso (g) no tempo t; *A* = peso na maturidade (g); *e* = 2,718282 (base do logaritmo neperiano); *B* = taxa de maturidade (/dia); *X* = idade (dias) e *t** = idade em que a taxa de crescimento é máxima (dias).

Tendo em vista que o crescimento do corpo e das penas e de seus componentes pode ser explicado através da função Gompertz, Emmans (1981) e Martin et al. (1994) aconselham mensurar estas variáveis em diferentes fases de crescimento da ave. Em adição, considerando que esta equação tem sido amplamente empregada em ensaios envolvendo frangos de corte, torna-se possível comparar o avanço genético dado uma determinada variável com trabalhos desenvolvidos anteriormente permitindo atualizar modelos de predição das exigências nutricionais das aves (Hancock et al., 1995; Gous et al., 1999; Marcato et al., 2008; Gonçalves, 2017).

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CAPÍTULO 2 – A description of the growth and moulting of feathers in commercial broilers

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A DESCRIPTION OF THE GROWTH AND MOULTING OF FEATHERS IN COMMERCIAL BROILERS

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Abstract 1. A study was conducted with males and females of two commercial broiler strains to measure the changes that occur in feather length and weight in feather tracts, and the daily losses of natal down, contour feathers, remiges and rectrices, the objective being to ascertain the extent to which feathers are moulted by broilers up to 112 d of age.

2. A total of 800 sex separate day old chicks were placed in 40 pens and assigned randomly according to two strains, two sex and 20 chicks per pen. The birds were fed adequate amounts of dietary protein using a four-phase feeding programme. One bird per pen (10 birds per genotype) was sampled and euthanized at 14, 28, 42, 56, 70, 84, 98 and 112 d of age. All feathers were dry-plucked from tracts, with representative feathers from the capital and cervical, dorsopelvic and interscapular, pectoral and femoral tracts being randomly selected during plucking. Three rectrices of the dorsocaudal tract and three primaries and secondaries of the alar tract of the right wing were also evaluated.

3. The length of the selected feathers was measured and the weight of the feathers from each tract was determined. The capital and cervical tracts were grouped when the feather weight was measured, as well as the humeral and alar tracts.

4. A wide range of rates of maturing (0.0329 /d) and mature weights (36.8 g) were evident between tracts. The slowest-growing tracts were the dorsocaudal, capital and cervical, and pectoral tracts with rates of maturing almost half of those of the femoral and interscapular tracts. The mature weights of the humeral and alar and femoral tracts were heavier than those in any other tracts.

5. In a sub-trial using 20 broilers of each of the genotypes evaluated, birds were housed individually, the mini pens surrounded by with a plastic net, and the daily losses of feathers was measured.

6. Using feather weight as an indicator of moulting was inaccurate compared with measuring feather losses. Moulting was evident only in the alar and dorsocaudal tracts, whereas when daily losses were measured, the greatest proportion that occurred over the 112-d trial period

(>0.70) were contour feathers. Logistic equations adequately described the cumulative losses of down, contour feathers and remiges.

7. The method commonly used to define feather growth might underestimate the growth of feathers by ignoring feather growth that occurs after moulting between 21 and 112 d of age.

Keywords: contour feathers, feather losses, feather tracts, feather length, rectrices, remiges

INTRODUCTION

Feathers are an integral part of the biology of all birds, providing protection and insulation, as well as assisting in flight and in courtship. In commercial broiler production the functions of the feather are more mundane, being restricted to insulating the bird in extreme environmental conditions and protecting the bird from abrasions that might otherwise be inflicted by birds housed in close proximity. Feather growth and development in broilers has not been as well researched as that of the whole body (including feathers), although there have been a few seminal works that provide the basis for much of what we know about feathers (Lucas and Stettenheim, 1972; Fisher, 2016). The considerable investment in essential nutrients required for the growth of feathers, and the widely different amino acid composition of feather and body protein, should have provided sufficient impetus for more research to have been conducted on these integuments.

Feathers are considered the most complex epidermal appendages that develop and grow from follicles present in the skin of birds (Lucas and Stettenheim, 1972). However, feather growth is not continuous: after reaching its maximum size the feather remains attached to the follicle as a keratinized structure until it is replaced (Hancock et al., 1995; Leeson and Walsh, 2004; Macari et al., 2017). The emerging feather is physically attached to the older feather and as it emerges from the outer sheath, the bond is broken and the older feather is shed (Leeson and Walsh, 2004). This moulting process results in a new generation of feathers, demonstrating the importance of evaluating feather growth during different phases of growth.

The sequence of molting is orderly and occurs under the action of hormones such as thyroxine and oestrogen and indirectly by testosterone (Voitkevich, 1966; Leeson and Walsh, 2004). The wing feathers are first to moult, followed by the body feathers and lastly the head and neck feathers (Leeson and Walsh, 2004). In most poultry, the replacement of feathers has been reported to begin at around 4-5 weeks, except for remiges and rectrices, and for the

modern broiler chicken this is the only moult of significance (Leeson and Walsh, 2004). The complete feather cover can be observed by 50 d of age, although in some strains the total growth may be later (Emmans, 1989; Edens, 2000).

Feather growth and composition, and factors influencing the growth and loss of feathers in commercial poultry, was reviewed by Leeson and Walsh (2004 a, b). They referred to Fisher et al. (1981) who weighed feathers of male and female broilers to seven weeks of age, to Dunnington and Siegel (1986) who had recorded the weights of male and female broiler breeders to sexual maturity and to McDougald and Keshavarz (1984) who measured the increase in the length of wing and back feathers. Similarly, Hancock et al. (1995) published the weights of feathers of males and females of six strains of broiler to 12 weeks of age and Sakomura et al. (2011) compared the rate of feathering growth in two broiler strains. To date, there has been no attempt to describe the growth of feathers in more detail, either by tract or by feathering phase and moult. These aspects were addressed in the research reported here.

The objective of this paper was to describe in detail the growth of feathers in the various tracts on the body, to identify which tracts undergo a moult and the extent to which feathers are lost during a moult. It was assumed that changes in the length of the feathers from the various tracts during the growing period would have enabled a better description of growth and moulting phases than would changes in the weight of these feathers. In addition, daily feather losses were measured in a sample of birds to provide additional information about moulting patterns in the two broiler strains.

MATERIALS AND METHODS

The study was approved by The Ethics Committee on Animal Use of the Faculdade de Ciências Agrárias e Veterinárias, UNESP, Jaboticabal, São Paulo, Brazil under protocol number n° 015111/17.

Bird husbandry and experimental design

A total of 800 one-day-old male and female broilers chicks of two slow-feathering genetic strains (Cobb 500 MX and Ross 308 AP (AP95)) were obtained from a local commercial hatchery, from 42-week-old Cobb 500 and 38-week-old Ross breeder flocks. In the main trial, chicks were assigned to floor pens in an environmentally controlled room consisting of 40 floor pens, with wood shavings being used as litter. Each pen was provided with four nipple drinkers and hanging tube feeders. In the sub-trial, birds were individually

housed in galvanized individual mini pens measuring 0.5 x 0.5 x 0.5 m, each equipped with a feeding trough and nipple drinkers. Each mini pen was surrounded by nylon netting with a 0.1 mm diameter opening and with a dropping tray to facilitate the collection of feathers and removal of excreta.

Upon arrival chicks were weighed individually, and those exceeding 2 SD (standard deviation) about the mean were excluded thereby ensuring that the range in initial body weight was similar for each strain and sex. In the main trial a total of 800 chicks was selected in this way to represent each of the four groups used in the trial, and these chicks were assigned randomly to ten pens of 20 chicks each. Twenty further chickens of each strain and sex were assigned to the individual growing mini pens.

Throughout the 112-d trial broilers had free access to water and feed. The lighting programme used was 12L:12D (Lewis & Gous, 2009; Lewis et al., 2009 a, b).

Experimental diets

A four-phase feeding programme was used (1 to 14, 15 to 28, 29 to 42 and 43 to 112 d of age). The experimental diets (Table 1) were formulated to contain 13.0 MJ AMEn/kg and meet or exceed the nutritional requirements suggested by the EFG broiler growth model (EFG Software, 2019) for males with a potential mature body protein weight of 1.2 kg and a rate of maturing of 0.038 /d. Feedstuffs and experimental diets were analyzed for dry matter, crude protein and gross energy (AOAC, 2005).

Data collection

In the main trial all birds were weighed at 13, 27, 41, 55, 69, 83, 97 and 111 d of age to calculate the mean body weight, based on which birds representing the mean weight of each pen were identified. One bird per pen (10 birds per genotype) was selected and fasted for 8 h, but with access to water during that time. The following day each sampled bird was euthanized by isoflurane inhalation (>1 ml/kg body weight) and weighed following cervical dislocation. All feathers were then carefully dry-plucked from tracts (capital, cervical, dorsopelvic, interscapular, humeral, alar, pectoral, femoral and dorsocaudal tracts) and stored separately in weighed paper bags. The capital and cervical tracts were grouped when the feather weight was measured, as well as the humeral and alar tracts. The tracts were identified according to the description given by Lucas and Stettenheim (1972) (Figure 1).

To determine feather length, five feathers from the capital and cervical, dorsopelvic and interscapular, pectoral and femoral tracts were randomly selected and plucked. Their lengths were measured in millimetres from the base of the pin feather to the furthest point of

emergence (Siegel et al., 1957). In the case of the alar and dorsocaudal tracts, specific feathers were measured: the 2nd, 4th and 6th rectrices of the dorsocaudal tract, the 1st, 4th and 7th primaries and the 3rd, 8th and 14th secondaries of the alar tract of the right wing were evaluated. In the case of rectrices and remiges, if the feather had not emerged, the measurement was recorded as zero.

Each bird was then weighed again to determine the feather-free body weight and the total weight of feathers. Carcasses were placed in identified plastics bags and frozen at a temperature of -4°C in a cold chamber for later processing. The results of these analyses are reported elsewhere (Vargas et al., 2019, unpublished data).

In the sub-trial, feathers were collected from each mini pen daily using tweezers, and these were stored in identified paper bags. After collection, all trays were cleaned to prevent feathers from being soiled by excreta. The feathers from each mini pen were separated into natal down, contour feathers, remiges and rectrices and then weighed, with natal down being weighed on an analytical balance of 1 µg and the remainder at a precision of 0.1 mg.

Statistical analyses

Mean feather length and feather weight were calculated for each strain x sex at each sampling, and in those cases where two distinct populations of lengths were present within a sampling, due to differences in the time of moult between individuals within each strain x sex combination, two mean values were calculated with their respective standard errors.

Gompertz growth curves were fitted to the feather weights of each tract for each strain x sex combination, as well as to the overall mean feather weights calculated from the difference between the live weight and the defeathered weight of each bird.

Feather losses were expressed both in terms of daily weights and cumulatively using an equation that fitted the data most accurately. Genstat 18th edition (VSN International, 2016) was the statistical package used to analyse these data.

RESULTS

Feather length

The mean length of feathers from the capital and cervical, dorsopelvic, interscapular, pectoral and femoral tracts of male and female broilers of the two strains at different ages are shown in Table 2. Feathers from each of these tracts were initially longer among females than males but this difference disappeared by 28 d in all cases, with male feathers then becoming longer than female feathers at different stages depending on the tract. Feathers of the pectoral tract were the first (42 d) to display such differences, followed by those from the dorsopelvic

and femoral tracts (56 d), the dorso-pelvic tract (70 d) and finally the capital and cervical tracts (84 d). The capital and cervical tracts showed the greatest difference in feather length between males and females at 112 d (1.38 cm) whereas the smallest difference was in feathers from the pectoral tract (0.44 cm).

There was no indication that the feathers in any of these five tracts had undergone a moult as they continued to show an increment in growth at each age. This was not the case, however, with the primary and secondary feathers, or the rectrices (Table 3). In all these cases, with the exception of secondary 14, males and females exhibited a significant decline in the mean length of feathers at some stage during the test period indicating that the mature feather had been moulted and a new feather had taken its place. In the case of primary 1, for example, females clearly began renewing these feathers after 28 d with a decrease in mean length from 10.9 to 2.1 cm in some individuals at 42 d whereas the feathers of others continued to grow to 13.3 cm. Males followed suit after 42 d (from 15.2 to 2.5 cm in some whilst others continued to grow to 15.7 cm. In all cases females moulted before males.

Mature feather lengths of primaries, secondaries and rectrices, achieved prior to moulting, were of the same order as those of the feathers that replaced them by 112 d, depending on the age at which the moult took place. For example, the length of primary 1 in Ross males at 70 d was 15.9 cm prior to moulting, compared with a length of 18.8 cm for the replacement feather by 112 d; and in Ross females at 84 d the length of primary 7 was 17.5 cm prior to moulting, with the next feather achieving 18.1 cm by 112 d. To illustrate the process of moulting and renewal, the growth in the mean length of the 4th primary and the 3rd secondary feathers of male and female broilers before and after the first moult are given in Fig's 2 and 3, respectively.

Feather weights

The mean weights of feathers from the capital and cervical, dorsopelvic, interscapular, humeral and alar, pectoral, femoral and dorsocaudal tracts of male and female broilers of the two strains at different ages are shown in Table 4. Feathers from these tracts were initially longer among females than males. However, this situation changed at 28 d for dorsopelvic and humeral and alar tracts, at 42 d for capital and cervical and dorsocaudal tracts, at 56 d for interscapular and pectoral tract and at 70 d for the femoral tract. The femoral tract demonstrated the greatest difference in feather weight between sexes at 112 d (13.2 g) whereas the smallest difference was in feathers from the dorsopelvic tract (2.00 g).

The Gompertz parameters describing the growth of feathers in each tract is given in Table 5. In all cases the rates of maturing of feathers in females were higher than in males. A

wide range of rates of maturing and mature weights were evident between tracts: the lowest rates in males was 0.0289 /d for the dorsocaudal tract and the highest was 0.0571 /d for the femoral tract; the range was similar in females (0.0389 to 0.0765 /d for the same tracts). The tract with the lightest mature weight was the interscapular tract (13.4 and 9.7 g for males and females, respectively) and that with the heaviest mature weight was the humeral and alar (wing), with mature weights of 52.2 and 42.5 g for males and females, respectively.

Daily feather losses

Mean weekly losses (mg/bird d) of natal down, contour feathers, remiges and rectrices from Cobb and Ross male and female broilers during the trial are given in Tables 6 a and b. Daily losses are illustrated in Fig. 4. where they have been plotted on a g/kg body weight scale, and the cumulative losses are plotted in Fig. 5 together with logistic curves for down, contour feathers and remiges. The pattern of losses in rectrices could not be described by any simple curve. The parameters of the logistic equation, fitted to the cumulative losses of natal down, contour feathers and remiges from males and females of both strains, are given in Table 7.

Losses in natal down were evident from the start of the trial, reaching a peak of around 25 mg/bird d during the 5th week in both strains and sexes. No further losses were evident after 11 weeks of age, and the total loss of down feathers was close to 0.6 g/bird for all genotypes.

Contour feathers started moulting during the 3rd week in females and the 4th (Cobb) and 5th (Ross) weeks in males. The peak in contour feather losses, of about 900 mg/bird d in females, occurred between weeks 10 and 12 in the two strains. This was similar for males, but the maximum rate of feather loss was higher (1058 vs. 945 mg/d) for Cobb than for Ross. The total weight of contour feather loss was identical for the males and females of each strain, but greater for Cobb (43 g) than for Ross (34 g).

The first remiges to moult were from females, at 5 w, with a peak rate of 145 mg/bird d being reached at between 10 and 11 w. Males started moulting two weeks later, with the peak rate also being two weeks later. Once moulting had commenced it continued throughout the trial period. The losses were greater among males, with the peak rate being 317 mg/d on average, compared with 145 mg/d for females. The total losses were higher among males (8.5 vs. 5.5 g/bird).

Greater differences in moulting patterns were noted for the rectrices between strains and sexes than in any of the other feather types measured. The first rectrices to fall in females occurred in the 6th week, reaching a peak of about 13 mg/bird d at 10 w. Cobb males started

losing rectrices at 8 w but the first such feathers to fall from Ross males were at only 12 w of age. The maximum rate, of 37 mg/d, the same in both strains, occurred at the same age (15 w). However, instead of a regular increase in the rate of feather loss, which occurred in all feather types, the rate in Ross males increased from 1.1 mg/d at 12 w to 61 mg/d the following week. Total losses were marginally greater (0.9 vs. 1.1 g) in males.

DISCUSSION

The main objective of this trial was to determine whether a single growth curve is appropriate when describing the growth of feathers in broilers, given the possibility that some or all the feathers grow, moult and are then replaced by others during the growing period. Were all the feathers on the body to have been replaced at different stages during the growth of the broiler, calculations of daily nutrient requirements based on a continuum of growth would be inaccurate, and possibly seriously underestimated. It is for this reason that the length of feathers from different tracts was measured during the growing period to 112 d of age, as it was thought that this would identify moulting patterns in the different tracts. In addition, actual daily losses of feathers were measured in a sub-group of broilers of the same sexes and genotypes used in the main trial. This enabled the quantification of feather losses to be made, which acted as a check on the assumption that changes in feather length would be sufficiently accurate to describe moulting patterns.

Changes in length as an indicator of moulting

Changes in the length of feathers from the different tracts during the growing period underestimated periods of growth and moulting. When using this method, only two tracts appeared to undergo a moult during the 112-d growing period. The length of feathers appeared to increase continuously throughout the growing period in all but the alar and the dorsocaudal tracts (Table 3). Because the moults occurred at different times (in females, for example, primary 1 moulted after 28 d, primary 4 after 56 d and primary 7 after 70 d) little or no disruption of the cumulative increment in weight of feathers of the alar tract could be discerned when the Gompertz parameters were estimated (Table 5). The R^2 value, representing the goodness of fit, was lower only for the dorsocaudal tract of females (0.762), with those for the alar tract being among the highest recorded of all the tracts. These subtle changes in feather length clearly have little effect on the cumulative weight of feathers in the humeral and alar or dorsocaudal tracts, the only tracts exhibiting a moult during the period tested when using changes in feather length as the criterion.

In some cases, when feathers were sampled and measured for statistical analysis, two distinct populations of feather length would be evident indicating that some of the individuals had moulted prior to being sampled whilst others had not. This was useful in identifying the age at which moulting of wing and tail feathers occurred.

Daily losses of feathers

This method proved to be more accurate in identifying moulting patterns than measuring changes in feather lengths. Moulting of contour feathers was not identified as taking place when feather length was used as the indicator, but considerable numbers of contour feathers were shown to be moulted from the 3rd week of age onwards. Indeed, the greatest proportion of feather losses that occurred over the 112-d trial period (>0.70) were contour feathers. The reason for not identifying these losses when measuring changes in feather length is possibly because contour feathers make up such a large proportion of feathers on the body and the sample size chosen for measurement of length was too small to pick up changes in length sufficient to identify moulting patterns.

The pattern of feather loss in down, contour feathers and remiges was typically Gaussian, with the greatest rate of loss occurring mid-way between the start and end of the recorded period of moulting. A logistic function was therefore fitted to describe the cumulative losses over time, and the parameters given in Table 7 provide evidence of the age at which the rate of moulting was greatest as well as the total loss of each type of feather per strain and sex. These equations, which describe the rate of feather losses, may be applied in determining the rate at which new feathers emerge, thereby improving the accuracy of measuring feather growth in different broiler strains or sexes.

Feather growth by tract

The rates of maturing of feathers in the femoral and interscapular tracts were markedly higher than those of other tracts, being unusual in the case of the femoral tract which had one of the highest mature feather weights also: usually these two parameters are negatively correlated. It is evident from the results in Table 5 that feather tracts differ in the rates at which their feathers grow, and that the mature weights of feathers in each tract differ also. The slowest-growing tracts were the dorsocaudal, capital and cervical and pectoral tracts with rates of maturing almost half of those of the femoral and interscapular tracts. The humeral and alar and femoral tracts had the heaviest mature weights of all tracts.

The Gompertz parameters describing the growth of feathers in each tract (Table 5) are consistent with those describing the growth of all feathers combined (Vargas et al., 2019), in

that the two strains were virtually identical in the growth of feathers in each tract, that the mature weight of the feathers in each tract was heavier in males than in females, and that the rate of maturing was, in each case, faster in females than in males. In only one case (dorsocaudal tract) did the moulting pattern influence the fitting of the Gompertz equation due to the decrease in the weight of feathers at 112 d, especially among the females where the mean feather weight decreased from 18.4 to 10.7 g between 98 and 112 d of age due to moulting in that period.

As the mature lengths of primaries, secondaries and rectrices, achieved prior to moulting, were of the same order as those of the feathers that replaced them, this indicates that the method commonly used to define feather growth underestimates the weight of growth of feather. The method used is that described by Hancock et al. (1985) and Vargas et al. (2019), where feather weight is measured as the difference in weight between the feathered and unfeathered carcasses sampled sequentially during the growing period, to which a Gompertz growth curve is fitted. From the results of this trial it appears that a considerable proportion of feathers is replaced through moulting before the bird reaches somatic maturity, hence the nutrients required for the growth of these feathers after a moult would have been ignored on the assumption that the mature feather weight had been achieved at an early age and maintained thereafter. The contour feathers, remiges and rectrices together make up the bulk of feathers in a broiler (Table 5) thus contributing substantially to the amino acid requirements for feather growth. The rate of moulting of feathers from these tracts, presented here, will be useful in calculating the additional amounts of amino acids required for the growth of the second phase of feathering.

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Table 1- Ingredients and nutrient composition (g/kg) of experimental diets

Ingredient (g/kg)	Phase			
	1-14 d	15-28 d	29-42 d	43-112 d
Corn	538	613	6950	680
Soybean meal (450 g/kg)	321	258	208	182
Corn gluten meal (600 g/kg)	5.65	66.1	48.8	
Wheat bran				76.4
Soybean oil	32.6	17.9	6.60	25.3
Dicalcium phosphate	20.2	18.2	16.2	14.3
Limestone	9.50	8.70	8.00	8.10
L-lysine (546 g/kg)	10.6	9.00	7.80	5.60
DL- methionine (980 g/kg)	2.20	1.50	1.20	1.20
L-arginine (990 g/kg	1.70	1.50	1.60	0.90
L-threonine (985 g/kg)	1.50	1.10	1.10	1.00
L-valine (965 g/kg)	0.90	0.00	0.70	0.80
Salt	3.60	3.60	3.60	3.50
Vitamin and mineral supplement[1]	1.00	1.00	1.00	1.00
Coccidiostat[2]	0.20	0.20	0.20	0.20
Calculated composition				
AMEn, MJ/kg	13.0	13.0	13.0	13.0
Crude protein	240	220	190	150
SID amino acids				
Lysine	15.6	13.3	11.4	9.40
Methionine + cysteine	8.60	7.60	6.60	5.50
Methionine	5.50	4.70	4.00	3.30
Threonine	9.00	8.00	7.10	5.90
Valine	10.5	8.90	8.40	7.00
Tryptophan	2.30	2.00	1.70	1.50
Arginine	14.8	13.1	11.5	9.70
Isoleucine	8.90	8.00	6.80	5.40
Leucine	15.1	13.8	12.9	12.5
Phenylalanine + tyrosine	19.0	17.7	15.1	11.3
Glycine + serine	18.3	16.7	14.4	11.3
Histidine	5.40	4.90	4.30	3.70
Calcium	9.60	8.70	7.80	7.40
Sodium,%	1.60	1.60	1.60	1.60
Non-phytate phosphorus	4.80	4.30	3.90	3.70
Potassium	7.50	6.50	5.80	6.00

[1]Content/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.

Table 2. Mean feather length (± standard deviation) (cm) of capital and cervical, dorsopelvic, interscapular, pectoral and femoral tracts of male and female broilers of two strains at different ages

	Males			Females		
Age, d	Ross	Cobb	Mean	Ross	Cobb	Mean
Capital and cervical tracts						
14	0.72±0.044	0.53±0.031	0.62[b]	1.53±0.075	1.43±0.082	1.48[a]
28	2.79±0.149	2.95±0.084	2.87[b]	3.38±0.135	3.10±0.271	3.24[a]
42	5.64±0.216	5.81±0.183	5.73	6.06±0.153	5.46±0.235	5.76
56	6.40±0.086	6.64±0.212	6.52	6.89±0.141	6.30±0.082	6.59
70	7.86±0.222	7.86±0.151	7.86	7.20±0.115	7.45±0.132	7.33
84	9.03±0.236	8.53±0.216	8.78[a]	7.89±0.138	7.86±0.135	7.87[b]
98	9.71±0.485	9.29±0.189	9.50[a]	7.83±0.148	8.24±0.167	8.03[b]
112	9.72±0.113	9.36±0.361	9.54[a]	8.21±0.074	8.10±0.137	8.16[b]
Dorsopelvic tract						
14	0.75±0.042	0.62±0.051	0.68[b]	1.53±0.064	1.65±0.085	1.59[a]
28	3.63±0.096	3.69±0.163	3.66[b]	4.85±0.087	4.83±0.149	4.84[a]
42	7.49±0.178	7.26±0.137	7.37	7.65±0.129	7.50±0.164	7.58
56	8.92±0.305	8.70±0.091	8.81[a]	7.89±0.141	8.25±0.085	8.07[b]
70	9.89±0.217	10.8±0.147	10.3[a]	8.49±0.153	8.37±0.234	8.43[b]
84	10.7±0.317	10.9±0.161	10.8[a]	9.26±0.048	9.18±0.117	9.22[b]
98	10.5±0.457	10.4±0.198	10.4[a]	9.45±0.163	9.65±0.247	9.55[b]
112	11.0±0.263	11.5±0.268	10.6[a]	9.78±0.139	9.50±0.100	9.64[b]
Interscapular tract						
14	0.48±0.059	0.46±0.055	0.47[b]	1.19±0.062	1.08±0.062	1.13[a]
28	2.86±0.155	2.71±0.091	2.79[b]	3.94±0.167	3.81±0.126	3.87[a]
42	5.99±0.198	5.76±0.213	5.87	6.06±0.136	5.60±0.123	5.83
56	6.93±0.088	6.81±0.150	6.87	6.85±0.091	6.73±0.102	6.79
70	7.65±0.081	8.50±0.065	8.08[a]	7.43±0.101	7.07±0.123	7.25[b]
84	8.01±0.178	8.56±0.212	8.29[a]	7.15±0.152	7.52±0.094	7.34[b]
98	8.30±0.068	8.66±0.142	8.48a	7.89±0.169	7.95±0.201	7.92[b]
112	9.00±0.111	8.51±0.101	8.76[a]	8.26±0.112	7.87±0.144	8.06[b]
Pectoral tract						
14	1.22±0.093	1.17±0.115	1.20[b]	2.03±0.067	1.90±0.075	1.96[a]
28	4.65±0.190	4.62±0.165	4.64[b]	5.00±0.160	5.07±0.142	5.04[a]
42	6.98±0.217	8.19±0.194	7.58[a]	7.13±0.100	6.95±0.253	7.04[b]
56	8.96±0.183	8.86±0.189	8.91[a]	8.82±0.119	8.16±0.172	8.49[b]
70	9.99±0.090	9.47±0.071	9.73[a]	8.65±0.176	8.77±0.160	8.71[b]
84	9.74±0.146	10.0±0.224	9.87[a]	8.60±0.247	8.73±0.138	8.66[b]
98	9.33±0.184	9.55±0.111	9.44[b]	9.53±0.203	10.16±0.108	9.84[a]
112	10.0±0.234	10.6±0.139	10.3[a]	9.89±0.171	9.83±0.182	9.86[b]
Femoral tract						
14	1.59±0.068	1.60±0.089	1.60	1.48±0.060	1.39±0.082	1.44
28	4.45±0.199	4.56±0.260	4.50[b]	5.26±0.234	4.63±0.137	4.94[a]
42	7.65±0.234	7.03±0.131	7.34	7.97±0.100	7.42±0.266	7.70
56	9.42±0.119	8.98±0.189	9.20[a]	8.49±0.107	8.41±0.067	8.45[b]
70	9.82±0.149	9.90±0.122	9.86[a]	8.47±0.213	8.33±0.284	8.40[b]
84	9.32±0.235	9.90±0.249	9.61	9.36±0.191	9.38±0.231	9.37
98	9.84±0.171	9.19±0.131	9.51	10.3±0.083	9.45±0.222	9.85
112	9.36±0.329	10.2±0.244	9.75[a]	9.11±0.179	9.34±0.286	9.23[b]

[a],[b] significantly different (P>0.05) within a row (at an age)

Table 3. Average feather length (± standard error) (cm) of primary (1st, 4th and 7th) and secondary (3rd, 8th and 14th) remiges and rectrices (2nd, 4th and 6th) of broilers at different ages according to genotype

Age, d	Males			Females		
	Ross	Cobb	Mean	Ross	Cobb	Mean
Primary 1						
14	6.93±0.157	6.82±0.197	6.93	8.01±0.060	7.96±0.081	7.99
28	12.5±0.166	12.0±0.144	12.3	10.8±0.155	11.0±0.146	10.9
42	15.5±0.118	14.9±0.174	15.2[a]	***2.20±0.058***[1] ***13.3±0.088***	***1.90±0.457*** ***13.3±0.328***	*2.05*[b] *13.3*[a]
56	***3.93±4.630*** ***15.9±1.150***	***1.00±1.410*** ***16.1±0.350***	2.45[b] 15.7[a]	11.3±0.315	***5.80±2.860*** ***10.7±1.000***	8.55[b] 11.0[b]
70	***5.00±0.503*** ***9.00±0.612***	***2.52±0.317*** ***8.92±0.784***	*3.76*[b] *8.96*[b]	15.4±0209	16.0±0.171	15.7[a]
84	12.7±1.589	13.2±1.235	10.6[b]	17.8±0.208	17.5±0.121	17.6[a]
98	16.5±1.270	17.6±1.874	15.8[b]	18.8±0.261	18.0±0.156	17.7[a]
112	18.8±0.489	19.2±0.330	19.0	18.6±0.287	17.9±0.155	18.3
Primary 4						
14	6.59±0.117	6.73±0.195	6.66[b]	8.74±0.054	8.55±0.052	8.64[a]
28	13.0±0.121	12.6±0.105	12.8	12.5±0.129	12.6±0.105	12.5
42	16.9±0.144	16.5±0.200	16.7[a]	14.6±0.082	15.1±0.141	14.8[b]
56	18.2±0.147	18.7±0.180	18.4[a]	15.5±0.097	15.8±0.136	15.6[b]
70	19.3±0.211	19.5±0.251	19.4[a]	9.04±0.210	9.44±0.301	9.24[b]
84	***4.55±0.810*** ***18.9±0.784***	***3.00±0.550*** ***20.3±0.350***	*3.78*[b] *19.6*[a]	15.9±0.229	15.5±0.236	15.7[a]
98	20.6±0.822	11.6±0.643	11.5[b]	18.8±0.172	19.1±0.137	18.9[a]
112	16.0±1.826	17.4±1.151	16.7[b]	20.6±0.215	19.6±0.266	20.1[a]
Primary 7						
14	4.46±0.250	4.85±0.344	4.65[b]	7.65±0.176	7.52±0.132	7.60[a]
28	10.9±0.279	10.7±0.212	10.8	11.7±0.193	11.9±0.140	11.8
42	15.4±0.183	15.4±0.284	15.3	15.0±0.143	14.5±0.160	14.7
56	18.2±0.209	17.8±0.126	18.0	16.5±0.083	16.8±0.143	16.6
70	20.1±0.180	19.7±0.160	19.8[a]	16.7±0.145	16.9±0.134	16.8[b]
84	20.2±0.264	20.8±0.150	20.5[a]	***5.20±0.173*** ***17.5±0.058***	***4.12±0.414*** ***8.05±0.050***	*4.7*[b] *12.8*[a]
98	20.6±0.327	20.7±2.657	18.2[a]	14.7±0.406	13.4±0.451	14.0[b]
112	***12.2±0.250*** ***20.7±0.225***	***5.33±0.484*** ***13.0±1.360***	*8.8*[b] *16.9*[a]	18.1±0.398	17.9±0.315	18.0[a]
Secondary 3						
14	5.19±0.177	5.19±0.184	5.19[b]	7.91±0.065	7.71±0.062	7.81[a]
28	12.1±0.186	11.6±0.125	11.8	11.7±0.136	11.8±0.116	11.8
42	16.2±0.164	15.9±0.179	16.0[a]	13.6±0.148	13.4±0.121	13.5[b]
56	18.2±0.187	18.3±0.091	18.2[a]	***3.66±0.276*** ***7.65±0.750***	***3.48±0.378*** ***14.9±0.250***	*3.57*[b] *11.3*[a]
70	19.3±0.160	18.6±0.401	19.0[a]	12.4±0.299	12.6±0.375	12.5[b]
84	***4.20±0.896*** ***19.1±0.550***	***3.74±0.466*** ***20.2±0.550***	*3.97*[b] *19.7*[a]	16.0±0.467	16.8±0.098	16.4[a]
98	16.4±1.055	13.8±0.512	15.1[b]	18.6±0.122	18.5±0.109	18.5[a]
112	17.6±0.169	18.2±0.206	17.9	19.0±0.179	18.6±0.173	18.8
Secondary 8						
14	4.56±0.101	4.39±0.137	4.50[b]	6.74±0.116	6.61±0.073	6.70[a]
28	11.3±0.126	10.9±0.161	11.0	11.7±0.145	11.7±0.101	11.6
42	15.2±0.138	14.9±0.213	15.0	14.3±0.087	14.4±0.089	14.3
56	17.6±0.133	17.8±0.104	17.7[a]	15.0±0.147	15.7±0.264	15.3[b]
70	17.2±1.720	18.7±0.164	17.9[a]	***3.47±0.654***	***2.84±0.482***	*3.16*[b]

				15.6±0.361	***15.7±0.173***	*15.7*[a]
84	18.9±1.963	16.9±0.243	17.7[a]	8.23±0.419	10.7±1.229	8.50[b]
98	***4.85±1.050*** ***9.80±0.426***	12.5±0.250 18.7±*0.450*	8.7[b] 14.3[a]	15.6±0.140	15.8±0.387	15.7[a]
112	15.2±0.268	16.1±0.429	15.6[b]	18.0±0.178	17.5±0.249	17.8[a]
			Secondary 14			
14	0.58±0.084	0.51±0.070	0.545	0.76±0.085	0.71±0.065	0.735
28	4.61±0.187	4.68±0.187	4.64[b]	5.64±0.275	5.15±0.250	5.45[a]
42	8.96±0.132	8.42±0.371	8.71	9.31±0.142	8.94±0.198	9.13
56	11.3±0.273	11.0±0.203	11.1[a]	10.0±0.196	10.4±0.230	10.2[b]
70	12.9±0.214	12.7±0.264	12.8[a]	10.6±0.273	11.5±0.055	11.0[b]
84	12.5±0.370	12.6±0.279	12.5[a]	11.7±0.063	11.1±0.174	11.4[b]
98	11.2±0.238	12.5±0.293	11.8	11.4±0.141	11.8±0.321	11.6
112	12.2±0.257	12.6±0.301	12.4[a]	10.8±0.168	11.3±0.284	11.0[b]
			Rectrix 2			
14	1.10±0.090	1.10±0.119	1.12[b]	3.40±0.255	3.80±0.079	3.56[a]
28	4.36±0.288	4.73±0.421	4.54[b]	7.74±0.346	7.57±0.168	7.65[a]
42	8.80±0.260	9.80±0.431	9.30[a]	***2.08±0.073*** ***10.0±0.784***	***1.16±0.068*** ***11.4±0.350***	*1.62*[b] *10.7*[a]
56	14.2±0.165	12.4±0.751	13.3[a]	4.56±1.029	5.10±0.821	6.41[b]
70	17.0±0.106	17.6±0.140	17.3[a]	10.6±0.315	11.4±0.620	11.0[b]
84	18.9±0.199	19.4±0.634	19.1[a]	14.0±0.315	15.3±0.372	14.6[b]
98	16.0±0.874	17.9±0.542	16.9	16.5±0.047	17.3±2.068	16.8
112	***5.05*±0.750** ***14.3*±0.590**	***13.9*±0.544** ***19.3±0.530***	*9.5*[b] *16.8*[a]	16.9±0.380	16.3±0.883	15.5[a]
			Rectrix 4			
14	1.46±0.075	1.56±0.071	1.51[b]	4.22±0.085	4.20±0.081	4.21[a]
28	4.87±0.399	5.33±0.392	5.10[b]	7.34±0.344	7.43±0.298	7.41[a]
42	9.87±0.213	10.6±0.386	10.2[a]	9.93±0.852	11.1±1.174	9.07[b]
56	14.5±0.275	14.1±0.320	14.3[a]	5.04±0.390	5.61±0.671	5.61[b]
70	17.0±0.172	16.8±0.217	16.9[a]	11.7±0.927	10.7±0.542	11.2[b]
84	17.6±0.252	17.5±0.204	17.6[a]	13.4±0.480	15.2±0.321	14.3[b]
98	17.8±0.297	*5.73±0.555*	11.7[b]	16.0±0.184	16.2±0.158	16.1[a]
112	*12.1±0.589*	17.0±0.214	14.5[b]	16.8±0.278	16.1±0.268	16.4[a]
			Rectrix 6			
14	0.91±0.143	0.90±0.071	0.900[b]	2.94±0.45	3.13±0.157	3.13[a]
28	2.83±0.098	2.73±0.233	2.72[b]	7.10±0.360	6.78±0.179	6.78[a]
42	8.67±0.260	9.27±0.478	9.30[b]	11.5±0.090	11.2±0.233	11.2[a]
56	12.8±0.250	13.7±0.220	13.7[a]	12.5±0.263	12.4±1.310	10.6[b]
70	15.6±0.237	15.1±0.296	15.1[a]	6.37±0.824	5.18±0.663	5.17[b]
84	16.2±0.193	16.7±0.314	16.7[a]	10.7±0.395	12.2±0.356	12.2[b]
98	17.0±0.337	16.5±0.319	16.5[a]	14.0±0.191	14.3±0.346	14.3[b]
112	***6.8*±1.150** ***11.3±0.124***	16.1±0.347	11.5 13.7	16.1±0.140	15.5±0.256	15.5

[a, b]significantly different (P>0.05) within a row (at an age)

[1]Where two distinct populations of feather length occurred within the ten replicates of each strain x sex at an age, the means of these populations are given with s.e.'s

Table 4. Mean weights (± standard deviation) (g) of feathers at different ages from the tracts of male and female Cobb and Ross broilers

Age, d	Male			Female		
	Ross	Cobb	Mean	Ross	Cobb	Mean
			Capital and cervical tracts			
14	0.51±0.053	0.47±0.040	0.50	1.05±0.0114	0.84±0.046	0.99
28	7.81±0.515	7.74±0.521	7.65	6.12±0.368	6.90±0.353	6.60
42	14.85±0.749	14.61±0.623	14.7[a]	11.43±0.245	11.90±0.770	11.6[b]
56	16.30±0.827	13.55±1.424	15.4	16.09±0.829	14.33±0.477	15.2
70	23.30±1.202	21.59±0.921	22.1[a]	17.23±1.117	16.72±0.375	17.41[b]
84	29.42±1.287	27.79±2.049	28.6[a]	18.29±1.083	19.33±0.807	18.82[b]
98	30.11±2.206	30.91±1.802	30.5[a]	18.94±.1259	19.01±1.632	19.6[b]
112	30.20±1.975	30.16±1.812	32.9[a]	19.58±0.761	20.46±1.024	20.0[b]
			Dorsopelvic tract			
14	0.06±0.009	0.06±0.005	0.06	0.10±0.031	0.07±0.020	0.12
28	2.96±0.231	3.34±0.263	3.07[b]	4.67±0.343	4.53±0.219	4.61[a]
42	7.94±0.457	9.70±0.398	8.83	8.23±0.278	8.23±0.674	8.44
56	10.74±0.421	10.66±0.900	11.0	11.28±0.543	10.31±0.375	10.7
70	13.38±0.923	12.08±0.885	13.8	13.90±0.740	12.39±0.493	12.9
84	15.08±0.667	14.14±1.229	14.7	14.57±0.720	15.10±0.478	14.6
98	19.00±1.559	18.69±1.558	18.8[a]	15.97±1.103	15.84±0.958	15.9[b]
112	14.37±1.018	17.89±0.733	16.1[a]	12.84±0.591	15.47±0.395	14.1[b]
			Interscapular tract			
14	0.06±0.003	0.07±0.007	0.07	0.19±0.025	0.17±0.021	0.18
28	1.67±0.239	1.42±0.177	1.55	2.92±0.293	1.99±0.223	2.60
42	5.98±0.385	4.98±0.319	5.55	5.74±0.516	5.40±0.308	5.77
56	7.92±0.829	8.41±0.467	8.52[a]	8.31±0.543	7.14±0.704	8.05[b]
70	10.80±0.559	10.09±0.981	11.2[a]	7.27±0.998	8.99±0.615	8.23[b]
84	11.85±0.673	11.55±0.825	11.7[a]	9.78±0.557	8.73±0.523	9.70[b]
98	13.20±1.017	13.22±0.681	13.6[a]	10.6±0.540	9.40±0.621	10.0[b]
112	12.30±0.877	12.78±0.536	12.8[a]	9.18±0.420	9.85±0.413	9.52[b]
			Pectoral tract			
14	0.43±0.058	0.37±0.042	0.42	0.70±0.080	0.55±0.039	0.70
28	5.55±0.395	5.38±0.324	5.63	6.83±0.402	5.74±0.360	6.30
42	14.77±0.741	14.32±0.905	14.5	13.16±0.861	12.77±0.311	12.9
56	13.96±0.965	11.93±0.914	12.9[b]	18.00±0.938	13.15±0.849	15.6[a]
70	21.24±1.348	19.95±1.53	20.6	19.60±0.842	19.64±0.962	19.6
84	27.6±1.112	25.28±1.834	26.9[a]	21.45±1.608	22.93±1.557	22.2[b]
98	28.3±1.514	27.55±2.380	28.8[a]	24.34±1.557	22.91±1.451	24.2[b]
112	30.3±1.856	31.01±1.175	30.6[a]	20.76±1.875	23.10±0.986	21.7[b]
			Femoral tract			
14	0.33±0.025	0.31±0.027	0.33	0.55±0.031	0.44±0.045	0.50
28	4.62±0.383	4.23±0.350	4.60	5.68±0.345	5.65±0.352	5.60
42	17.15±1.344	17.81±0.963	17.5	16.24±0.710	16.81±0.902	16.5
56	29.30±1.802	26.21±1.087	27.6	31.10±1.332	25.47±0.833	28.7
70	43.23±1.984	37.82±1.354	40.5[a]	32.32±1.647	30.78±0.994	31.5[b]
84	45.34±0.673	39.94±2.028	42.6[a]	33.60±0.557	31.58±1.301	32.6[b]
98	45.32±2.287	41.75±2.216	43.4[a]	36.05±1.768	34.05±1.506	34.5[b]

112	50.98±3.261	45.76±1.553	47.1[a]	33.52±1.601	34.23±1.109	33.8[b]
			Humeral and alar tracts			
14	1.71±0.109	1.41±0.073	1.50	2.73±0.127	2.35±0.057	2.63
28	17.49±0.772	16.73±0.813	17.1[a]	14.02±0.507	13.62±0.502	13.8[b]
42	31.56±1.033	28.54±0.634	30.0[a]	21.93±0.554	23.12±1.003	22.7[b]
56	31.75±1.460	31.81±0.535	32.7[a]	30.87±0.677	26.93±1.002	28.9[b]
70	41.47±1.206	38.48±0.928	40.0[a]	34.27±0.834	33.78±0.888	33.7[b]
84	41.64±1.298	38.76±1.474	40.2[a]	38.74±1.055	37.30±1.416	38.0[b]
98	47.35±1.922	50.37±1.879	47.8[a]	41.24±0.871	39.26±1.144	40.7[b]
112	55.87±2.354	52.59±1.498	54.2[a]	43.44±1.452	39.57±0.970	41.5[b]
			Dorsocaudal tract			
14	0.11±0.017	0.12±0.008	0.12	0.36±0.029	0.31±0.017	0.36
28	1.83±0.243	1.95±0.139	1.92	2.26±0.133	2.13±0.294	2.33
42	5.76±0.433	6.15±0.308	6.13[a]	4.93±0.246	3.88±0.331	4.41[b]
56	8.24±0.411	7.25±0.280	7.75	7.43±0.712	7.54±0.494	7.60
70	10.57±0.531	9.72±0491	9.94	8.83±0.686	9.89±0.358	9.23
84	10.56±0.607	10.26±1.070	11.0	10.97±0.530	11.68±0.697	11.3
98	18.69±0.699	18.13±0.602	18.3	19.14±0.586	18.40±0.566	19.1
112	13.72±1.223	11.42±1.490	15.1[a]	10.04±0.550	10.71±0.921	11.1[b]

[a,b] significantly different (P>0.05) within a row (at an age)

Table 5. Mean ± s.e. of Gompertz parameters[1] describing the growth of feathers in tracts of male and female Cobb and Ross broilers

Tract	Males				Females			
	A, g	B, /d	t*, d	R^2	A, g	B, /d	t*, d	R^2
Capital and	38.2	0.0294	46.9	0.857	20.0	0.0539	31.1	0.862
cervical	2.38	0.0035	2.87		0.453	0.0049	1.10	
Dorsocaudal	19.9	0.0289	54.2	0.816	15.9	0.0389	48.1	0.762
	1.78	0.0044	4.06		1.05	0.0062	2.68	
Dorsopelvic	17.5	0.0492	38.0	0.809	15.3	0.0536	33.2	0.873
	0.634	0.0061	1.60		0.350	0.0048	1.11	
Femoral	47.1	0.0571	42.6	0.911	34.2	0.0765	36.6	0.920
	1.10	0.0049	0.985		0.539	0.0059	0.738	
Humeral and	52.2	0.0385	33.4	0.893	42.5	0.0437	32.6	0.946
alar	1.47	0.0032	1.28		0.706	0.0024	0.771	
Interscapular	13.4	0.0565	40.73	0.863	9.66	0.0653	32.2	0.808
	0.383	0.0060	1.24		0.247	0.0077	1.26	
Pectoral	36.0	0.0299	48.4	0.849	23.5	0.0506	34.12	0.826
	2.37	0.0038	2.99		0.699	0.0055	1.39	

[1] Gompertz equation of the form A*exp (-exp (-B*(X-t*))) where X is age, d

Table 6a. Mean weekly losses (mg/bird d) in natal down, contour feathers, remiges and rectrices from Cobb and Ross male broilers over time

Age (w)	Cobb				Ross			
	Natal down	Contour	Remiges	Rectrices	Natal down	Contour	Remige	Rectrices
1	0.32	-	-	-	0.40	-	-	-
2	0.76	-	-	-	0.69	-	-	-
3	5.99	-	-	-	5.33	-	-	-
4	20.2	0.11	-	-	18.5	-	-	-
5	22.2	4.23	-	-	27.8	3.76	-	-
6	14.7	17.4	-	-	18.3	11.3	-	-
7	9.87	140	1.28	-	11.4	77.4	5.63	-
8	4.81	313	9.53	0.27	5.61	228	8.90	-
9	1.46	536	31.2	0.00	1.56	444	32.9	-
10	0.55	891	60.3	0.67	0.47	661	50.3	-
11	0.15	1058	144	7.50	0.08	945	143	-
12	-	1056	301	17.0	-	841	314	1.03
13	-	936	308	24.4	-	651	325	60.8
14	-	595	154	35.1	-	377	196	27.3
15	-	356	95.2	36.6	-	278	148	44.4
16	-	214	50.5	8.07	-	150	64.4	25.4
Total, g	0.57	42.8	8.09	0.91	0.63	32.7	9.02	1.11

Table 6b. Mean weekly losses (mg/bird d) of natal down, contour feathers, remiges and rectrices from Cobb and Ross female broilers over time

Age (wk)	Cobb				Ross			
	Natal down	Contour	Remiges	Rectrices	Natal down	Contour	Remiges	Rectrices
1	0.48	-	-	-	0.48	-	-	-
2	1.89	-	-	-	1.45	-	-	-
3	7.89	0.34	-	-	7.07	0.06	-	-
4	20.0	9.16	-	-	20.3	3.85	-	-
5	25.2	43.5	0.63	-	26.7	42.0	-	-
6	14.3	124	13.3	0.61	15.5	109	7.23	0.59
7	8.51	360	43.5	9.17	9.82	293	37.1	10.4
8	3.75	572	84.1	17.0	3.92	502	92.4	14.7
9	0.74	840	134	11.2	1.18	746	135	11.3
10	0.38	916	138	11.3	0.41	882	145	15.4
11	0.08	876	147	4.84	0.13	678	142	12.5
12	-	932	90.8	0.88	-	576	116	3.01
13	-	687	64.9	4.98	-	507	45.0	0.00
14	-	460	43.2	17.9	-	316	36.9	3.52
15	-	261	28.9	11.8	-	149	20.3	0.00
16	-	122	17.7	10.8	-	55.2	7.60	0.00
Total, g	0.58	43.4	5.64	0.70	0.61	34.0	5.49	0.50

Table 7. Mean ± s.e. of logistic parameters[1] describing the cumulative losses of natal down, contour feathers and remiges from male and female Cobb and Ross broilers

Type	Cobb							
	Males				Females			
	A, g	B, /d	t*, d	R^2	A, g	B, /d	t*, d	R^2
Natal down	0.56	0.1699	32.6	0.99	0.58	0.1778	31.4	0.99
	0.0025	0.0035	0.14		0.0014	0.0021	0.08	
Contour	43.4	0.1091	78.0	0.99	44.2	0.0953	72.55	0.99
	0.1509	0.001	0.11		0.2119	0.0012	0.18	
Remiges	8.05	0.1586	84.8	0.99	5.56	0.1127	69.3	0.99
	0.0364	0.0022	0.11		0.0276	0.0019	0.18	
Total feather loss	53.9	0.1057	79.7	0.99	51.2	0.0941	71.9	0.99
	0.0876	0.0004	0.05		0.2015	0.0010	0.15	
Type	Ross							
	Males				Females			
	A, g	B, /d	t*, d	R^2	A, g	B, /d	t*, d	R^2
Natal down	0.63	0.1794	33.4	0.99	0.60	0.1787	32.0	0.99
	0.002	0.0032	0.12		0.002	0.0026	0.10	
Contour	32.6	0.1175	77.1	0.99	34.2	0.1024	69.8	0.99
	0.109	0.0011	0.11		0.159	0.0015	0.18	
Remiges	9.11	0.1472	86.4	0.99	5.45	0.1215	70.0	0.99
	0.041	0.0018	0.11		0.023	0.0019	0.15	
Total feather loss	44.5	0.1079	79.9	0.99	40.8	0.1020	69.3	0.99
	0.072	0.0004	0.05		0.136	0.0010	0.13	

[1] Logistic equation of the form A/ (1+exp (-B*(X-t*))) where X is age, d

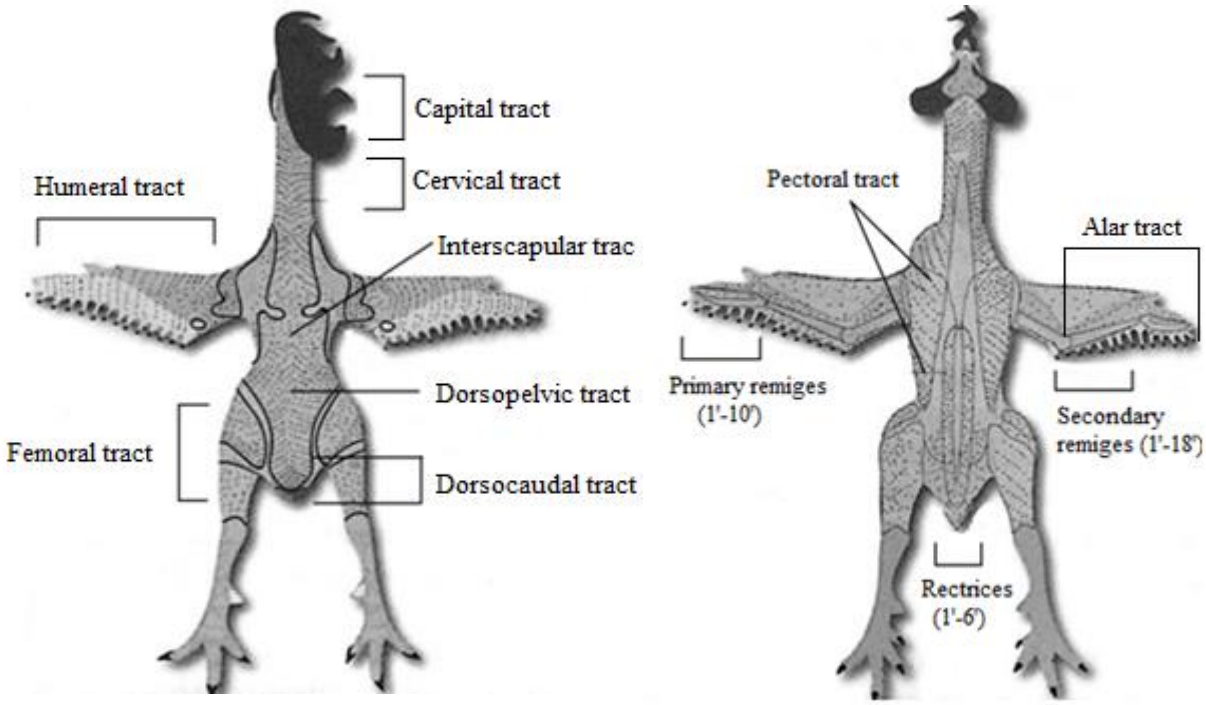

Figure 1. Diagram of feather tracts (Adapted from Lucas and Stettenheim, 1972).

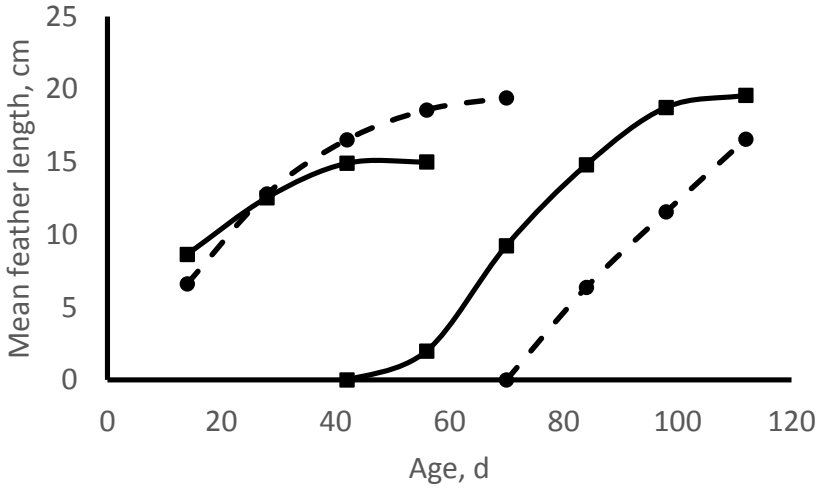

Figure 2. Illustration of the growth in the mean length of the 4th Primary feather of male and female broilers before and after the first moult. Males are shown as dashed lines and females as solid lines.

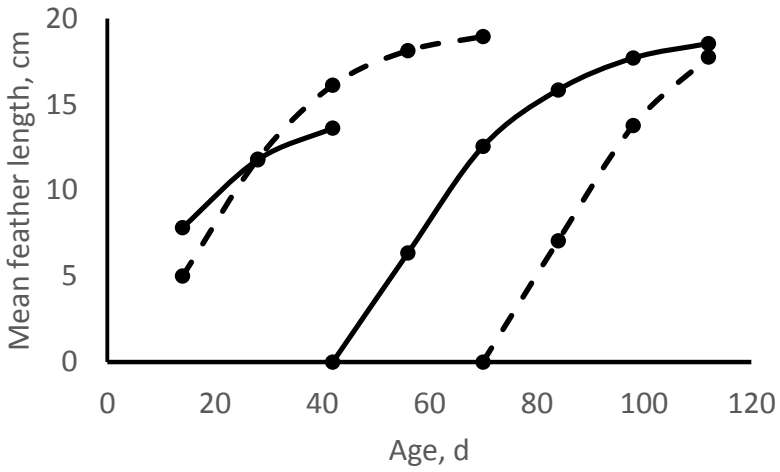

Figure 3. Illustration of the growth in the mean length of the 3rd Secondary feather of male and female broilers before and after the first moult.

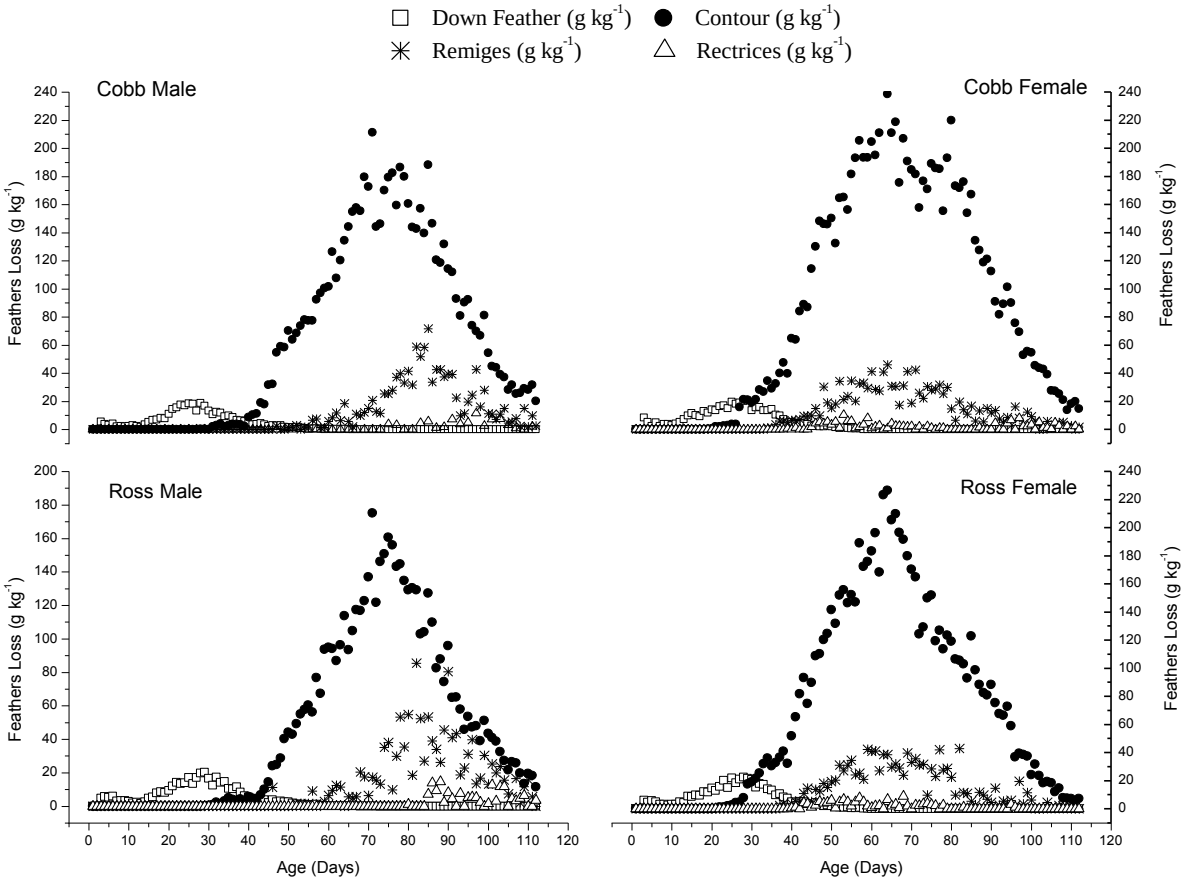

Figure 4. Daily losses (g/kg body weight) of natal down, contour feathers, remiges and rectrices of male and female Ross and Cobb broilers.

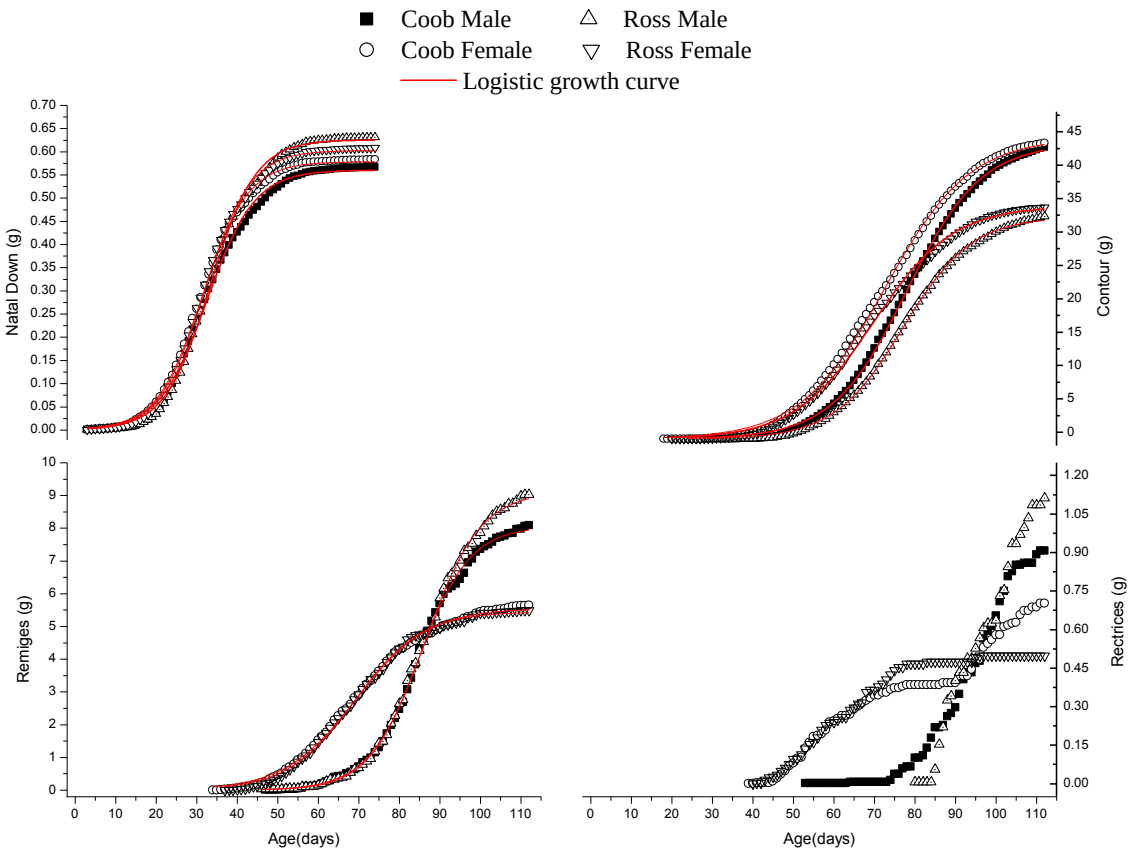

Figure 5. Cumulative losses (g/bird) of natal down, contour feathers, remiges and rectrices of male and female Ross and Cobb broilers.

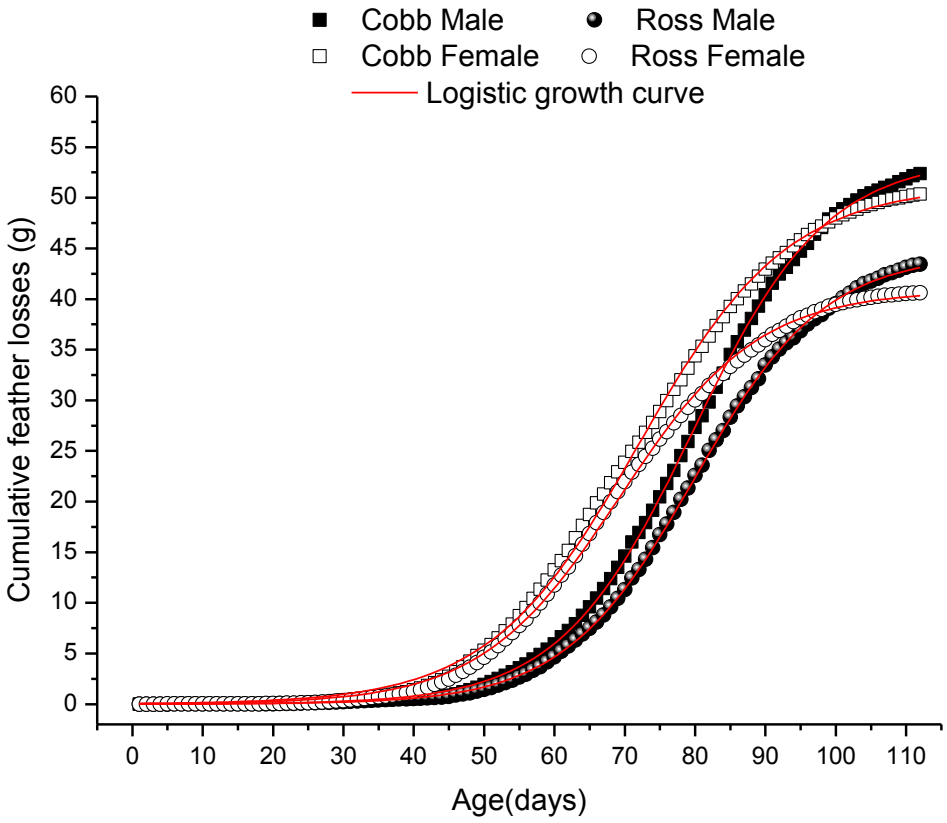

Figure 6. Cumalative losses (g/bird) of natal down, contour feathers, remiges and rectrices by Ross and Cobb males and females.

CAPÍTULO 3 – A description of the potential growth and body composition of two commercial broiler strains

Este capítulo foi submetido e está de acordo com as normas da **British Poultry Science.**

A DESCRIPTION OF THE POTENTIAL GROWTH AND BODY COMPOSITION OF TWO COMMERCIAL BROILER STRAINS

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Abstract 1. A study was conducted with males and females of two commercial broiler strains with a view to describing the potential growth of feathers and feather-free body and its chemical components.

2. A total of 800 sex separate day old chicks were placed in 40 pens and assigned randomly according to two strains, two sex and 20 chicks per pen. The birds were fed adequate amounts of dietary protein using a four-phase feeding programme. One bird per pen (10 birds per genotype) was sampled and euthanized at 14, 28, 42, 56, 70, 84, 98 and 112 d of age, a day after all the birds in each pen had been weighed. Sampled birds were weighed before and after being dry-plucked to determine the weight of feathers, and the feather-free body was then minced and analysed for water, protein and lipid.

3. Body weights and chemical composition of males of the two strains were similar throughout the trial. Females of the two strains differed only in their body lipid contents, with that of Cobb females at maturity being higher than Ross (1371 *vs*. 1210 g).

4. Mature body weights of males and females of both strains averaged 8420 and 6650 g; mature body protein weights averaged 1555 and 1030 g; and mature body lipid contents averaged 908 and 1290 g, respectively.

5. Rates of maturing (/d) of body weights of males and females of both strains averaged 0.0385 and 0.0368; of feather-free body protein content, 0.0316 and 0.0348; and of body lipid, 0.0503 and 0.0375, respectively. These rates differed between Cobb and Ross females (0.0352 vs. 0.0397 /d).

6. Separate equations were required to describe the allometric relationship between lipid and protein in the feather-free body in males and females due to genetic differences in the ability to deposit body lipid in the two sexes.

7. The rate of maturing of feathers in females was higher than in males (0.0526 vs. 0.0398 /d) and the mature weight was lower (205 vs. 266 g). Feather weight was allometrically related to body protein weight, but separate equations were needed for males and females. The two strains did not differ in this relationship.

8. The consequences of the increase in body protein and decrease in body lipid presented here are discussed.

Keywords: allometry, body weight, carcass, feathers, gompertz, protein

INTRODUCTION

Geneticists have been, and continue to be, successful in increasing the growth rate and feed efficiency of broiler chickens, as evidenced by many reports over the years of the decrease in age at a given harvest weight (Gous, 1986; Havenstein et al, 1994; McKay et al., 2000; Tallentire et al., 2016; Tavárez & de los Santos, 2016). Formal comparisons of the changes in growth potential of these genotypes over time are difficult to make as it is not only the genotype that has been changed, but changes have also been made to the nutrition of broilers, and to the environment in which they are reared. But more importantly, no formal description was used to describe the potential performance of these broiler genotypes over the past decades until Hancock et al. (1995) and Gous et al. (1996; 1999) published a method that leads to a description of such performance. The method used is based on the theoretical framework for predicting feed intake and growth of monogastric animals described by Emmans (1987, 1997) which has been used in the development of growth models for broilers (Gous, 1998; Sakomura, 2017), pigs (Ferguson & Gous, 1993; Ferguson et al., 1994; Green & Whittemore, 2005) and ostriches (Gous & Brand, 2008).

Feed intake may be accurately predicted from the potential protein growth of an animal (Emmans, 1987; 1997) and this enables the optimisation of feed composition and the feeding programme used for any of the variables predicted by this simulation modelling method, such as margin/m^2 per annum, margin over feed cost, breast meat yield, cost/kg etc. (Gous, 2014). It is imperative, therefore, to evaluate the potential performance changes of broiler genotypes at intervals to ensure that the prediction of food intake and its associated advantages keep up to date with the changes in the genotype accomplished by poultry geneticists.

It is for this reason that the trial described here was conducted, given that more than two decades have elapsed since the last such evaluation was made (Hancock et al., 1995). The genotypes used in this trial were the latest genotypes available in Brazil in 2018 from the world's two major broiler breeding companies.

MATERIALS AND METHODS

The study was approved by The Ethics Committee on Animal Use of the Faculdade de Ciências Agrárias e Veterinárias, UNESP, Jaboticabal, São Paulo, Brazil under protocol number n° 015111/17.

Bird husbandry and experimental design

A total of 800 one-day-old male and female broilers chicks of two slow-feathering genetic strains (Cobb 500 MX and Ross 308 AP (AP95)) were obtained from a local commercial hatchery, from 42-week-old Cobb 500, and 38-week-old Ross breeder flocks. Chicks were housed in an environmentally controlled room consisting of 40 pens, with wood shavings being used as litter. Each pen was provided with nipple drinkers and hanging tube feeders.

Upon arrival, chicks were weighed individually, and those exceeding 2 SD (standard deviation) away from the mean were excluded thereby ensuring that the range in initial body weight was similar for each strain and sex. A total of 200 chicks was selected in this way to represent each of the four groups used in the trial (800 birds in total), and these chicks were assigned randomly to ten pens of 20 chicks each.

Throughout the 112-d trial, broilers had free access to water and feed. The lighting programme used was 12L:12D (Lewis et al., 2009 a, b, c).

Experimental diets

A four-phase feeding programme was used (1 to 14, 15 to 28, 29 to 42 and 43 to 112 d of age). The experimental diets (Table 1) were formulated to contain 13.0 MJ AMEn/kg and meet or exceed the nutritional requirements suggested by the EFG broiler growth model (EFG Software, 2019) for males with a potential mature body protein weight of 1.2 kg and a rate of maturing of 0.038 /d. Feedstuffs and experimental diets were analyzed for dry matter, crude protein and gross energy (AOAC, 2005).

Data collection

All birds were weighed at 13, 27, 41, 55, 69, 83, 97 and 111 d of age to calculate the mean body weight, based on which birds representing the mean weight of each pen were identified. One bird per pen (10 birds per genotype) was selected and fasted for 8 h, but with access to water during that time. The following day each sampled bird was euthanized by isoflurane inhalation (> 1 ml/kg body weight) followed by cervical dislocation and weighed. All feathers were removed by dry- plucking after which each bird was again weighed to

determine the feather-free body weight and the total weight of feathers. Whole carcass with giblets were placed in identified plastics bags and frozen at a temperature of -4°C in a cold chamber for later processing. Data relating to specific aspects of the growth and moulting of feathers measured in this trial are reported elsewhere (Vargas et al., 2019).

All feather-free carcasses were cut with a saw and ground in an industrial meat grinder in order to obtain homogeneous samples. A 60 to 80 g subsample was removed, placed in a disposable plastic Petri dish and freeze-dried at -50°C in a Thermo VLP200 apparatus. Dried samples were then ground in an IKA micro-grinder and submitted to the laboratory for nitrogen and lipid determination, according to standards of AOAC (2005). Nitrogen was determined by Kjeldahl method (Kjeltec 8400, Foss, Sweden) (method 2001.11). Lipid was measured using Ankom^{XT15} Extractor (ANKOM Technology, Macedon, NY) with petroleum ether solvent (method 920.39) and the dry matter by lyophilisation and oven drying at 105°C for 16 h (method 920.39). Crude protein was calculated by multiplying nitrogen content by 6.25.

Mean feather weight, feather-free body weight and the content (g/kg) of feather-free body protein, water and lipid were calculated for each strain x sex at each sampling age using ANOVA. The linear relationship between lipid and water in the feather-free body was determined using linear regression, and the allometric relationships between the weights of water and protein, lipid and protein, and feather and protein in the feather-free body were determined by converting the weights of these components to natural logs (ln), and in the case of feather and body lipid weights separating the two regressions using Simple Linear Regression with Groups. The Gompertz function (Gompertz, 1825) was fitted to feather weights, the feather-free body weights and to the weights of the chemical components (body protein, water, and lipid) for each strain and sex. Genstat 18th edition (VSN International 2016) was used for all the above analyses.

RESULTS

Growth rates for the two strains were similar throughout the trial but males grew significantly faster than females from 28 d onwards (Table 2). Mean body weights achieved by the two strains at 112 d of age were 7880 g in males and 6227 g in females.

Chemical composition

Body protein content (Table 3) increased from 120 g/kg at day-old to 169 g/kg feather-free body weight by 112 d, there being no difference between the two strains. The sexes

differed in body protein content with a significant age x sex interaction ($P<0.001$): this was due to the increase from 120 to 160 g protein/kg in females and to 177 g/kg in males.

Body lipid content (Table 3) increased from 56 g/kg at day-old to 162 and 152 g/kg at 112 d for the Cobb and Ross strains, respectively. Females reached a body lipid content of 198 g/kg by 112 d whilst the lipid content of males at that age, over both strains, was 115 g/kg.

There was a decline in the content of water in the feather-free body over the trial period (Table 3), which decreased from 777 to 645 g/kg over both strains and sexes. At day 112 the Cobb strain had a similar amount of body water to Ross, being 639 and 646 g/kg, respectively. Over both strains, females had a lower body water content than males (609 vs. 675 g/kg). A negative correlation existed between body lipid and body water, the equation for predicting body lipid (g/kg) over both strain and sex being $684 \pm 8.62 - 0.8183 \pm 0.0125$ * body water, ($R^2 = 0.993$).

Allometric relationships in chemical components of the body

Body protein content was negatively related to body water, as indicated by the equation: Body protein (g/kg) = $312 - 0.2418 \pm 0.0142$ * body water ($R^2 = 0.46$). This relationship was weak during the early growing period but the fit improved at the later samplings. Nevertheless, a strong allometric relationship existed between water and protein weight in the feather-free body over both strains and sexes, the equation describing this relationship being:
ln Body water, g = $1.422 \pm 0.008 + 0.8765 \pm 0.004$ * *ln* body protein ($R^2 = 0.993$)

Separate equations were required to describe the allometric relationship between lipid and protein in the feather-free body in males and females due to genetic differences in the ability to deposit body lipid in the two sexes. The respective equations ($R^2 = 0.986$) are:
For females: *ln* body lipid, g = $0.1558 \pm 0.0207 + 1.2099 \pm 0.0111$ * *ln* body protein,
and for males: *ln* body protein = -0.3438 + 1.0875 * *ln* body protein.

Gompertz parameter comparisons

The mature body weights of males of the two strains (Table 4), calculated by fitting the Gompertz growth curve to the mean body weights of the two strains at each sampling, were almost identical, at 8420 g with similar rates of maturing (0.0381 and 0.0390 /d for Cobb and Ross, respectively). Female mature weights differed by only 182 g (6558 and 6740 g for Cobb and Ross, respectively) and their rates of maturing were also similar (0.0372 and 0.0364 /d respectively).

Males of the two sexes shared similar body protein and body lipid weights at maturity (Table 4) and the rates of maturing of these chemical components were also alike. The body water content at maturity was higher in Cobb males (5595 *vs*. 5311 g) with the rates of maturing being negatively related to mature weight, so B for Ross was higher (0.0348 *vs.* 0.0395 /d, respectively). Mature body protein and water weights were both heavier in males than in females, but the opposite was true of body lipid weight.

Mature body protein weight was similar in the females of both strains (Table 4) but the B for Ross females was lower than for Cobb (0.0345 *vs.* 0.0351 /d, respectively). Cobb females had higher mature body lipid contents (1371 *vs*. 1210 g) but lower B's (0.0352 *vs*. 0.0397 /d) than Ross. Mature body water content and the related B values were similar in females of the two strains.

Feather growth

The mean total weight of feathers per sex and strain at each of the sampling ages is given in Table 5. Feather weights at day old and at 14 d were heavier in females than in males but this was reversed from 84 d onwards, with the weight at 112 d being 59 g heavier in males. When fitting Gompertz equations to these data there were no significant differences in the three parameters between strains, but separate equations were required for males and females (Table 6). The rate of maturing (B) of feathers in females was considerably higher than in males (0.0526 vs. 0398 /d) but the mature weight was lower (205 vs. 266 g).

DISCUSSION

The two commercial broiler strains evaluated in this trial proved to be almost identical, especially the males which shared the same mature body weight, body protein and body lipid contents, with rates of maturing also proving to be remarkably similar. Females of the two strains differed slightly in these characteristics, with mature body weight and body water being slightly higher in Ross females, and body lipid being slightly higher in Cobb females. Mature body protein content was the same in both strains. Without knowing the selection goals and techniques of the geneticists, working for the two companies it could be surmised that these are not identical, so the similarities in the genetic potential performance of the two strains are surprising.

The mature body weights achieved by birds in this trial are considerably higher than those measured using the same protocol 24 years ago. In the trial reported by Hancock et al. (1995) males and females of the strain achieving the highest mature weight reached 6145 and

4705 g, respectively. Their respective rates of maturing were 0.0355 and 0.0363 /d and the ages at maximum rate of growth were 41.7 and 44.2 d, respectively. In the interim, mature weights have increased by 0.37 in males and 0.29 in females whilst the rate of maturing of males has increased by 0.10 and in females, by only 0.01. Whereas the rate of maturing appears to have changed very little by selection over the past 24 years, the relative growth rate (l/W)(dW/dt) has increased because of the higher mature weights that are potentially achievable in the latest strains.

When relative growth rate is plotted against the *ln* of body weight the slope of the resultant regression is the rate of maturing of the individual (Emmans, 1988; Hancock et al., 1995). If, as in this case, the regression runs parallel to that plotted by Hancock et al. (1995) (Fig. 1) the relative growth rate is greater than in the past in spite of the rates of maturing remaining the same. The relative growth rates at six intervals during growth are compared in Table 5, in which the potential growth rates of male and female broilers characterised by the Gompertz parameters reported here, and by those reported by Hancock et al (1995), are compared. Differences can be seen to be greatest during early growth and to diminish with time. A consequence of this increase in relative growth rate is that the potential age at which 2 kg is achieved in present male and female broilers is 33 and 38 d, respectively, whereas those reported by Hancock et al. (1995) would have achieved the same weight at 41 and 46 d. At 35 d of age, past males would have had the potential to weigh 1.53 kg whilst the equivalent weight for present males is 2.23 kg. These comparisons illustrate how successful poultry geneticists have been in increasing the potential growth rate of broilers over the past 24 years. Such comparisons are made possible when the genetic potential of the genotypes is formalised with the use of Gompertz parameters.

Body protein

As with mature body weight, the mature body protein content of the two strains evaluated in this study are considerably higher than those reported by Hancock *et al.* (1995). The highest mature protein weight of male broilers in the 1995 trial was 928 g (186 g protein/kg feather-free body weight) compared with 1557 g (185 g/kg) reported here, with the equivalent weights for females being 746 g (196 g/kg) and 1030 g (153), respectively. The concentration of protein in the feather-free body at maturity in male broilers (0.185 g/kg) has not changed, so the increase in protein weight is due entirely to the increase in mature feather-free body weight. In females, the increase in mature protein weight has been achieved in spite of a lower protein content in the body at maturity. Rates of maturing of body protein have

decreased in male broilers (0.0340 vs. 0.0316 /d, respectively) but increased in females (0.0331 vs. 0.0348 /d, respectively).

The heavier body protein content in the latest broiler strains would be accompanied by a higher breast meat yield due to the allometric relationship between these components (Danisman & Gous, 2011; 2013). Using such a relationship, a body protein weight of 414 g will yield a breast meat weight of 500 g, and this would have been achieved in males at 42 d in 1995 and now at 33 d, and in female boilers at 52 and 38 d, respectively. This again demonstrates the value of using a formal approach when comparing the potential performance of different strains of broiler.

Body lipid

There is no doubt that the amount of body lipid in broilers has decreased markedly over the past 24 years. Fleming et al. (2007) showed body lipid content to have reduced from 269 g/kg in the 1970s to 153 g/kg in commercial breeds used in the last decade, when birds were compared after being reared on a modern diet. Tallentire et al. (2016) questioned the extent to which genetic selection has been responsible for this, as broilers have been selected for high efficiency and low fatness on ever-improving diets, and there is considerable nutritional influence on body composition (Gous et al., 1990). The mature lipid contents of the fastest-growing males and females in the trial by Hancock et al. (1995) were 186 and 219 g/kg, respectively, compared with those of Cobb and Ross males (110 and 106 g/kg) and females (209 and 180 g/kg), respectively. The method used in these evaluations was to provide a feed that always exceeded the amino acid requirements of the broilers under test at the given energy level chosen, so these lipid contents would be close to the genetically-determined mature lipid contents in the different genotypes evaluated. It appears that the lipid content of male broilers has been reduced to a greater extent than that in females, and that Ross females are leaner than those of Cobb, and the evidence suggests that genetic selection has been the primary cause of these changes, even if no direct selection for leanness has taken place.

Males vs. females

Compared with the mean of all six genotypes evaluated by Hancock et al. (1995) the ratio between the mature body weights of males and females has changed very little in 24 years, remaining at between 1.25 and 1.31, but the mature body protein and lipid ratios have changed significantly: for body protein the ratio has increased from 1.24 to 1.50, and for body lipid this has decreased from 1.17 to 0.67 (Cobb) and 0.74 (Ross). The ratios of body protein and body lipid content (g/kg feather-free body weight) have also changed, from 1.00 to 1.20

in the case of body protein, and from 0.92 to 0.53 (Cobb) and 0.58 (Ross), respectively. These changes have consequences in the yield of the final product in a commercial broiler operation, with males now having the potential to produce more breast meat per kg live weight in relation to that produced by females than was the case in the past.

Feather growth and allometry

There are few publications that report on the rates of feather growth in commercial broilers, the most comprehensive being that of Hancock et al. (1995) who measured the rates of growth of feathers in males and females of six broiler strains. By fitting Gompertz growth curves to these data the mature weights of feathers of these 12 genotypes were predicted. Prior to this, feather weights, measured to various ages, had been reported by Fisher et al. (1981) and Dunnington and Siegel (1986). The weights recorded by Fisher et al. (1981) of the feathers of male and female broilers at 49 d were 62 ± 7.2 and 52 ± 6.1 g, respectively, these being less than half of the weight of feathers at that age recorded here. Similarly, Dunnington and Siegel's (1986) weights of 169 and 235 g for male and female breeders at sexual maturity are lower than the mature weights of feathers estimated in this paper (205 and 266 g for females and males, respectively, Table 3)). These most recent results are below the range of mature feather weights recorded by Hancock et al. (1995) of 233 – 339 g for females but within the range 242 – 342 g for males. Rates of maturing reported here fall outside of the range reported by Hancock et al. (1995): the range for females was from 0.0441 to 0.0517 /d and the latest estimate is 0.0526 /d (Table 3); and for males the equivalent values are 0.0444 to 0.0506 /d whilst the B value in the present trial (Table 3) is 0.0398 /d. The longer growing period used in the present trial (112 vs. 84 d) would have improved the accuracy of these estimates.

The allometric regression of feather weight on body protein weight was the same for both strains but differed between males and females. For males this relationship was:
ln feather weight = -1.524 (± 0.0207) + 0.9539 (± 0.0153) ln body protein weight (R^2 = 0.954)
and for females the coefficients are -1.4195 and 0.8706, respectively. Two variables are allometrically related only if they share the same rate of maturing, which is not the case between feather and body protein weight, but the linear regressions above fit the data so well that this relationship could be used with relative accuracy to predict the weight of feathers from the prevailing body protein weight. A similar close relationship was reported for turkeys by Gous et al. (2019) suggesting that it may not be necessary to predict the growth of feathers using a separate Gompertz equation, but instead make use of this allometric relationship.

In conclusion, poultry geneticists have been highly successful in increasing the potential protein growth rate of broilers by selection, and this has resulted in a concomitant decrease in body lipid content. Consequences include an increased efficiency in energy utilisation (Tallentire et al., 2016), a reduction in the age at which the birds achieve a given market weight, and an increase in the breast meat yield of the birds at any given age. These changes are more marked in males than in females. The description of the potential growth of broilers currently available to producers, presented here, will enable broiler growth models to predict more accurately the feed intake and growth of the body and feathers and the chemical and physical composition of growth of these broilers.

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Table 1- Ingredients and nutrient composition (g/kg) of experimental diets

Ingredient (g/kg)	Phase			
	1-14 d	15-28 d	29-42 d	43-112 d
Corn	538	613	6950	680
Soybean meal (450 g/kg)	321	258	208	182
Corn gluten meal (600 g/kg)	5.65	66.1	48.8	
Wheat bran				76.4
Soybean oil	32.6	17.9	6.60	25.3
Dicalcium phosphate	20.2	18.2	16.2	14.3
Limestone	9.50	8.70	8.00	8.10
L-lysine (546 g/kg)	10.6	9.00	7.80	5.60
DL- methionine (980 g/kg)	2.20	1.50	1.20	1.20
L-arginine (990 g/kg	1.70	1.50	1.60	0.90
L-threonine (985 g/kg)	1.50	1.10	1.10	1.00
L-valine (965 g/kg)	0.90	0.00	0.70	0.80
Salt	3.60	3.60	3.60	3.50
Vitamin and mineral supplement[1]	1.00	1.00	1.00	1.00
Coccidiostat[2]	0.20	0.20	0.20	0.20
Calculated composition				
AMEn, MJ/kg	13.0	13.0	13.0	13.0
Crude protein	240	220	190	150
SID amino acids				
Lysine	15.6	13.3	11.4	9.40
Methionine + cysteine	8.60	7.60	6.60	5.50
Methionine	5.50	4.70	4.00	3.30
Threonine	9.00	8.00	7.10	5.90
Valine	10.5	8.90	8.40	7.00
Tryptophan	2.30	2.00	1.70	1.50
Arginine	14.8	13.1	11.5	9.70
Isoleucine	8.90	8.00	6.80	5.40
Leucine	15.1	13.8	12.9	12.5
Phenylalanine + tyrosine	19.0	17.7	15.1	11.3
Glycine + serine	18.3	16.7	14.4	11.3
Histidine	5.40	4.90	4.30	3.70
Calcium	9.60	8.70	7.80	7.40
Sodium,%	1.60	1.60	1.60	1.60
Non-phytate phosphorus	4.80	4.30	3.90	3.70
Potassium	7.50	6.50	5.80	6.00

[1]Content/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.

Table 2. Mean body weight (g) of male and female broilers of Cobb and Ross strains at different ages

Age, d	Cobb		Ross	
	Male	Female	Male	Female
1	45.0	45.0	43.0	43.0
14	408	394	394	372
28	1450	1328	1421	1237
42	3045	2582	3065	2511
56	4615	3754	4679	3705
70	5921	4685	5999	4656
84	6779	5284	6811	5334
98	7480	5821	7533	5926
112	7853	6180	7908	6273

Table 3. Mean feather-free body protein, lipid and water content (g/kg) of male and female Cobb and Ross broilers at different ages

	Cobb		Ross		Cobb		Ross		Cobb		Ross	
Age[1]	M	F	M	F	M	F	M	F	M	F	M	F
	Body protein				Body lipid				Body water			
1	118	121	121	120	59.6	61.3	55.5	54.0	779	772	779	777
14	121	118	109	109	64.8	66.3	52.5	64.4	764	766	789	781
28	137	133	140	137	77.3	91.3	79.3	78.7	732	719	732	729
42	134	128	131	130	92.9	116	77.6	106	721	706	734	710
56	152	153	153	158	129	155	118	157	672	648	678	654
70	148	147	150	139	125	180	112	179	671	620	680	625
84	170	162	173	164	124	188	116	175	672	614	670	625
98	172	156	169	156	116	203	124	183	673	607	674	626
112	172	159	183	161	121	203	110	193	673	605	678	613
R.M.S.[2]	64.9				424				452			

[1] Values correspond to the average of 10 individual measurements per strain and sex
[2] Residual Mean Square, 303 d.f.

Table 4. Gompertz parameters[1] describing the growth of the body, and of the protein, water, and lipid in the feather-free body of male and female Cobb and Ross broilers

	Mature weight (A), g		Rate of maturing (B), /d		t*, d		R^2
	Mean	s.e.	Mean	s.e.	Mean	s.e.	
Body weight							
Cobb M	8416	111	0.0381	0.001	42.7	0.57	0.993
Cobb F	6558	81.9	0.0372	0.001	40.6	0.55	0.994
Ross M	8423	106	0.0390	0.001	42.5	0.54	0.994
Ross F	6740	105	0.0364	0.001	42.3	0.68	0.991
Body protein							
Cobb M	1557	57.2	0.0310	0.003	52.5	1.61	0.978
Cobb F	1024	31.3	0.0351	0.002	45.7	1.31	0.973
Ross M	1551	55.7	0.0322	0.002	51.4	1.55	0.976
Ross F	1033	35.8	0.0345	0.003	45.7	1.49	0.967
Body water							
Cobb M	5595	135	0.0348	0.001	43.4	1.05	0.981
Cobb F	3676	72.4	0.0384	0.002	36.7	0.89	0.978
Ross M	5311	94.6	0.0395	0.002	40.4	0.77	0.864
Ross F	3773	73.5	0.0380	0.002	37.4	0.09	0.980
Body lipid							
Cobb M	925	36.1	0.0504	0.006	44.4	1.58	0.915
Cobb F	1371	95.6	0.0352	0.005	54.1	2.81	0.915
Ross M	891	45.8	0.0502	0.008	45.3	2.07	0.985
Ross F	1210	73.0	0.0397	0.006	51.2	2.35	0.908

[1]Gompertz equation of the form A*exp (-exp (-B*(X-t*))) where X is age, d

Table 5. Mean[1] feather weight (g) of male and female Cobb and Ross broilers at different ages

Age, d	Male			Female			S.E.M[2]
	Ross	Cobb	Mean	Ross	Cobb	Mean	
1	1.08	1.21	1.15[b]	1.40	1.72	1.56[a]	0.101
14	8.00	9.00	8.50[b]	13.0	12.0	12.5[a]	0.943
28	55.5	52.5	54.0	54.5	53.5	54.0	2.24
42	116	107	111	103	104	104	4.28
56	158	153	155	156[a]	138[b]	147[a]	5.59
70	206[a]	178[b]	192	185	176	180	8.77
84	226	217	221[a]	187	200	193[b]	8.00
98	241	241	241[a]	195	206	201[b]	8.95
112	257	252	254[a]	198	192	195[b]	8.65

[1]Values correspond to the average of 10 individual measurements per strain and sex

[2]Standard error of the mean, 10 d.f.

[a], [b]Means within a row differ $P<0.05$

Table 6. Gompertz parameters describing the growth of feathers in male and female broilers, both genotypes combined

Parameter[1]	Females		Males	
	Mean	s.e.	Mean	s.e.
A, g	205	3.25	266	7.12
B, /d	0.0526	0.0032	0.0398	0.0029
t*, d	34.0	0.747	40.1	1.16
R^2	0.94		0.93	

[1]Gompertz equation of the form A*exp (-exp (-B*(X-t*))) where X is age, d

Table 7. Relative growth rates of male and female broilers characterised by Gompertz parameters[1] describing their potential performance in 1995[2] and at present

Age	Relative growth rate (1/W.dW/dt)			
	Past males	Present males	Past females	Present females
7	0.098	0.106	0.096	0.101
14	0.080	0.086	0.078	0.082
21	0.068	0.072	0.066	0.069
28	0.056	0.060	0.054	0.057
35	0.049	0.051	0.046	0.049
42	0.038	0.039	0.036	0.038

[1] Mature weight: past males, 6145 g; present males, 8419 g. Past females, 4705 g; present females, 6649 g. Rate of maturing: Past males, 0.0355 /d; present males, 0.0386 /d. Past females, 0.0363 /d; present females, 0.0368 /d.

[2] Hancock et al. (1995)

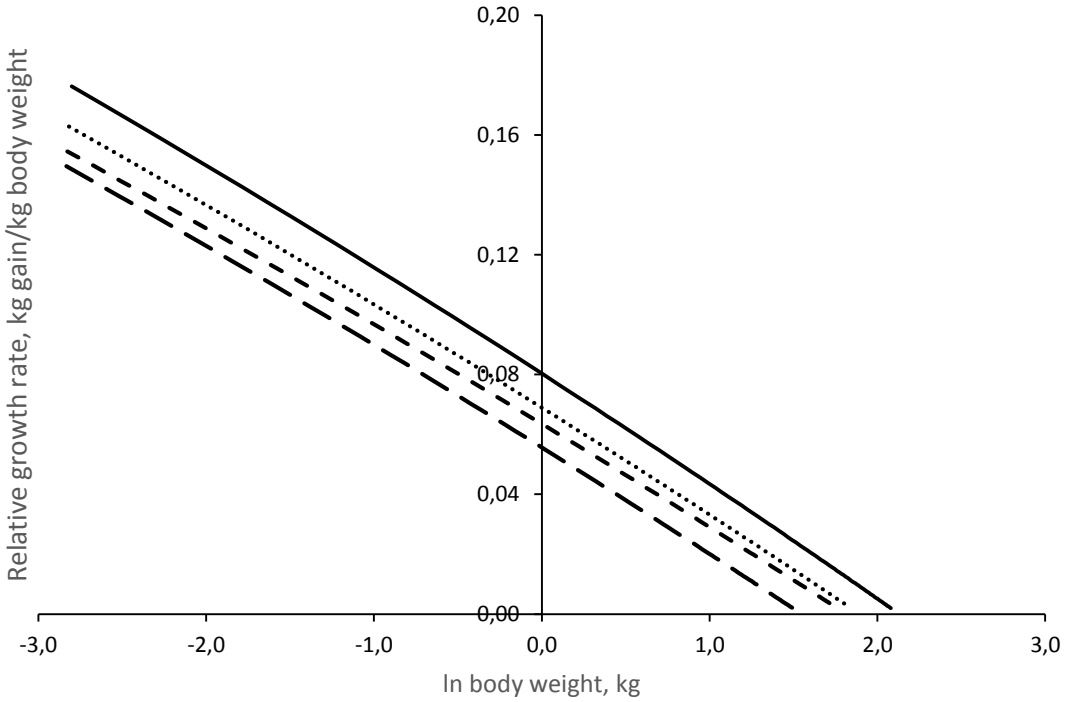

Figure 1. A comparison of the relative growth rates of male and female broiler genotypes described by Hancock et al (1985) and in this study, when plotted against their *ln* body weight. 1985 Males (- - - - -), 1985 females (-- -- --), recent males (_____), recent females (……..).

CAPÍTULO 4 – Implicações

O propósito do presente estudo, além de descrever o potencial de crescimento e composição do corpo em frangos de corte foi detalhar o crescimento e a perda das penas nos tratos do corpo das aves, bem como identificar os períodos em que ocorre a muda nos diferentes sexos e linhagens. Os resultados têm como finalidade demonstrar o perfil de crescimento das linhagens atuais, assim como de seus componentes e composição corporais. Em adição, gerar informações para auxiliar no estabelecimento de modelos matemáticos para determinação de necessidades de aminoácidos para frangos de corte machos e fêmeas.

Os dados coletados demonstraram que a metodologia usualmente utilizada para determinar o crescimento das penas subestima esta variável, tendo em vista que uma porção considerável de penas é substituída durante o período que antecede a maturidade das aves dando origem a novas gerações de penas. Concomitantemente, as exigências de aminoácidos para o crescimento das penas após a ocorrência das mudas foram ignoradas até o presente momento. Ao estimar a curva de crescimento das penas considerando as perdas que ocorrem durante o avanço da idade das aves é possível observar uma correção nos parâmetros da função Gompertz (A = 205 g; B = 0.052 e t* = 34 d ***vs*** A = 275.5 g; B = 0.039 e t* = 41.5 d). A partir destes resultados, torna-se possível definir quantidades adicionais de aminoácidos exigidos para o crescimento das penas referente à segunda fase do empenamento.

Diante dos resultados apresentados referentes ao potencial de crescimento do corpo nas linhagens Cobb e Ross, fica evidente o sucesso dos geneticistas em aumentar a taxa de crescimento proteico e diminuir o conteúdo lipídico corporal, favorecendo a redução na idade de abate.

Em conclusão, os parâmetros estimados neste estudo permitem o ajuste das equações de predição das exigências nutricionais com maior acurácia em frangos de corte.