UNIVERSIDADE ESTADUAL PAULISTA – UNESP

CAMPUS DE JABOTICABAL

COMPOSIÇÃO DAS PENAS E DA PULPA DE FRANGOS DE CORTE

Bruno Balbino Leme

Zootecnista

2020

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

2020

L551c

Leme, Bruno Balbino
Composição das penas e da pulpa de frangos de corte / Bruno Balbino Leme. -- Jaboticabal, 2020
47 p. : tabs.

Dissertação (mestrado) - Universidade Estadual Paulista (Unesp), Faculdade de Ciências Agrárias e Veterinárias, Jaboticabal
Orientadora: Nilva Kazue Sakomura
Coorientador: Robert Mervin Gous; Kênia Cardoso Bícego

1. Frango de corte. 2. Penas. 3. Aminoácidos. 4. Remiges. 5. Penas de contorno. I. Título.

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

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Câmpus de Jaboticabal

CERTIFICADO DE APROVAÇÃO

TÍTULO DA DISSERTAÇÃO: COMPOSIÇÃO DAS PENAS E DA PULPA DE FRANGOS DE CORTE

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Jaboticabal, 20 de fevereiro de 2020

DADOS CURRICULARES DO AUTOR

BRUNO BALBINO LEME, filho de Flávio Donizete Leme e Aparecida de Fátima Balbino Leme, nascido no dia 27 de novembro de 1995 em Mirassol, 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 2013. Em fevereiro de 2018 obteve o título de Zootecnista. Em março de 2018 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, sob orientação da Profª Drª Nilva Kazue Sakomura, submetendo-se à defesa da dissertação em fevereiro de 2020.

Dedico

Aos meus pais Flávio e Aparecida, 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.

AGRADECIMENTOS

Primeiramente a Deus, pela força, apoio, sabedoria, coragem nesta caminhada, por ter guiado meus passos e atender todos meus pedidos.

A minha orientadora, Prof.ª Dr.ª Nilva Kazue Sakomura, pela confiança em deixar aos meus cuidados este estudo, por todo apoio, dedicação e credibilidade. O meu muito obrigado!

Aos meus pais, Aparecida e Flávio, por todo apoio, carinho, dedicação, amor e contribuição para poder ter chegado até aqui, minha irmã, Fabiana, por sempre estar ao meu lado, ajudando nas decisões a serem tomadas para meu bem, pelo carinho e amor ímpar e por nunca desistir de mim, meu cunhado, Fábio, pelo companheirismo e força para alcançar meu sonho almejado.

A Letícia, pelo companheirismo, amor, carinho e muita paciência, principalmente nos momentos difíceis.

A Carol, por toda contribuição para a realização desta dissertação, pela amizade e companheirismo.

A todos os amigos, graduandos e pós-graduandos, e funcionários do aviário, em especial Larissa (Pioia), Thaísa (Lorota), Gabriel (Macaé), Bernardo (Murango), Letícia (Pomba), Mariana, Rafael (Kuki), Thaís, Palloma, Mirella, Jefferson, Felipe (Torcido), Rony, Freddy, Luís, Matheus, Guilherme, Marllon e Heloísa pela paciência e aprendizado e aos funcionários Robson, Izildo e Vicente pela experiência.

Aos meus co-orientadores, Profa. Dra. Kênia e Prof. Dr. Gous, pela paciência, credibilidade e ensinamento, e em me dar todo suporte necessário para realizar este trabalho.

Ao Conselho Nacional de Pesquisa e Desenvolvimento (CNPq) pelo bolsa de estudo concedida.

A Faculdade de Ciências Agrárias e Veterinárias, campus Jaboticabal, pelo acolhimento e estrutura concedida.

A todos que contribuíram de forma direta ou indireta para que eu pudesse obter o título de Mestre.

Sumário

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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
Coordenadora – CEUA

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COMPOSIÇÃO DAS PENAS E DA PULPA DE FRANGOS DE CORTE

RESUMO – A composição em aminoácidos das penas é utilizada como base para predição das exigências nutricionais para o seu crescimento. No entanto, durante o crescimento dos frangos de corte as penas sofrem mudas e consequentemente ocorrem alterações em sua composição, e até então este evento não foi contemplado nos modelos de predição de exigências nutricionais para aves. Neste contexto, esta dissertação foi realizada com o objetivo de: 1) descrever a composição das penas em diferentes tratos do corpo durante o crescimento das aves; 2) descrever a composição da pulpa presente nas penas em crescimento; 3) descrever a composição dos diferentes tipos de penas maduras. Para descrever a composição das penas em diferentes tratos e da pulpa durante o crescimento das aves, 200 frangos de corte de cada sexo (macho e fêmea) x linhagem (Cobb 500 MX e Ross 308 AP (AP95)) foram distribuídos aleatoriamente em dez boxes de 20 aves cada e alimentadas com quantidades adequadas de proteína dietética usando um programa alimentar de quatro fases. Uma ave por box (10 aves por genótipo) foi amostrada e eutanasiada aos 14, 28, 42, 56, 70, 84, 98 e 112 dias de idade. Todas as penas foram arrancadas de cada um dos sete tratos, sendo eles capital-cervical, dorsopélvico, interescapular, peitoral, femoral, humeral-alar e dorsocaudal. Das remiges (primárias e secundárias) foram coletadas toda a pulpa presente. As penas foram secas em estufa de ventilação forçada (55°C por 72 horas) e a pulpa foi seca por liofilização (-80°C por 72 horas), após esses procedimentos foram quantificados os teores de água e proteína. Os aminoácidos foram quantificados apenas nos frangos machos da linhagem cobb, nas idades de 1, 28 e 70 dias. Para descrever a composição das penas maduras, um sub-ensaio foi conduzido utilizando 20 aves de cada um dos genótipos avaliados, as aves foram alojadas individualmente em gaiolas e as penas perdidas naturalmente foram coletadas diariamente. Foram separadas as penugens, penas de contorno, remiges e retrices, analisado os teores de água e proteína. Novamente, apenas as penas de frangos Cobb macho foram quantificados o conteúdo de aminoácidos. Foi verificada uma pequena variação nos teores de proteína, em base de matéria seca, em todas as idades, linhagem e sexo. Os tratos dorsopélvico e interescapular apresentaram um aumento discreto nos teores de proteína com o avanço da idade. No conteúdo de água, uma redução foi observada com o aumento da idade para ambos sexo e linhagem, em todos os tratos. Nas penas em crescimento, os aminoácidos metionina, lisina e ácidos aspártico tiveram uma redução durante o crescimento das aves, já os aminoácidos cistina, valina, leucina e serina aumentaram. Em relação a pulpa, o teor de proteína foi menor apenas aos 112 dias, para água foi semelhante ao longo de todo período. As penas maduras apresentaram baixo teor de água, e para proteína os valores foram semelhantes ao das penas em crescimento. Os aminoácidos metionina, lisina e histidina foram consideravelmente maiores na pulpa do que nas penas maduras. Cistina e valina foram maiores nas penas maduras do que na pulpa. Diferenças que evidenciam o processo de queratinização das penas. Contudo, há mudanças na composição de aminoácidos durante o crescimento das penas de frangos de corte, e que comumente não são computadas em modelos de predição de exigências de aminoácidos.

Palavras chave: Aminoácidos, tratos das penas, penas de contorno, remiges

FEATHER AND PULP COMPOSITION OF BROILERS

ABSTRACT – The amino acid composition of feathers is used to predict the nutritional requirements for their growth. However, during the growth of broilers the moult is current and consequently changes in their composition occur, and at the present moment this event was not contemplated in the prediction models of nutritional requirements for birds. In this context, this dissertation aimed: 1) describe the composition of feathers in different body tracts during the growth of birds; 2) describe the composition of the pulp present in growing feathers; 3) describe the composition of the different types of mature feathers. In order to describe the composition of feathers in different tracts and pulp during poultry growth, 200 broilers of each sex (male and female) x strain (Cobb 500 MX and Ross 308 AP (AP95)) were randomly distributed in ten boxes with 20 birds each and fed adequate amounts of dietary protein using a four-phase feeding program. One bird per pen (10 birds per genotype) was sampled and euthanized at 14, 28, 42, 56, 70, 84, 98 and 112 days of age. All feathers were plucked from each of the seven tracts, namely capital-cervical, dorso-pelvic, interscapular, pectoral, femoral, humeral-alar and dorso-caudal. From the remige (primary and secondary) all the pulp present was collected. The feathers were dried in a forced ventilation oven (55 ° C for 72 hours) and the pulp dried by lyophilization (-80 ° C for 72 hours), after which the water and protein contents were quantified. Amino acids were quantified only in male cobb broilers at the ages of 1, 28 and 70 days. In order to describe the composition of mature feathers, a sub-trial was conducted using 20 birds from each of the genotypes, the birds were individually housed in cages and the feather loss was collected daily. Down feathers, contour feathers, remiges and rectrices were separated, analyzed for water and protein contents. The same procedure, only male cobb broiler feathers were quantified for amino acid content. The protein content, on the dry matter basis, remains relatively constant throughout growth, strain, and sex. The dorso-pelvic and interscapular tracts showed a slight increase in protein content over time. In water content, a decrease was observed with the age for both sex and strain in all treatments. In growing feathers, the amino acids methionine, lysine and aspartic acids decreased during the growth of birds, while the amino acids cystine, valine, leucine and serine increased. Regarding pulp, the protein content was lower only at 112 days, for water content was similar throughout the period. The mature feathers had low water content, and for protein the values were similar to the growing feathers. The amino acids methionine, lysine and histidine were considerably higher in pulp than in mature feathers. Cystine and valine were higher in mature feathers than in pulp. Differences that evidence the process of feather keratinization. Therefore, there are changes in amino acid composition during the growth of broiler feathers, which are not commonly computed in amino acid requirement prediction models.

Keywords: amino acids, feather tracts, contour feathers, remiges

CAPÍTULO 1. Considerações gerais

INTRODUÇÃO

A automação do setor avícola e os avanços em pesquisa elevaram a cadeia produtiva de frangos de corte a um patamar de excelência e competitividade que permitiu ao longo de anos a conquista e manutenção de importantes mercados consumidores. É indubitável a influência da nutrição e ambiência na produtividade de frangos de corte. Todavia, vale salientar que tais fatores, quando fornecidos em condições exigidas e adequadas, são o gatilho para a expressão de um potencial genético pré-existente, e que tal potencial é o fator determinante nas exigências de aves por nutrientes (Emmans, 1981).

O crescimento do corpo deve ser compreendido como a soma dos componentes químicos tais como proteínas, água, cinzas e lipídios, cujas taxas de deposições no corpo e nas penas 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). Em função de 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. Ao contrário do corpo o crescimento das penas é descontínuo, ou seja, novas gerações nascem após a perda de penas maduras (Macari et al., 2017). Sob a ótica da nutrição, a principal implicação do crescimento de novas penas é que ocorre aumento na demanda do organismo por nutrientes, sobretudo aminoácidos, e que esta demanda deve ser vista como processo dinâmico uma vez que em função do estágio de maturação, a pena apresenta diferenças quanto ao perfil de aminoácidos (Rivera-torres et al*.,* 2011).

A descrição do crescimento de penas, assim como sua composição em aminoácidos é contemplada em modelos fatorais de predição de exigências de aves por aminoácidos propostos por Martin et al. (1994). Contudo, estes modelos não comtemplam as variações na composição em aminoácidos das penas durante o crescimento das aves. O entendimento do perfil de aminoácidos em função da idade poderia aumentar o refinamento com o qual os modelos fatorais acima citados predizem as exigências de aves por aminoácidos, o que consequentemente permitiria atender com maior precisão exigências nutricionais aumentando a eficiência de conversão de proteína dietética em proteína corporal.

OBJETIVOS

Descrever a composição das penas em diferentes tratos do corpo durante o crescimento das aves;

Descrever a composição da pulpa presente nas penas em crescimento;

Descrever a composição dos diferentes tipos de penas maduras.

REVISÃO DE LITERATURA

Anagênese

O crescimento das penas é denominado como anagênese, e tem seu início ainda na fase embrionária em frangos de corte (Lucas e Stettenheim 1972; Macari et. al., 2017). O início do desenvolvimento folicular ocorre no quinto dia de incubação por meio da condensação das células mesenquimais na camada dérmica (Yu et al., 2004). Após essa condensação, os aglomerados de células formam linhas que definirão os tratos de penas no corpo da ave (Lucas e Stettenheim 1972). Entre os dias 6 e 7 de incubação é possível observar os aglomerados de células que delimitam os tratos femoral, humeral, peitoral, esternal, espinhal, capital e cranial. A organização

dos tratos ocorre de forma sincronizada que definirá também o padrão de muda das penas de 2ª geração em diante (Stuart e Moscona, 1967).

Durante o desenvolvimento embrionário os folículos em desenvolvimento darão origem as penugens (1ª geração) e após sofrerem muda, a penas de contorno, remiges e retrices. Aos 9 dias de incubação é possível observar a olho nu os folículos em desenvolvimento no embrião (Leeson e Walsh, 2004). Entre o 5° e 10° dia de incubação a diferenciação celular nos folículos em desenvolvimento é intenso (Lucas e Stettenheim, 1972), uma vez que no 12° dia os folículos já estão formados e as penas começam a apresentar características adultas (Watterson, 1942). Durante esse período, as penas não crescem apenas para cima (Fig. 1), mas também para baixo dando continuidade no desenvolvimento do folículo da pena (Leeson e Walsh, 2004).

Ainda, neste período, ocorre a diferenciação dos tipos de penas, onde ráquis e barbas começam se desenvolver de acordo com sua função (Lucas e Stettenheim, 1972). Entre os dias 13-19 de incubação as penugens sofrem o processo de queratinização, uma vez que neste período já emergiram do folículo na epiderme (Beckingham-Smith, 1973). Contudo, o processo de desenvolvimento folicular e formação das penas é um processo complexo, e ainda, caso haja algum trauma no desenvolvimento folicular, este irá prosseguir durante toda a vida da ave, apresentando deformações nas penas juvenis e adulta (Lucas e Stettenheim, 1972).

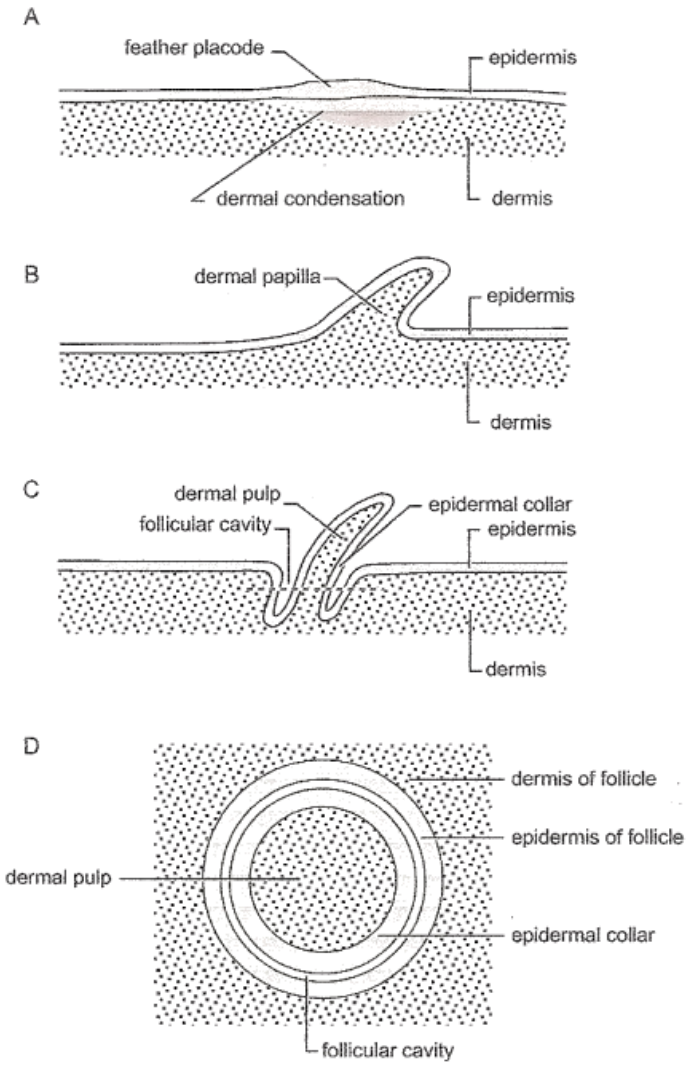

Figura 1. Diagrama do desenvolvimento de um folículo da pena. (A) Desenvolvimento do placode da pena epidérmica e condensação dérmica. (B) Desenvolvimento de uma papila de penas através da proliferação de células dérmicas. (C) Formação do folículo da pena pela invaginação de um cilindro de tecido epidérmico em torno da base da papila. (D) Corte transversal do folículo da pena (Prum e Williamson, 2001).

Produção e composição da pulpa

"A pulpa é um amplo retículo mesenquimal, cujos interstícios são ocupados principalmente por uma substância gelatinosa homogênea que confere a pulpa uma consistência firme, resistente e elástica" Lillie, 1940. Esta é a definição mais completa da pulpa presente na literatura, porém pouco foi estudado sobre sua produção e composição até o momento.

Segundo Smith e Bath (1995) o crescimento das penas necessita da síntese da pulpa que é responsável por todo aporte nutricional das penas. Portanto, a pulpa apresenta aminoácidos em sua composição e é muito rica em fluido sérico. Lillie (1940) relata em seu estudo que a produção de pulpa é em média três vezes maior que a quantidade de pena produzida, ou seja, a relação da quantidade de pulpa para produção de penas é de 3:1.

A pulpa está presente no interior do cálamo e da ráquis da pena em desenvolvimento, ainda apresenta uma ligação intima com o folículo da pena aderido na derme por meio do colarinho da pena, assim vasos sanguíneos e artérias conseguem manter o tecido irrigado e nutrido (Lillie, 1940; Lucas e Stettenheim, 1972). Segundo Moran et al. (1966) na pulpa ocorre conversão de metionina para cistina assim como ocorre no fígado, mostrando que a pulpa é um tecido proteico dinâmico diferentemente das penas que uma vez sintetizada não há mais degradação.

Smith e Bath (1995) avaliaram a composição de água e proteína presentes na pulpa de remiges de frangos pescoço pelado até as 15 semanas de idade. Verificaram que à medida que a pena cresce a pulpa regride para 1 a 2%, ficando difícil coletá-la nos estágios de crescimento final das penas. Aos 14 dias de idade, as aves apresentavam penas com aproximadamente 50% pena e 50% pulpa, e a pena apresentava cerca de 50% de matéria seca enquanto a pulpa de 13 a 15%. No final do estudo, na 15ª semana, algumas penas apresentavam teor de matéria de seca de 85% enquanto a pulpa era de 10%. Além disso, Smith e Bath (1995) verificaram que a pulpa apresentava um teor de proteína, em base de matéria seca, entre 75 e 80%, enquanto as penas tinham de 90 a 92%.

Entretanto, não há relatos da composição de aminoácidos presentes na pulpa dérmica das aves. Porém, essa informação é relevante quando se trata de exigências nutricionais, uma vez que, para a formação das proteínas presentes nas penas ou em qualquer outro tecido é necessária uma cadeia de aminoácidos.

Estrutura e queratinização das penas

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 (Fig. 2). As barbas apresentam ramificações secundárias suportadas por um ramo, nomeadas de bárbulas que possuem ramificações ainda menores denominadas de barbículas (Prum e Williamson, 2001; Macari et al., 2017).

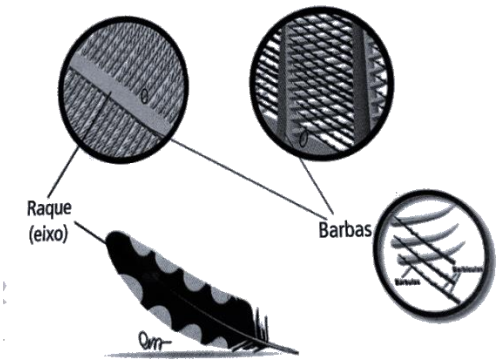

Figura 2. Estrutura das penas (Macari et al., 2017)

A estrutura e o tamanho das penas são diversos. Entretanto, segundo Leeson e Walsh (2004) existem três principais tipos de penas em aves comerciais, sendo as penas de contorno, remiges (são as penas de voo presentes nas asas) e retrices (são as penas presentes na cauda). As penas de contorno estão presentes em todos os

tratos do corpo das aves e são responsáveis pela cobertura da pele protegendo-a de lesões e auxiliando no equilíbrio térmico da ave. Ainda, existem as penugens que estão presentes em sua maioria nos pintinhos de um dia, que conferem uma estrutura “fofa” evitando a perda de calor para o meio.

A pena se desenvolve a partir da queratinização de suas estruturas, onde durante o seu crescimento a divisão celular ocorre 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 (Prum e Williamson, 2001).

A queratina é uma escleroproteína que é muito resistente a degradação pela maioria das enzimas proteolíticas (Leeson e Walsh, 2004), sendo dividida em duas classes por Block (1935), as euqueratinas e pseudoqueratinas, porém as penas de aves domésticas apresentam em sua composição as euqueratinas. Segundo Leeson e Walsh (2004) a queratina representa 85% das proteínas presentes nas penas, e é caracterizada por um alto teor de enxofre, em sua maioria na forma do aminoácido cistina. Contudo a exigência deste aminoácido é maior em períodos de crescimento das penas.

Composição das penas

As penas são compostas por aproximadamente 90% de proteínas, 7,9% de umidade e 1,3% de lipídeos (Maccasland & Richardson, 1966; Leeson & Summers, 1997). A proteína está presente, em sua grande maioria, na forma de queratina,

substância constituída principalmente por aminoácidos sulfurados que confere rigidez às penas (Macari et al., 2017; Maciel et al., 2005).

Entretanto, durante o crescimento das aves a composição das penas pode variar, uma vez que a pena não apresenta um crescimento contínuo, após atingir seu tamanho máximo a mesma é substituída por uma nova pena (Macari et al., 2017). Hancock et al. (1995) ao avaliarem a composição das penas de seis linhagens de frangos de corte durante o crescimento, verificaram que os teores de proteína na matéria seca permaneceram constante em todo tempo. Porém, o conteúdo de água diminuiu consideravelmente com o avançar da idade das aves. Martin et al. (1994) avaliaram a composição das penas de frangas em crescimento e observaram o mesmo comportamento para água, já para proteína houve um pequeno aumento durante o crescimento das aves.

Em um estudo mais recente, Gonçalves (2017), avaliou a composição das penas de três linhagens de frangos de corte durante o crescimento, os teores de proteína encontrado em base de matéria seca foram muito semelhantes aos observados por Hancock et al. (1995), porém, os teores de água encontrados foram distintos, sendo abaixo em todas as idades.

Segundo Emmans et al. (1989) a composição em aminoácidos do corpo e das penas são distintos. Ferket et. al., (1997) observaram que o perfil de aminoácidos do corpo depenado não parece mudar durante o crescimento da ave, porém o das penas apresenta diferença. De forma similar, Rivera-torres et al*.,* (2011) também não verificaram diferenças na composição aminoacídica do corpo de perus ao decorrer do crescimento. Contudo, os mesmos autores observaram decréscimo no percentual de lisina, metionina, triptofano, histidina, tirosina, arginina, asparagina e glutamina nas penas das aves com o avançar da idade, enquanto os teores de treonina, cistina,

isoleucina, leucina, valina, glicina, serina, alanina e prolina aumentaram, e de fenilalanina se mantiveram constante. Estes resultados corroboram aqueles encontrados por Fisher et. al., (1981) com frangos de corte machos de 1 a 49 dias de idade.

Dentre os aminoácidos que compõem as penas os aminoácidos sulfurados, metionina e cistina, são os mais exigidos para frangos de corte durante o crescimento das penas (Macari et al., 2017). Segundo Leeson e Summers, (2008) 25% da cistina e 2% da metionina dietética são utilizadas exclusivamente para a síntese da queratina. Ainda, vale salientar que a cistina participa diretamente deste processo enquanto a metionina atua na conversão para cistina (Moran et al., 1966).

Outros aminoácidos de grande importância para a formação da queratina, e consequentemente para o crescimento das penas, são os aminoácidos de cadeia ramificada (valina, leucina e isoleucina). Estes, juntos, correspondem a mais de 18% da queratina (Macari et al., 2017). Contudo, como a composição de aminoácidos das penas são utilizadas como base para predição das exigências em aminoácidos para o crescimento das mesmas, é vantajoso conhecer o efeito da idade nestes valores (Fisher et al., 1981).

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CAPÍTULO 2 - Composition of feathers and pulp of two broiler genotypes

Este capítulo é apresentado de acordo com as normas da **British Poultry Science.**

Composition of feathers and pulp of two broiler genotypes

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Abstract 1. Male and female Cobb and Ross broilers were used to measure the water, protein and amino acid composition of feathers in seven tracts at two-weekly intervals from 14 to 112 d of age and in moulted natal down, contour feathers, remiges and rectrices. In addition, the composition of feather pulp was measured in the remiges collected over the growing period.

2. 200 chicks of each sex and strain were assigned randomly to ten pens of 20 chicks each and fed adequate amounts of dietary protein *ad libitum* using a four-phase feeding program. Ten birds per genotype were sampled and euthanized at each age. All feathers were dry-plucked from each of the seven tracts and pulp was removed from primary and secondary remiges.

3. Daily losses of feathers were collected from 20 individually-caged broilers of each genotype.

4. Amino acid contents of feathers from the seven tracts were measured only in Cobb males on days 1, 28 and 70; for pulp on days 28 and 70 of age; and for the four types of moulted feathers.

5. Protein content on a dry matter basis remained relatively constant over all ages and tracts during growth. Water content decreased with age in both sexes and strains. Lysine and methionine content in feathers decreased with age while cystine, valine, leucine and serine increased.

6. Contents of lysine, methionine and histidine were considerably higher in pulp than in mature feathers whereas cystine and valine contents were higher in mature feathers than in pulp.

7. These results, together with information about moulting patterns in broilers, enable the effects of age of the bird and of the feather, and of the type of feather being considered, to be taken into account thereby more accurately calculating the amino acid content of feathers.

Keywords: amino acids; chicken; feather tracts; natal down.

INTRODUCTION

Feather protein consists mainly (850 g/kg) of the scleroprotein keratin (Leeson and Walsh, 2004). Keratins have been divided into two classes, eukeratins and pseudokeratins (Block, 1935). It was suggested that those keratins which are chemically similar to cattle horn be named eukeratins, which are defined as insoluble proteins, resistant to enzymatic digestion, and which yield histidine, lysine, and arginine in the molecular ratios of approximately 1: 4: 12 respectively. Feathers from the domestic fowl have been classified as eukeratins (Block and Bolling, 1938). But the amino acid composition of feathers, as reported by various authors, appears to vary considerably (Leeson and Walsh, 2004). This may be due, in part, to changes that occur in the chemical composition of feathers over time (Hancock et al., 1995; Stilborn et al., 1997), that feathers are not always harvested and handled under similar conditions (Leeson and Walsh, 2004) and because of between-laboratory differences in the analytical techniques used to measure amino acids in protein.

The most notable change that occurs in feather composition during the broiler growing period is that the water content is reduced. Feather protein content, on a dry matter basis, remains relatively constant throughout growth (Martin et al., 1994; Hancock et al., 1995).

Few studies have been made of the amino acid composition of feathers and whether this changes during the growing period. The most comprehensive are those by Fisher et al. (1981) and Stilborn et al. (1997), both of whom concluded that only minor changes occur in some of the amino acids, with the remainder retaining relative stability throughout growth. Also, little research has been done on the composition of the pulp that is responsible for nourishing the feather as it grows.

The results reported here are from a larger study of feathering in broilers, where feathers were collected not only at different stages of growth to 112 d of age but also from different feather tracts during that period (Vargas et al., 2020). In addition to the results reported in that paper, pulp samples and moulted feathers were also collected and analysed. The objective of the study was to ascertain the extent to which the amino acid composition of feathers from the different tracts, and at different ages, remained constant.

MATERIALS AND METHODS

The study was approved by The Ethics Committee on Animal Use of the São Paulo State University (Unesp), School of Agricultural and Veterinarian Sciences, Jaboticabal, São Paulo, Brazil, under protocol number n° 015111/17.

The experiment reported here formed part of a larger experiment conducted at the above research facility, and the experimental design, husbandry and feeds and feeding program used in the main trial, involving male and female broilers chicks of two slow-feathering genetic strains (Cobb 500 MX and Ross 308 AP (AP95)), have been comprehensively described elsewhere (Vargas et al., 2020).

At day-old, five chickens were randomly sampled from each strain x sex combination to provide information on the weight and chemical composition of down feathers at that age. On eight further occasions, with an interval of 14 days, between 14 and 112 d of age, ten birds were selected from each strain and sex, euthanized using isoflurane inhalation, and then defeathered. All feathers were dry-plucked from each of seven tracts (capital-cervical, dorso-pelvic, interscapular, pectoral, femoral, humeral-alar and dorso-caudal tracts). The feathers of each tract and age were analysed for water and crude protein contents. Only those feathers collected from male Cobb 500 MX broilers at 1, 28 and 70 d of age were analyzed for amino acid content.

Pulp was removed manually from the remiges (primary and secondary) of males and females of both strains sampled on the above eight occasions, with the aid of blade and forceps. The pulp was stored in a freezer at -20 ° C, after which the first drying in freeze-drying was carried out to quantify water and protein contents. At 28 and 70 d, a pool of the pulp samples from male Cobb 500 MX broilers was used to quantify the amino acid contents.

In a sub-trial, in which 20 broilers of each genotype were evaluated, birds were housed individually in cages surrounded by netting, and the daily losses of feathers were collected. These feathers were separated into natal down, contour feathers, remiges and rectrices and then pooled for each feather type, sex and strain to quantify their water and protein contents. Only those feathers collected from male Cobb 500 MX broilers were analysed for amino acid content.

Chemical analysis

The feathers were dried in forced air ventilation (55° C for 72 h) whilst the pulp was freeze-dried at -80°C in a Thermo VLP200 apparatus. Dried samples were finely milled in a

multipurpose mill (Tecnal, TE 631/4) and analyzed for dry matter and N content according to AOAC methods 920.39 and 2001.11, respectively, the latter with the use of Foss Kjeltec 8400. Crude protein was calculated by multiplying N content by 6.25.

Samples were analyzed for amino acids in Germany by Evonik Nutrition & Care GmbH using ion-exchange chromatography with post-column derivatization with ninhydrin (Commission Directive 1998). Amino acids were oxidized with performic acid which was neutralized with Na metabisulfite, liberated from the protein by hydrolysis with 6 N hydrochloric acid for 24 h at 110°C and then quantified with the internal standard by measuring the absorption of reaction products with ninhydrin at 570 nm. The amino acid contents were calculated to a 100% dry matter basis and then expressed as a proportion (g/kg) of feather protein for statistical purposes.

Statistical analysis

Mean feather and pulp water and protein contents were calculated for each strain x sex combination. The data were analyzed by analysis of variance as a factorial arrangement of strain, sex, and age, using the ANOVA procedure in Genstat 18th edition (VSN International, 2016). Values were considered significant at $P < 0.05$. Regression analyses were conducted to determine the change in protein and water contents over time for the feathers from each of the seven tracts. The constant terms and slopes from each tract and over all tracts were compared using simple linear regression with groups in Genstat.

RESULTS

The mean protein and water contents of feathers from each of the seven tracts and at each sampling age are given in Table 1. There was a greater variation in protein weight within tracts at 28 d than at any other age, as evidenced by the generally higher standard error (SE) at that age over all tracts. There was no discernable pattern in SE of water contents over time. There were no distinct trends in protein and water content with strain or sex, although both factors had some influence in some cases. Of more importance was the trend over time in the mean protein and water content over strains and sexes combined for each tract.

In Table 2 the protein (dry matter) and water contents of feathers in each of the tracts have been regressed against age, with data from both strains and sexes being averaged for each age. It is apparent from this table that the protein contents of feathers from both the dorso-pelvic tract, which was used as the reference tract, and the interscapular tract, increased significantly (0.78 ± 0.042 g/kg.d^{-1}) over time, and more so than that of the other tracts whose regression

coefficients are all lower than that of the dorso-pelvic tract. These lower slopes were exacerbated by higher intercepts compared with the reference tract. In spite of the change in protein content over time it is instructive to view the mean protein content over the entire test period for each tract, and these values are given in Table 3.

Unlike the protein contents, the feather water contents (Table 2) all decreased with time, the rate of decline being the same for the dorso-pelvic, interscapular, dorso-caudal and femoral tracts, although the total amount of water initially was higher in the interscapular and dorso-caudal tracts. The rate of decline was lower for the remaining three tracts.

When the feather protein and water contents from each strain and sex were averaged over all tracts (Table 4) and regressed against age, protein content increased (922±1.23 + 0.467±0.017 g/kg.d^{-1}), and the water content decreased (580±3.66 – 3.035±0.052 g/kg.d^{-1}). In both cases that fit was improved by separating the strains and sexes using Linear regression with Groups in Genstat (Table 5). The increase with time of the protein content of feathers from Cobb females, used for reference, was lower than for the males of both strains, but higher than for Ross females. However, the decrease in water content over time for Cobb females was the same as for Cobb males, but greater than for Ross females and males.

The amino acid composition of natal down at day-old and feathers from seven tracts of Cobb males at 28 and 70 d of age is given in Table 6. In only a few cases were differences apparent at these three ages: the lysine content of natal down was the same as that at 70 d, but at 28 d it was 34 % higher than at the other ages. Methionine showed a similar pattern, with the content being 30 % higher at 28 d. Arginine and phenylalanine contents were 14 % higher at day-old than at the two later ages, when they were the same. Histidine content decreased by 59 % from day-old to 28 d and then by a further 34 % at 70 d of age. In all other cases the difference between ages was less than about 7 %.

The content of water and protein in the moulted feathers (natal down, contour, remiges and rectrices) and from pulp is presented in Table 7. Water content was lowest in natal down and highest in the remiges, and protein content was highest in the remiges. Water content in feather pulp exhibited an exponential increase over time, with significant differences between males and females, as indicated in the equation $Y = A + B (R^X)$. For males, water content of pulp was 900 (± 1.10) – 88.4 (± 11.7) x 0.9406 (± 0.0084)^Tt where T is age (d). For females, the A coefficient was 904. R^2 for these equations was 50.3. The protein content of feather pulp exhibited a linear decline over time, with differences being evident between strains. The

equation for Cobb broilers was 887 (± 4.12) – 0.7136 (±0.0583) T, where T is age, d, and for Ross, 859 (± 5.83) – 0.5101 (± 0.0824) T. The R^2 value for these equations was 44.5.

The amino acid composition of the moulted feathers and pulp is given in Table 8. Contour feathers had a higher total amino acid content than the remiges or rectrices, due to higher concentrations of cysteine, threonine, arginine, isoleucine, serine and proline. However, the mean concentration of each amino acid over the three types of feathers measured was very similar to the mean of feathers at 70 d (Table 6). The amino acid content of feather pulp remained constant over the two periods of measurement, but these differed markedly from the amino acid content of feathers.

DISCUSSION

In this study, the protein content of feathers in the different feather tracts of both strains and sexes, on a dry matter basis, remained constant throughout the growth period. When averaged over the feather tracts these results were the same as those reported by Hancock et al. (1995) and Gonçalves (2017). Interestingly, Hancock et al. (1995) observed that at 28 days of age the variation in feather protein content was greater than at other ages, and the same was observed in the results presented here. In an earlier publication on this study (Vargas et al., 2020) it was reported that peak feather loss occurred between 4 and 5 weeks of age, which may explain the greater variation in protein content of feathers at 28 d.

Unlike feather protein content, the water content of feathers in all tracts decreased over time. These results mirror those observed by Hancock et al. (1995) but not by Gonçalves (2017) who could not detect any pattern in water content over the growth period. The latter result is possibly related to the way in which the feathers were sampled, emphasising the importance of sampling all feathers on the body when evaluating the mean composition. The decrease in water content over time is likely to be related partly to the presence of pulp in feathers. During feather growth, the pulp is responsible for providing the necessary nutrients for this growth (Lillie, 1940), and as shown in Table 7, feather pulp has a considerably higher water content than do feathers themselves. Smith and Bath (1995) evaluated the water content of feathers from broiler chickens at different stages of maturation and reported that as the feather grows the pulp percentage decreases and dry matter content increases. The water content of feather pulp, as reported by these authors (850 to 870 g/kg) was similar to that reported here (863 to 909 g/kg) whilst the protein content reported by them (750 to 800 g/kg dry matter) was similar to that at 112 d of age in the present study (797 g/kg) but lower than from 14 to 98 d of age (816 to 874

g/kg). This difference could be related to the stage of feather maturation, since as the feathers mature less pulp is present to be irrigated by plasma (Lillie, 1940).

Smith and Bath (1995) evaluated the composition of individual primary remiges and observed that when these feathers were mature they contained about 110 g of water/kg and 900 to 920 g protein/kg dry matter. This composition is similar to that of moulted, i.e. mature, remiges in our study for both sexes and strains. The higher water content and lower protein content in the rectrices and contours feathers (136 and 843 to 850 g/kg, respectively) when compared to remiges is possibly related to the higher proportion of calamus and rachis present in the remiges (Harrap and Woods, 1964), which also influenced the amino acid composition of these three feather types, as discussed below.

The amino acid contents of feathers in male Cobb broilers are in general agreement with those reported by Stilborn et al. (1997) and by Rivera-Torres et al. (2011) who evaluated the amino acid composition of feathers of growing male turkeys. Some variation was apparent as the birds aged, but not in relation to the different tracts. Of particular interest in the present trial was the increase in both lysine and methionine content at 28 d compared with the levels in natal down and at 70 d, and the step-down in histidine content over the three periods measured. Stilborn et al. (1997) reported a continual decline in the contents of lysine, methionine, tryptophan, tyrosine and histidine over the period from 14 to 112 d. Fisher et al. (1981) reported decreasing methionine contents with age and increases in isoleucine, threonine and valine, which occurred in the study of Stilborn et al. (1997) and in the present study. They did not report the highly significant decline in histidine content which was found in both our study and that of Stilborn et al. (1997). These relatively consistent changes in amino acid content with age should be taken into account when calculating the daily amino acid requirements of a given broiler.

The amino acid content of feather pulp differed markedly from that of feathers themselves. The contents of both lysine and methionine in pulp were higher than in feathers (38 vs. 12 and 11 vs. 3.2 g/kg protein, respectively), whereas cysteine (33 vs. 68 g/kg), valine (47 vs. 71 g/kg), isoleucine (33 vs. 46 g/kg) and histidine (11.8 vs. 4.2 g/kg) were all at a lower concentration in the pulp. The higher levels of lysine and methionine in pulp are probably due to the presence of muscle tissue, blood, veins and arteries in the pulp (Lillie, 1940; Lucas and Stettenheim, 1972; Yu et al., 2004) which contain high levels of these amino acids in their composition (Conde-Aguilera et al., 2013). According to Moran et al. (1966) methionine is converted to cystine in the pulp, as happens also in the liver, evidencing this higher concentration of methionine in the pulp. Pacheco et al. (2018) in a study using labelled amino acids, indicated

that the conversion of methionine to cystine in the body was 54%, corresponding closely with the ratio of pulp to feathers in our study of 52%.

A possible reason for the higher levels of methionine, lysine and histidine at 28 d than at 70 d is that new feathers are emerging at 28d following a moult (Vargas et al., 2020) and, being new, they would contain more pulp, and hence more of these three amino acids, than the feathers at 70 d that had by then attained their mature condition (Vargas et al., 2020). Mature feathers are higher in cystine, valine, serine and leucine than pulp, and these amino acids are consequently present in higher proportions at 70 d than at 28 d. Cystine, in particular, with its disulfide bond (Moran et al., 1966) plays a key role in ensuring the rigidity of the feather through the process of keratinization.

As mentioned above, the amino acid composition of the three different types of moulted feathers differed, with remiges containing lower contents of all amino acids other than leucine and glycine. Harrap and Woods (1964) reported a higher proportion of these two amino acids in the calamus and rachis, these being morphological portions of feathers that are present in larger concentrations in the remiges. In addition, the same authors reported higher contents of cystine in feather barbs, which would explain our findings of higher cystine concentrations in contour feathers, as these have a higher proportion of barbs than do other feathers. These results give us insight into the reason for the small differences in amino acid composition observed between the types of feathers present in broilers.

If differences in feather amino acid content with age, reported here and by Fisher et al. (1981) and Stilborn et al. (1997), are ignored. a comparison can be made of the amino acid composition of feathers reported in this and in four previous studies (Table 9). Inevitably there will be some variation in the amino acid composition reported, depending on the age at sampling and the composition of the samples taken, making it difficult to decide upon a reliable set of definitive values to use to describe the amino acid composition of feathers. The results presented in this present exercise, combined with information about moulting patterns in broilers (Vargas et al., 2020) enable the effects of age of the bird and of the feather, and of the type of feather being considered, to be taken into account when describing the amino acid content of feathers.

These results also suggest that in considering the amounts of each amino acid used in the production of feathers, due consideration should be given to the composition of feather pulp, bearing in mind that the protein present in pulp is dynamic, with synthesis and degradation

both occurring, whereas feathers once synthesized are not degraded (Smith and Bath 1995). Lillie (1940) calculated that 3 g of pulp was required to manufacture each g of feather. Thus, since the amino acid requirements for feather growth have always been based on the composition of keratinized tissue making up the feather, with only synthesis occurring, the cost of feather development may have been underestimated by 25-30% (Smith and Bath 1995). As a result, by knowing the composition of pulp, growing feathers and mature feathers, it would be possible to better estimate the amino acid requirements for feather growth in broilers.

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Table 1. Mean feather protein (dry matter) and water content (g/kg) of feathers from seven feather tracts of male and female Cobb and Ross broilers from 14 d, at 14-d intervals, to 112 d of age

	Protein content (g/kg)						Water content (g/kg)					
	Cobb		Ross				Cobb		Ross			
	Male	Female	Male	Female	Mean	S.E.M[2]	Male	Female	Male	Female	Mean	S.E.M
[1]Age	Capital-cervical tract											
14	913	949	944	947	938	2.55	433	392	488	529	461	19.3
28	904	910	924	966	926	8.64	570	523	564	508	542	9.48
42	975	975	955	958	966	4.56	451	423	471	450	449	11.9
56	957	958	953	961	957	7.39	332	350	383	394	365	15.3
70	959	949	936	952	949	4.84	395	349	379	332	364	17.4
84	968	960	965	974	967	4.60	382	317	407	311	354	16.1
98	978	958	972	971	970	5.09	324	256	315	271	292	16.3
112	965	955	973	970	966	5.04	245	194	275	187	228	8.70
	Dorso-pelvic tract											
14	871	908	840	932	887	-	436	610	440	532	505	-
28	888	902	909	953	913	7.88	626	544	636	545	587	9.26
42	973	968	947	957	961	5.40	517	426	545	439	482	10.4

56	953	952	972	966	961	5.66	344	371	387	387	373	14.1
70	946	947	949	955	948	9.23	350	340	325	334	338	14.0
84	981	958	980	979	974	5.90	301	292	348	305	312	13.2
98	981	969	973	972	974	4.98	309	255	313	248	282	10.5
112	973	956	978	978	971	4.85	241	194	268	185	222	11.0
Interscapular tract												
14	902	902	908	934	912	-[3]	433	547	437	542	490	-
28	875	910	912	952	912	9.79	692	591	704	586	644	13.4
42	978	976	945	961	965	5.67	559	465	539	480	522	14.0
56	958	952	960	955	957	5.93	385	393	441	403	406	12.1
70	956	945	944	958	951	6.41	396	361	369	338	366	13.8
84	968	960	984	986	975	4.98	303	279	346	295	306	15.9
98	987	982	986	978	983	3.95	305	276	317	262	290	13.6
112	976	965	985	979	976	4.24	233	214	242	189	220	11.7
Pectoral tract												
14	937	933	922	934	932	3.31	469	418	564	581	509	22.6
28	897	905	923	960	921	8.51	573	527	552	527	545	11.8

42	975	968	953	962	964	4.60	460	429	488	438	454	10.1
56	958	950	962	958	957	4.66	336	397	391	455	395	12.6
70	960	935	940	934	942	6.27	395	406	403	379	396	15.6
84	965	950	968	958	960	5.43	390	335	422	353	375	15.7
98	966	954	971	963	963	5.49	337	294	340	277	312	19.9
112	968	950	984	974	969	4.31	234	213	250	203	225	10.9
Femoral tract												
14	905	941	933	941	930	1.91	504	499	536	569	527	27.7
28	910	905	930	961	926	6.18	555	536	555	530	545	9.47
42	974	966	947	959	962	5.38	499	476	513	492	495	12.4
56	952	947	957	956	953	4.78	349	364	403	399	379	12.2
70	957	937	949	953	949	5.61	338	307	363	284	323	23.9
84	974	958	978	974	971	3.76	285	273	307	279	287	12.9
98	975	968	980	972	974	4.23	275	260	283	249	268	13.3
112	971	964	984	979	975	3.92	227	217	244	192	220	10.8
Humeral-alar tract												
14	946	957	939	954	949	2.82	468	450	518	510	487	5.60

28	925	899	936	973	934	8.23	585	502	579	488	539	8.00
42	976	978	968	975	974	4.92	435	426	461	424	437	5.12
56	966	965	975	967	968	5.07	309	345	327	399	345	6.78
70	965	955	967	966	963	6.65	288	371	294	363	329	7.78
84	977	964	968	981	972	4.31	297	367	349	370	346	7.15
98	974	972	978	979	976	5.05	354	299	377	299	332	7.31
112	975	965	986	981	977	4.08	294	207	335	217	263	9.53
Dorso-caudal tract												
14	905	929	909	950	923	-	655	561	656	568	610	-
28	888	887	907	959	910	6.88	616	523	647	517	630	12.1
42	944	956	929	954	946	6.62	551	459	564	475	512	17.1
56	931	931	923	930	929	6.04	372	444	425	467	427	18.0
70	918	918	925	932	923	6.34	346	433	348	445	393	14.5
84	935	939	941	956	943	8.86	297	357	334	411	350	14.2
98	936	949	935	952	943	6.56	346	325	378	352	356	18.4
112	932	941	936	958	942	7.11	313	242	329	235	280	15.3

[1]Values correspond to the average of 10 individual measurements per strain and sex
[2] Standard error of the mean
[3] Samples were pooled due to Insufficient material for individual analysis, hence no mean square error

Table 2. Linear regression with groups of feather protein and water contents against age for each of the seven feather tracts[1], averaged over both strains and sexes

Tract	Constant term	s.e.	Regression coefficient	s.e.	R^2
Protein content					
Dorso-pelvic	900	2.98	+0.780	0.042	0.37
Interscapular	+9.61		N.S.[2]		
Dorso-caudal	+17.8		-0.544		
Femoral	+24.5		-0.294		
Pectoral	+27.4		-0.400		
Capital-cervical	+33.3		-0.437		
Humeral-alar	+42.9		-0.439		
Water content					
Dorso-pelvic	605	8.44	-3.444	0.119	0.70
Interscapular	+33.9		N.S.		
Dorso-caudal	+44.4		N.S.		
Femoral	N.S.		N.S.		
Pectoral	-22.0		+0.566		
Capital-cervical	-53.1		+0.748		
Humeral-alar	-65.3		+0.985		

1 Using dorso-pelvic tract as reference

2 Not significantly different from the reference tract

Table 3. Mean feather protein (dry matter) content (g/kg) over all ages, strains and sexes per feather tract

Tract	Protein	
	Mean	S.E.M
Pectoral	951	5.52
Femoral	955	4.64
Dorso-pelvic	949	6.04
Capital-cervical	955	5.62
Dorso-caudal	932	6.52
Interscapular	954	5.73
Humeral-alar	964	5.37

Table 4. Mean feather protein (dry matter) and water content (g/kg) over all feather tracts, strains and sexes per age of sampling

Age	Protein		Water	
	Mean	S.E.M	Mean	S.E.M
14	924	2.04	511	4.92
28	920	8.09	568	3.72
42	963	5.35	479	3.56
56	954	5.71	384	3.37
70	947	6.60	358	3.74
84	966	5.62	332	3.63
98	969	5.11	304	3.86
112	968	4.90	237	3.17

Table 5. Linear regression with groups of feather protein and water contents against age averaged over feather tracts, strains and sexes

Factor	Constant term	s.e.	Regression coefficient	s.e.	R^2
Protein content					
Cobb females	923	2.36	0.369	0.033	0.30
Cobb males	-13.8		+0.253		
Ross females	+21.5		-0.115		
Ross males	-12.5		+0.253		
Water content					
Cobb females	584	5.20	-3.219	0.089	0.91
Cobb males	N.S.[1]		-0.211		
Ross females	+15.4		N.S.		
Ross males	+24.0		-0.206		

1 Not significantly different from Cobb females

Table 6. Amino acid composition (g/kg feather protein) of natal down and feathers from seven tracts of Cobb males at 1, 28 and 70 d of age

	Amino acids																
[1]Feathers tracts	Lys	Met + cys	Met	Cys	Thr	Val	Arg	Ile	Leu	His	Phe	Gly	Ser	Pro	Ala	Glu acid	Asp acid	Total
								1 d										
Natal down	11.4	66.8	2.9	64.0	39.6	62.0	73.0	41.7	70.6	15.2	50.4	67.5	105	90.8	30.3	84.3	64.1	872
								28 d										
Capital-cervical	20.1	71.3	4.8	66.5	42.8	65.1	60.9	42.2	68.8	7.2	42.0	61.4	97.6	91.5	35.7	93.9	61.5	862
Interscapular	17.2	70.2	4.5	65.7	42.6	68.0	63.7	45.7	69.6	6.1	42.9	61.9	103	92.9	35.9	94.7	60.4	875
Dorso-pelvic	18.1	69.6	4.7	64.8	42.6	67.4	63.9	45.5	70.0	6.3	43.0	62.1	103	93.1	36.5	95.0	60.4	877
Pectoral	18.7	71.3	4.6	66.6	42.7	64.6	62.0	42.9	67.7	6.6	41.6	60.8	98.5	91.1	35.0	92.4	60.9	857
Femoral	18.5	72.4	4.7	67.6	43.0	67.2	63.6	45.2	69.8	6.6	43.1	62.4	102	94.5	35.7	95.2	61.5	881
Humeral-alar	17.6	71.9	4.3	67.6	42.9	67.6	62.2	41.4	73.4	5.5	43.4	66.1	102	93.6	41.9	94.0	62.8	886
Dorso-caudal	16.1	71.8	4.2	67.6	42.9	67.6	61.6	42.5	71.2	5.7	43.3	64.0	102	93.6	38.5	94.2	62.3	877
Mean	18.0	71.2	4.5	66.6	42.8	66.8	62.6	43.6	70.1	6.3	42.8	62.7	101	92.9	37.0	94.2	61.4	874
								70 d										

Capital-cervical	11.7	74.8	3.0	71.7	43.6	69.4	64.7	44.2	70.0	4.3	43.0	63.6	110	97.4	35.2	90.3	58.6	881
Interscapular	12.4	70.7	3.4	67.3	42.4	71.1	64.8	46.8	72.5	4.4	44.4	65.8	113	97.0	38.0	93.4	58.1	895
Dorso-pelvic	12.3	71.6	3.3	68.3	42.6	71.8	65.2	47.6	71.8	4.1	43.8	65.0	113	97.6	36.9	92.6	56.9	893
Pectoral	11.1	71.4	3.0	68.3	42.5	71.7	63.8	46.7	73.0	3.9	43.8	66.4	114	98.8	38.6	91.2	56.9	894
Femoral	13.2	68.2	3.5	64.7	42.0	72.1	63.5	48.9	71.5	4.5	43.7	64.5	112	97.8	37.2	93.3	56.2	889
Humeral-alar	9.9	71.8	2.7	69.1	42.5	72.5	62.1	41.5	79.4	3.4	45.3	72.9	113	98.7	47.6	91.1	61.2	913
Dorso-caudal	12.8	73.2	3.4	69.7	43.0	71.3	62.2	43.5	73.7	4.5	44.8	67.2	108	97.5	40.6	94.8	62.4	900
Mean	11.9	71.7	3.2	68.4	42.7	71.4	63.8	45.6	73.1	4.2	44.1	66.5	112	97.8	39.2	92.4	58.6	895

[1]Values correspond to the pool of 10 feather samples

Table 7. Mean protein (g/kg dry matter) and water content (g/kg) of feathers and pulp moulted by male and female Cobb and Ross broilers

	Cobb		Ross			Cobb		Ross			
	Male	Female	Male	Female		Male	Female	Male	Female		
	Protein (g/kg)				Mean	Water (g/kg)				Mean	S.E.M
Type	Moulted feathers										
Natal Down	638	664	648	648	650	127	123	157	132	135	-
Contour	850	817	823	873	841	137	141	145	123	136	-
Remiges	917	893	891	906	902	112	123	117	115	117	-
Rectrices	842	857	864	851	853	139	131	135	139	136	-
Mean	812	808	807	820	812	129	130	139	127	131	
Age, d	Pulp										
14	863	864	852	874	863	861	866	861	864	863	1.20
28	922	902	838	832	874	887	899	881	897	891	1.32
42	826	813	809	834	821	894	894	895	894	894	1.19
56	807	845	819	859	833	904	895	893	876	892	2.78
70	903	821	823	840	847	916	903	894	899	903	1.61

84	837	837	806	830	828		882	898	881	904	891	2.13
98	818	821	821	803	816		901	912	906	918	909	1.36
112	804	788	797	797	797	-	912	913	903	899	906	1.59

Table 8. Amino acid composition (g/kg of feather protein) of moulted contour feathers, remiges, rectrices and pulp from Cobb males

	Amino acids																	
[1]Feather types	Lys	Met + cys	Met	Cys	Thr	Val	Arg	Ile	Leu	His	Phe	Gly	Ser	Pro	Ala	Glu acid	Asp acid	Total
	Moulted feathers																	
Contour	12.1	74.5	3.4	71.1	43.4	71.6	64.1	44.6	75.4	4.0	44.6	69.3	116	101	41.1	91.1	58.8	911
Remiges	10.5	67.4	3.0	64.4	38.9	68.6	56.4	35.2	79.1	3.4	42.9	75.1	105	91.6	52.5	86.6	60.7	874
Rectrices	12.7	67.1	3.8	63.3	39.7	66.5	57.5	37.5	74.6	4.1	42.1	68.6	102	88.0	45.4	88.1	60.1	854
Mean	11.8	69.7	3.4	66.3	40.7	68.9	59.3	39.1	76.4	3.8	43.2	71.0	107	93.5	46.3	88.6	59.9	880
[2]Age	Pulp																	
28 d	37.0	47.4	10.4	37.0	35.9	49.7	53.9	34.4	61.7	11.7	34.0	50.0	61.1	55.3	38.8	94.9	62.4	728
70 d	37.9	40.4	11.4	29.0	32.8	43.3	52.3	31.2	57.5	11.9	31.4	53.1	52.1	50.5	39.5	93.2	61.3	688

[1]Values correspond to the pool of 20 feather samples

[2]Values correspond to the pool of 10 pulp samples

Table 9. The content of essential amino acids (g/kg feather protein) of feathers as reported by various authors

Amino acid	Nitsan[1] 1981	Hurwitz[2] 1983	Fisher[3] 1981	Stilborn[4] 1997	This study[5]
Arg	61	72	78	67	71
Cys	67	84	69	75	76
His	8	7	10	7	6
Ile	37	50	50	46	50
Leu	66	81	90	79	81
Lys	18	19	24	20	17
Met	5	7	6	7	4
Phe	40	51	54	47	49
Thr	42	46	53	48	48
Val	57	77	84	62	78

[1] Nitsan et al. (1981)

[2] Hurwitz et al. (1983)

[3] Fisher et al. (1981)

[4] Stilborn et al. (1997) mean of six observations spanning period from 14 to 112 d of age

[5] Mean of eight observations spanning period from 14 to 112 d of age