UNIVERSIDADE ESTADUAL PAULISTA
CÂMPUS DE JABOTICABAL

DINÂMICA DA UTILIZAÇÃO DE ENERGIA EM MATRIZES DE FRANGO DE CORTE AO LONGO DO PERÍODO DE POSTURA

Guilherme Ferreira da Silva Teofilo
Zootecnista

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IMPACTO POTENCIAL DESTA PESQUISA

Em torno de 70% dos custos de produção na criação avícola é destinado á alimentação. Logo, obter estimativas mais acuradas das exigências energéticas das matrizes de corte permitirá um maior desempenho das aves e a redução dos custos de alimentação, associado ao menor impacto ambiental. Este estudo caracterizou a dinâmica de utilização energética e como as reprodutoras particionam a energia ingerida para mantença, deposição de tecidos corporais e para produção de ovos ao longo de todo ciclo produtivo, permitindo propor estratégias nutricionais e programas alimentares para diferentes condições práticas, possibilitando uma melhora no desempenho produtivo, reprodutivo e no bem-estar das aves.

Como impacto científico, esse conhecimento facilitará a implementação do sistema de energia líquida em matrizes de frangos de corte, o sistema mais acurado da partição energética. Esses achados têm o potencial de tornar a produção de matrizes de corte mais sustentável e com redução dos impactos ambientais sem deixar de lado a excelente produtividade, contribuindo com os Objetivos de Desenvolvimento Sustentável (ODS) 2 (fome zero e agricultura sustentável), 12 (consumo e produção responsáveis), 13 (ação contra mudança global do clima) e 15 (vida terrestre).

POTENTIAL IMPACT OF THIS RESEARCH

Around 70% of production costs in poultry industry are used for feed. Therefore, obtaining more accurate estimates of the energy requirements of the broiler breeders will allow for greater bird performance and a reduction in feed costs, associated with a lower environmental impact. This study determined the dynamics of energy utilization and how the broiler breeders partition the energy intake for maintenance, deposition of body tissues and for egg production throughout the production cycle, allowing to propose nutritional strategies and feeding programs for different practical conditions, enabling an improvement on the productive, reproductive performance and welfare of the birds.

As a scientific impact, this knowledge will facilitate the implementation of the net energy system in broiler breeders, the most accurate system of energy partition. These findings have the potential to make the production of broiler breeders more sustainable and reduce environmental impacts without neglecting excellent productivity, contributing to the Sustainable Development Goals (SDG) 2 (zero hunger and sustainable agriculture), 12 (responsible consumption and production), 13 (action against global climate change) and 15 (land life).

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Câmpus de Jaboticabal

CERTIFICADO DE APROVAÇÃO

TÍTULO DA DISSERTAÇÃO: DINÂMICA DA UTILIZAÇÃO DE ENERGIA EM MATRIZES DE FRANGO DE CORTE AO LONGO DO PERÍODO DE POSTURA

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Kênia Cardoso Bícego

Jaboticabal, 27 de março de 2023

DADOS CURRICULARES

GUILHERME FERREIRA DA SILVA TEOFILO, filho de Solange Maria da Silva e Silvio Ferreira da Silva Teófilo, nascido no dia 11 de maio de 1998 em Diadema, São Paulo. Em 2016, ingressou no curso de Zootecnia na Universidade Estadual Paulista – "Júlio de Mesquita Filho" (UNESP) – Faculdade de Ciências Agrarias e Veterinárias, Campus de Jaboticabal. Em outubro de 2020 obteve o título de Zootecnista. Durante esse período realizou iniciação cientifica com bolsa financiada pela FAPESP, sob orientação da Prof.ª Dr.ª Nilva Kazue Sakomura. Em outubro de 2020 iniciou o curso de mestrado em zootecnia no programa de pós-graduação da mesma universidade, com bolsa financiada pela FAPESP e sob orientação da referida professora, submetendo-se à defesa da dissertação em março de 2023.

Dê um Rolê
Gal Costa

Não se assuste pessoa
Se eu lhe disser que a vida é boa
Enquanto eles se batem
Dê um rolê e você vai ouvir
Apenas quem já dizia
Eu não tenho nada
antes de você ser eu sou
Eu sou, eu sou, eu sou amor
Da cabeça aos pés
Eu sou, eu sou, eu sou amor
Da cabeça aos pés
E só tô beijando o rosto de quem dá valor
Pra quem vale mais o gosto do que cem mil réis
Eu sou, eu sou, eu sou amor
Da cabeça aos pés

(Moraes Moreira e Luiz Galvão, 1971)

À Deus

À minha avó Venera

Aos meus pais Solange e Silvio

À minha irmã Mariana e meu sobrinho Derick

A vocês, dedico

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CEUA – COMISSÃO DE ÉTICA NO USO DE ANIMAIS

CERTIFICADO

Certificamos que o projeto de pesquisa intitulado **"Efeito do nível prévio de alimentação sobre fasting heat production e descrição do metabolismo energético ao longo da fase de postura em matrizes de corte"**, protocolo nº 5398/20, 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 10 de dezembro de 2020.

Vigência do Projeto	07/01/2021 a 19/06/2021
Espécie / Linhagem	*Gallus gallus domesticus* / Cobb 500
Nº de animais	300
Peso / Idade	3100 g / 21 semanas
Sexo	Fêmeas
Origem	Cobb – Vantress, Guapiaçu - SP

Jaboticabal, 10 de dezembro de 2020.

Fabiana Pilarski

Profa. Dra. Fabiana Pilarski
Coordenadora – CEUA

Faculdade de Ciências Agrárias e Veterinárias
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DINÂMICA DA UTILIZAÇÃO DE ENERGIA EM MATRIZES DE FRANGO DE CORTE AO LONGO DO PERÍODO DE POSTURA

RESUMO

Compreender a dinâmica de utilização energética em matrizes de corte permite propor estratégias nutricionais e melhorarias no desempenho reprodutivo. Baseado nisso, o presente estudo objetivou descrever a utilização e o particionamento da energia ingerida em matrizes de corte durante o período de postura e propor modelos de exigências de energia. Para tal, foram conduzidos dois ensaios experimentais utilizando matrizes de corte da linhagem Cobb 500. O primeiro ensaio teve como objetivo fracionar a energia ingerida em: mantença e energia retida (**ER**) no corpo e no ovo. Foram utilizadas 50 aves de 27 a 63 semanas de idade, sendo 5 aves avaliadas a cada 4 semanas. Cada ave foi alojada individualmente em câmaras respirométricas e alimentada com base nas recomendações do guia de manejo. A produção total de calor total (**PCT**) e em jejum (**PCJ**) foram calculadas pela equação de Brouwer. O consumo de ração (**CR**), excretas produzidas e a massa de ovo (**MO**) foram registrados diariamente. Ao final desse período a composição corporal das aves foi estimada pelo **DEXA**. Os dados foram analisados em função da idade por meio de regressões lineares ($P \leq 0{,}05$). O segundo ensaio objetivou determinar a utilização energética e propor modelos de exigências. Foram utilizadas 60 aves de 29 a 65 semanas de idade, sendo 6 aves avaliadas a cada 4 semanas. Oito dias anteriores às medições, as aves foram adaptadas a três níveis de ingestão energética e em seguida, as aves foram alojadas em câmaras respirométricas. O **CR**, peso corporal, **MO** e coleta de excretas foram realizados diariamente. Ao final das avaliações de respirometria, as aves foram eutanasiadas para mensuração da massa visceral. Para avaliar o efeito da idade e energia metabolizável ingerida (**EMAi)** nos dados do balanço energético foi ajustada uma regressão multifatorial. Além disso, foi realizada a correlação de Pearson entre a massa visceral e os parâmetros do metabolismo energético. Para obter a exigência de energia metabolizável (**EM**) e líquida (**EL**), quatro modelos mistos foram ajustados, incluindo ou não o efeito de idade. Para o primeiro ensaio o **CR** e consequentemente o **EMAi** foram decrescentes com o avanço da idade ($P<0{,}001$), com maiores valores durante pico de produção (31 e 35 semanas). Não houve efeitos significativos ($P>0{,}05$) da idade na **PCJ**, **PCT** e incremento calórico. A **MO** e o **ER** no ovo como gordura e proteína foram constantes ao longo das idades ($P>0{,}05$), enquanto o **ER** no corpo como proteína aumentou linearmente ($P=0{,}0011$) conforme as aves envelheceram. A maior **EMAi** no pico de produção resultou em aumento da **ER** como gordura no corpo ($P<0{,}0001$). Para o segundo ensaio, os resultados mostraram que a **PCJ** (259 $kJ/kg^{0,75}$*d) permaneceu constante durante todo o ciclo de produção independente do nível de **EMAi** ($P>0{,}05$). A **PCJ** e o **PCT** apresentaram correlação positiva com os órgãos digestivos e reprodutivos ($P<0{,}05$). A eficiência de utilização de energia para depositar proteína e gordura no corpo mudou com a idade da ave. Os modelos de **EL** e **EM** desconsiderando o efeito da idade apresentou menor erro. As eficiências de utilização de energia foram 0,89; 0,78 e 0,80 para mantença, ganho e produção de ovos, respectivamente. O modelo de **EL** não foi afetado pela idade e apresentou menor erro quando comparado ao de **EM**. Conclui-se que para matrizes de corte a **EMAi** é usada principalmente para suportar a demanda de **EL** para mantença e produção de ovos, e o restante é depositado nos tecidos corporais em maior eficiência como gordura, enquanto a **ER** como proteína no corpo aumenta com a idade da ave. Os modelos mistos são viáveis para construir modelos de recomendações energéticas para os sistemas de **EM** e **EL,** sendo a **EL** mais acurada em expressar as exigências energéticas de matrizes pesadas.

Palavras-chave: energia líquida, energia para mantença, balanço energético, balanço de nitrogênio, calorimetria indireta

DYNAMICS OF ENERGY USE IN BROILER BREEDERS DURING THE LAYING PERIOD

ABSTRACT

Understanding the dynamics of energy utilization in broiler breeders allows proposing nutritional strategies and improvements in reproductive performance. Based on this, the present study aimed to describe the utilization and partitioning of energy intake in broiler breeders during the laying period and to propose models of energy requirements. For this purpose, two experimental trials were carried out using Cobb 500 broiler breeders. The first trial aimed to partitioning the energy intake into: maintenance and retained energy (**RE**) in the body and in the egg. Fifty birds from 27 to 63 wks of age were used, with 5 birds evaluated every 4 wks. Each bird was individually housed in respirometric chambers and fed based on the guideline recommendations. Total heat production (**THP**) and fasting (**FHP**) were calculated using the Brouwer equation. Feed intake (**FI**), excreta produced, and egg mass (**EM**) were recorded daily. At the end of this period, the body composition of the birds was estimated by DEXA. Data were analyzed as a function of age using linear regressions (P≤0.05). The second trial aimed to determine energy utilization and propose models of energy requirements. Sixty birds from 29 to 65 weeks of age were used, with 6 birds evaluated every 4 wks. Eight days prior to the measurements, the birds were adapted to three levels of energy intake. Then, the birds were housed in respirometric chambers. The **FI**, body weight, **EM** and excreta collection were performed daily. At the end of the respirometry evaluations, the birds were euthanized to measure the visceral mass. To assess the effect of age and apparent metabolizable energy intake (**AMEi)** on energy balance data, a multifactor regression was fitted. In addition, Pearson's correlation between visceral mass and parameters of energy metabolism was performed. To obtain metabolizable (**ME**) and net (**NE**) energy requirements, four mixed models were fitted, including, or not including the effect of age. For the first trial, the **FI** and consequently the **AMEi** decreased with the age of the birds (P<0.001), with higher values during peak production (31 and 35 wks). There were no significant effects (P>0.05) of age on **FHP**, **THP** and heat increment. The **EM** and **RE** in the egg as fat and protein were constant across ages (P>0.05), while **RE** in the body as protein increased linearly (P=0.0011) as the birds aged. Higher **AMEi** at peak production resulted in increased **RE** as body fat (P<0.0001). For the second trial, the **FHP** (259 kJ/kg0.75*d) remained constant throughout the production cycle regardless of the **AMEi** level (P>0.05). The **FHP** and **THP** showed a positive correlation with digestive and reproductive organs (P<0.05). The efficiency of energy utilization to deposit protein and fat in the body changed with bird age. The **NE** and **ME** models disregarding the effect of age showed the lowest error. Efficiencies of energy utilization were 0.89; 0.78 and 0.80 for maintenance, gain and egg production, respectively. The **NE** model was not affected by age and presented a smaller error when compared to the **ME**. It is concluded that for broiler breeders **AMEi** is mainly used to support the **NE** demand for maintenance and egg production, and the remainder is deposited in body tissues more efficiently as fat, while **RE** as protein in the body increases with the age of the bird. Mixed models are feasible to build energy recommendation models for **ME** and **NE** systems, with **NE** being more accurate in expressing the energy requirements of broiler breeders.

Keywords: net energy, energy for maintenance, energy balance, nitrogen balance, indirect calorimetry

CAPÍTULO 1 – CONSIDERAÇÕES GERAIS

1.1. Introdução

O aumento na demanda de proteína animal em função do aumento da população mundial caracterizou uma oportunidade para a produção de frangos de corte, por ser uma fonte de proteína de menor custo, de rápida obtenção e acessível ao consumidor de diversos perfis econômicos e sociais. No Brasil, nos últimos dez anos o volume da produção de carne de frango aumentou aproximadamente 15%, posicionando o Brasil como o maior exportador e terceiro maior produtor de carne de frango no mundo (ABPA, 2022). Com o aumento na demanda de carne de frango, houve necessidade de aumentar a produção e eficiência reprodutiva das matrizes de corte, a partir de melhorias genéticas, sanitárias e nutricionais (Furtado et al., 2011).

A seleção genética para aumentar a taxa de crescimento dos frangos de corte promoveu aumento no consumo de ração, peso corporal e na deposição de gordura nas galinhas reprodutoras. Em aves domésticas o aumento na deposição de gordura leva a redução da produção de ovos, fertilidade e eclodibilidade (Pearson e Herron, 1981). Nesse sentido, programas de restrição alimentar são comumente usados para limitar a ingestão de energia e nutrientes (Renema e Robinson, 2004; Salas et al., 2019), controlando a excessiva deposição de gordura e seus efeitos deletérios na reprodução.

Na nutrição comercial de aves, a formulação das dietas é baseada no sistema de energia metabolizável (**EM**), no entanto este sistema apresenta certas limitações. Ao longo dos anos foi proposto que o sistema de energia líquida (**EL**) seria o sistema de energia mais acurado para expressar tanto o valor energético do alimento, quanto as exigências do animal, pois permite quantificar as perdas energéticas decorrente dos processos digestivos, absortivos e metabólicos, denominado incremento calórico (**IC**) (Noblet, 2007). Com base na abordagem fatorial, as exigências de **EL** são divididas em mantença e produção, de modo que a mantença é atribuída à produção de calor em jejum (**PCJ**) ou gasto energético destinado as funções essenciais do organismo, enquanto a energia para produção é atribuída a energia bruta retida nos tecidos e/ou massa de ovo (Zuidhof, 2019). A **PCT** e a **PCJ** podem ser obtidas por meio da técnica de calorimetria indireta (**CI**), utilizada para determinar o consumo de oxigênio e produção de dióxido de carbônio em câmaras respirométricas, permitindo calcular a produção de calor (**PC**) e quociente respiratório (**QR)** (Brouwer, 1965; Spratt et al., 1990; Caldas et al., 2018). O princípio do cálculo da **PC** usando calorimetria indireta se baseia na relação estequiométrica da oxidação dos nutrientes durante o metabolismo animal.

Ao longo dos anos, grande parte dos estudos sobre metabolismo e utilização energética foram desenvolvidos principalmente em frangos de corte no sistema **EM**, e seus resultados têm sido aplicados para outras categorias de aves (NRC, 1994). No entanto, sabe-se que existem diferenças no aproveitamento de energia entre as diferentes categorias comerciais de aves. Estas diferenças estão associadas com idade, sexo, nível de produção, nível prévio de alimentação, genética, etc. (Zelenka, 1968), sendo necessário contrastar os resultados obtidos em aves em crescimento com outras categorias de aves de produção, permitindo futuras melhorias na nutrição comercial de aves. Em matrizes de corte, poucos estudos investigaram a partição da energia com base na **EM**, e, estudos com base na **EL** são ainda mais escassos. O presente estudo teve como objetivo descrever a dinâmica do particionamento e da utilização da energia ingerida para mantença, deposição de tecidos e produção de ovos, bem como as exigências energéticas de matrizes de corte durante o período de postura.

1.2. Matrizes de corte: alimentação, crescimento e reprodução

As reprodutoras de frango de corte foram selecionadas ao longo dos anos para expressarem alto potencial genético de ganho de peso e rápido crescimento para transmitir essas caraterísticas fenotípicas para sua progênie, concomitantemente com uma alta eficiência reprodutiva para produção de ovos férteis, promovendo aumento na produção de pintos viáveis (Zuidhof et al., 2007). Estudos demonstraram que em matrizes de frango de corte há uma relação negativa entre gordura corporal e eficiência reprodutiva, associada a ovulações múltiplas causada pela presença de mais de uma hierarquia de folículos ovarianos amarelos (Hocking et al., 1989; Robinson e Robinson, 1991), caracterizando um complexo dilema entre o rápido crescimento e saúde/reprodução (Decuypere et al., 2010). A principal estratégia utilizada na criação de matrizes de corte para o controle da excessiva deposição de gordura e das desordens reprodutivas, são os programas de restrição alimentar durante a fase de recria e produção de ovos (Decuypere et al., 2010).

A restrição alimentar (**RA**) consiste em limitar o acesso livre ao alimento, fornecendo quantidades de ração inferiores ao consumo voluntário, evitando o excessivo consumo de energia e reduzindo a deposição de gordura. O fornecimento controlado de nutrientes e de energia exige maior atenção quando comparado com a formulação de rações para aves sob alimentação *ad libitum*, pois sob **RA**, as aves não são capazes de regular a ingestão de ração para suprir as exigências de energia, caso ocorram falhas na formulação e preparação da dieta (Noblet, 2007). Vários sistemas de **RA** são amplamente conhecidos e aplicados de acordo com o peso das aves e homogeneidade do plantel, seguindo os padrões determinados pelos manuais das linhagens para a obtenção de uma boa performance reprodutiva.

Por outro lado, a alimentação *ad libitum* em matrizes de corte leva a um aumento do peso corporal e da gordura abdominal (Leksrisompong et al., 2014), responsável pelo aumento da mortalidade e redução do número de ovos férteis (Hocking et al., 1987), redução do início da postura (maturidade sexual) e da taxa de postura, além ocorrer uma estabilização do peso corporal após atingirem a maturidade sexual (Heck, et al., 2004). No entanto, matrizes de frango de corte alimentadas sob **RA** apresentam maior eficiência reprodutiva e um aumento gradual no peso corporal mesmo após o início da postura de ovos (maturidade sexual), explicado pela deposição lipídica e proteica (Zuidhof, 2020; Heck, et al., 2004). Deste modo durante a fase produtiva, as reprodutoras pesadas sob **RA** demandam energia para produção de ovos, crescimento e para mantença, diferentemente de outras categorias de aves adultas em fase de produção alimentadas *ad libitum,* tornando ainda mais dinâmica a utilização de energia (Rivera-Torres et al., 2011; Zuidhof, 2020).

1.3. Metabolismo energético

O metabolismo pode ser definido como o conjunto das reações químicas catalisadas por enzimas em diversas vias metabólicas (Lehninger et al. 2019). Esses processos metabólicos são responsáveis por converter a energia contida nos alimentos em moléculas energéticas (ATP, GTP etc.), sendo eles processos catabólicos ou anabólicos. O catabolismo corresponde aos processos de degradação e liberação de energia, enquanto o anabolismo corresponde a biossíntese, onde precursores simples formam moléculas maiores, necessitando de energia para que as reações ocorram (Lehninger et al., 2019).

Na criação de aves, a fonte de energia é proveniente da dieta que é composta por um conjunto de ingredientes, capazes de fornecer nutrientes (carboidratos, proteínas e lipídios). Estes, por sua vez, são digeridos, absorvidos e utilizados a nível metabólico, permitindo assim a utilização da energia neles contida (Lehninger et al., 2019). A energia química presente nas ligações destas macromoléculas é liberada através de processos oxidativos, e armazenada entre as ligações dos grupos fosfato do ATP para ser usado como fonte de energia em contrações musculares, transporte ativo de íons, síntese de macromoléculas e outras biomoléculas (Haynie, 2001). Portanto, a energia não pode ser definida como um nutriente, mas sim como uma propriedade da oxidação dos nutrientes durante os processos metabólicos (NRC, 1994).

A energia obtida dos alimentos é liberada em três etapas principais, como mostra a **Figura 1**. A primeira etapa está relacionada com os processos digestivos, em que ocorre a quebra de macromoléculas em unidades menores, proteínas em peptídeos e aminoácidos, polissacarídeos em monossacarídeos e gorduras em glicerol e ácidos graxos; esses monômeros são absorvidos pelo intestino e distribuídos por todo o corpo para serem utilizados em processos metabólicos (McDonald et al., 2010). A segunda etapa (Figura 1) ocorre no citoplasma celular, onde a maioria dos açúcares, ácidos graxos, glicerol e aminoácidos são convertidos em acetil-CoA, para serem usados no ciclo do ácido cítrico na matriz mitocondrial, onde uma pequena quantidade de ATP é gerada bem como transportadores de elétrons reduzidos (NADH, NADPH e $FADH_2$). A terceira etapa ocorre na membrana mitocondrial, onde o ATP é sintetizado a partir dos transportadores de elétrons através do ciclo da fosforilação oxidativa (Lehninger et al., 2019). Kleiber (1932) propôs que o metabolismo energético animal ocorre muito similar a combustão, de modo que, ambas reações consomem oxigênio (O_2) do ar e liberam dióxido de carbono (CO_2), água (H_2O) e calor.

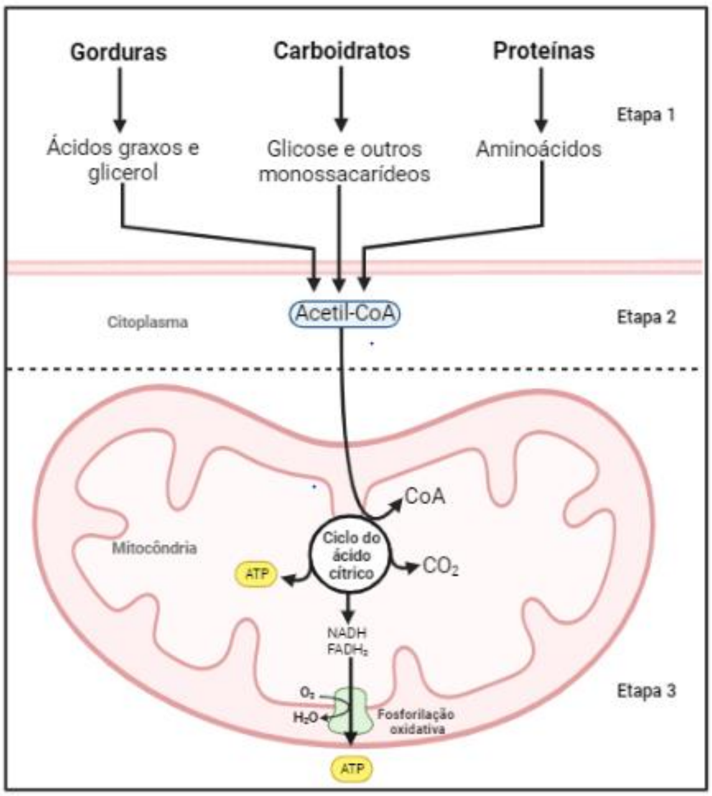

Figura 1. Etapas da extração de energia dos alimentos (Adaptado de Berg et al., 2012).

Todos os processos que ocorrem no metabolismo energético seguem o princípio da lei de conservação da energia, que para qualquer mudança física ou química a quantidade total de energia se mantém, e que a energia pode apenas mudar de forma, isto significa que a energia ingerida pelo animal é transformada e depositada como tecido, utilizada para desenvolver trabalho celular e dissipado como calor para o meio externo (Speakman, 2013). O conhecimento desses princípios, permitiu quantificar o potencial calórico dos compostos orgânicos por meio da técnica de calorímetros adiabáticos, que se baseia no princípio da combustão total e mensurar a produção de calor em ensaios biológicos por meio de diferentes métodos experimentais.

1.3.1. Partição da energia

Baseado na lei da conservação da energia, o aproveitamento energético pelos animais pode ser estudado considerando as percas de energia durante os processos absortivos, digestórios e do metabolismo dos nutrientes, o que determina o potencial de cada nutriente em disponibilizar energia (McDonald et al. 2010).

Como esquematizado na **Figura 2**, a energia química total dos alimentos é mensurada pela sua combustão completa em bomba calorimétrica, sendo denominada como energia bruta (**EB**), dependendo apenas da composição química do alimento. A energia digestível (**ED**) representa a energia do alimento que foi absorvida após o processo de digestão, calculada pela diferença entre **EB** do alimento ingerido e **EB** das fezes. A energia metabolizável aparente (**EMA**) refere-se à **ED** menos a energia perdida na urina e nos gases. Considerando que a energia perdida na forma de gases é muito baixa em aves, esse valor tem sido desprezado no cálculo da **EM** (Sakomura e Rostagno, 2016).

A **EMA** somada as perdas de energia fecal metabólica e urinaria endógena, resulta na energia metabolizável verdadeira (**EMV**). A **EM** pode ser corrigida para uma situação de zero retenção de nitrogênio, esse cálculo se baseia no fato de que, para aves em crescimento, a proteína é depositada como tecido e não é catabolizada e excretada, não contribuindo para perda de energia nas excretas (Sibbald, 1982).

Durante o processo de digestão, absorção e metabolismo do alimento ingerido, há um aumento na produção de calor total (**PCT**), esse aumento é denominado **IC** (Sakomura e Rostagno, 2016). O **IC** é calculado pela diferença entre a **PCT** e a **PCJ**, o qual depende exclusivamente do consumo e da natureza do alimento. A **EL** é obtida pela **EM** menos a energia perdida como **IC**, e representa a quantidade de energia que está disponível para fins úteis, como mantença, crescimento e produção (ovos). O sistema de **EL** para aves em postura, a energia é particionada em mantença (**ELm**) e produção (**ELp**). A **ELm** é geralmente estimada por meio da **PCJ** enquanto a **ELp** é determinada mensurando a energia depositada nos ovos e tecidos, também chamado de energia retida (**ER**) (Sakomura e Rostagno, 2016).

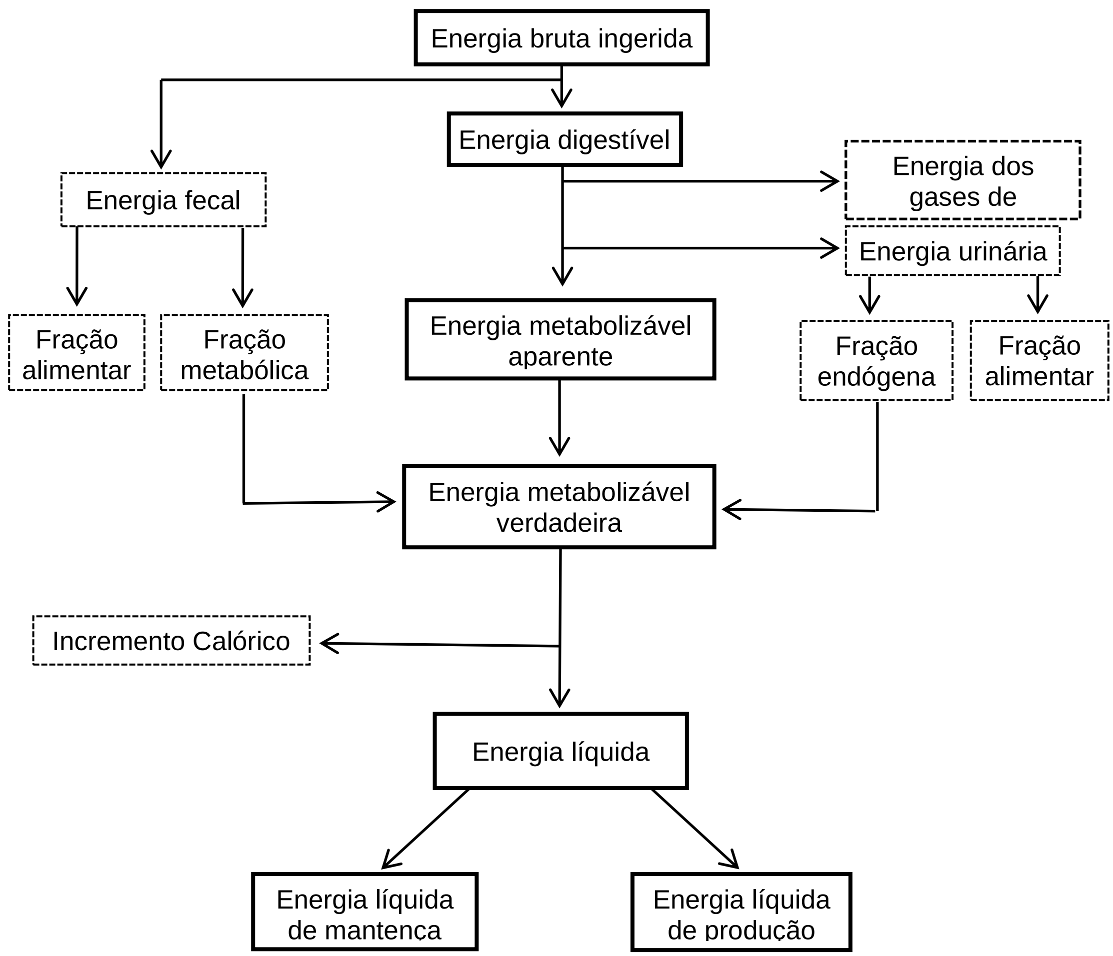

Figura 2. Partição da energia ingerida (Adaptado de Sibbald, 1982)

1.3.2. Sistema de energia metabolizável

A **EM** é atualmente o sistema de energia mais utilizado na nutrição comercial de aves, tanto para avaliação do valor energético dos alimentos, quanto para descrever as necessidades energéticas dos animais. Como descrito previamente, a **EM** é calculada pela diferença entre a **EB** do alimento consumido e a **EB** das excretas (NRC, 1994; Sakomura e Rostagno, 2016).

Para estudar o metabolismo energético, o conhecimento das exigências nutricionais é muito importante, podendo ser determinada através do método dose resposta (teste de níveis), na qual a necessidade de energia está relacionada aos critérios de desempenho da ave, como o nível ótimo para uma resposta máxima. Uma outra abordagem é o método fatorial, que se baseia na suposição aditiva dos componentes, onde as exigências de energia são separadas em mantença (manutenção dos processos vitais), crescimento e produção (Sakomura e Rostagno, 2016). Com base na abordagem fatorial as exigências energéticas das aves podem ser mensuradas usando a técnica do abate comparativo para a determinação da retenção de tecido corporais em um período, e a calorimetria indireta para a determinação da produção de calor.

A energia metabolizável de mantença é definida como a quantidade de energia para manter um equilíbrio dinâmico de renovação de proteína e gordura, para manter uma temperatura corporal constante e um nível “normal” de locomoção (Chwalibog, 1985), ou seja, quando o balanço de energia em cada um desses componentes é igual a zero. Enquanto a energia requerida para produção é dividida entre crescimento e produção de ovos, no caso de aves em postura.

Usando a técnica dos ensaios de níveis de alimentação, calorimetria indireta e abate comparativo, determina-se de forma direta ou indireta o balanço energético/**ER** das aves, sendo obtido pela equação

$$\mathbf{ER = EMi - PC}$$

Onde, **ER** é energia retida, **EMi** é a energia metabolizável ingerida e **PC** é a produção de calor.

Apesar de ser amplamente utilizado na avicultura, o sistema de **EM** apresenta algumas imprecisões. Os valores de **EM** dos ingredientes que aparecem nas tabelas de composições nutricionais podem não refletir exatamente os teores energéticos de diferentes amostras de ingredientes (Moscoso Muñoz, 2021), bem como o valor de **EM** dos alimentos é afetado por diversos fatores, como forma e composição da dieta (Wu et al., 2019), taxa crescimento (Garnsworthy et al., 2000), aptidão zootécnica e idade das aves, acarretando diferentes valores de energia para cada ingrediente em função do estado fisiológico e das particularidades animal (Lopez e Leeson, 2005; Cozannet et al., 2010). Além de não considerar as perdas de energia decorrentes dos processos digestivos e metabólicos, denominado **IC**.

Quando se considera as perdas de energia por **IC** no sistema de **EM**, surge o sistema de **EL**, que é preconizado como o sistema mais acurado para expressar o valor energético dos ingredientes, pois leva em consideração as diferenças na utilização da **EM** entre os nutrientes e o efeito térmico da dieta (Van Milgen et al., 1997).

1.3.3. Sistema de energia líquida

A **EL** é o sistema que mais se aproxima do “verdadeiro teor energético dos alimentos e das necessidades energéticas dos animais” (Noblet, 2007), pois leva em consideração as diferenças na utilização da **EM** entre os nutrientes e o **IC** da dieta (Van Milgen et al., 1997). Portanto o sistema de **EL** representa um método potencial na formulação dietas de forma mais acurada, otimizando o uso dos recursos (ingredientes) e favorecendo a uma maior flexibilidade na formulação de dietas mais eficientes.

No sistema de **EL** para aves em postura, e com base na proposta fatorial a energia é particionada em **ELm,** e produção de ovos e deposição de tecidos (**ELp**). A **ELm** é a energia utilizada para manter as funções vitais dos animais (Noblet, 2007) e é geralmente estimada por meio da **PCJ**. A mensuração da **ELm** influência de forma direta nos valores absolutos de **EL** e, consequentemente no valor de **EL** dos alimentos e ingredientes. Infelizmente, **ELm** não pode ser determinada diretamente, e os métodos indiretos são bastante caros e dispendiosos.

A **ELm** pode ser estimada a partir de níveis de alimentação, e estabelecer o intercepto entre a energia ingerida e a **PC**, correspondente ao calor produzido ao nível de ingestão energética igual a zero, estimando assim a **PC** para manter as funções vitais (Liu et al., 2014). Essa metodologia tem sido questionada em estudos com bovinos, pois assume linearidade do efeito da ingestão de energia sobre a **PC**, sendo essa uma tendência não linear (Labussiere et al., 2011), além disso, estudos com suínos em crescimento demonstraram que o nível prévio de alimentação tem efeito sobre o **PCT** (Labussiere et al., 2007). Nesse sentido, é de suma importância avaliar os fatores que afetam a determinação da exigência energética de mantença para estabelecer de forma correta o valor do **PCJ** ou **ELm** (Kleiber, 1961).

A **ELp** denominada como energia retida, representa a energia ingerida que é utilizada para crescimento e produção (NRC, 1994). A **ER** no corpo predominantemente como proteína e gordura, pode ser medida através da técnica do abate comparativo (Koh e Macleod, 1999; Sakomura e Rostagno, 2016). Enquanto a **ER** nos ovos pode ser mensurada por meio de calorímetros adiabático. Na literatura existem alguns estudos de determinação das necessidades de **EL** para galinhas de postura, frangos de corte e suínos (Noblet, 2007; Liu et al., 2014; Noblet et al., 2015; Wu et al., 2019), no entanto poucos estudos avaliam o aproveitamento de energia baseado no sistema **EL** em matrizes pesadas (Caldas et al., 2018). A medição do **IC** é fundamental para determinar os valores de **EL** dos alimentos e as exigências dos animais.

1.3.4. Eficiências de utilização energética

A eficiência de utilização energética (**k**) se refere a proporção da **EM** ingerida que foi efetivamente usada para mantença, deposição de tecido e produção de ovos no sistema de **EL** (Sakomura e Rostagno, 2016). Baseado nesse conceito, parte da **EM** ingerida é retida no corpo e ovos ou usada para funções de manutenção e outra fração é perdida como incremento calórico, a proporção aproveitada pela ave representa então a eficiência de conversão da **EM** da dieta em **EL** para mantença e produção (Blaxter, 1989).

A eficiência de utilização da **EM** para produção, foi definido por De Groote (1974) como o aumento na retenção de energia o qual ocorre para cada 100 kcal na ingestão de **EM**, podendo ser calculado como o quociente entre a retenção energético ou **ELp** pela **EMp**.

$$\boldsymbol{kp} = \frac{ELp}{EMp}$$

Enquanto a eficiência de utilização da **EM** para mantença podem ser expressas pela razão entre a **PCJ** sobre a exigência de **EMm**:

$$\boldsymbol{km} = \frac{ELm}{EMm}$$

Para matrizes de corte, seguindo este mesmo princípio podemos determinar a eficiência de utilização energética para ganho de tecido (**kg**) e para produção de ovos (**ko**). Além disso, a eficiência de ganho pode ser fracionada em tecido gorduroso ou proteico (**kgp** e **kgg** respectivamente) (Sakomura e Rostagno, 2016).

1.4. Produção de calor

A **PCT** de um animal representa a atividade metabólica do mesmo, como resultado do trabalho celular e do desenvolvimento das funções do organismo que demandam energia, podendo ser afetada pela temperatura ambiental, estado fisiológico do animal, comportamento, característica da alimentação e entre outros (McLean, 1987). A **PCT** pode ser particionada em diferentes componentes, sendo destinada para funções de mantença, como respiração, manutenção da temperatura corporal, atividade neuro simpática, manutenção do tônus muscular e fluxo sanguíneo, podendo ser denominada como o calor metabólico basal ou **PCJ**. A energia excedente consumida é depositada como tecido corporal ou produtos e uma fração liberada como **IC** (Zuidhof, 2019). O **IC** é definido como o efeito térmico decorrente dos processos de digestão, absorção e metabolismo dos nutrientes, sendo influenciada principalmente pelas caraterísticas físico-químicas da dieta. Nesse sentido, a **PCT** é particionada em **PCJ**, **IC** e a produção de calor associado à atividade física em um nível normal do animal (Zuidhof, 2019) que corresponde as condições de comportamento normais do indivíduo. A medição do calor produzido é geralmente realizada pelo método de calorimetria (McLean, 1987).

1.4.1. Produção de calor em jejum

A **PCJ** refere-se à mensuração da **PC** de um animal durante o estado metabólico de jejum, referindo-se ao catabolismo de reserva energética, principalmente das reservas de lipídeos do corpo para manter os processos metabólicos basais, ou seja, manter o animal vivo (Fernandez et al., 2012). O gasto energético para manter a taxa metabólica basal medido pela **PCJ** exige algumas condições especificas durante a sua mensuração, de modo que o animal deve estar com o mínimo de atividade física, em estado pós-absortivo, em condições de termoneutralidade e em fase circadiana inativa (Bennett e Harvey, 1987).

Labussiere et al. (2008) relata que a **ELm** determinada a partir da **PCJ** é independente da natureza da dieta, mas tem um efeito do nível prévio de alimentação, já que a atividade metabólica está relacionada com uma determinada quantidade de ração ingerida. Essa variação no metabolismo basal tem como fundamento a atividade da massa visceral, relacionada com a demanda energética para digerir, absorver e metabolizar os nutrientes ingeridos (De Lange et al., 2006; Labussiere et al., 2008). Alguns estudos já determinaram a **PCJ** para outras espécies (Noblet et al., 2015; Rivera-Torres et al., 2011; Barzegar et al., 2019), no entanto poucos estudos têm sido desenvolvidos com o propósito de determinar as exigências de **ELm** e o efeito do nível prévio de alimentação em matrizes em produção ao longo das idades.

1.4.2. Energia retida e composição corporal

Ao longo dos anos a seleção genética para aumentar o potencial de crescimento dos frangos de corte, resultou em mudanças na composição corporal (Decuypere et al., 2010). Essa intensa seleção não alterou somente a conversão alimentar, a taxa de crescimento e a composição corporal dos frangos de corte, também alterou as condições nutricionais, corporais e de eficiência das reprodutoras. As matrizes de corte modernas apresentam menos gordura e mais músculo peitoral do que em algumas décadas atrás, resultando em um atraso de maturidade e em uma maior necessidade de energia para manter esse tecido metabolicamente ativo (Heck et al., 2004; Decuypere et al., 2010).

Da energia ingerida, a quantidade excedente da destinada para manutenção dos processos vitais, é depositada no corpo na forma de tecido proteico, adiposo e em produtos, no caso de aves em fase de postura, o ovo (Sakomura e Rostagno, 2016). Esses acréscimos de tecido corporal associados com a produção de ovos refletem em variações na composição corporal das aves. Em matrizes de corte compreender como a **ER** e a composição corporal se comportam é importante, pois como abordado anteriormente o teor de gordura corporal impacta de forma negativa na eficiência reprodutiva e deve ser controlado durante o período de postura (Caldas et al., 2018).

Ao longo da vida reprodutiva das matrizes de corte ocorrem alterações na composição corporal (Caldas et al., 2018). Nas semanas de pico produtivo ocorre uma redução no teor de massa magra e um aumento na degradação de proteínas do músculo peitoral (Salas et al., 2010; Vignale et al., 2017; Salas et al., 2019), demostrando que a produção de ovos apresenta uma demanda de nutrientes além dos que vem da dieta, sendo necessário o catabolismo do tecido magro (Caldas et al., 2018). Alguns estudos já reportaram como a energia retida e a composição corporal se comportam (Spratt et al., 1990; Caldas et al., 2018; Johnson e Farrel, 1983), porém, poucos estudos associam com energia requerida para mantença e como ocorre o particionamento e dinâmica de utilização energética.

1.5. Técnicas de calorimetria

A calorimetria é a medida da **PC** e vem sendo utilizada há mais de 200 anos para medir a produção de calor através de métodos físicos (calorimetria direta) ou pela mensuração quantitativa de subprodutos químicos do metabolismo (calorimetria indireta) (Caldas, 2015). A diferença entre calorimetria direta e indireta é que na primeira o calor produzido pelo animal é medido em um ambiente controlado, mensurando a **PC** através da quantidade de água obtida do derretimento de um volume conhecido de gelo (disposto em uma camada ao redor da câmara), como resultado do calor produzido pelo animal, ou seja, é mensurada a taxa de dissipação de calor de um corpo. Enquanto a calorimetria indireta estima a **PC** a partir da relação estequiométrica, usando a relação entre o volume de O_2 consumido e volume CO_2 produzido.

A calorimetria direta apresenta algumas dificuldades de utilização, pois exige constante monitoramento dos equipamentos e controle da temperatura na câmara, tornando a análise complexa e minuciosa, além de requerer maior preparo dos operadores do sistema. Adicionalmente, o método supõe que nenhum calor é armazenado no corpo do animal durante a mensuração.

1.5.1. Calorimetria indireta

A **CI** mede a quantidade de oxigênio consumida e a quantidade produzida de dióxido de carbono durante os processos metabólicos, permitindo calcular a produção de calor a partir do princípio da estequiometria. A estequiometria é uma área da química que investiga e determina quantitativamente as relações molares entre reagentes e produtos de uma reação química. Partindo desse princípio, para calcular a **PC** em estudos usando a **CI**, têm-se utilizado a equação publicada por Brouwer (1965), que se baseia na mensuração do VO_2, VCO_2 e da **PC** liberado. Deste modo, medindo o volume dos gases que fazem parte das trocas gasosas da respiração, é possível calcular a produção de calor de aves e mamíferos, com a equação proposta por Brouwer (1965).

$$\mathrm{PC\ (kJ)} = 16{,}18 * \mathrm{VO_2} + 5{,}02 * \mathrm{VCO_2}$$

Como mencionado, os diferentes substratos apresentam variações no consumo de O_2 e na produção de CO_2. Com a razão de troca respiratória ou **QR** (VCO_2/VO_2) é possível explicar a oxidação dos nutrientes envolvidos no metabolismo animal, de modo que para carboidratos, proteínas e gorduras são 1,0; 0,8 e 0,7 respectivamente. Logo, se o animal estiver em estado de jejum este quociente estará por volta de 0,7 a 0,8 indicando o catabolismo de gordura ou proteína corporal, enquanto no estado alimentado o **QR** estará próximo de 1,0 em função da oxidação de carboidratos advindos da dieta (Gerrits et al., 2015).

Os métodos de **CI** para mensuração do gasto energético é baseado nos princípios de que todos os combustíveis consumidos têm um conteúdo energético intrínseco e que durante os processos metabólicos nos animais libera calor/energia. A oxidação de carboidratos, gordura ou proteína resulta em uma razão fixa entre as quantidades de O_2 consumidas e CO_2 produzidas e que a perda de substratos nas fezes e na urina é desprezível (Mtaweh et al., 2018).

Vários sistemas de calorimetria indireta são fabricados em todo o mundo, e podem ser classificados como sistemas de circuito aberto ou fechado. Na **CI** de circuito aberto, o animal respira o ar do ambiente que passa pela câmara de respirometria, sendo a sua composição amostrada e analisada na entrada da câmara. O ar que sai da câmara é amostrado e analisado quanto a sua composição em O_2 e CO_2. A diferença entre a concentração de gás de entrada e saída é usada para calcular o consumo de oxigênio e a produção de dióxido de carbono (Sakomura e Rostagno, 2016).

Os sistemas de circuito fechado, o ar é recirculado dentro do sistema, de modo que o ar que sai da câmara recebe novas quantidades de oxigênio, enquanto o CO_2 expirado é absorvido por uma solução de KOH. Antes de retornar para a câmara o ar é seco usando CaSO4 para absorver a umidade advinda da respiração. O consumo de oxigênio é calculado pela perda de peso no cilindro de O_2 e o CO_2 pode ser recuperado da solução de KOH por técnicas de precipitação (Sakomura e Rostagno, 2016; Lighton, 2008).

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CAPÍTULO 2 – PARTITIONING OF ENERGY INTAKE IN BROILER BREEDERS FROM 27 TO 63 WEEKS

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Partitioning of energy intake in broiler breeders from 27 to 63 weeks old

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Abstract

Describing the energy partition during the production phase of broiler breeders helps to define the energy requirements of breeders. This study aimed to determine the energy intake partition for maintenance, tissue growth, and egg production in broiler breeders during the laying phase. An energy and nitrogen balance study was carried out in a respirometry chambers with fifty Cobb 500 broiler breeders from 27 to 63 weeks old. Every four weeks, 5 birds were individually housed in a respirometry chamber and fed according to the guidelines. Feed intake (**FI**), excreta, and egg output were recorded daily. O_2 consumption (**VO_2**) and CO_2 production (**VCO_2**) were measured under feeding and fasting conditions to calculate total and fasting heat production (**THP** and **FHP**, respectively). The collected data were used to calculate the retained energy (**RE**) in the egg and body as protein or fat by using energy balance calculations. Linear regressions were used to fit the collected data as a function of age. The measured apparent metabolizable energy corrected for zero-nitrogen retention **(AMEn**, kJ/kg feed) was higher than formulated. The FI and apparent metabolizable energy intake (**AMEi**) showed the highest values at 31 and 35 weeks (*P* > 0.05). Linear regression was not significant (*P* > 0.05) for FHP, THP, heat increment (**HI**), egg mass, and RE in the egg as fat and as protein, suggesting that these parameters remained constant as the bird aged. The RE in the body as protein increased (*P* < 0.005), while the RE in the body as fat decreased (*P* < 0.0001) as the birds aged. Variation in the AMEi influenced RE in the body (*P* < 0.05) but not in the egg (*P* = 0.109). It can be concluded that net energy for maintenance does not change during the laying phase and represents an expenditure of 267.1 $kJ/kg^{0.75}$ per day in broiler breeders under a feed-controlled program. As expected,

energy is primarily used for maintenance and egg production in the net energy system, with excess energy stored preferentially as fat rather than protein.

Keywords: Body composition, energy balance, energy system, fasting heat production, indirect calorimetry.

1. Introduction

Over the years, broiler breeders have been genetically selected to increase the growth potential of their offspring (Zuidhof et al., 2014). However, contrary to commercial broilers, breeders are reared for longer periods, thereby resulting in increased body fat when fed *ad libitum* (Costa, 1981; Richards et al., 2010). Excessive fat in the liver and ovaries can cause metabolic and reproductive disorders (Bacon et al., 1978; Pym and Dillon, 1974; Renema et al., 1999) and decrease egg production (Hocking et al.,1987; Katanbaf et al., 1989; Robinson et al., 1991). To mitigate these adverse reproductive and metabolic conditions, broiler breeders are commonly fed under feed restriction (**FR**) programs, as this delays the growth rate (Hocking et al., 1989).

Considering that broiler breeders are subjected to controlled feeding, it is important to formulate diets to meet maintenance and optimize production needs. In commercial poultry nutrition, diet formulation is based on the metabolizable energy (**ME**) system. However, studies with pigs have shown that the net energy (**NE**) system is more accurate in expressing energy requirements and feed energy values (Noblet, 2007), as it allows the supply of an energy level close to the expected production level. In the NE system, the energy required for maintenance is generally attributed to fasting heat production (**FHP)**, while the NE for production is the energy deposited in eggs or body tissues (Zuidhof, 2019). NE has been well established in swine nutrition, as supported by many research data. However, for poultry, further research on energy requirements and feed energy values is needed to establish the NE system in commercial nutrition.

Due to the differences in genetic improvement and feeding systems used for broiler chickens, laying hens and broiler breeders (Buzala and Janick, 2016; Hafez and Hauck, 2005), it is important to continue assessing how the broiler breeder partitions the energy intake into maintenance and production throughout the egg production phase. Under the ME system, the last detailed report about energy partitioning measured in broiler breeders was in Spratt et al. (1990). Although Caldas et al. (2018) described the dynamics of heat production (**HP**) and body composition in broiler breeders, they did not measure FHP, limiting their description of energy partitioning in the NE system. To define energy requirements, it is necessary to know how broiler breeders use energy from the diet during the laying cycle. This study aims to describe energy partitioning for maintenance, tissue deposition, and egg production in modern broiler breeders during the laying phase.

2. Materials and methods

This study was conducted at the Poultry Science Laboratory (LAVINESP) of the School of Agricultural and Veterinary Sciences, São Paulo State University (UNESP). All procedures were approved by the Animal Care and Use Committee of UNESP (CEUA, Protocol n° 5398/20).

2.1 Birds, housing, and management

A total of 300 21-week-old Cobb 500 broiler breeders were obtained from the Cobb Vantress Brazil flock (Guapiaçu-SP, Brazil) and reared according to the management guidelines. The birds were housed in a poultry house with fans, feeders, nipple drinkers, lighting system managed by a timer, and wooden nests. The lighting program and nest management were set according to guideline recommendations (Cobb, 2016). Corn–soybean diets were formulated following the recommendations of the Cobb 500 nutritional guidelines for the prelay and lay phases (Table 1). The birds received a prelay diet up to 23 wk and a layer diet during the remaining experimental period (24 to 63 wk). The broiler breeders were restrictively fed 154, 166, 160, and 154 g/bird per day at 21-27, 28-43, 44-51, and 52-63 weeks of age, respectively.

2.2 Trial procedures

Data were collected at 27, 31, 35, 39, 43, 47, 51, 55, 59, and 63 weeks of age. At each age, 8 hens were selected from the initial population (300 birds) based on BW (Cobb, 2016), individually housed in wire cages (0.45 m x 0.45 m x 0. 40 m) and fed according to the feeding program. BW and egg production were recorded for seven days, and five birds were selected and individually housed in respiration chambers.

2.3 Respirometry chambers and gas analyzer system

The indirect calorimetry system consisted of five respiration chambers and gas analysis systems. The chambers (internal volume, 0.65 m^3) had a temperature and humidity control system (adjusted to 21°C), lighting system (16 L:8D), metabolic cage with excreta collection tray, feeder, and drinker. The chambers were connected to a mass flow pump (FK-100; Sable System, USA) set at 8 L/min to maintain the CO_2 concentration below 1% (Lighton, 2018). A pull-mode subsample pump (SS4; Sable System, USA) maintained airflow through the analyzer system, which included a multiplexer (MUX RM-8; Sable System, USA), water vapor pressure analyzer (RH -300; Sable System, USA), scrubbing columns to remove water vapor (Drierite, W. A. Hammond Drierite Co., LTD), CO_2 analyzer (CA-10A; Sable System, USA) and O_2 analyzer (PA- 10; Sable System, USA). Every second, the flowmeter and analyzer voltage signals were coded by a universal interface (UI-2; Sable System, USA) and saved using ExpeData software (version 1.9.22, Sable Systems).

The multiplexed system was set to obtain both baseline and chamber gas concentrations at regular timed intervals per hour. The multiplexed sequence was set as follows: initial baseline (5 min), chambers (10 min per chamber), and final baseline (5 min). The passage of air through the respiration chamber was not interrupted during the measurements. At the beginning of each trial, both CO_2 and O_2 analyzers were calibrated to a zero-point using pure N_2 and gas of known composition (standard gas mixture, 21% O_2 and 1% CO_2), and at the end, the same gases were passed through analyzers to allow instantaneous corrections of CO_2 and O_2 concentrations during the measurement period.

2.4 Data collection and heat production calculations

The birds were acclimatized to the conditions in the respiration chamber (1 d), and then gas exchanges were measured in fed (2 d) and fasting (30 h) conditions. The birds used in each measurement period were not used for further measurements. During the feeding period, the feed was supplied at 8:00 AM, according to the feeding programs used in the poultry house. During the period of acclimatization, hens were fed a diet containing 0.5% of an indigestible marker (iron oxide), and at the beginning of the fasting period, one-third of the amount of feed supplied on the previous day with marker was offered to allow collecting excreta. BW, feed intake (**FI)**, excreta production, egg production, and egg weight were recorded daily. Samples of excreta, feed, and eggs were collected and stored to determine dry matter, nitrogen by the Kjeldahl method (AOAC, 2005: method 2001.11), and energy content by total combustion of samples in an adiabatic bomb calorimeter (IKA C 2000 basic, USA).

The air inflow (**F_{in}**), O_2 consumption (**VO_2**, L/bird per day) and CO_2 production (**VCO_2**, L/bird per day) were calculated following the methodology described by Lighton (2018) for an open circuit indirect calorimeter.

$$\mathbf{F_{in}(L/d)} = (F_{out} \times \frac{(100 - [O_2]_{out} - [CO_2]_{out})}{(100 - [O_2]_{in} - [CO_2]_{in})} \times 1.440 \quad (\text{Eq. } 1)$$

$$\mathbf{VO_2(L/d)} = F_{in} \times [O_2]_{in} - F_{out} \times [O_2]_{out} \quad (\text{Eq. } 2)$$

$$\mathbf{VCO_2(L/d)} = F_{out} \times [CO_2]_{out} - F_{in} \times [O_2]_{in} \quad (\text{Eq. } 3)$$

where F_{out} is the air outflow and $[O_2]_{in}$ and $[CO_2]_{in}$ are the atmospheric gas concentrations or baseline.

The HP for both feeding (**THP**) and fasting conditions (**FHP**) was calculated using the Brouwer equation (1965):

$$\mathbf{HP\ (kJ/d)} = 16.17 \times VO_2 + 5.02 \times VCO_2 \quad (\text{Eq. } 4)$$

The FHP was determined after 14 hours of fasting as the mean of the lowest HP values in the dark phase (Bennett and Harvey, 1987). The respiratory quotient (**RQ**) was obtained from the VCO_2/VO_2 ratio.

2.5 Body composition

Hens were scanned after the fasting phase by dual-energy X-ray absorptiometry (DEXA, Hologic-QDR® model 13.4.2., Marlborough, MA, USA) to determine the lean, fat, and bone mineral contents. Hens were anesthetized with isoflurane (2%) diluted in 100% oxygen and placed in the dorsal decubitus position. The legs and wings were stretched and fixed to avoid overlapping in the scanner.

2.6 Energy and nitrogen balance calculations

The nitrogen and energy balances were calculated per bird. The energy balance was combined with the nitrogen balance to calculate the energy retained as protein and fat in the body and eggs. The FI (g/bird per day), nitrogen content in excreta (%), and THP represent the average of two days. The egg mass (g/bird per day) was the average total egg weight collected over 5 days. The AMEi was calculated as gross energy intake minus gross energy losses in excreta. The RE was calculated by subtracting the THP from the AMEi. The RE in the body was calculated as RE minus RE in the egg (egg mass * 6.54 kJ/g), while the heat increment (**HI**) was calculated as THP minus FHP.

Total nitrogen retained (**NR**) (total; body and egg) was calculated as the difference between nitrogen in the feed and losses in excreta. The total RE as protein was calculated as the NR multiplied by the conversion factor for protein (6.25) and by the energy content of protein (23.84 kJ/g N). Total RE as fat (body and egg) was obtained by the difference between total RE and RE as protein. The NR in the body was obtained by the difference between the total NR and the NR in the egg. Both the NR in the body and the NR in the egg were multiplied by 6.25, and their caloric coefficients (23.84 kJ/g N) were used to calculate the RE in the egg as protein and the RE in the body as protein. The RE in the body as fat was calculated by the difference between the total RE in the body and the RE in the body as protein. The RE in the egg as fat was calculated by subtracting the RE in the egg as protein from the total RE in the egg. Nitrogen and energy balance were calculated as g N/bird and kJ/bird per day, respectively, and the results were expressed in kJ/kg$^{0.75}$ per day.

2.7 Statistical analysis

Data were analyzed using linear regression to determine the effects of age on energy balance and body composition. Statistical significance was determined at $P \leq 0.05$ using the PROC REG of the Statistical Analysis System (SAS Institute Inc., Cary, NC). Outliers, normality, and homoscedasticity were checked before analysis.

3. Results

3.1 Performance

The results of performance during the measurements in the respiration chambers are shown in Table 2. The average FI of broiler breeders in the chambers was 9% lower than the amount of feed supplied. During the peak of egg production (31 to 35 weeks of age), more feed was supplied (as recommended by the breeder's guideline). Nevertheless, there were some feed refusals (5%), which were slightly lower than the average refusals. The linear regression analysis in Table 3 shows that the BW increased and the number of eggs decreased with age, while egg mass was constant during the laying phase.

3.2 Energy partitioning and utilization

Table 3 shows the linear regression of the change in energy partitioning and body composition with age. As defined by the feeding program, the AMEi decreased with broiler breeders aging. Additionally, the highest values of AMEi were observed during peak egg production (31 to 35 weeks old). The total RE decreased as the birds aged ($P < 0.05$), with the highest values observed during peak egg production.

Figure 1 shows the partition of AMEi between maintenance, growth, and egg production in broiler breeders at different ages, while Figure 2 shows these results as a percentage of AME intake. The RE in the body as fat reached a maximum during the production peak (31 and 35 weeks), corresponding to the period when AMEi was highest (Figure 1, Table 2). Specifically, at the production peak, the RE in the body as fat was 27% of AMEi**,** compared to an average of 14% for the rest of the cycle (Figure 2). The total RE in egg and its partitioning (as protein and fat) remained constant ($P > 0.05$) as the bird aged, and the average of total RE in the egg amounts to 19% of AMEi (8% as protein and 11% as fat). The negative slope of the linear regression for RE as fat and body fat is due to higher AMEi during peak production. The total RE as protein increased as the birds aged.

THP, FHP and HI were not affected by age ($P > 0.05$) during the laying phase, and FHP and HI represented 45% and 11% of the AMEi, respectively. Given the relatively constant values of the HI, FHP, and RE in eggs, coupled with a minor change in RE in the body as protein, the variation in AMEi primarily affected RE in the body as fat ($P < 0.0001$). The RQ in the fed state (intercept 0.99) was higher than that in the fasted state (intercept 0.77), and both showed no significant effect (P > 0.05) for linear regression.

3.3 Feed energy values

The average apparent metabolizable energy corrected for nitrogen balance (**AMEn**) value (12.8 MJ/kg feed) measured during the experiment was 9% higher than the value used in the feed formulation (11.7 MJ/kg feed) in dry matter (Table 4). The feed used in the study had an average value of 11.7 MJ/kg of net energy feed. The efficiency in taking advantage of AMEn in relation to GE was 73%, so 27% of the energy is lost during the digestive processes and nitrogen excretion. On the other hand, birds used 92% of AMEn for NE, with 8% lost as HI.

3.4 Body composition

The age of broiler breeders influenced their body composition as a percentage of BW, as evidenced by the increase in the percentage of fat (Table 3 and Table 5) and decrease in the percentage of lean as the bird aged. Furthermore, the fat percentage increased rapidly around the production peak (Table 5) at the expense of the lean percentage. The bone mineral percentage did not change with age.

4. Discussion

4.1 Performance and feed energy values

Genetic selection in broiler breeders has focused on high growth rate and feed conversion, while laying hens have been selected for increased laying rate and their persistence (Zuidhof et al., 2014). These differences have led to changes in FI, growth rate, efficiency of utilization for tissue deposition, and metabolism (Buzala and Janicki, 2016). In addition, there are differences in the feeding program between broiler breeders and laying hens. Laying hens are fed ad libitum, while broiler breeders are fed restrictively (Buzala and Janicki, 2016; Hafez and Hauck, 2005). Broiler breeders are fed ad libitum until four weeks of age, after which they are fed under feed restriction programs (Hocking et al., 1989). Due to this feeding strategy, they continue to grow, even after sexual maturity, and the energy intake is used for both tissue deposition and egg production (Heck et al., 2004).

The FI of the broiler breeders was somewhat lower than the amount of feed recommended by the guidelines. This result may be due to the change in the environment of the respiration chambers compared to the open shed where the birds were being raised before. Additionally, group-housed hens tend to consume more feed than individually housed birds due to imitation, arousal, and disinhibition between birds, which have a positive effect on feeding behavior (Rajecki et al., 1975; Hale, 1977). In addition, the period of acclimatization to respiration chambers may have been enough to mitigate the impact of individual housing on the birds' feeding behavior. In addition, this study finds an increase of 9% of AMEn utilization used in feed formulation as a consequence of the gastrointestinal tract and their digestive capacities increase as birds age (Zelenka, 1968), and the mean retention time of digesta is greater in mature birds because of an increase in the intestinal length (Shires et al., 1987). However, despite the lower-than-expected feed intake, the energy balance remained largely positive, both in the body and for egg production.

4.2 Energy partitioning and utilization

Based on a factorial approach, nutrient and energy intake in broiler breeders is partitioned into maintenance, egg production, and tissue deposition (Armsby and Fries, 1915; Zuidhof, 2019). In the NE system, the FHP is considered a constant value per unit of scaled BW for poultry (Noblet et al., 2015). However, across commercial species on growth fed ad libitum, some authors have reported differences between scaled FHP by genotype (Van Milgen et al., 1998) and level of feed intake in growing animals (Koong et al., 1985). An accurate estimation of NE for maintenance (or FHP) is fundamental to quantify energy partitioning and to assign NE value to feed ingredients (Cerrate et al., 2019, Barzegar et al., 2019; Noblet et al., 1994). However, few studies have been performed to determine the FHP in broiler breeders. Despite the fact that broiler breeders continue to grow during the first year, the variation in BW during the egg production period is limited (Table 2), and the FHP expressed per $kg^{0.75}$ was not affected by age (Table 3). Consequently, using the scalar of 0.75 seems appropriate to express traits related to energy metabolism on this scale.

Previous studies have related the basal metabolic rate to body lean or protein mass and to body composition (Scott et al., 1996; Van Milgen and Noblet, 2003), but these concepts are more appropriate for growing animals, as BW and body composition change more during early growth stages. Spratt et al. (1987) found similar FHP values between the Hubbard and Arbor acres strains. Their FHP value of 283 $kJ/kg^{0.75}$ per day (by recalculation) was similar to that in this study (267 $kJ/kg^{0.75}$ per day). In sham-ovariectomized broiler breeders (Balnave et al., 1978), higher values of FHP were observed (378 to 413 $kJ/kg^{0.75}$ per day). Based on the above, maintenance is a priority in energy utilization (Leeson and Summers, 2009), leading to the remaining energy available for growth and/or product formation if the bird is under positive energy balance.

Research on AMEi partitioning for RE in the body and egg and as protein and fat in broiler breeders is very scarce in the literature. Spratt et al. (1990) carried out a study with broiler breeders at peak production (28-26 wks) subjected to four levels of energy intake and showed that the increase in AMEi did not affect the RE in the egg, while the RE in the body increased linearly. At high energy intake, 28% of the AMEi was retained in the body and eggs, and 72% was lost as heat. In the present study, at an identical energy intake level, 42% of AMEi was retained, and 52% was lost as heat. The differences observed in the fraction of AMEi destined for total energy retention are attributed to RE in the body, since the % RE in the egg was very similar between the birds used in the study by Spratt et al. (1990) and in the present study (approximately 21% of AMEi). This finding suggests that modern broiler breeders retain more energy in their body than old broiler breeders.

Based on the energy balance result (kJ/kg$^{0.75}$ per day), the extra amount of energy intake at peak egg production was retained mostly as body fat. After the production peak, the reduction in energy supply results in a decrease in RE as body fat. Despite the decreasing RE as fat in the body as the birds aged, a greater amount of energy retained in the body occurs in the form of fat than as protein for the overall production cycle. The cumulative RE in the body as fat resulted in fatter birds as the birds aged, combined with a reduced lean percentage and constant bone mineral percentage. This result is similar to that obtained by Caldas et al. (2018) for broiler breeders. In summary, this study provides valuable insights into the energy budget of broiler breeders and emphasizes the need for careful management of their feed intake at different stages of the egg production cycle.

5. Conclusion

The results of the study indicate that the net energy requirement for maintenance does not change during the reproductive cycle and represents an expenditure of 267 kJ/kg$^{0.75}$ per day in broiler breeders under a feed-controlled program. Furthermore, energy is primarily used for maintenance and egg production in the net energy system, with extra energy stored preferentially as fat rather than protein.

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Conflict of interest

None of the authors has any financial or personal relationships that could inappropriately influence or bias the content of the paper.

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Table 1. Diet composition and calculated nutritional composition

Ingredients (%)	**Prelay [A]**	**Laying [B]**
Corn grain (7,88%)	60.00	57.30
Soybean meal (45%)	16.25	19.74
Wheat bran	18.60	11.04
Soy oil	0.79	2.50
Dicalcium phosphate	1.41	1.59
Limestone	2.02	6.68
Salt	0.19	0.24
Sodium bicarbonate	0.35	0.28
Mineral and Vitamin Premix[1, 2]	0.20	0.50
DL-Methionine	0.11	0.14
L-Lysine (54,6%)	0.04	0.00
L-Threonine	0.04	0.00
Calculated nutritional composition (%)		
Crude protein 1	15.0	15.2
Metabolizable energy (MJ/kg)	11.7	11.7
Calcium	1.20	3.00
Available phosphorus	0.42	0.42
Sodium	0.18	0.18
Potassium	0.69	0.67
Chlorine	0.19	0.21
Digestible lysine	0.63	0.66
Digestible methionine	0.32	0.35
Digestible Methionine + Cystine	0.54	0.57
Digestible threonine	0.53	0.51
Digestible tryptophan	0.16	0.17

[1] **Nutrients per kilogram of product (Prelaying):** Methionine 180 g; Fe 7,200 mg; Cu 1500 mg; Mn 14 g; Zn 12 g; I 288 mg; Se 60 mg; Vit. At 2,000,000 I.U.; Vit. D3 600.00 I.U; Vit. E 3,200 I.U; Vit, K3 440 mg; Vit. B1 300 mg; Vit. B2 1200 mg; Vit. B6 600 mg; Vit. B12 3000 mcg; Niacin 7000 mg; Calcium Pantothenate 1800 mg; Folic Acid 200 mg; Biotin 12 mg; Choline Chloride 70 g; Halquinol 6000 mg; Bacillus amyloliquefa-ciens 2*1011 CFU.

[2] **Nutrients per kilogram of product (Laying):** Methionine 150 g; Fe 7.200 mg; Cu 1500 mg; Mn 14 g; Zn 12 g; I 288 mg; Se 60 mg; Vit. A 2,000,000 I.U.; Vit. D3 700,00 I.U; Vit. E 5.400 I.U; Vit. K3 300 mg; Vit. B1 300 mg; Vit. B2 1400 mg; Vit. B6 600 mg; Vit. B12 4000 mcg; Niacin 6400 mg; Calcium Pantothenate 2600 mg; Folic Acid 400 mg; Biotin 20 mg; Choline Chloride 66 g; Phytase 60,000 FTU; Halquinol 6000 mg; Bacillus amyloliquefa-ciens 2*1011 CFU.

[A]**Pre-lay diet:** From housing (21 weeks) up to 5% egg production (23 weeks).

[B]**Diet Lay:** From 5% of egg production.

NB: Marker (Iron oxide) was added as 0.05% of the weight of feed offered at the beginning and ending of the excreta collection.

Table 2. Data collected performance per bird during the trial

Age (weeks)	**Feed intake (g*d)**	**Body weight (kg)**	**Egg mass[2] (g*d)**
27	126	3.39	41.1
31	157	3.72	51.1
35	160	3.91	52.5
39	139	3.95	48.0
43	147	3.85	47.2
47	155	4.17	45.3
51	152	4.17	47.4
55	147	4.06	51.5
59	138	4.44	50.9
63	141	4.23	42.9

[1]The value of each variable represents the average of 5 birds per age and are expressed per bird.
[2]**Egg mass** = Weight of eggs laid calculated as total weight of eggs/number of days;

Table 3. Parameters of linear regressions as a function of age (in wks) on the variables of energy partitioning, performance, and body composition of broiler breeders throughout the laying phase

Parameter[1]	Intercept		Slope	
	parameter	P value	Parameter	P value
Performance (per bird)				
BW (kg)	3.00	<0.0001	0.022	<0.0001
Egg mass (g per day)	47.4	<0.0001	0.009	0.937
Number of eggs (per day)	0.88	<0.0001	-0.004	0.029
Energy Partitioning (kJ/kg$^{0.75}$ per day)				
AMEi	699	<0.0001	-2.23	<0.01
THP	326	<0.0001	0.26	0.519
FHP	265	<0.0001	0.03	0.933
HI	75.6	<0.0001	-0.21	0.503
RE	366	<0.0001	-2.30	<0.01
RE as protein	66.2	<0.0001	0.68	<0.01
RE as fat	300	<0.0001	-2.98	<0.0001
RE in egg	131	<0.0001	-0.45	0.109
RE as protein in egg	54.5	<0.0001	-0.22	0.053
RE as fat in egg	76.7	<0.0001	-0.23	0.169
RE in body	235	<0.0001	-1.87	0.024
RE as protein in body	11.6	0.367	0.89	<0.01
RE as fat in body	224	<0.0001	-2.77	<0.0001
Calorimetry parameters				
RQ (feed)	0.99	<0.0001	0.0003	0.280
RQ (fasting)	0.77	<0.0001	0.0003	0.136
Body composition (% BW)				
Fat	9.69	<0.0001	0.13	<0.01
Lean	88.4	<0.0001	-0.13	<0.01
Bone mineral	1.89	<0.0001	0.003	0.210

[1]**BW**= Body weight, **AMEi**= Apparent metabolizable energy intake, **THP** = Total heat production, **FHP**= Fasting heat production, **HI**= Heat increment, **RE**= Retained energy.

Table 4. Feed energy values analyzed for broiler breeders during the trial

Variable	Average	± Std
==== Energy values (MJ/kg DM) ====		
GE[1]	17.3	**-**
AME[2]	13.3	414
AMEn[3]	12.8	392
NE[4]	11.7	871
====== Efficiencies ======		
AME/GE	76.3	3.11
AMEn/GE	73.8	2.26
NE/AME	88.9	4.04
NE/AMEn	92.3	4.39

[1]**GE=** Gross energy; [2]**AME** = Apparent metabolizable energy as [(FI × GEf) – (E × GEe)]/FI; [3]**AMEn** = AME corrected for zero N retention as [AME – [8.22 × (NR)]]/FI; [4]**NE** = (RE + FHP)/FI; Where **GEf** and **GEe** are the gross energy of feed and excreta (kJ/g DM); **E** = Excreta output (g DM/b*d); **FI** = Feed intake (g DM/bird*d); **NR** = nitrogen retained (g/b*d); **RE** = Total retained energy; **FHP** = Fasting heat production.

Table 5. Measurements of body composition determined by DEXA scan of broiler breeders during the laying phase

Age (weeks)	Fat (%)	Lean (%)	Bone mineral (%)
27	11.9	86.1	1.9
31	12.0	85.8	2.2
35	15.0	83.1	1.9
39	19.1	78.9	1.9
43	15.1	82.9	1.9
47	18.7	79.2	2.2
51	14.8	83.0	2.1
55	15.5	82.5	1.9
59	16.7	81.3	2.0
63	17.8	79.9	2.2

The value of each variable represents the average of 5 birds per age, during respiratory measurements.

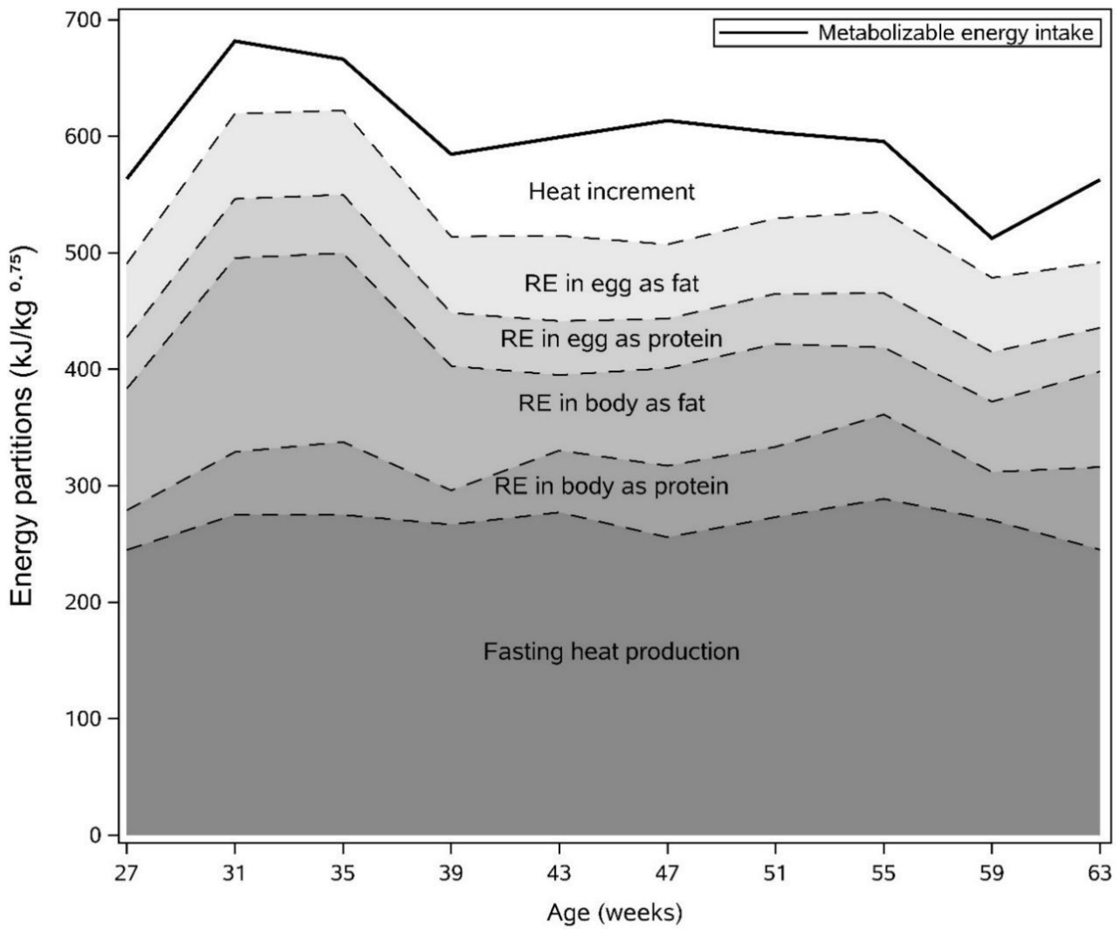

Figure 1. Overview of metabolizable energy intake partitioning in broiler breeders across weeks

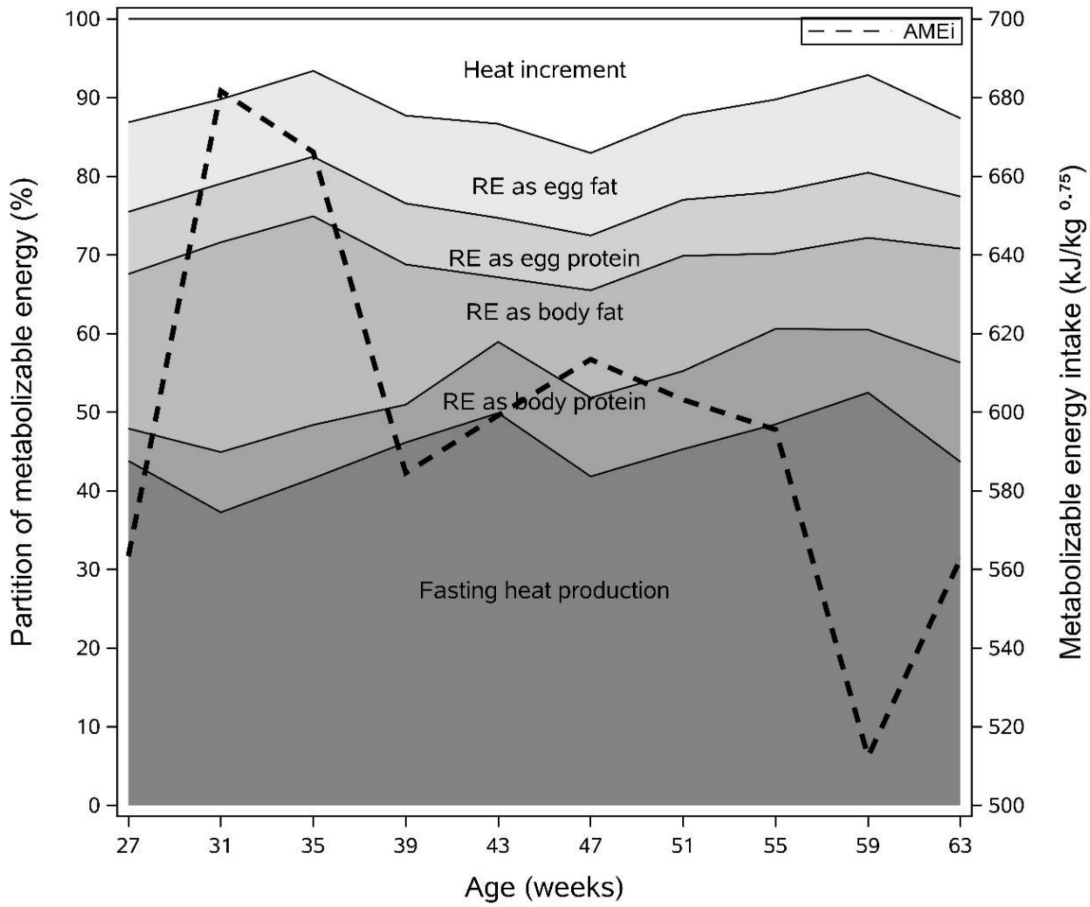

Figure 2. Percentage partition of metabolizable energy intake in broiler breeders over weeks

7. Supplementary material

Table 1. Energy balance of broiler breeders during the laying phase

Variable[1]	Age (weeks)									
	27	**31**	**35**	**39**	**43**	**47**	**51**	**55**	**59**	**63**
	Energy balance (kJ/kg$^{0.75}$*d)									
AMEi[2]	563	682	666	585	599	613	603	596	512	563
THP[3]	318	323	319	337	377	370	347	349	309	316
FHP[4]	245	275	275	267	277	256	273	289	270	245
HI[5]	72.8	70.6	43.9	70.7	80.3	83.6	73.7	60.5	37.0	71.6
	Retained energy (kJ/kg$^{0.75}$*d)									
Total[6]	246	359	347	247	223	244	257	246	213	249
As protein[7]	68.9	103	97.8	74.9	99.3	105	103	119	85.3	111
As fat[8]	177	256	250	172	123	139	153	127	130	140
	Retained energy in egg (kJ/kg$^{0.75}$*d)									
RE egg[9]	107	124	123	111	116	105	108	116	107	93.4
As protein[10]	43.9	50.8	50.2	45.6	44.8	41.8	43.0	46.6	42.8	37.3
As fat[11]	63.3	73.3	72.4	65.6	70.9	62.9	64.7	69.8	64.2	56.0
	Retained energy in body (kJ/kg$^{0.75}$*d)									
RE body[12]	138	235	225	136	107	139	149	130	106	157
As protein[13]	37.8	52.3	62.6	29.3	54.5	63.3	60.3	72.5	42.5	73.3
As fat[14]	114	183	177	107	52.4	75.6	88.4	57.5	65.1	85.4
	Nitrogen retained (g/bird per day)									
Total[15]	1.33	1.85	2.11	1.60	1.84	2.06	2.03	2.29	1.75	2.20
Body[16]	0.64	0.94	1.17	0.55	1.01	1.24	1.18	1.40	0.87	1.46
Egg[17]	0.74	0.91	0.94	0.86	0.83	0.82	0.84	0.89	0.88	0.74

[1]The value of each variable represents the average of 5 birds per age, during respiratory measurements.
[2]**AMEi** = Apparent metabolizable energy intake [(FI × GEf) – (E × GEe)]; [3]**THP** = Total heat production; [4]**FHP** = Fasting heat production; [5]**HI** = Heat increment (THP – FHP); [6]**Total RE** = AMEi – THP, [7]**RE as protein** = Total N retained × 6.25 × 23.8; [8]**RE as fat** = Total RE – RE as protein; [9]**Total RE in egg** = GE egg × egg mass; [10]**RE in egg as protein** = Retained N in egg × 6.25 × 23.8; [11]**RE in egg as fat** = Total RE egg – RE egg as protein; [12]**Total RE in body** = Total RE – RE egg; [13]**RE in body as protein** = Retained N in body × 6.25 × 23.8; [14]**RE in body as fat** = Total RE body – RE body as protein.); [15]**Total N retained** = N intake – N in excreta; [16] **Retained N in body =** Total N retained – retained N in egg; [17] **Retained N in egg =** N% in egg × egg mass.
Where **GE** = Gross energy, **GEf** and **GEe** are the **GE** of feed (17312 kJ/kg) and excreta (kJ/g DM); **FI** = Feed intake (g DM/b*d); **E** = Excreta output (g DM/b*d); **RE** = retained energy.

CAPÍTULO 3 – ENERGY UTILIZATION AND REQUIREMENT OF BROILER BREEDERS DURING THE PRODUCTION PHASE

Este capítulo é apresentado segundo as normas da revista *Poultry Science*

Energy utilization and requirement of broiler breeders during the production phase

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Metabolism and Nutrition

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ABSTRACT

This study aimed to evaluate energy utilization and propose models for metabolizable and net energy requirements in broiler breeders during the egg production phase. Sixty Cobb500 broiler breeders aged between 29 and 65 weeks were randomly assigned to three feeding levels. At each age, six birds were adapted for eight days to three levels of metabolizable energy intake **(MEi)**, established based on the amount of feed allocated: (1) the amount of feed recommended in the guideline, (2) 25% above, and (3) 25% below. The birds were housed in respirometry chambers to measure oxygen consumption and carbon dioxide production to calculate heat production **(HP)** and fasting heat production **(FHP)**. Daily measurements of feed intake, egg weight, egg production, and total excreta were recorded. Variables of **MEi**, **HP**, and retained energy **(RE)** in the egg were calculated, while RE in the body and its partitioning into fat and protein in the egg and body were calculated from **MEi**, total heat production **(THP)**, and **RE** in the egg. Statistical analysis involved linear regression of multiple factors with **MEi** and age (categorical) as the independent variables. Pearson correlation analysis was conducted to investigate the relationship between visceral mass and the evaluated variables. The study proposed mixed models for developing models of energy requirements for both metabolizable (**ME**) and net systems (**NE**). The study found that **FHP** (average 259 $kJ/kg^{0.75}*d$) remained constant throughout the production cycle regardless of the **MEi** level ($P>0.05$). The efficiency of energy utilization for depositing protein and fat in the body changed with the bird's age. The lower error model was considered to select **ME** requirements for maintenance, egg, and gain efficiencies, disregarding the effect of age. The efficiencies were 0.89, 0.78, and 0.80 for maintenance, gain, and egg production, respectively. The NE was unaffected by age and showed a lower error than the ME model.

The NE system was found to be more accurate in expressing the energy requirements of broiler breeders.

Key words: Energy retention, energy balance, fasting heat production, heat production, indirect calorimetry.

INTRODUCTION

The broiler breeders are genetically selected for their high growth rate and heritable muscle deposition, which aims to produce fast-growing and high-quality progeny. This selection has resulted in breeders with a voracious appetite for large amounts of feed (Renema and Robinson, 2004; Carneiro et al., 2019). However, the high rates of fat deposition in the body can lead to reproductive performance injuries in hens. Controlled feeding is a strategy to manage body weight and reduce excessive fat deposition (Renema and Robinson, 2004; Carneiro et al., 2019; Dixon et al., 2022). The amount of feed offered is based on the energy supply to cover the needs for maintenance, egg production, and controlled tissue storage for weight gain (Sakomura and Rostagno, 2016; Zuidhof, 2020).

An essential point for evaluation is the energy requirement expression on metabolizable **(ME)** and net energy **(NE)** bases. Commonly, the coefficients to calculate the requirements of the ME system are estimated under several assumptions as constant maintenance and efficiencies of utilization (Romero et al., 2009; van der Klein et al., 2020; Afrouziyeh et al., 2022). It is known that many factors, such as the diets, physical and social environment, and the production level of the hens, lead to variations in energy utilization during the egg production period (Sakomura et al., 2003; Reyes et al., 2011). This dynamism is observed in the variation of egg production and changes in body weight and composition, which consequently results in different energy utilization efficiencies during the laying period (Joyner et al., 1987; Spratt et al., 1990[a]; Rabello et al., 2006; Salas et al., 2012; Cobb Vantress, 2016; Vignale et al., 2017; Caldas et al., 2018; van der Klein et al., 2020). The NE system can better express and elucidate the influence of the factors and in which components of energy partitioning it affected. In addition, the NE system considers the thermal effect of feed or heat increment **(HI)**, which is directly related to energy utilization efficiencies, making it a more accurate system for expressing energy requirements (Barzegar et al., 2019).

Usually, the trials to describe energy partitioning are conducted at a specific age (Spratt et al., 1990[a]; Rabello et al., 2006) because of methodological limitations such as the comparative slaughter technique that assumed linearity between the referential and final slaughter, ignoring the dynamics of energy partitioning (Liu et al., 2014). In contrast, energy utilization during the production period evaluated by the indirect calorimetry method can describe how the energy is fractioned for maintenance, egg production, and changes in body tissues calculated through energy and nitrogen balance. However, the methodological procedure to define utilization efficiencies is based on feeding levels, which can alter energy partitioning components and influence visceral mass, as evidenced in other species (de Lange et al., 2006; Labussière et al., 2009). Therefore, this method can be a factor that alters energy used for maintenance (Koong et al., 1985; Zubair and Leeson, 1994, Noblet et al., 1999; Labussière et al., 2011).

This study aims to evaluate the effect of broiler breeders' age and energy intake level on energy utilization and propose models for ME and NE requirements, considering the age effect or not.

MATERIALS AND METHODS

This study was conducted at the Poultry Science Laboratory of the School of Agricultural and Veterinary Sciences, São Paulo State University (UNESP). All procedures were approved by the Animal Care and Use Committee of UNESP (CEUA, Protocol n° 5398/20).

***Birds, Housing, and Management*.**

We obtained 300 Cobb500 broiler breeders from the Cobb Vantress Brazil flock (Guapiaçu-SP, Brazil) at 21-wks-old. The birds were reared on an open poultry house floor with a stocking density of 3.88 birds/m^2. The facility was equipped with fans, feeders, nipple drinkers, and wooden nests (5 birds per nest). The lighting program followed the recommended guidelines, providing 16 hours of light and eight hours of darkness from 23-wks-old until the end of the cycle (Cobb Vantress, 2016).

The birds were fed a diet based on corn and soybean meal, formulated to meet the nutritional recommendations for Cobb500 breeders. The feeding program consisted of two phases (pre-layer and layer). The pre-layer diet was provided from 21-wks-old until the birds reached 5% production (around 23-wks-old), after which the laying feed was supplied during the experiment (27 to 65-wks-old). The birds were subject to a feeding restriction program with 154, 166, 160, and 154 g/bird*d of feed provided during the age internals of 21-27, 28-43, 44-51, and 52-63-wks-old, respectively, according to the Cobb breeder management guide (Cobb Vantress, 2016).

Experimental Procedures.

The data collection was scheduled for 29, 33, 37, 41, 45, 49, 53, 57, 61, and 65 weeks old, with six hens evaluated at each age. Before measurement at each age, ten hens were selected from the initial population (300) based on their target BW±100 g (Cobb Vantress, 2016). These hens were individually housed in cages (0.45 m x 0.45 m x 0.40 m) and fed according to the controlled feed mentioned above. The body weight **(BW)** and egg production were recorded, and health status was monitored for seven days, allowing six birds laying eggs to be selected. Subsequently, the six birds were adapted to the feeding levels for eight days. A single feed was offered to the hens, with the amount of feed allocated varied to establish the different levels of energy intake: (1) the recommended amount of feed according to the Cobb Vantress guideline, (2) 25% above the recommended amount, and (3) 25% below the recommended amount. After the adaptation to feed intake **(FI)** levels, the birds were housed individually in respirometric chambers to measure oxygen consumption and CO_2 production.

The birds were adapted to respirometric chambers for two days without data collection or measurements. Afterward, the data collection began under feeding conditions with the respective treatments for three days. On the last day, the feed was withdrawn, and gas exchange was measured under fasting conditions for 30 h.

Respiratory Chambers and Gas Analyzer System.

The indirect calorimetry system consisted of six respiratory chambers and gas analyzer systems. The chambers (internal volume, 0.65 m^3) had temperature and humidity automatic controllers (adjusted to 21°C), a light timer (16L:8D), and a metabolic cage with an excreta collection tray, feeder, and nipple-type drinker. The chambers were connected to a mass flow pump (FK-100; Sable System, USA) set at 8 L/min to maintain the CO_2 concentration below 1% (Lighton, 2018). A pull-mode sub-sample pump (SS4; Sable System, USA) constantly flowed sampled air through the analyzer system. The air analyzers consisted of the multiplexer (MUX RM-8; Sable System, USA), water vapor pressure analyzer (RH -300; Sable System, USA), and scrubbing columns of 99.5% $CaSO_4$ to capture the water vapor molecules (Drierite, W. A. Hammond Drierite Co., LTD). Subsequently, the dry air was analyzed by an infrared analyzer of CO_2 (CA-10A; Sable System, USA) and a paramagnetic analyzer of O_2 (PA- 10; Sable System, USA). The flowmeter and analyzer signals were coded by a universal interface (UI-2; Sable System, USA) and saved one record per second using ExpeData software (version 1.9.22, Sable Systems).

The gas sampling was programmed from each chamber and baseline in an intermittent sequence: initial baseline (3 min), chambers (9 min per chamber), and final baseline (3 min). The gas analyzer was calibrated at the start and end of each data collection with concentrated gas (>99.99% N_2) and a certified gas mixture (21% O_2 and 1% CO_2).

Performance and Heat Production Calculations.

The BW, FI, excreta production, egg weight, and laying were recorded daily during the feeding condition. The daily body weight gain **(BWG)** was calculated as the difference between the final BW (at the start of the fasting condition) and the initial BW when it was assigned to the feeding levels.

The air ingoing flow (**F_{in}**), volumetric O_2 consumption (VO_2, L/b*d), and CO_2 production (VCO_2, L/b*d) were calculated following the methodology described by Lighton (2018) for an open circuit indirect calorimetry.

$$F_{in}(L/d)=(F_{out}\times\frac{(100-[O_2]_{out}-[CO_2]_{out})}{(100-[O_2]_{in}-[CO_2]_{in})}\times 1.440 \qquad \text{(Eq. 1)}$$

$$VO_2(L/d)= F_{in}\times[O_2]_{in}-F_{out}\times[O_2]_{out} \qquad \text{(Eq. 2)}$$

$$VCO_2(L/d)= F_{out}\times[CO_2]_{out}-F_{in}\times[O_2]_{in} \qquad \text{(Eq. 3)}$$

Where $\mathbf{F_{out}}$ is the air outgoing flow, $[O_2]_{in}$ and $[CO_2]_{in}$ are the atmospheric gas concentrations or baseline.

The total heat production **(THP)** and fasting heat production **(FHP)** were calculated using the Brouwer equation (1965):

$$HP\ (kJ/d) = 16.17 \times VO_2 + 5.02 \times VCO_2 \qquad \text{(Eq. 4)}$$

The FHP was determined after 14 hours of fasting during the dark period (Bennett and Harvey, 1987).

Visceral Mass.

After the metabolic trial, the birds were stunned and slaughtered by the inhalation of isoflurane (>1ml/kg of BW). Subsequently, the coelomic cavity was exposed to separate and weighed the visceral components of the liver, gut, oviduct and ovary, proventriculus and gizzard, abdominal fat, and feathers. The weight of the digestive organs represented the sum of the gut, proventriculus, and gizzard, while the sum of the weights of the oviduct and ovary resulted in the weight of the reproductive organs. The digestive organs added to the reproductive ones resulted in the weight of the total viscera.

Chemical and Laboratory Analysis.

Samples of egg, feed, and excreta were collected and analyzed for crude protein and gross energy content. All samples were first subjected to dry matter content determination at 105°C for six hours. The total nitrogen content was analyzed by Kjehdal method (AOAC, 2005), and the crude protein was calculated using the coefficient of 6.25 g of crude protein per g of nitrogen. Finally, the gross energy was obtained by the total combustion of samples through the adiabatic calorimeter (IKA C 2000 basic, USA).

Nitrogen and Energy Balance Trial.

The nitrogen and energy balance were carried out on daily bases per bird. The value of FI, BW, excreta production, and THP was obtained as the average of three days of data collection. The egg mass **(EO)** was calculated from the average egg weight multiplied by the laying rate (%) during seven days (adaptation period and measurement period).

The apparent metabolizable energy intake **(MEi)** was calculated as the difference between the gross energy on the feed and excreta times the feed intake and excreta production, respectively. The RE was calculated by subtracting the THP from the MEi. The RE was partitioned as RE in the body (RE_{body}) and RE in the egg (RE_{egg} = egg mass*6.54 kJ/g). The HI was obtained from the difference between THP and FHP. The net energy intake **(NEi)** values were calculated as the sum of FHP and RE for each bird on each measurement.

The RE_{egg} was divided into RE in the egg as protein ($RE_{egg\text{-}pt}$ = egg mass*N content in the egg*6.25 g N/g protein *23.84 kJ/g protein) and the RE in the egg as fat ($RE_{egg\text{-}fat}$), which was obtained by subtracting the $RE_{egg\text{-}pt}$ from RE_{egg}. The partitioning of energy retention in whole tissues (body and egg) was calculated from the nitrogen retention (NR = N intake – N excreted) to determine the total RE as protein (RE_{pt} = NR*6.25 gN/gProtein*23.84 kJ/g Protein). The energy retained as fat (RE_{fat}) was calculated from the difference between RE and RE_{fat}. Finally, the RE_{body} was partitioned into $RE_{body\text{-}pt}$ (RE_{pt} - $RE_{egg\text{-}pt}$) and $RE_{body\text{-}fat}$ (RE_{fat} - $RE_{egg\text{-}fat}$).

Model of MEi and NEi Utilization.

Mixed models were used to describe the MEi and NEi as a function of the BW, BWG, and egg mass to obtain the energy requirement for maintenance (kJ/$BW^{0.75}$), BWG, and egg production (kJ/g egg mass) (Table 1). Metabolic body weight was defined as $BW^{0.75}$ to enable comparison with other studies. Models 1.1 and 1.2 were used to describe the NEi utilization, using the parameters *a*, *p*, and *q* to express the energy required for maintenance, weight gain, and production, respectively. For the MEi (models 2.1 and 2.2), additional parameters were included to estimate the efficiencies of utilization for maintenance (k_m), weight gain (k_{gain}), and production (k_{eeg}). Models 1.2 and 2.2 included a term u_i to evaluate the effect of age as a random term on each parameter, with a normal distribution $u_i \sim N\ (0, \sigma^2{}_i)$ to account for individual age variation.

The models were compared based on their accuracy in predicting the energy requirements in kJ/bird in both bases (ME and NE). To evaluate each model, the root of the mean and standard error of the estimate (RMSE) were calculated between the observed data of ME determined on each trial by the total collection method and the NE determined as the sum of the FHP and RE, and the predicted using the variables of performance collected during the experiment.

$$\mathrm{RMSE} = \sum \sqrt{\frac{\left(\mathrm{Y_{obs}} - \mathrm{Y_{pred}}\right)^2}{\mathrm{n}}}$$

Additionally, the determination coefficient (R^2), the intercept, and the slope of the regression between observed and predicted values were evaluated.

Statistical Analysis.

The data and calculations were evaluated based on the actual variations in measured FI, irrespective of the allocated feeding level, so that FI was measured daily to calculate energy intake levels for each bird at each age. This procedure was performed to ensure a wide variation in the energy intake of the birds. The energy balance data were analyzed using linear regression analysis of multiple factors to evaluate the effect of the energy partitioning components varying in relation to the MEi, age of the hens, or their interaction. For that, the following linear additive model was used for variance analyses:

$$Yij=\beta_0+\beta_1*MEi+\beta_{age}+\beta_{MEi*age}+\varepsilon$$

Where Yij corresponds to the energy balance variables (THP, FHP, HI, RE, RE as protein, RE as fat, RE in the body, RE in the body as protein, RE in the body as fat, and RE in the egg, β_0 is the general intercept, β_1 is the slope or effect of the continuous predictor MEi, β_{age} is the effect of the age (categorical predictor), $\beta_{EMAi*age}$ is the interaction, and ε is the error.

Pearson's correlation was performed to assess the direction and strength of the relationship between energy balance variables (MEi, THP, FHP, RE, and RE as fat) and visceral mass components (gut, liver, gizzard, proventriculus, ovarium, and abdominal fat), considering a 95% confidence interval.

All data were analyzed using the statistical software SAS, considering a 95% confidence interval to indicate the significant difference. The regression analyses between the MEi and energy metabolism variables were performed using the PROC GLM procedure, while the correlation was analyzed using the PROC CORR procedure, and the mixed model evaluation was done using the PROC NLMIXED procedure.

RESULTS

The variables of energy metabolism with their respective average, minimum and maximum values are shown in Table 2. The measured FI varied from 0.103 to 0.196 (kg/bird*d), providing a wide variation in the MEi from 1126 to 2311 kJ/b*d. The BW ranged from 3.42 to 4.49 kg. These results were favorable in observing the responses of the birds to MEi and age, or both on the energy partitioning components.

The results of the energy partitioning evaluated separately for the MEi and age effect are shown in Table 3. The variables assessed demonstrated a significant fit for the linear additive model, except for the FHP, which did not present an effect on the level of MEi or the age of the birds, obtaining an average value of 259 kJ/kg$^{0.75}$*d. On the other hand, the RE and THP were linearly influenced by the level of MEi ($P<0.001$) but not by the age of the hens ($P>0.05$), nor was there any interaction ($P>0.05$). A similar result was observed for the partitioning in RE_{fat}, which responded linearly to the increase in MEi ($P<0.001$), but it was similar at all ages ($P>0.05$). While the RE_{pt} was affected by MEi ($P<0.001$), age ($P<0.01$) as well as the interaction between them ($P<0.01$). A similar response was observed for the energy partitioning of RE_{body}, which increased linearly to the MEi ($P<0.001$), varied between the ages ($P<0.05$), and an interaction effect was observed ($P<0.01$). When we explore the RE_{body} partitioning on their components of $RE_{body-pt}$ and $RE_{body-fat}$, both had the same behavior, responding to MEi ($P<0.001$), age ($P<0.05$), and interaction ($P<0.01$).

On the other hand, the total RE_{egg} and their components of $RE_{egg\text{-}pt}$ and $RE_{egg\text{-}fat}$ were unaffected by the MEi level (P>0.05), age (P>0.05), or interaction (P>0.05). When the interaction effect for RE_{pt} was evaluated (Figure 1 A), birds after 45-weeks-old (45, 53, 61, and 65 wks old) presented a reduction in efficiency of utilization (expressed by the slope). This result is reflected directly in $RE_{body\text{-}pt}$ (Figure 1 C), where the slope was smaller for the same ages (45, 53, 61, and 65 wks old). For RE in the body and body as fat (Figure 1B and 1 D, respectively), lower slopes were observed at ages 29 and 33 weeks. In addition, a higher slope was observed at week 41 for the RE_{body}, $RE_{body\text{-}fat}$, and $RE_{body\text{-}pt}$ variables. This result matches with the BWG increases up to the final peak of production (around 41-wks-old), observing a high rate of energy retention in both tissues.

Additionally, exploring the correlation between energy metabolism and visceral mass variables (Figure 2), it was evidenced that the MEi was correlated with the liver (P<0.01, r=0.354), digestive organs (P<0.05, r=0.278) and total viscera (P<0.05, r=0.3). Additionally, the abdominal fat was correlated with the MEi (P<0.05, r=0.319), RE_{fat} (P<0.05, r-=0.35), and RE (P<0.05, r=0.311). The FHP and THP were significantly correlated with all variables of visceral mass except with the liver (r=0.218 and r=0.193, respectively).

The estimated parameters obtained from the models for ME and NE energy requirements, based on the BW, BWG, and EO, are presented in Table 4. All the models and parameters showed significance, except for the effect of the age represented by u_1, when considering the NE description (model 1.2). Therefore, no model was built for NE considering age as a factor. However, age had a significant impact (p<0.05) on the ME model (model 2.2), with a parameter (u_2=0.004) used to correct the ME requirement according to age advancement.

The Models 2.1 and 2.2 used to describe the ME requirements presented differences in their parameters when the term u_i was included, mainly in the maintenance (from 357 to 321 kJ/kg$^{0.75}$ for models 2.1 and 2.2, respectively) and weight gain (from 14.4 to 15.5 kJ/g BWG for models 2.1 and 2.2, respectively) requirements. However, the parameter *p* for egg production was similar between both models (around 4.6 kJ/g EO). For describing the efficiencies of the ME models, model 2.1 (without considering age) showed k_m, k_{egg}, and k_{gain} values of 0.89, 0.78, and 0.80, while model 2.2 (including u_i factor) had an increase of k_m to 0.96, and k_{egg} and k_{gain} were reduced to 0.72 and 0.72, respectively.

The comparison of model predictions is shown in Figure 3. In general, the ME models predictions of requirements resulted in values lower than observed, mainly considering the age effect (Model 2.2). Although both models 2.1 and 2.2 presented the same behavior (slope of 0.83 and 0.87, respectively, and R^2=0.84), also including the age effect showed higher error (RMSE=169 for model 2.1 and RMSE=229 for model 2.2). On the other hand, when comparing both systems, the NE system prediction of energy requirements (model 1.1) presented greater accuracy (RMSE = 102) than the ME system (model 2.1, RMSE = 169) in describing the energy requirements of broiler breeders.

DISCUSSION

Based on the result found in this study, we have deduced that the energy used for egg formation is constant, regardless of the energy intake level (above the maintenance) and the age of the hens. During the production period, the birds hierarchically prioritized maintenance and egg production (Leeson and Summers, 2009). Variations in energy intake led to alterations in the efficiency of energy utilization to maintain the metabolic work (maintenance requirement) or support of egg production (Romero et al., 2009), which in turn triggers variations in the energy retention in the body tissues, resulting in a more fluctuating dynamism. For instance, high energy intake is associated with fatness tissues deposition and weight gain, while weight loss is observed during the mobilization of reserves to support the production of eggs (Leeson and Summers, 2009; Gous and Nonis, 2010; Zuidhof, 2019).

In 1999[a], Spratt et al. conducted a study using Hubbard broiler breeders at 22-wks-old, subjecting them to four levels of energy intake. The authors reported a linear relationship between RE and RE_{body} in the function of MEi, which is consistent with our findings. However, caution must be taken when considering this linearity, as it may not be applicable in all conditions and is not constant along the birds' age since it constantly changes mainly due to egg production. Although this suggests that a regression between ME and RE used to estimate maintenance requirements and energy utilization efficiencies, the approach classically carried to estimating ME for maintenance has several assumptions, such as constant requirement and efficiency independent of feeding level, that have been challenged by Kielanowski (1965) and Romero et al. (2009). Previous studies on broiler breeders (Johnson and Farrell, 1983; Sakomura, 2004; Rabello et al., 2004) have shown that energy intake level and temporal variations in energy utilization can affect the efficiency of ME utilization. Therefore, it is essential to consider age and energy intake level when estimating maintenance requirements and energy utilization efficiencies for broiler breeders since they are fed in a controlled manner to prevent excessive weight gain and fat deposition.

Additionally, changes in feeding levels can cause variations in visceral mass and abdominal fat deposition, as demonstrated in pigs (Labussiere et al., 2013) and birds (Spratt et al., 1990[b]). We also observed a correlation between basal metabolic work (expressed by the FHP) and the thermal effect of feed (expressed by the HI) paired with the weight of visceral and reproductive organs. These findings suggest that these organs contribute significantly to the metabolic rate of broiler breeders and should be considered when estimating their maintenance requirements and energy utilization efficiencies. Moreover, the previous level of feeding can induce variations in the energy expenditure of these organs and can even influence the measurements of FHP (Labussière et al., 2013; Spratt et al., 1990[b]). However, this variation in visceral mass was not enough to be statistically detected along the age and MEi levels. Even though a constant value of FHP related to the NE for maintenance was found, some factors must be considered for its measurement. In this regard, reports have demonstrated the variation of FHP due to methodological or procedural approaches. For example, Teofilo et al. (2022) found similar values (296 $kJ/kg^{0.75}$*d) to those obtained here in a restricted-fed broiler breeder using the indirect calorimetry method.

On the other hand, Sakomura. (2004) reported values between 246 to 271 $kJ/kg^{0.75}$*d by extrapolating HP as a function of MEi (for MEi=0) using the method of comparative slaughter. The variations found are attributed to environmental factors such as floor production or cages that interfere with the energy cost of physical activity for floor-reared birds (Sakomura et al., 2003). As mentioned by van der Klein (2020), Rabello et al. (2004), and Teofilo et al. (2022), the maintenance requirement is affected by factors like environmental temperature and feeding program (restricted or *ad libitum*) and have statistical implication when the feeding level is altered. Therefore, this method was questioned in other species (de Lange et al., 2006; Koong et al., 1985; Labussière et al., 2011). Therefore, the regression method has limitations in expressing the requirements for maintenance and the efficiency of utilization. In this sense, other methodologies and procedures should be considered for developing robust models that accurately express the requirements and consider the principal inherent factors that influence energy utilization.

The mixed model offers several advantages over other statistical procedures in estimating parameters, such as including the factor "age" and not assuming independence between the components of partitioning or collinearity. The maintenance value obtained through the mixed model was higher than the FHP average. Still, it was comparable to the value reported by Sakomura (2004), which ranged from 271 to 326 kJ/kg$^{0.75}$*d for broiler breeders reared in cages and subject to different environmental conditions. The ME for maintenance obtained (NEm*1/k_m) was 356 kJ/kg$^{0.75}$*d. In this way, the k_m obtained (k_m = 0.89) was slightly higher than that reported by Sakomura (2004), who found values ranging from 0.6 to 0.8. The determination of maintenance requirements expressed in NE and ME and the k_m is limited by conflicting reported values. The lack of a standard procedure to determine these values and the statistical procedures used to estimate them, along with factors that interact to produce variation in results, contribute to these discrepancies between reports.

In addition, energy utilization efficiency is estimated separately by regression of RE (body and egg) against MEi, producing values that are not influenced by other components. Rabello et al. (2006); Sakomura (2004) reported RE_{body} efficiencies ranging from 0.7 to 0.8. In this study, using the mixed model, we obtained very similar values (k_{gain} = 0.72 and 0.80). However, we observed that birds are more efficient in using energy for maintenance, as BW represents a significant proportion of the energy partitioning. This contrast with laying hens, which have efficiencies of around 0.7 (Sakomura, 2004; Barzegar et al., 2019).

The energy demand for egg production remained constant, and birds prioritized the laying throughout the production cycle, resulting in a slightly higher utilization efficiency than that reported by Romero et al. (2009) of k_{egg} ranging from 0.48 to 0.66 for the linear and mixed model, respectively. The sample size and control of egg production influence this variation observed in the reported values. Populational observations may lead to underestimating egg efficiencies, while individual observation, as was made in this study, may be influenced by the production monitoring. However, these factors did not limit the development of models for energy requirements with high accuracy.

Limited literature is available on models that determine energy requirements for broiler breeders while considering the age factor. In this study, we evaluated energy utilization separately (for each age) using variance analyses and a mixed model including age as a factor. As described in the results, was showed coincidence between the two methods in estimating bird requirements. The NE model was not influenced by age, and its components of FHP and RE (total) were also not affected by the age of the bird, similar to what was shown with the variance analyses. As previously mentioned, the FHP can be constant, and the RE changes are influenced and proportional to the weight gain and egg production, not changing along the production period. Therefore, using the correspondent inputs, NE system predictions could be applied to broiler breeders during the production phase. However, the mixed model for ME showed a significant age effect. These results suggest that age is mainly influenced by the efficiency of utilization, not specifically NE partitioning, which can impact ME utilization during the production cycle. Our finding was supported by the variance analyses, which showed that the components of RE in the body tissues primarily varied between ages, and the ME requirement for gain differed significantly between models with and without age effects, as well as ME for maintenance.

In conclusion, regardless of the level of metabolizable energy intake, the net energy required for maintenance remains constant throughout the production cycle. However, the efficiency of energy utilization for retention as protein and fat in the body changes with the age of the birds. The mixed models are a feasible approach for building power requirement models for both ME and NE systems, even when considering the alterations in ME utilization during the production cycle due to changes in egg production and compensatory behavior of body storage tissues. Moreover, NE provides a more accurate expression of the energy requirement for broiler breeders in production.

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Table 1. Models to describe the requirements of metabolizable and net energy

	Models
1.1	$NEi = \boldsymbol{a}BW^{0.75} + \boldsymbol{p}BWG + \boldsymbol{q}EO + \boldsymbol{\varepsilon}\,;\ NEi\sim N(\mu, \sigma^2)$
1.2	$NEi = (\boldsymbol{a} + \boldsymbol{u_1})BW^{0.75} + (\boldsymbol{p} + \boldsymbol{u_1})BWG + (\boldsymbol{q} + \boldsymbol{u_1})EO + \boldsymbol{\varepsilon}\,;\ NEi\sim N(\mu, \sigma^2), u_1\sim N(0, \sigma^2{}_{u_1})$
2.1	$MEi = \boldsymbol{a}\frac{1}{\boldsymbol{k_m}}BW^{0.75} + \boldsymbol{p}\frac{1}{\boldsymbol{k_{gain}}}BWG + \boldsymbol{q}\frac{1}{\boldsymbol{k_{egg}}}EO + \boldsymbol{\varepsilon}\,;\ MEi\sim N(\mu, \sigma^2)$
2.2	$MEi = (\boldsymbol{a} + \boldsymbol{u_2})\frac{1}{\boldsymbol{k_m}}BW^{0.75} + (\boldsymbol{p} + \boldsymbol{u_2})\frac{1}{\boldsymbol{k_{gain}}}BWG + (\boldsymbol{q} + \boldsymbol{u_2})\frac{1}{\boldsymbol{k_{egg}}}EO + \boldsymbol{\varepsilon}\,;\ MEi\sim N(\mu, \sigma^2), u_2\sim N(0, \sigma^2{}_{u_1})$

a, p and ***q*** are the estimated parameters per unit of maintenance (kJ/kg$^{0.75}$), weight gain (kJ/g weight gain), and egg production (kJ/g egg mass), respectively. $\boldsymbol{k_m}$: efficiency for maintenance; $\boldsymbol{k_{egg}}$: efficiency for egg production and $\boldsymbol{k_{gain}}$: efficiency of tissue deposition for body weight gain for the **ME** system. **BW**: body weight, **BWG**: daily body weight gain, and **EO**: egg mass. The term ui was associated with each age of evaluation as a random effect with a normal distribution (i = 1 and 2 are related to model 1.2 and 2.2, respectively).

Table 2. Average, minimum, and maximum values of performance, calorimetry parameters, and retained energy of broiler-breeder hens during the experimental period (27-65-wks-old).

Variable[1]	**Average**	**Minimum**	**Maximum**	**SD**
Performance				
BW (kg)	4.047	3.420	4.489	0.27
Feed intake (g/b*d)	0.140	0.103	0.196	0.02
Egg mass (g/b*d)	46.26	21.57	60.00	8.25
Body weight gain (g/b.d)	21.1	-1.5	56.0	16.2
ME intake (kJ/b*d)	1603	1126	2311	288.77
ME intake (kJ/kg$^{0.75}$*d)	561.3	379.4	789.3	92.28
Calorimetry parameters (kJ/kg$^{0.75}$*d)				
THP	333.0	284.5	393.9	25.97
FHP	258.6	212.4	308.0	20.08
HI	74.42	24.02	131.2	23.36
Retained energy (kJ/kg$^{0.75}$*d)				
Total	228.3	92.73	395.4	80.95
As protein	88.66	30.04	138.5	23.48
As fat	140.1	33.17	268.7	61.80
Egg	106.4	64.33	142.4	18.63
Body	121.9	-19.17	281.7	77.91
Body as fat	75.93	-29.65	189.4	60.21
Body as protein	45.91	-14.98	95.53	22.59

[1]The value of each variable represents the average of 60 birds and ten ages collected during this experiment. **BW:** Body weight, **Egg mass:** Weight of eggs laid calculated as the total weight of eggs/number of days; **HP:** Heat production, **FHP:** Fasting Heat production**, HI:** Heat increment, **SD:** Standard deviation.

Table 3. Linear additive model parameters for energy metabolism variables (expressed in kJ/kg$^{0.75}$*d) evaluated in broiler breeders during egg production.

Sources	**RE**	**FHP†**	**HP**	**RE_{pt}**	**RE_{fat}**	**RE_{body}**	**RE_{egg}**	**$RE_{body-fat}$**	**$RE_{body-pt}$**	**RE_{egg-pt}**	**$RE_{egg-fat}$**
MEi	***	*ns*	***	***	***	***	*ns*	***	***	*ns*	*ns*
Age	*ns*	*ns*	*Ns*	**	*ns*	*	*ns*	*	*	*ns*	*ns*
MEi*Age	*ns*	*ns*	*Ns*	**	*ns*	**	*ns*	*	**	*ns*	*ns*
R-sq	0.966	0.359	0.671	0.921	0.926	0.947	0.577	0.914	0.891	0.601	0.555
Root MSE	18.26	19.69	8.24	8.10	20.55	21.91	14.85	21.67	9.14	14.17	8.93

[1]**RE:** Retained energy, **FHP**: fasting heat production; **THP:** Total heat production; **RE_{pt}**: RE as protein; **RE_{fat}:** RE as fat; **RE_{body}:** RE in the body; **RE_{egg}:** RE in the egg; **RE_{b-fat}:** RE in the body as fat; **RE_{b-pt}:** RE in the body as protein; **RE_{egg-p}:** RE in the egg as protein, **$RE_{egg-fat}$:** RE in the egg as fat. [2]**MEi:** Apparent metabolizable energy intake. **R^2:** coefficient of determination**;** [4] **Root MSE:** Root mean squared error. †The model fit no was significant. The probability expressed as * (P<0.05), ** (P<0.01), *** (P<0.001), and *ns* is non-significative.

Table 4. Parameters of metabolizable energy intake utilization models

Model	Parameters	Estimated		SE	t-value	P-value
1.1	$NE = 318 \times BW^{0.75} + 5.75 \times EO + 11.2 \times BWG$					
	a	318	±	33.63	9.45	***
	p	5.75	±	2.016	2.85	**
	q	11.2	±	1.019	11	***
1.2	$ME = 357 \times BW^{0.75} + 4.60 \times EO + 14.36 \times BWG$					
	k_m	0.891	±	0.053	16.75	***
	k_{egg}	0.78	±	0.037	5.78	***
	k_{gain}	0.801	±	0.037	21.72	***
2.1	*Ns*					
	a	308	±	33.85	9.09	***
	p	6.41	±	2.033	3.15	**
	q	11.16	±	0.93	12	***
	u_1	0.273	±	0.394	0.69	*ns*
2.2	$ME = (321.8 + u2 \times age) \times BW^{0.75} + (4.61 + u2 \times age) \times EO + (15.5 + +u2 \times age) \times BWG$					
	k_m	0.957	±	0.087	11.01	***
	k_{egg}	0.719	±	0.135	5.31	**
	k_{gain}	0.721	±	0.038	18.79	***
	u_2	0.004	±	0.002	1.87	*

a, ***p*** and ***q*** are the estimated parameters per unit of maintenance (kJ/kg $BW^{0.75}$), weight gain (kJ/g BWG) and egg production (kJ/g EO), respectively. $\boldsymbol{k_m}$: efficiency for maintenance; $\boldsymbol{k_{egg}}$**:** efficiency for egg production and $\boldsymbol{k_{gain}}$**:** efficiency of tissue deposition in body weight gain. **SE:** Standard error, **EO:** Egg mass. The term $\boldsymbol{u_i}$ was associated with each age of evaluation (*i* = 1 and 2 is related to model 1.2 and 2.2, respectively). The probability expressed as * (P<0.05), ** (P<0.01), *** (P<0.001) and *ns* is non-significative.

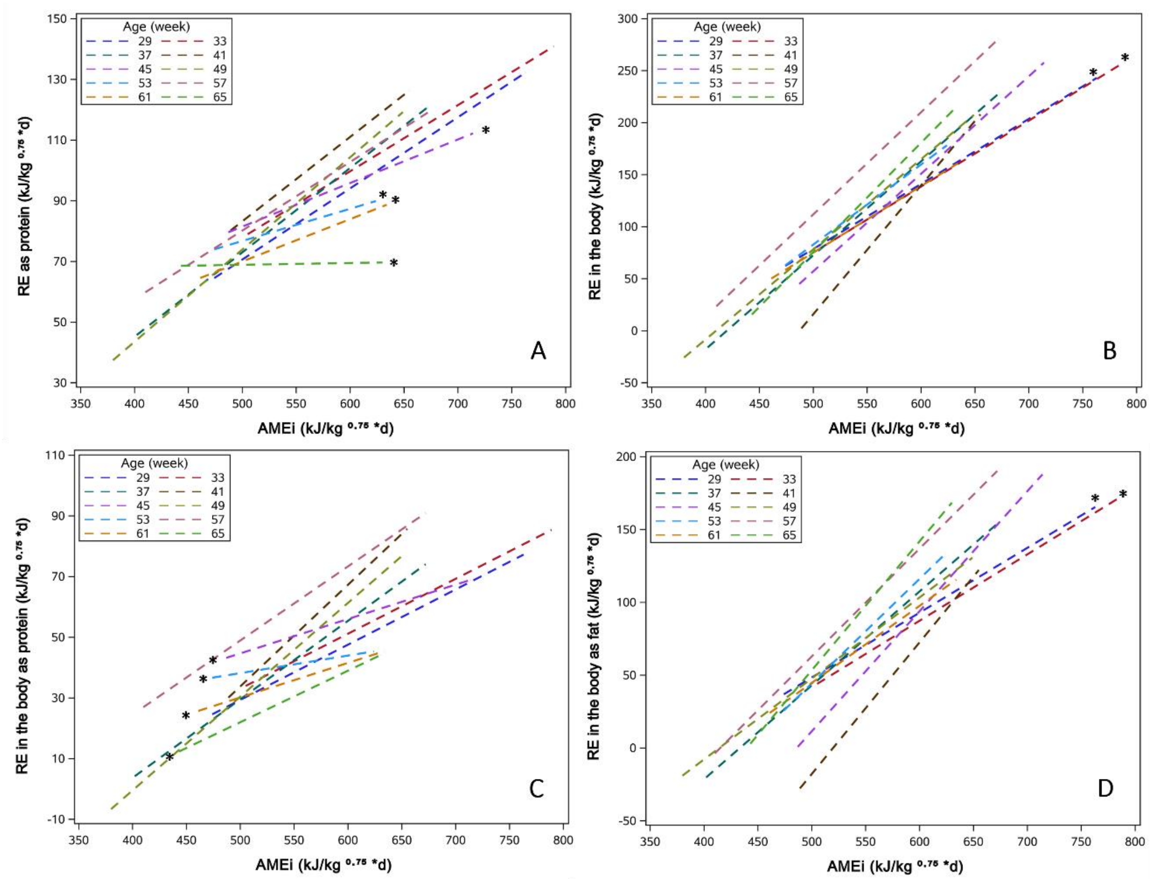

Figure 1. Changes in the relationship between retained energy and apparent metabolizable energy intake at each age of broiler breeder hens in the production phase. **A**, retained energy as protein; **B**, retained energy in the body weight; **C**, retained energy as protein in the body; **D**, retained energy as fat in the body.

*significant p≤0.05
**significant p≤0.005
***significant p≤0.0005

(kJ/bird*d)

(g/bird)	FHP	THP	AMEi	RE_f	RE
Liver	0.218 ns	0.193 ns	0.354 **	0.354 **	0.327 *
Gut	0.417 **	0.389 **	0.094 ns	-0.005 ns	-0.022 ns
Ovary	0.302 *	0.313 *	0.242 ns	0.179 ns	0.166 ns
Proventriculus	0.457 ***	0.484 ***	0.167 ns	-0.007 ns	0.036 ns
Abdominal fat	0.334 *	0.129 ns	0.319 *	0.350 *	0.311 *
Gizzard	0.274 *	0.361 **	0.223 ns	0.082 ns	0.137 ns
Digestive organs	0.418 **	0.445 ***	0.278 *	0.168 ns	0.163
Reproductive organs	0.297 *	0.307 *	0.152 ns	0.060 ns	0.069 ns
Viscera	0.505 ***	0.517 ***	0.300 *	0.163 ns	0.164 ns

Pearson Correlation: 1, 0.5, 0, -0.5, -1

Figure 2. Paired Pearson correlation between energy metabolism variables (kJ/kg$^{0.75}$*d) and visceral mass and organ size (g/bird). The blue color represents the gradient of the correlation degree. ***ns***: non-significative.

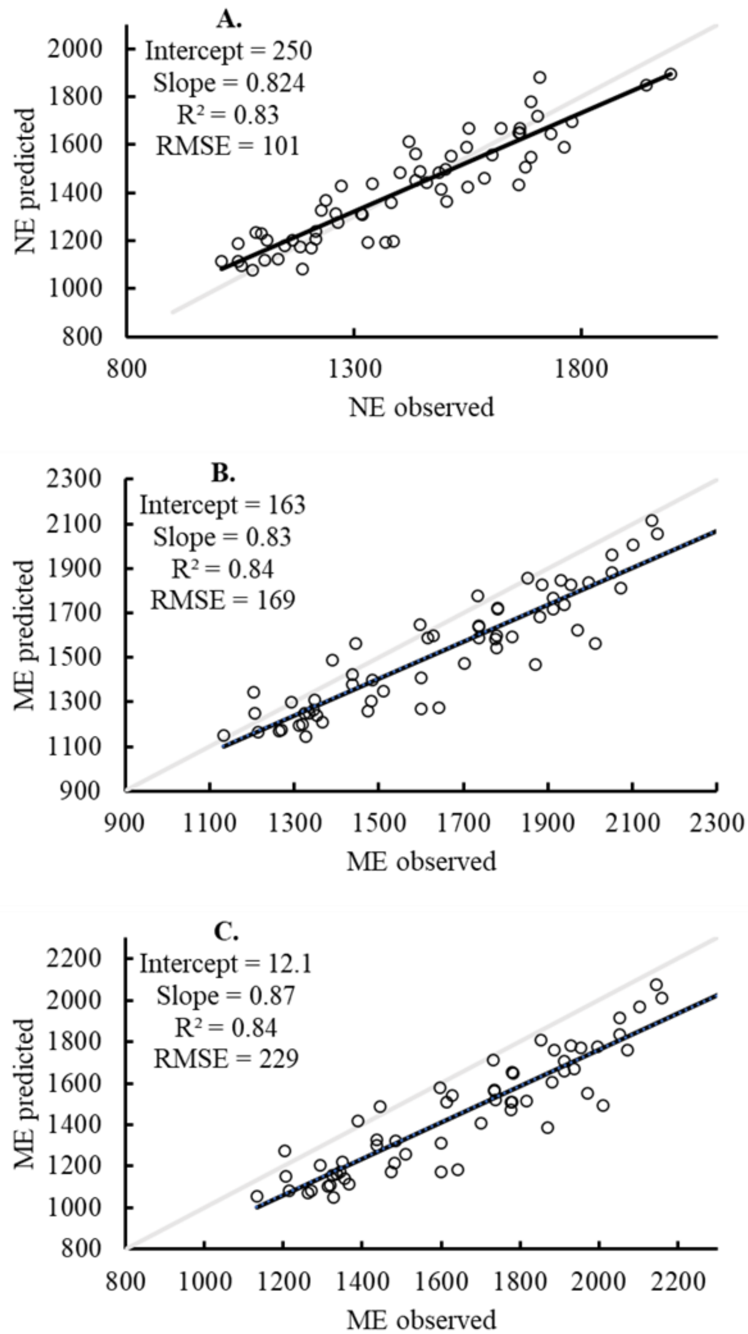

Figure 3. Dispersion plots are used to compare the observed and predicted values of net energy (**NE**) as described by model 1.1 (**A**), and for metabolizable energy (**ME**) disregarding the age effect as described by model 2.1 (**B**), and regarding age effect by model 2.2 (**C**). The observed data takes into consideration the results determined from the biological trial, while the predicted data were obtained using the models and the variables of body weight, body weight gain, and egg mass. The intercept and slope refer to the regression between predicted and observed values. R^2 is the degree of determination, and RMSE is the standard error.

CAPÍTULO 4 – IMPLICAÇÕES

As matrizes de corte apresentam certas particularidades metabólicas como resultado da intensa seleção genética para maior apetite e rápido crescimento. Nesse sentido, é adotado o sistema de restrição alimentar utilizado para conciliar a alta eficiência de deposição de tecidos com a produção de ovos férteis. Portanto, ter o conhecimento da dinâmica de utilização energética e de como as reprodutoras pesadas particionam a energia ingerida para mantença, deposição de proteína e gordura no corpo e para produção de ovos ao longo do ciclo produtivo, permite propor estratégias nutricionais e programas alimentares para diferentes condições práticas (estresse térmico, desuniformidade do lote, aves acima ou abaixo do peso recomendado etc.) possibilitando uma melhora no desempenho produtivo, reprodutivo e no bem-estar das aves.

Com os dados de desempenho disponibilizados pelo manual da linhagem (Cobb 500), encontramos que para reprodutoras com peso corporal de 3,66 kg, ganho de peso de 5,71 g/dia e massa de ovo de 49,3 g/ave, as exigências de energia líquida e metabolizável resultante dos modelos sem considerar o efeito da idade foram 1426 e 1693 kJ/ave*dia respectivamente. Além disso o menor erro no modelo de energia líquida indica que esse sistema é mais acurado em predizer as exigências energéticas das matrizes de corte durante a fase de produção de ovos.

Além disso, a alimentação das aves comerciais representa cerca de 70% dos custos de produção, de modo que obter estimativas mais acurada das exigências energéticas das matrizes de corte resultará em um maior desempenho das aves e na redução dos custos de alimentação, associado ao menor impacto ambiental.

Por fim, os resultados deste estudo mostraram que em matrizes de corte as exigências de energia líquida de mantença não se alteram ao longo do ciclo produtivo independentemente do nível de ingestão energética, no entanto, outros componentes como a retenção de energia nos tecidos do corpo apresentam uma maior variação ao longo da idade da ave, mudando a eficiência de deposição. Logo, no âmbito científico esses achados facilitarão a implementação do sistema de energia líquida em matrizes de frangos de corte, bem como estabelecer programas de alimentação apropriados a cada condição durante a fase de produção das reprodutoras de frangos de corte.