UNIVERSIDADE ESTADUAL DO NORTE FLUMINENSE DARCY RIBEIRO

RAPHAEL PAVESI ARAUJO

AVALIAÇÃO QUANTITATIVA DE PERFIS DE CRESCIMENTO DE CAPRINOS MACHOS CASTRADOS

CAMPOS DOS GOYTACAZES

2014

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AVALIAÇÃO QUANTITATIVA DE PERFIS DE CRESCIMENTO DE CAPRINOS MACHOS CASTRADOS

Tese apresentada ao Centro de Ciências e Tecnologias Agropecuárias da Universidade Estadual do Norte Fluminense Darcy Ribeiro, como requisito para obtenção do grau de Doutor em Ciência Animal na Área de Concentração em Nutrição e Produção Animal.

ORIENTADOR Profº. D.Sc. Ricardo Augusto Mendonça Vieira

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Aprovada em 27 de janeiro de 2014.

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(**Orientador**)

Dedico esta tese à minha família, em especial a minha mãe Luizeni, meu pai Juarez, meu irmão Leandro e a minha noiva Talita, que sempre estiveram ao meu lado nos momentos difíceis.

AGRADECIMENTOS

A Deus que me deu força, sabedoria e discernimento para enfrentar os obstáculos e prosperar diante das dificuldades encontradas durante esta batalha;

Ao Programa de Pós-Graduação em Ciência Animal da Universidade estadual do Norte Fluminense Darcy Ribeiro pela oportunidade de dar continuidade aos meus estudos;

A CAPES, pela concessão da bolsa, que me deu apoio financeiro durante o curso;

Aos meus pais Juarez Barbosa Araujo e Luizeni Soares Pavesi pelo amor, pela dedicação e pelo incentivo, os quais foram de suma importância para minha caminhada até aqui. Tenho muito orgulho de ser filho de vocês!

Á minha Noiva Talita Pinheiro Bonaparte pelo amor, carinho e companheirismo durante toda nossa trajetória juntos, em especial pela ajuda nos momentos difíceis no decorrer do doutorado, que foram extremamente importantes para que eu conseguisse concluir esta etapa;

Ao meu irmão Leandro Pavesi Araujo, à sua esposa Maria Isabel Mendes dos Santos e aos meus sobrinhos Murilo e Matheus, pelo carinho e apoio quando necessitei;

Ao meu orientador Profº D.Sc. Ricardo Augusto Mendonça Vieira pela amizade, pelo incentivo e pelos ensinamentos, que me fizeram crescer como pessoa e principalmente como profissional;

Ao meu orientador de Graduação e mestrado Profº D.Sc. João Carlos de Carvalho Almeida pela amizade, pelos incentivo e apoio durante os momentos difíceis;

A Unidade de Apoio à Pesquisa em Zootecnia (Colégio Agrícola Antônio Sarlo) pela oportunidade de realização do experimento, em especial aos funcionários Robson Alves de Carvalho (matrícula 10376-2), Alcir Manhães da silva (matrícula 10290-5) e Antônio Pereira de Souza (matrícula 10456-2) pela amizade, e pelo apoio na condução do experimento;

Aos amigos de labuta Wagner, Matheus, Raphael Gomes, Flavio, Leonardo, Marcelo, Nardele, Carlos e Jeferson pelo companheirismo, pela ajuda e pela convivência durante os três anos de trabalho no setor de caprinocultura;

Aos amigos Bob, Andréia, Talles, Suelen, Robocop, Maraca, Bruno Deminicis, Forró, Marcelo, Raphael Medina e Renato Silveira, obrigado pela valiosa amizade;

A todas as pessoas com quem convivi durante este período e aqueles que de alguma maneira, contribuíram para a realização deste trabalho, muito obrigado.

RESUMO

Araujo, Raphael Pavesi, D.Sc., Universidade Estadual do Norte Fluminense Darcy Ribeiro. Janeiro de 2014. Avaliação quantitativa de perfis de crescimento de caprinos machos castrados. Professor Orientador: Ricardo Augusto Mendonça Vieira.

O objetivo com este estudo foi caracterizar o crescimento corporal e a composição do corpo vazio de caprinos machos castrados de raças leiteiras em um período longo de crescimento. Os animais foram abatidos ao nascimento (dia zero), e próximos às idades de 15, 90, 135, 210, 270, 365, 485, 610, 735, 790, 840, 890 e 920 dias. Todas as partes do corpo foram pesadas, amostradas e determinados seus constituintes químicos em matéria seca, proteína bruta, gordura bruta, cinzas e energia específica. Os modelos de crescimento Richards, Gompertz e o bifásico Brody-Gompertz foram ajustados para os perfis de crescimento com as diferentes estruturas de variância e covariância (homogênea, exponencial e assintótica) e foram todos avaliados pelo critério de máxima verossimilhança. A eliminação dos outliers melhoraram a probabilidade de verossimilhança de alguns modelos, de forma que diferenças notáveis puderam ser observadas no ponto de inflexão, taxa de crescimento e na tendência das variáveis estudadas. A existência de um ponto de inflexão verdadeiro para muitas variáveis estudadas foi duvidosa, embora o modelo de Richards tenha sido a melhor escolha para descrever a maioria dos perfis avaliados. O modelo bifásico não superou o modelo de Richards, em termos de probabilidade, provavelmente devido ao fato de que o ponto de inflexão relativo à puberdade se confundiu com o efeito da desmama, e pela falta de informações no intervalo entre 15 e 90 dias. De forma geral, os padrões de crescimento exibidos pelas partes do corpo e constituintes químicos foram alométricos em relação a W. Este comportamento alométrico resultou em diferentes tendências assintóticas: algumas partes do corpo ou componentes químicos atingiram a maturidade mais cedo do que outras. Portanto, o crescimento das partes corporais e a composição do ganho de corpo vazio ao longo do tempo em caprinos castrados não foram constantes em toda a gama de massa corporal estudada.

Palavras-chave: Análises de crescimento, Caprino, Máxima verossimilhança, Modelos matemáticos.

ABSTRACT

Araujo, Raphael Pavesi, D.Sc., Universidade Estadual do Norte Fluminense Darcy Ribeiro; January 2014; Quantitative assessment of growth of goat wethers profiles. Adiviser: Ricardo Augusto Mendonça Vieira.
The goal of this study was to characterize the growth of body parts and composition of the growing empty body to infer how these aspects relate to the long-term growth of goat wethers from dairy breeds. In addition to birth (day zero) and to 15 days of age, the animals were slaughtered at ages close to 90, 135, 210, 270, 365, 485, 610, 735, 790, 840, 890, and 920 days. All body parts were weighed and sampled to determine chemical constituents dry matter, crude protein, crude fat, ash, and specific energy. The Richards, Gompertz, and a biphasic model formed by the combined Brody and Gompertz growth functions were fitted to the growth profiles with different variance functions and were all evaluated by means of likelihood criteria. The elimination of outliers enhanced the likelihood probability (w_r) of some models. Remarkable differences can be noticed regarding inflection points, growth rates, and trends for the variables studied. The existence of a true inflection point for many variables studied was dubious, although the Richards model was the best choice to describe many growth profiles. The biphasic model did not supplanted the Richards model in terms of likelihood, and the suspicious additional inflection point prior to the point about puberty due to a transient weaning period lacks data of sufficient quantity between 15 and 90 days of age for an adequate characterization. Generally, the growth patterns exhibited by the body parts and chemical constituents were allometric with respect to W. This allometric behaviour yielded different asymptotic trends: some body parts or chemical constituents reached maturity earlier than others did. Therefore, growth of body parts and composition of gain in the growing empty body of the goat wethers were not constants in the entire range of body mass studied.

Keywords: Growth analysis, Goats, Mathematical models, Maximum likelihood

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1. INTRODUÇÂO

Crescimento e desenvolvimento de ruminantes têm sido discutidos e revisados por muitos anos. Vários autores têm especulado ou modelado a taxa e composição do acréscimo de tecido pela idade cronológica, pela idade fisiológica (tamanho adulto, maturidade), pelo consumo de energia, pelo status hormonal, pelo turnover ou renovação relativa dos tecidos e pelo número de células (Owens et al., 1995)

Crescimento usualmente pode ser definido como a produção de novas células, porém, devido ao crescimento ser medido rotineiramente como incremento em massa, pode-se incluir não somente a multiplicação de células (hiperplasia), mas também o aumento do tamanho das células (hipertrofia). Durante o crescimento embrionário, todos os tecidos crescem por hiperplasia, mas em mamíferos adultos as células especializadas (células musculares esqueléticas e tecido adiposo) perdem sua habilidade em se replicar e crescem somente por hipertrofia ou incorporação de células satélites. No entanto, outros tecidos, como precursores de células sanguíneas, folículo capilar, epitélio gastrintestinal, órgãos do trato digestivo, entre outros continuam a se dividir por toda a vida (Owens et al., 1993).

Nem toda porção do corpo se desenvolve igualmente ou ao mesmo tempo durante o crescimento, este crescimento diferenciado por parte do corpo é chamado de desenvolvimento que ocorre do estágio embrionário até a maturidade. Um exemplo bastante corriqueiro é que a cabeça de todos os animais compreende uma maior porção do peso ao nascimento, do que em qualquer estágio posterior da vida, porém o aumento pós-natal é menor que outras partes do corpo (Boggs e Merkel, 1993).

Da antológica obra de Brody (1945), pode-se depreender que o crescimento difere do desenvolvimento pelo fato de este obedecer a uma diretriz biológica; isto é, o crescimento "orquestrado" geneticamente desde a sua concepção à maturidade. O crescimento, dentro desta lógica biológica, ou seja, determinado pela herança e pelas restrições do meio, constitui desenvolvimento. O crescimento, por seu turno, se traduz por síntese biológica, isto é, a produção de novas unidades bioquímicas. É o aspecto do desenvolvimento relacionado aos processos de multiplicação celular, expansão celular e a incorporação de matéria colhida do meio-ambiente. Contudo, o crescimento pode não implicar desenvolvimento; nos tumores, por exemplo, há o crescimento sem função de diferenciação. O desenvolvimento é o processo de consolidação da heterogenidade biológica que constitui os seres vivos, particularmente aquele verificado nos animais superiores. Dessa forma, a exigência e a eficiência energética dos animais variam de acordo com o estágio fisiológico.

O estudo do processo de transferência de energia em animais e o mecanismo regulatório envolvido são usualmente definidos como bioenergética. A bioenergética pode ser estudada por vários caminhos, dentre eles, destacam-se: 1- transferências de energia que ocorrem em pequenas etapas químicas, comumente investigados por bioquímicos; 2 – aspectos neurais ou hormonais, que são tratados pelos fisiologistas; 3 - predição da demanda energética do animal como um todo e a habilidade de diferentes alimentos em satisfazer esta exigência, estes, investigados por nutricionistas (Blaxter,1962).

A utilização da energia pelos animais depende de vários fatores, os quais irão determinar a eficiência da utilização do alimento pelo animal. Em termos termodinâmicos, a eficiência energética de crescimento refere-se à relação do desempenho do crescimento com a energia livre despendida. Tradicionalmente, entretanto, a eficiência energética de crescimento é definida pela relação da energia armazenada no organismo e energia consumida (Brody, 1945).

2. REVISÃO DE LITERATURA

2.1 CURVA DE CRESCIMENTO

O crescimento e o desenvolvimento são processos complexos fundamentais na vida dos seres vivos. Em síntese, o crescimento animal está relacionado com o aumento de massa e volume, o que determina o tamanho corporal, enquanto o desenvolvimento está envolvido com a diferenciação dos componentes corporais.

Diversos fatores podem influenciar o crescimento de cabritos jovens, desde o nascimento até idades mais avançadas, podendo ser destacados: o peso ao nascimento, sexo e o ganho de peso. O peso ao nascimento indica o desenvolvimento intrauterino do animal, o qual está diretamente relacionado com fatores genéticos, número de animais por parto e a nutrição da cabra durante o período de gestação.

O ganho de peso pode ser definido, basicamente, como o resultado entre o genótipo e o ambiente oferecido ao animal. Os trabalhos na literatura têm apontado grande variação entre os ganhos de peso diário de caprinos durante o crescimento, sendo relatada uma faixa de 45 a 190g dia^{-1} para as raças especializadas na produção leiteira. Oliveira (2001) relatou que, em geral, os melhores ganhos de peso na espécie caprina foram observados no período compreendido entre o nascimento e os 5,5 meses de idade, o que evidencia o maior desempenho dos animais nesta fase de produção. Em suma, Fisher (1975) relatou que o aporte alimentar que os animais recebem é determinante para o ritmo de crescimento do animal e, consequentemente, para o peso corporal final.

Os principais componentes que influenciam no peso de um animal são os tecidos ósseo, muscular, visceral e adiposo. No processo de crescimento o animal apresenta incremento do peso corporal devido ao acúmulo destes referidos tecidos, respeitando certa ordem de prioridade. Assim, o processo de crescimento animal influência a seguinte ordenação no desenvolvimento dos tecidos: nervoso, ósseo, muscular e adiposo. Por esta razão, a composição corporal altera-se ao longo do tempo em decorrência das diferentes velocidades de crescimento e maturação dos tecidos (ALLEN et al., 1979; OWENS et al. 1993).

Segundo Fitzhugh Jr. (1976), as curvas de crescimento refletem as inter-relações entre o impulso individual do animal recém-nascido para crescer e atingir a maturação de todas as partes do corpo e o ambiente no qual este impulso se expressa. Owens et al. (1993) sugeriram que o crescimento animal ocorre de forma acelerada na fase inicial, reduzindo com o avanço da idade, sendo que sua respectiva curva apresenta ponto de inflexão associado à puberdade. Os melhores índices de ganho de peso e de conversão alimentar são obtidos pelos animais em crescimento, aproximadamente quando o animal atinge 30% do peso adulto. Taylor, (1985) enfatizou que a obtenção de resultados econômicos positivos na produção animal está, portanto, na dependência do melhor aproveitamento da fase inicial de crescimento.

O interesse no estudo de curvas de crescimento que possa descrever toda a vida do animal já existe há mais de um século (FRANCE et al. 1996). Na tentativa de descrever a curva de crescimento dos animais adequadamente, iniciou-se a utilização de modelos matemáticos não lineares. Uma das primeiras tentativas em descrever o crescimento através de funções matemáticas foi realizada por Quetelet, em 1835, sendo o primeiro a fazer analogias entre as diferentes fases do crescimento de um organismo e a propor uma curva sigmoide para descrevê-lo.

O conhecimento preciso da taxa de crescimento, grau de maturidade e tamanho à maturidade, entre outras características correlacionadas, podem ser obtidas a partir das curvas de crescimento. Tais informações podem constituir interessante ferramenta no processo de tomada de decisões para aumentar a eficiência do rebanho, com destaque para a seleção dos melhores animais para a reprodução, a otimização de dietas apropriadas para suprir as diferentes exigências nutricionais ao longo do desenvolvimento dos animais, a redução dos custos e dos riscos da exploração e o ponto ideal (produtivo e econômico) de abate dos animais.

Para Fitzhugh Jr. (1976), os dados de peso e idade tomados em diferentes períodos de crescimento podem ser chamados de dados longitudinais. A análise dessas medidas repetidas mostra-se de grande importância na produção animal, possibilitando que indivíduos de diferentes subpopulações ou tratamentos (sexo, raça, entre outros) sejam analisados ao longo de diferentes condições de avaliação (tempo, doses, etc.).

A utilização de curvas de crescimento que relacionam o peso do animal à sua idade tem despertado o interesse de muitos pesquisadores em diversas áreas. Para McManus et al. (1997), uma das principais vantagens de utilizar modelos matemáticos para descrever o crescimento é a consolidação das informações contidas em dados de peso–idade dentro de parâmetros biologicamente interpretáveis.

Poucos estudos sobre curva de crescimento têm sido desenvolvidos no Brasil, estando estes escassos trabalhos concentrados nas áreas de bovinocultura, suinocultura e avicultura. A utilização de modelos matemáticos para descrever a curva de crescimento da espécie caprina é muito recente e conta com número reduzido de publicações.

Esta informação é confirmada por Malhado et al. (2008), em que diz que o número de publicações com caprinos utilizando os modelos de curvas de crescimento é muito reduzido (FREITAS, 2005; OLIVEIRA et al., 2009).

2.2 MODELOS MATEMÁTICOS

Os principais modelos matemáticos utilizados na descrição do crescimento dos animais domésticos de interesse zootécnico são: Brody ou monomolecular, Von Bertalanffy, Gompertz, Logístico e Richards (BROWN et al., 1976; FITZHUGH Jr., 1976; OLIVEIRA et al., 2000; MAZZINI et al., 2003; FREITAS, 2005). Segundo Richards (1959), o estudo de curvas de crescimento iniciou com o modelo de Von de Bertalanffy em experimentos sobre metabolismo. France et al. (1996) caracterizaram as funções de crescimento dividindo-as em dois tipos: simples e conjugadas. Dentre as funções simples são destacados os modelos de Brody, Von Bertalanffy, Gompertz e Logístico. A função de Richards é classificada como uma função conjugada.

Segundo Guedes et al. (2004), alguns requisitos devem ser seguidos para que uma função de crescimento seja descrita como uma relação peso-idade. Entre eles destacam-se: (a) a interpretação biológica dos parâmetros (confiabilidade); (b) o ajuste com pequenos desvios (precisão); e (c) o grau de dificuldade do ajuste (operacionalidade do processo).

Sarmento et al. (2006) reportaram que, uma vez escolhido o modelo que melhor se ajusta ao padrão de crescimento, os parâmetros que o descreve devem ser estudados para identificar os fatores que podem influenciá-los, como raça, sexo, tipo de nascimento, época e ano de nascimento e idade da mãe ao parto, e possibilitar ajustes no padrão de crescimento.

2.2.1 Modelo Brody

O modelo da curva de crescimento pode ser dividido em dois segmentos principais: o primeiro como a fase de aumento da velocidade de crescimento (autoaceleração); e o segundo como a fase de diminuição da velocidade (autoinibição) do crescimento. A passagem de uma fase para outra é marcada por um ponto de inflexão, o qual marca a posição em que o aumento da velocidade de crescimento cessa e a diminuição da velocidade de crescimento ainda não iniciou, sugerindo que o crescimento neste ponto é linear. Neste ponto, o ganho de peso é mais eficiente e mais econômico. Na ausência de forças inibitórias, a taxa de crescimento tenderia a permanecer constante.

France et al. (1996) citaram que o modelo de Brody teve como norte o estudo monomolecular desenvolvido por Spillman e colaboradores para avaliar a lei dos retornos decrescentes para descrever o peso corporal de um animal como uma função do seu consumo de alimentos. Assim, utilizou-se este modelo em conjunção com o modelo exponencial para contabilizar a forma de “S” exibida pelos padrões de crescimento de populações, animais e outros organismos ao longo do tempo.

Segundo Doren et al. (1989), o modelo de Brody foi inicialmente utilizado para descrever o crescimento animal ocorrido após o ponto de inflexão. Entretanto, seu uso não está restrito à fixação dos valores iniciais. Assim, considera-se o nascimento como ponto de inflexão, que pode ser aplicado para descrever todo o crescimento pós-natal.

A taxa de crescimento relativo instantâneo pode ser obtida pela equação:

$$k = \left({}^{dW}\!/_{dt}\right)\!/_{W} \qquad \text{equação 1}$$

onde,

k é a taxa relativa de crescimento instantâneo;

dW é o diferencial do peso;

dt é o diferencial do tempo;

W é o peso no instante em que ${dW}/{dt}$ foi medido.

No entanto, com a dificuldade de medir o ganho instantâneo, utilizou-se um método de integração para modificar a equação de ${dW}/{dt} = kW$ para

$W_t = W_0 e^{kt}$ equação 2

em que,

W é o peso acumulado no tempo t;

W_0 é o peso inicial;

k é a taxa de crescimento específica**.**

Linearizando a equação 2, tem-se:

$lnW_t = lnW_0 + kt$ equação 3

No entanto, as equações 2 e 3 só se mostraram adequadas por um período inicial do crescimento. O autor relata que a taxa de crescimento declina com o aumento da idade, mantendo-se relativamente constante em determinados intervalos de tempo. O declínio da taxa de crescimento é muito mais lento do que antes (não parecendo ser constante) e depois declina de forma relativamente abrupta a um novo nível mais baixo. Brody (1945) teoriza que o ponto de inflexão da curva, onde a aceleração seria zero, estaria relacionado a um momento de mudança fisiológica, que ocorre em todos os animais, a puberdade.

Para a elaboração de uma equação que represente a fase de inibição do crescimento após a inflexão da curva, segundo o autor, pode-se também utilizar o princípio de ação das massas. Ao invés da taxa de crescimento ser proporcional ao tamanho do animal, ela agora será proporcional à disponibilidade de alimentos, à retirada de produtos deletérios ao crescimento, ou a qualquer elemento que se mostre limitante. Se o suprimento de alimento limitante é necessário para atingir o máximo tamanho individual (A) e Wo fornecimento de alimento até um dado tempo, então A-W representa a concentração do alimento limitante, que permite atingir o máximo tamanho individual.

Para Brody (1945), é razoável assumir que a velocidade de crescimento instantânea, ${dW}/{dt}$, em um dado momento será proporcional ao fornecimento da concentração de alimentos limitante $(A - W)$:

${dW}/{dt} = -k(A - W)$ equação 4

onde, o sinal negativo atribuído ao k indica o declínio da velocidade de crescimento.

Portanto, de maneira geral, os valores numéricos das constantes são estimados como: A, representando a concentração do fator limitante de crescimento, quando o crescimento é completamente inibido, podendo ser usada para representar o peso à maturidade do animal; W pode representar o peso do animal em um dado tempo; $A - W$ representa, então, o crescimento ainda a ser realizado para atingir o peso à maturidade.

Integrando-se a equação 4 tem-se (FRANCE et al., 1996):

$W = A - Be^{-kt}$ equação 5

em que,

B é a diferença $A - W_0$;

k é a taxa de crescimento relativa ao crescimento a ser realizado.

A constante B é empregada para corrigir o fato de que, embora a idade seja contada a partir do nascimento ou concepção, a equação 5 ajusta os dados somente durante a fase de crescimento posterior à inflexão da curva. O expoente k é o declínio da velocidade de crescimento em taxa constante.

Brody (1945) enfatiza que as duas equações utilizadas para descrever o crescimento (2 e 5), poderiam ser combinadas em uma única equação, ${dW}/{dt} = kW(A - W)$. Porém, tal equação (com adição de constantes ou não), segundo o autor, não representa o ciclo todo de crescimento dos animais apresentando quebras na curva de crescimento e irregularidades similares no crescimento de populações. Portanto, Brody (1945) optou por descrever o crescimento a partir de duas equações (2 e 5) que explicassem as fases de aceleração e inibição do crescimento.

2.2.2 Modelo Gompertz

A função Gompertz, desenvolvida originalmente em 1825, utiliza a taxa de inibição proporcional ao logaritmo desta variável, ou seja, a taxa de crescimento é grande no início do processo, mudando rapidamente para um crescimento mais lento (SCAPIM, 2008). Segundo Laird (1965), tal função foi apontada como própria para a descrição do crescimento dos organismos vivos, com base no argumento de que a capacidade média de crescimento, medida pela velocidade relativa de aumento, tende a cair em uma taxa mais ou menos uniforme, conduzindo a tipos assimétricos de curvas sigmoides.

Seguindo o mesmo raciocínio, France et al. (1996) descreveram o modelo de Gompertz com um comportamento sigmoidal suave, sem descontinuidade. E com a efetividade do crescimento diminuindo ao longo do tempo de acordo com a cinética de primeira ordem.

Para Fialho (1999), a função de Gompertz tem propriedades desejáveis como modelo de curva de crescimento, principalmente pelo fato de considerar que a massa corporal inicial é sempre superior à zero, o que reflete o fato de que o animal já nasce com alguma massa.

A função Gompertz proposta por Laird (1965) e citada por Ludwig (1977) tem a seguinte forma:

$$w_t = w_0 \exp(k(1 - \exp(-Dt))/D) \qquad \text{equação 6}$$

Onde, w_0= massa inicial; k=taxa de crescimento específica; D= taxa de redução fracional do crescimento.

Ainda segundo France et al. (1996), a taxa de crescimento relativo instantâneo ou a primeira derivada pode ser expressa da seguinte forma:

$$dy_t/_{dt} = k \exp -dt \times w_0 \exp(k(1 - \exp(-Dt))/D) \qquad \text{equação 7}$$

2.2.3 Modelo Richards

France et al. (1996) expuseram que o modelo de Richards, por ser determinado como função conjugada, engloba as funções simples de crescimento (Brody, Bertalanffy, logística e Gompertz), conferindo uma generalidade que é frequentemente útil para descrever o crescimento animal.

Em seu trabalho “Uma função de crescimento flexível para uso empírico”, Richards retoma considerações de Von Bertalanffy (1957) como a relação alométrica de crescimento entre a taxa metabólica do animal e seu peso, afirmando que a inclinação

(n) da linha alométrica é de 2/3 para espécies obedecendo à lei de superfície do metabolismo. Richards também retoma a afirmação de que a taxa de anabolismo é proporcional ao peso elevado a m-*ésima* potência, mas a taxa de catabolismo é proporcional ao próprio peso. Assim a taxa de crescimento em peso, dada pela diferença entre anabolismo e catabolismo, é dada por: $\eta W^{n} - kW$, onde η e κ são constantes de anabolismo e catabolismo, respectivamente. Quando m=1, $dW/dt = (\eta - k)^{W}$ o crescimento é exponencial. Para baixos valores de n a integração leva a equação de crescimento a seguir (FRANCE et al.,1996):

$$\mu_{Y_t} = Y_0 \times Y_f / \left(Y_0^{m} + \left(Y_f^{m} - Y_0^{m}\right)\exp(-kt)\right)^{1/m} \qquad \text{equação 8}$$

Onde, $Y_0 =$ massa inicial; $Y_f =$ massa final; m= escalonamento da massa; k= taxa de crescimento relativo; t= tempo.

Richards afirmou que embora seja interessante, a derivação da taxa de crescimento contém algumas considerações que colocam em dúvida sua validade teórica; além disso, valores de m acima de 1 são rejeitados, não por nunca ocorrerem, mas provavelmente pela necessidade teórica de manter η e κ em uma variação numérica compatível com sua interpretação como constantes de anabolismo e catabolismo, respectivamente. Tal fato pode ser facilmente comprovado pelo uso de m > 1, já que os valores de η e κ seriam negativos.

Uma vez que a equação 8 proporciona resultados irreais de m e k em situações nas quais m >1, ela foi reescrita para:

$$W^{1-m} = A^{1-m} - \beta e^{-kt}$$

Em que $A^{1\text{-m}}$, β e k, são constantes:

$$A^{1-m} = (\eta/k), \beta = \eta/kW_0^{(1-m)} = A^{1-m} - W_0^{(1-m)}, ek = (1-m)k$$

Posteriormente foi reparametrizada para:

$$W^{1-m} = A(1 \pm be^{-kt}) \qquad \text{equação 9}$$

Em que $b = \pm\beta A^{1-m}$, onde o sinal é negativo quando m < 1 e positivo quando m > 1.

Neste sentido a curva de crescimento de Richards (1959) descreve mudanças no tamanho W (peso) em relação à idade t, representada como:

$$W_t = A(1 - be^{-kt})^{m} \qquad \text{equação 10}$$

O modelo Richards considera que o ponto de inflexão das curvas é variável, mesmo que dentro de uma mesma população. Isto ocorre devido à relevância do parâmetro m, que é relativo à forma da curva, com ponto de inflexão variável. Assim, dependendo do valor de m, a função de Richards pode apresentar as formas das outras funções de ponto de inflexão fixo. Desta forma, dependendo do valor do parâmetro m na equação 10, tem-se:

Brody	$W = A(1 - be^{-kt})$	(m = 0)
Von Bertalanffy	$W = A(1 - be^{-kt})^3$	(m = 2/3)
Logístico	$W = A/(1 + be^{-kt})$	(m = 2)
Gompertz	$W = Ae^{-be^{-kt}}$	(m > 1)
Richards	$W = A(1 - be^{-kt})^m$	(m variável)

Em resumo, quando $0 < m < 1$, tem-se um modelo intermediário entre o de Brody e Gompertz; quando $1 < m < 2$, o formato se situa entre o modelo de Gompertz e o modelo Logístico; quando $m > 2$ o resultado é um modelo similar ao logístico, porém assimétrico, em que o ponto de inflexão pode ser alterado para um valor maior do que $W = A/W$.

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4. CAPITULO 1

O CAPITULO 1 APRESENTADO A SEGUIR FOI SUBMETIDO PARA PUBLICAÇÃO NO PERIÓDICO “THE JOURNAL OF AGRICULTURAL SCIENCE” (ISSN:0021-8596; IMPACT FACTOR: 1.691), DE MODO QUE O MESMO FOI EDITADO CONFORME AS NORMAS ESPECÍFICAS DESTE PERIÓDICO, QUE PODEM SER OBTIDAS NO SEGUINTE ENDEREÇO ELETRÔNICO: http://assets.cambridge.org/AGS/AGS_ifc.pdf

Growth of goat wethers from birth to maturity: quantitative description of the growing body, body parts, and composition of gain

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Summary

The goal of this study was to characterize the growth of body parts and composition of the growing empty body to infer how these aspects relate to the long-term growth of goat wethers from dairy breeds. In addition to birth (day zero) and to 15 days of age, the animals were slaughtered at ages close to 90, 135, 210, 270, 365, 485, 610, 735, 790, 840, 890, and 920 days. All body parts were weighed and sampled to determine chemical constituents dry matter, crude protein, crude fat, ash, and specific energy. The Richards, Gompertz, and a biphasic model formed by the combined Brody and Gompertz growth functions were fitted to the growth profiles with different variance functions and were all evaluated by means of likelihood criteria. The elimination of outliers enhanced the likelihood probability (w_r) of some models. Remarkable differences can be noticed regarding inflection points, growth rates, and trends for the variables studied. The existence of a true inflection point for many variables studied was dubious, although the Richards model was the best choice to describe many growth profiles. The biphasic model did not supplanted the Richards model in terms of likelihood, and the suspicious additional inflection point prior to the point about puberty due to a transient weaning period lacks data of sufficient quantity between 15 and 90 days of age for an adequate characterization. Generally, the growth patterns exhibited by the body parts and chemical constituents were allometric with respect to W. This allometric behaviour yielded different asymptotic trends: some body parts or chemical constituents reached maturity earlier than others did. Therefore, growth of body parts and composition of gain in the growing empty body of the goat wethers were not constants in the entire range of body mass studied.

Keywords: Growth analysis, Goats, Mathematical models, Maximum likelihood

Introduction

Mathematical functions have been used to describe growth of domestic ruminants for predictive purposes, and the information can be used at both scientific and farm levels. Nonlinear models are mathematical functions that are nonlinear in its parameters. Parameters do not belong to the real world but they are useful as representations of reality, they are ideally computed from random samples taken unbiasedly for point and interval estimation of the same parameters that are inferred to the population of interest. Parameters of traditional growth functions are empirical and can be aggregated, for instance, at the organismal level; they summarize information about the growth profile into a few parameters such as the specific growth rate and weights at birth and maturity in addition to a homoscedastic residual variance. Whenever detected in the growth profile, the inflection point is usually attributable to puberty, the point at which sexual maturity begins and the growth rate starts to reduce asymptotically to zero. Nonetheless, progress in computation statistics have been introduced into statistical software that allow a more general quantitative description of growth by generalizing not only the expected growth but also the variance about growth trends, thus accommodating heteroscedasticity and co-variation at both between and within individuals including repeated records as time advances.

The growth of ruminants is centripetal, which means that head and foreparts achieves asymptotic growth prior to inner body counterparts (Lawrence & Fowler 2002). However, goat wethers, like other castrated farm ruminants, probably grow further in length of long bones compared to intact animals, but hormones other than oestrogen and testosterone may act as determinants of complete ossification of epiphyseal plates after puberty (Doumit & Merkel 2005; Hossner 2005). In general, weight records of ruminants resemble a sigmoid-shaped pattern, and body parts such as bones, muscles, and fat exhibit remarkable differences in their growth profiles; besides, maturity of these major body constituents occurs earlier for bones, intermediate for muscles, and later for fat with reference to the timing for body maturing (Doumit & Merkel 2005).

The growth of body mass of castrated male goats can be described by the Richards (1959) model because of the flexible nature of this model for fitting a myriad of growth profiles (France et al. 1996; López et al. 2000). Nevertheless, how body parts and body composition change from birth to maturity in goats? The distribution of fat in the body of goats differ from other ruminant species, and visceral fat accretion is a striking characteristic that may help goats to survive and even produce in the face of seasonal food shortages (Carmichael et al. 2012). Despite the fact that castrates usually have intermediary growth profiles if compared to intact males and females, information gathered may be of use for predictive purposes. Therefore, the goal of this study was to characterize the growth of body parts and composition of the empty body to infer how these aspects relate to the long-term growth of goat wethers from specialized dairy breeds.

Material and methods

Alpine (chamois) and Saanen kids used in the present study were sampled from the annual offspring of a large dairy herd raised in the county of Viçosa (20°46’22” S, 42°51’12” W, and elevation 706 m), Zona da Mata Region, State of Minas Gerais (Brazil), where predominates a Cwa climate according to the Köppen standards. Two Saanen and two Alpine kids were slaughtered at birth and at 15 days old, one Saanen and three Alpine kids were slaughtered. Afterwards, 50 kids (37 Alpine and 13 Saanen) were moved to be raised in the county of Campos dos Goytacazes (21°42’36” S, 41°20’22” W, and elevation 15 m), northern Rio de Janeiro state, where an Aw climate predominates and the kids were castrated immediately after their arrival.

The kids were reared in a floor-bed type barn until weaning at 90 d. A milk replacer was fed, and a soybean meal and grounded corn mixture was offered to the animals on a daily basis. Cunhã (*Clitoria ternatea* L.), Elephant-grass (*Pennisetum purpureum*, Schum.), and occasionally, Sabiá (*Mimosa caesalpiniifolia*, Bentham) were the roughages available and offered ad libitum to the kids until weaning. After 90 days, the kids were transferred to a stilted-type barn with slatted floor and the animals received a ration based on soybean meal, grounded corn, minerals, and Mayze silage (*Zea mays*, L.). Additional roughage was offered (Cunhã, Elephant-grass, and occasionally Sabiá) ad libitum according to the availability of forages. The diet was formulated for a target average daily weight gain of 0.150 kg/day (AFRC 1997), and was adjusted over time according to the availability of forage.

In addition to birth (day zero) and to 15 days of age, the animals were slaughtered at ages close to 90, 135, 210, 270, 365, 485, 610, 735, 790, 840, 890, and 920 days. Nonetheless, the growth profiles were obtained with the actual age at slaughter for each animal to avoid bias. The oldest age at slaughter was chosen at the time of replacement of the last deciduous incisive teeth. Four animals were slaughtered at each age, excepting the last age when six animals were slaughtered. Half of the animals were slaughtered two hours after the morning meal and the other half two hours after the afternoon meal to measure the contents of the full gastrointestinal tract. At slaughter, the animals were rendered insensible, bled, flayed, and eviscerated. Individual parts, i.e., the head, members, half carcasses, blood, skin, organs (including the remaining of reproductive tract and bladder), the segments of the gastrointestinal tract and their contents, total abdominal fat (omental, pelvic, and renal), and trimmed cuts (diaphragm, non-carcass muscle pieces, and thymus) were weighed to the nearest 0.005 kg. All body parts, including carcass, head, and members were grounded in a cutting mill.

The body parts were dried at 55°C, and except for blood and skin samples, the excess fat from body parts was prior removed by petroleum ether extraction in large volume (500 ml) Soxhlet apparatus. The defatted samples were ball-milled and their dry matter (DM, method 967.03; AOAC, 1998), crude protein (CP, method 2001.11; Thiex et al., (2002)), crude fat (CF, method 2003.06; Thiex et al. (2003)), and ashes (Ash; method 942.05; AOAC (1998)) contents were determined. Another exception was the abdominal fat that undergone all chemical analysis without prior ball-milling. The energy content of the body was computed from the caloric equivalents of protein and fat, i.e., 23.4 and 39.3 MJ/kg, respectively (Maynard et al. 1979). The DM , CP, CF, Ash, and energy contents were computed in the empty body weight (EBW), namely $EBDM$, $EBCP$, $EBCF$, $EBAsh$, and EBE. The water content of the EBW was computed as $EB\mathrm{H_2O} = EBW - EBDM$.

The general structure attributed to the growth models was $Y_t \sim Normal\left(\mu_{Y_t}, \sigma^2_{Y_t}\right)$, and the form of the mean (μ_{Y_t}) and variance ($\sigma^2_{Y_t}$) are as follows:

$$\mu_{Y_t} = Y_0 \exp(k(1 - \exp(-Dt))/D); \quad \text{Eqn (1)}$$

$$\mu_{Y_t} = Y_0 \times Y_f / \left(Y_0^n + \left(Y_f^n - Y_0^n\right)\exp(-kt)\right)^{1/n} \quad \text{Eqn (2)}$$

$$\mu_{Y_t} = Y_{f1} - \left(Y_{f1} - Y_{10}\right)\exp(-k_1 t) + Y_{20}\exp(k_2(1 - \exp(-Dt))/D); \quad \text{Eqn (3)}$$

$$\sigma_{Y_t}^2 = \sigma^2; \quad \text{Eqn (4)}$$

$$\sigma_{Y_t}^2 = \sigma_0^2 \exp(ct); \quad \text{Eqn (5)}$$

$$\sigma_{Y_t}^2 = \sigma_0^2 + \sigma_b^2(1 - \exp(-st)). \quad \text{Eqn (6)}$$

The Eqn (1) is the Gompertz model and its parameters Y_0, k, and D are the intercept (mass units), specific growth rate (days^{-1}), and fractional reduction rate of the specific growth rate (days^{-1}), respectively. The Richards model or Eqn (2) is the general model used as a reference for describing growth (Richards 1959). In Eqn (2), Y_0 is the intercept, Y_f is the asymptotic growth parameter, k is the specific growth rate, and n is a size-scaling-related parameter that could be constrained, for instance, by the metabolic body size. The monomolecular or Brody growth model is combined with the Gompertz model to form the biphasic function shown by Eqn (3), in which Y_{f1} is a scale parameter (mass units) representing the asymptotic phase of the monomolecular growth phase, Y_{10} is the scale intercept (mass units), and k_1 (days^{-1}) is the specific growth rate of the first order initial growth. The parameter Y_{20} (mass units) is a scale parameter representing the intercept of the sigmoid phase of growth, and k_2 and D, both expressed as days^{-1}, are the specific growth rate and its fractional rate of reduction during the sigmoid growth phase, respectively. The variances was modelled as follows: homogeneous variances (σ^2) as shown by Eqn (4); as exponential variances or Eqn (5), in which σ_0^2 represents the starting variance associated to weights at birth ($t = 0$) that increases exponentially during growth at a fractional rate c (days^{-1}); and as an asymptotically growing variance or Eqn (6), in which σ_0^2 is the variance related to weights at birth, σ_b^2 is the asymptotic increase in variance over time, and s (days^{-1}) is the fractional rate or first-order rate of increase in the variance. Therefore, nine models were fitted to the growth profiles: the Gompertz model or Eqn (1) associated to Eqn (4), Eqn (5), or Eqn (6); Eqn (2) combined with Eqns (4), (5), or (6); and the Brody-Gompertz model or Eqn (3) combined with Eqns (4), (5), or (6), respectively.

The nine models were fitted to the growth profiles by using the nonlinear mixed models procedure (NLMIXED) of SAS (v.9, SAS Systems, Inc., Cary, NC, USA). The chosen Newton-Raphson algorithm solved the maximum likelihood estimation method. Absolute residuals (observed minus predicted values) and 95% confidence intervals (95% CI) for the predicted growth were requested as an additional output. A residual analysis was performed to detect outliers common to the nine models fitted. An individual observation was considered as an outlier whenever its absolute residual exceeds three times the absolute value of the half amplitude of the 95% CI for the respective predicted value. Those observations that shared common residuals to all models were removed from the original dataset. In sequence, the models were fitted again and likelihood criteria were computed to evaluate the quality of fit of the nine models. The corrected Akaike information criterion (Akaike 1974; Sugiura 1978) is an output of the SAS System. The derived likelihood criteria were computed as follows (Burnham & Anderson 2004):

$$\varDelta_r = AICc_r - \min AICc_r; \qquad \text{Eqn (7)}$$

$$w_r = \exp(-\varDelta_r/2)/(\textstyle\sum_{r=1}^{9} \exp(-\varDelta_r/2)); \qquad \text{Eqn (8)}$$

$$ER_r = (\max w_r)/w_r. \qquad \text{Eqn (9)}$$

The corrected Akaike criterion, namely $AICc_r$, computed for the r-th model in the set of nine models was used to calculate the differences ($\varDelta_r$) between the r-th model and the minimum (min) $AICc_r$ computed in the set of nine models fitted (Eqn (7)). In Eqn (8) w_r

is the likelihood probability computed for the r-th model fitted in the set. In Eqn (9) ER_r is the evidence ratio computed from the maximum (max) w_r in the set of models fitted and the respective w_r value of r-th fitted model under evaluation. Models that presented $0 \leq \Delta_r \leq 2$ also presented higher w_r and lower ER_r values, and therefore were considered the best choice giving the data. Models with $2 < \Delta_r \leq 8$ were considered to have less support, and models with $\Delta_r > 8$ were considered the worse choices among models. The number of parameters was considered as an additional parsimony criterion whenever the models were equally likely, and the model with a smaller number of parameters was preferably chosen. A fully estimated correlation matrix and parameters different from zero were considered additional distinguishing criteria indicative of a well-conditioned model.

Once chosen the two models that most likely fit each growth profile the original residuals obtained after the first fit of the two models were inspected again to identify possible outliers. After the elimination of the outliers to both models, they were fitted again and their quality of fit was assessed by the same likelihood criteria described by Eqns (7), (8), and (9).

Results

Because of the lack of information between 15 and 90 days, the estimation of the variance of the parameter k_1 of Eqn (3) presented numerical problems and did not converge into a limit, i.e., tended to infinity. All of the remaining parameters of this equation presented plausible point and interval estimates. Therefore, to fit this equation more properly, the starting value for k_1 was fixed at one.

Some variables were fitted in grams (g) and other variables were fitted in kg because scale interfered in convergence during the optimization process. The likelihoods were categorized and only those models that presented $\Delta_r < 6$ after the first fit are shown in Table 1. This multimodel selection was performed first to eliminate models that presented no support in mimicking the growth profiles. In sequence, the likelihoods of the two models that best fitted to the growth profiles are presented in Table 2.

The plot of the absolute residuals for some variables were presented as an additional information to illustrate the performance of some models studied by contrasting the worse and the better choices in mimicking data (Fig. 1). In the first case presented (W), the resulting fit of Eqn (2) combined with Eqn (5) (panel b) is compared to Eqn (3) combined with Eqn (4) (panel a). In the second case ($AbFat$), the worst choice would be Eqn (1) fitted under the assumption of homoscedasticity (Eqn (4)) (panel c), whereas the best choice was Eqn (1) fitted to data assuming Eqn (6) (panel d). Clearly, in the case of $AbFat$, the residual variability increases over time, thus indicating that the homoscedastic assumption did not hold true. In the third case ($Carcass$), the same improvement of fit can be noted because the variance increased exponentially (Eqns (2) and (5)) (panel f), and apparently the Richards-Exponential model mimicked the growth profile better than Eqn (3) fitted under the assumption of homogeneity (panel e). The fourth case was presented to illustrate the improved fit of combined Eqns (2) and (5) (panel h) in relation to the fit of combined Eqns (3) and (4) (panel g), because the former presents a more even distribution of the residuals than the latter and accounted for an exponential increase in the variances over the time interval studied.

The elimination of outliers enhanced the likelihood probability (w_r) of some models, and it can be saw by contrasting likelihood measures from Tables 1 and 2 (e.g., the combined Eqns (2) and (5) for describing W and EBW). The Gompertz model or Eqn (1) was unequivocally the best choice for six of the 16 variables studied, thus indicating a pure sigmoid behaviour for organs ($Organs$), gastrointestinal tract (GIT), skin ($Skin$), abdominal fat ($AbFat$), trimmed cuts ($Trimcut$), and ruminoreticular contents (RRC). This means that the additional parameter of Eqn (2) did not improved the fit of the Richards model to highly sigmoid growth profiles. The other 10 variables, namely body weight (W), empty body weight (EBW), carcass weight ($Carcass$), blood ($Blood$), fresh weight of the gastrointestinal tract contents ($GITC$), the dry matter content of the empty body ($EBDM$), and the empty body ash ($EBAsh$), crude fat ($EBCF$), crude protein ($EBCP$), and energy (EBE) had their growth profiles best mimicked by Eqn (2) (Table 2). Despite the major influence of the sigmoid growth pattern of $AbFat$ (Fig. 2g) over the EBE (Fig. 3h), i.e., the former was better described by Eqn (1), the Richards model or Eqn (2) was the best choice for describing the energy retained in the empty body of the castrated male goats.

In terms of variance, a homogeneous model or Eqn (4) was more likely for RRC; an exponential model or Eqn (5) was the best choice for describing W, EBW, $Carcass$, $Skin$, $Blood$, $EBDM$, $EBAsh$, and $EBCP$; whereas an asymptotic variance trend was more likely to describe the variability about $Organs$, GIT, $AbFat$, $Trimcut$, $GITC$, $EBCF$, and EBE (Table 2).

The estimated $\hat{\mu}_{Y_t}$ and $\hat{\sigma}^2_{Y_t}$ for each variable are presented in Table 3. Graphs were built to illustrate point and interval estimates for μ_{Y_t} in the continuum of the time-axis (Figs. 2 and 3). One can note that visually well-defined asymptotes were reached for variables of Fig. 2, excepting EBW in panel (b) and $Carcass$ in panel (c). The same can be said about variables $EBDM$ (panel d), $EBCF$ (panel f), and EBE (panel h) of Fig. 3 because a well-defined asymptotic phase was not apparent. In Figs. 2 and 3 are also displayed the 95% CI of the intercept and asymptote of the variables indicating masses at birth and at maturity. Some limits of the growth functions yielded plausible estimates at maturity; nonetheless, as mentioned before, some asymptotic values were overestimated, thus indicating that, for some variables, weights at maturity were less likely and a well-defined asymptote had not been reached (e.g., $EBDM$ in Fig. 3d).

The age of the animals from birth to maturity (approximately at 900 days) was categorized into six age classes to better illustrate the average daily gain in W, EBW, $EBCP$, $EBCF$, and EBE at these stages of growth. As such, one can draw some interesting results from Table 4. For instance, the protein and energy gain in the EBW can be estimated. Between 90 and 210 days of age, the average daily rate of net protein retention, i.e., $\Delta EBCP/\Delta t$, divided by the average daily rate of gain in the EBW, i.e., $\Delta EBW/\Delta t$, is $1000 \times 0.015/0.106 = 142\ \mathrm{g.kg^{-1}}$. The same approach can be used to compute the net rate of energy retention, i.e., at the same age interval, $1.456/0.106 = 13.736\ \mathrm{MJ.kg^{-1}}$ of EBW. One can calculate the limits of the confidence intervals in the same way.

Other relevant relationships about observed and predicted body composition as functions of the predicted empty body weight and amount of crude protein retained in the empty body weight were drawn (Fig. 4). The behaviour of $EBCP$, EBF, and EBE remained nonlinear with respect to the predicted EBW (Fig. 4, panels a, b, and d). The exception was the nearly linear behaviour exhibited by $EBAsh$ as a function of the predicted EBW. The increase in the retained crude protein was similar to a diminishing returns trend, whereas the fat and energy contents appears to have increased exponentially within the EBW interval studied; the $EBAsh$ appears to have increased at a constant rate in relation to EBW because it resembles a linear increase (Fig. 4c). The fat, energy, and ash amounts in the empty body augmented in an exponential-like fashion as the predicted crude protein amount in the empty body increased (Fig. 4, panels e, f, and g). Nevertheless, the water amount in the empty body (EBH_2O) increased in an almost linear fashion as the predicted $EBCP$ increased (Fig. 4h). A simple no intercept linear regression model was fitted by means of ordinary least squares (PROC REG of SAS) to the data pairs (W, EBW), and a constant EBW/W ratio of 92.58 ± 1.51 kg/100 kg was estimated with an adjusted $R^2 = 0.9776$.

Generally, the growth patterns exhibited by the body parts and chemical constituents were allometric with respect to W. Remarkable differences can be noticed regarding inflection points, growth rates, and trends for the variables studied (Figs. 2 and 3, and Table 5). The existence of a true inflection point for many variables studied was dubious, although the Richards model was the best choice to describe many growth profiles (Table 2). Table 5 contains large confidence intervals that were estimated for the age at the point of inflection for Eqn (2): negative estimates indicate no inflection during the postnatal life of the animal; there were no reason for rejecting the hypothesis that $t_i = 0$ for W, $Carcass$, and $EBCP$; and despite the variability the point of inflection for EBW was detectable. The applicability of the weights at the inflection lacks generality for W and $Carcass$ in which, clearly, the large confidence intervals did not exclude $t_i = 0$; for $Blood$ and $EBCP$ is nonsense to compute a predicted weight at the points of inflection $\left(\hat{Y}_{t_i}\right)$ for negative t_i. For all other variables of Table 5, the existence of an inflection point was likely and, therefore, also likely the existence of a predictable weight at the point of inflection. The weight of body, body parts, and chemical constituents of the empty body at the point of inflection of EBW were presented in Table 5 to illustrate the rates of mass gain and its ratio between weight at 142.9 days and the weight at 900 days, i.e., close to maturity. In this regard, for instance, one can calculate the mass ratio between this two time points for the protein amount of the body: $100 \times 3.3/9.7 = 34.02\%$ of the mature protein mass was deposited about 5 months of age. The animals reached 30.66% of the mature weight at the inflection point of EBW.

Discussion

The examination of residuals have been used for evaluating the quality of fit of regression models (Draper & Smith 1966; Bard 1974; Motulsky & Cristopoulos 2003; Strathe et al. 2010). Departures from randomness in the plots of the residuals obtained after fitting the models characterized by combining Eqns (1)–(3) and Eqns (4)–(6) were difficult to distinguish; to the eye, the examination of the residuals was insufficient as a tool for model selection in the present study. For all examples illustrated (Fig. 1) and other variables studied (not shown), residuals presented evenly distributed patterns irrespective of the model used. Other measures used to judge the quality of fit of different nested and non-nested models, such as the F-ratio test and R^2 would not be effective. In fact, F-ratio brings the dichotomy about rejecting or not rejecting the null hypothesis and do not provide a reasonable basis for testing multiple hypotheses or multi-model selection (Burnham & Anderson 2004; Stang et al. 2010), and the R^2 or adjusted R^2 were inherited from linear models and its computation was not even mentioned or said to be necessary according to the specialized literature about nonlinear models, e.g., Bard (1974), Ratkowsky (1990), and Pinheiro and Bates (2000). Therefore, approaches that are more robust are recommended for such cases. Provided that the sample is representative of the population, i.e., data gathered represent the truth, the Akaike information criterion (Akaike 1974) corrected for samples of smaller sizes or $AICc_r$ (Sugiura 1978) and its derived measures as additional information criteria (Burnham & Anderson 2004) have been used efficiently to assess the likelihood of different linear and nonlinear models in a multiple-hypotheses framework (Wolfinger 1993; Motulsky & Cristopoulos 2003; Burnham & Anderson 2004; Vieira et al. 2012).

The theory related to nonlinear mixed models allows establishing relationships among a dependent variable and a set of independent variables in a general way not constrained by linear functions. A nonlinear mixed model is a general mathematical function built on parametric constants or parameter functions with physical or biological meaning to which fixed and random effects that may influence parameters of the general nonlinear relationship are introduced. The structure is completed with an additional model that represent the variation between and within experimental units (subjects or individuals) that accommodate both correlations among repeated measures taken over time on the same individual and heteroscedasticity between and, whenever pertinent, within individuals. To complete this framework, the artefact parameters can be estimated by the method of maximum likelihood that further provides additional measures of the strength of evidence that the model mimics the real world (McCulloch & Searle 2001; Littell et al. 2006; Vonesh 2012). An important feature of this framework is the possibility to model variation assuming a multivariate normal distribution of the parameters among individuals (Brunel et al. 2013). There are some examples in the literature in which the variance-covariance structures are modelled by accommodating correlated errors among longitudinal data and accounting for a general exponential increase in the variance over time (Littell et al. 2006; Strathe et al. 2010; Vonesh 2012). In this study, for those variables in which a well-defined asymptotic phase was not evident, the exponential model or Eqn (5) mimicked the variability of the growth profiles and resulted in a better description of the variance increase over time, just like the same way as Littell et al. (2006), Strathe et al. (2010), and Vonesh (2012) reported. Nonetheless, some variables presented a distinguishable asymptotic phase, and this well-established attribute of the growth profile was probably associated to an asymptotic variance increase over time, as modelled in the form of Eqn (6). The two patterns described by Eqns (5) and (6) are departures from the homoscedasticity assumption. The exception was the description of the growth of the ruminoreticular contents because of the high variability of homoscedastic nature recorded throughout the time profile (Fig. 3c). The definition of the asymptotic growth phase is crucial to establish the weights and its variability at maturity, particularly for vertical production systems that host breeding categories, as still is the case of goat dairying systems. Only experiments that last long enough to characterize maturity allow a proper estimation of the asymptotic weights (Blaxter et al. 1982; France et al. 1996; Strathe et al. 2010); otherwise, smaller time-trend effects jeopardize inferences regarding asymptotic weights (Strathe et al. 2010).

Several nonlinear models have been applied to describe the growth of farm animals (France et al. 1996; López et al. 2000; Marinho et al. 2013; Souza et al. 2013), and their parameter estimates are inferred to the population of interest by averaging out temporary environmental effects and by accounting for the nonlinear effect of time (Brown et al. 1976). However, there are events and processes that may constrain the growth trajectory such as weaning, puberty, maturation, seasonal food availability and quality (Morand-Fehr 1981; Brunel et al. 2013; Magistrelli et al. 2013) interfering directly in the orchestrated genetic plan of growth, which demand nonconventional approaches for its quantitative description. Therefore, multiphasic nonlinear models may be useful for interpreting growth profiles that present more than one detectable inflection points, i.e., additional inflection points to the one related to puberty because of constraints to growth impinged by the environment may retard or accelerates the rate of weight gain (Koops 1986; Nesetrilova 2005; Mendes et al. 2008; Rocha 2013). Some growth profiles presented in this study stand the reasonable doubt of an additional inflection point close to the earliest ages (0–90 days) perceptible by visual appraisal after the enlargement of the time scale. The biphasic model described by Eqn (3) was employed by Rocha (2013) to characterize the transition from the suckling phase to a solid diet and subsequent weaning as an additional constraint that introduces another inflection point to the growth profile of castrated male kids. Nonetheless, the biphasic model or Eqn (3) did not supplanted the Richards model or Eqn (2) in terms of likelihood, and the suspicious additional inflection point prior to the point about puberty due to the transient weaning period lacks data of sufficient quantity between 15 and 90 days of age for an adequate characterization. Although puberty is not strictly applicable to wethers, puberty in specialized dairy goat breeds occurs between 90–120 days when the growth rate starts to decrease and may be confounded with weaning effects due to the close proximity of these two events in time (Morand-Fehr 1981; Rocha 2013). In this study, the age at inflection for the empty body weight (EBW) occurred later than 120 days (Table 5). Somehow, the high variability observed for gut contents at earlier ages and long-term nonlinear effects of time over the gut contents might had affected the estimated precocious age at the inflection point for W, despite the constant ratio observed between EBW and W.

Some postnatal growth profiles resembled the first-order or monomolecular growth traditionally described by the law of diminishing returns (Figs. 2 and 3), as Brody (1945) pointed out as the self-inhibiting growth phase. This can be attributed to the fact that the inflection point has had occurred during the kid's prenatal life. In fact, a Gompertz-like model have been applied to anticipate the growth of kids during prenatal life (AFRC 1993; 1997). Therefore, self-accelerating phase occurring during prenatal growth and self-inhibiting phase initiating nearby birth or soon after birth may be a clear indicative of the large variation about the age at the point of inflection observed for W in Table 5. Therefore, Eqn (3) or the Richards (1959) model was unequivocally superior in terms of likelihood to describe a self-inhibiting-like profile because the referred model has a flexible nature that mimics growth patterns such as those described by the Brody's model (France et al. 1996; López et al. 2000).

Describing growth as a simple sequence of self-accelerating followed by self-inhibiting processes may be an oversimplification; even after adding an intermediary phase as the linear logarithmic phase to represent a tripartite description of growth can be considered an oversimplification. It is worthy to remember that models are fitted to the growth patterns and empirically aggregate into a few parametric constants the thermodynamically unfavourable and complex biochemical growth phenomena (Brody 1945; Lawrence & Fowler 2002). The sigmoid pattern of growth is the integrated sum of the growth rates of many body parts (Owens et al. 1993). As taught by France et al. (1996), there are growth rates that can be described empirically by a first-order growth or $dY/dt = k\left(Y_f - Y\right)$. Sigmoid models mimic growth profiles that may be attributed to a gradual reduction of the fractional growth rate at birth, i.e., $dY/dt = Yk\exp(-Dt)$, that yields the Gompertz model or Eqn (1). The general model built by Richards (1959) owes its general nature to fit monomolecular or sigmoid profiles due to the assumed growth rate $dY/dt = kY\left(Y_f^n - Y^n\right)/\left(nY_f^n\right)$, that generalizes the balance between catabolic and anabolic processes scaled to the body proper suggested by von Bertalanffy (1957). Biphasic models can be introduced to deal with an asymptotic first-order growth combined with sigmoid growth so that $dY/dt = k_1\left(Y_{f1} - Y\right) + Yk_2\exp(-Dt)$; the first-order growth occurs primarily during the birth-weaning period and the sigmoid growth after the weaning shock (Rocha 2013). This latter model is not constrained by any break point; it mimics empirically the net result of simultaneously growing body parts with different timings. Nonetheless, due to the reduced influence of short-term effects upon a more complete time profile for animals growing up to maturity (Strathe et al. 2010), and for the sake of statistical rigour, Eqn (3) was considered not likely for representing the growth of goat wethers.

The growing animal faces seasonal changes in the environment. As it grows upon an unlimited food supply, growth is mainly constrained by genotype and daily intake rate will stabilize at maturity (Blaxter et al. 1982; Lawrence & Fowler 2002). Generally, after puberty, there are expenditures of nutrients for maintenance, somatic growth, and reproduction (including lactation) that shall be balanced by rate of nutrient intake (Brunel et al. 2013). The growth condition for does achieves this complexity, because well managed does still grow after first kidding and reach their variable mature size only after the second kidding (Morand-Fehr 1981). For castrates, a balance between nutrient acquisition and expense may explain stabilization of growth (Blaxter et al. 1982), but the reproductive cycle constrain doelings and bucklings as they grown into adulthood. Blaxter et al. (1982) theorized that maturity weight is achieved when nutrient intake and expenditure reach a balance because long-term intake at maturity as well as body composition reach a steady-state condition. This condition does not mean that maturity weight is immutable; but rather is the balance between maintenance and reproductive expenditures, as well as efforts for harvesting nutrients from the environment (Lawrence & Fowler 2002).

The long-term profiles studied here by extending the EBW range from birth to maturity revealed a nonlinear behaviour for the body composition (Fig. 4). The result was that body parts grew in an allometric fashion as demonstrated by different ages at the points of inflection (Table 5) and by different growth patterns (Figs. 2, 3, and 4). This allometric behaviour yielded different asymptotic trends: some body parts or chemical constituents reached maturity earlier than others did. Therefore, growth of body parts and composition of gain in the growing empty body of the goat wethers were not constants, i.e., $dY/dEBW \neq \beta$, for β representing a dimensionless constant. Blaxter et al. (1982) observed a linear increase for the lipid mass in the empty body of sheep, but they studied a narrower EBW range, i.e., from 40 to 120 kg as those authors focused on the post-puberal phase of growth. The linear relationships for $EBash$ and EBW and for water in the empty body (EBH_2O) and $EBCP$ observed by Blaxter et al. (1982) for sheep also appears to have had occurred for goat wethers. Other relationships reported here were nonlinear (Fig. 4) if compared to the growth behaviours reported by Blaxter et al. (1982). The rate of fat deposition in does is larger than in wethers, which in turn is larger than in bucks; in addition, differences are more remarkable at heavier body weights (Mahgoub et al. 2004). Crossbreds of Alpine × Hair, and Saanen × Hair goats have heavier carcass weights and internal fat weights than Hair breeds (Gokdal 2013). Carmichael et al. (2012) argued that adult dairy goats (Saanen) probably have more carcass fat than younger ones. By taking weights at 900 and 142.9 days from Table 5, the difference $EBCF - AbFat$ was 13.6 and 1.7 kg of non-abdominal fat for adults and younglings, respectively, what represented non-abdominal fat contents of 18.63 and 9.24 kg/100 kg of EBW for the respective categories. The adipose tissue grows by both hypertrophic and hyperplasic mechanisms (Hossner 2005). Therefore, an unrestricted food supply may explain the absence of an asymptotic phase for $EBCF$ profile in Fig. 3f, in which the predicted asymptote was higher than the predicted value at 900 days of age. As the growth rate of the animal increases the accretion rate of fat increases and protein decreases (NRC 2007); this was confirmed by results shown in Tables 4 and 5 that also confirmed the fact that fat and protein contents in the empty body respectively increase and decrease as wethers mature (Tedeschi et al. 2010). Nonetheless, given the scarcity of information regarding body composition of goats (NRC 2007), the obtained estimates of chemical composition of wethers (Tables 3, 4, and 5) can be ad interim used to predict net energy and protein deposition in the empty body of females, at least for ages not greater than 210 days; for older ages, reproduction hampers generalizations.

Acknowledgements

This research was supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq (Brazil), process numbers 306584/2012-3 and 479593/2010-8, and by Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro – FAPERJ (RJ, Brazil), process number E-26/110.231/2011. The first author thanks the fellowship provided by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES, Brazil). We are also deeply indebted to Professor Marcelo T. Rodrigues (Universidade Federal de Viçosa – UFV)) for providing the kids used in this research. We thank Professors M. T. Rodrigues and Fabyano Fonseca e Silva (UFV) for critical readings of the manuscript.

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Table 1. Likelihood of the models fitted* to the growing body, body parts, and chemical composition of the body of castrated male goats.

Variable	Model	$AICc_r$†	Δ_r†	w_r†	ER_r†	Θ_r†
W‡ (kg)	Eqns (2), (5)	292.1	0.0	0.922	1	6
	Eqns (2), (6)	297.8	5.7	0.053	17	7
EBW‡ (kg)	Eqns (2), (5)	330.0	0.0	0.988	1	6
$Carcass$ (kg)	Eqns (2), (5)	259.8	0.0	0.811	1	6
	Eqns (2), (6)	265.5	5.7	0.047	17	7
	Eqns (3), (5)	263.9	4.1	0.104	8	8
Organs (g)	Eqns (1), (6)	671.3	0.0	0.712	1	6
	Eqns (2), (6)	673.4	2.1	0.249	3	7
GIT‡ (g)	Eqns (3), (6)	725.5	0.0	0.981	1	9
$Skin$ (g)	Eqns (1), (4)	684.6	2.2	0.137	3	4
	Eqns (1), (5)	682.4	0.0	0.412	1	5
	Eqns (1), (6)	683.9	1.5	0.195	2	6
	Eqns (2), (5)	684.0	1.6	0.185	2	6
$AbFat$‡ (g)	Eqns (1), (5)	860.9	5.0	0.063	12	5
	Eqns (1), (6)	855.9	0.0	0.770	1	6
	Eqns (3), (6)	859	3.1	0.163	5	9
$Trimcut$‡ (g)	Eqns (1), (6)	621.7	0.0	0.646	1	6
	Eqns (2), (6)	622.9	1.2	0.354	2	7
$Blood$ (kg)	Eqns (2), (5)	719.6	0.0	0.854	1	6
	Eqns (3), (6)	723.7	4.1	0.110	8	9
$GITC$‡(g)	Eqns (1), (6)	912.4	0.0	0.550	1	6
	Eqns (2), (6)	912.8	0.4	0.450	1	7
RRC‡(g)	Eqns (1), (4)	654.8	0.0	0.919	1	4
	Eqns (1), (6)	660.2	5.4	0.062	15	6
$EBDM$‡ (kg)	Eqns (2), (5)	242.5	0.0	0.851	1	6
	Eqns (2), (6)	246.40	3.9	0.121	7	7
$EBash$‡ (kg)	Eqns (1), (5)	−24.1	0.3	0.428	1	5
	Eqns (2), (5)	−24.4	0.0	0.497	1	6
	Eqns (3), (5)	−19.0	5.4	0.033	15	8
$EBCF$‡ (kg)	Eqns (2), (5)	207.0	4.8	0.077	11	6
	Eqns (2), (6)	202.2	0.0	0.850	1	7
	Eqns (3), (6)	207.3	5.1	0.066	13	9
$EBCP$‡ (kg)	Eqns (2), (5)	94.9	0.0	0.768	1	6
	Eqns (2), (6)	98.4	3.5	0.133	6	7
	Eqns (3), (5)	99.8	4.9	0.066	12	8
EBE‡ (MJ)	Eqns (2), (5)	620.4	0.0	0.475	1	6
	Eqns (2), (6)	620.4	0.0	0.475	1	7
	Eqns (3), (6)	625.4	5.0	0.039	12	9

*Likelihood results obtained after the elimination of common outliers. Details of Eqns (1), (2), (3), (4), (5), and (6) are in the text.;

†$AICc_r$, corrected Akaike information criterion of the r-th model; Δ_r, difference between the $AICc_r$ and the minimum of the $AICc_r$ in the set of all models tested; w_r, likelihood probability of the r-th model; ER_r, evidence ratio against the r-th model; Θ_r, number of parameters of the r-th model including the related variance parameters.

‡W, body weight; EBW, empty body weight; GIT, gastrointestinal tract weight; $AbFat$, weight of the abdominal fat; $Trimcut$, weight of the trimmed cuts; $GITC$, fresh weight of the gastrointestinal contents; RRC, fresh weight of the ruminoreticular contents; empty body contents of dry matter ($EBDM$), ash ($EBAsh$), crude fat ($EBCF$), crude protein ($EBCP$), and energy (EBE).

Table 2. Likelihood of the two best models fitted* to the growing body, body parts, and chemical composition of the body of castrated male goats.

Variable	Model	$AICc_r$†	Δ_r†	w_r†	ER_r†	Θ_r†
W‡ (kg)	Eqns (2), (5)	285.0	0.0	0.950	1	6
	Eqns (2), (6)	290.9	5.9	0.050	19	7
EBW‡ (kg)	Eqns (2), (5)	275.3	0.0	0.998	1	6
	Eqns (2), (6)	288.3	13.0	0.002	665	7
$Carcass$ (kg)	Eqns (2), (5)	259.8	0.0	0.886	1	6
	Eqns (3), (5)	263.9	4.1	0.114	8	8
$Organs$ (g)	Eqns (1), (6)	662.1	0.0	0.711	1	6
	Eqns (2), (6)	663.9	1.8	0.289	3	7
GIT‡ (g)	Eqns (1), (6)	652.0	0.0	0.512	1	6
	Eqns (3), (6)	652.1	0.1	0.488	1.1	9
$Skin$ (g)	Eqns (1), (5)	664.4	0.0	0.668	1	4
	Eqns (1), (6)	665.8	1.4	0.332	2	5
$AbFat$‡ (g)	Eqns (1), (6)	770.9	0.0	0.973	1	5
	Eqns (3), (6)	778.1	7.2	0.027	37	6
$Trimcut$‡ (g)	Eqns (1), (6)	621.7	0.0	0.646	1	6
	Eqns (2), (6)	622.9	1.2	0.354	2	7
$Blood$ (g)	Eqns (2), (5)	674.8	0.0	0.999	1	6
	Eqns (3), (6)	689.2	14.4	0.001	1339	9
$GITC$‡ (g)	Eqns (1), (6)	827.8	0.3	0.463	1	6
	Eqns (2), (6)	827.5	0.0	0.537	1	7
RRC‡ (g)	Eqns (1), (4)	625.5	0.0	0.966	1	4
	Eqns (1), (6)	632.2	6.7	0.034	29	6
$EBDM$‡ (kg)	Eqns (2), (5)	220.4	0.0	0.875	1	6
	Eqns (2), (6)	224.3	3.9	0.125	7	7
$EBAsh$‡ (kg)	Eqns (2), (5)	−48.9	0.0	0.750	1	6
	Eqns (1), (5)	−46.7	2.2	0.250	3	5
$EBCF$‡ (kg)	Eqns (2), (6)	184.8	0.0	0.999	1	7
	Eqns (2), (5)	198.6	13.8	0.001	992	6
$EBCP$‡ (kg)	Eqns (2), (5)	86.8	0.0	0.818	1	6
	Eqns (2), (6)	89.8	3.0	0.182	5	7
EBE‡ (MJ)	Eqns (2), (6)	503.8	0.0	0.999	1	7
	Eqns (2), (5)	517.4	13.6	0.001	898	6

*Likelihood results obtained after the elimination of common outliers. Details of Eqns (1), (2), (3), (4), (5), and (6) are in the text.

†$AICc_r$, corrected Akaike information criterion of the r-th model; Δ_r, difference between the $AICc_r$ and the minimum of the $AICc_r$ in the set of all models tested; w_r, likelihood probability of the r-th model; ER_r, evidence ratio against the r-th model; Θ_r, number of parameters of the r-th model including the related variance parameters.

‡W, body weight; EBW, empty body weight; GIT, gastrointestinal tract weight; $AbFat$, weight of the abdominal fat; $Trimcut$, weight of the trimmed cuts; $GITC$, fresh weight of the gastrointestinal contents; RRC, fresh weight of the ruminoreticular contents; empty body contents of dry matter ($EBDM$), ash ($EBAsh$), crude fat ($EBCF$), crude protein ($EBCP$), and energy (EBE).

Table 3. Computed parameter estimates of the chosen models.

Variable	Model	Mean $\left(\hat{\mu}_{Y_t}\right)$	Variance $\left(\hat{\sigma}^2_{Y_t}\right)$
W^*(kg)	Eqns (2), (5)	$4.7 \times 94.0/(4.7^{-0.8926} + (94.0^{-0.8926} - 4.7^{-0.8926})\exp(-0.002t))^{-1/0.8926}$	$1.9\exp(0.002t)$
EBW^*(kg)	Eqns (2), (5)	$4.7 \times 96.6/(4.7^{-0.6704} + (96.6^{-0.6704} - 4.7^{-0.6704})\exp(-0.002t))^{-1/0.6704}$	$1.4\exp(0.004t)$
$Carcass$ (kg)	Eqns (2), (5)	$3.1 \times 65.1/(3.1^{-0.8708} + (65.1^{-0.8708} - 3.1^{-0.8708})\exp(-0.001t))^{-1/0.8708}$	$1.3\exp(0.003t)$
$Organs$ (g)	Eqns (1), (6)	$317.3\exp(0.018(1 - \exp(-0.009t))/0.009)$	$1286.1 + 1.2 \times 10^5(1 - \exp(-4.6 \times 10^{-4}t))$
GIT^*(g)	Eqns (1), (6)	$145.3\exp(0.035(1 - \exp(-0.013t))/0.013)$	$81.4 + 5.3 \times 10^4(1 - \exp(-0.011t))$
$Skin$ (g)	Eqns (1), (5)	$659.6\exp(0.007(1 - \exp(-0.005t))/0.005)$	$1.3 \times 10^4\exp(0.002t)$
$AbFat^*$(g)	Eqns (1), (6)	$64.3\exp(0.026(1 - \exp(-0.005t))/0.005)$	$102.7 + 1.8 \times 10^7(1 - \exp(-8.3 \times 10^{-5}t))$
$Trimcut^*$(g)	Eqns (1), (6)	$56.8\exp(0.031(1 - \exp(-0.014t))/0.014)$	$29.9 + 1.4 \times 10^4(1 - \exp(-0.009t))$
$Blood$ (g)	Eqns (2), (5)	$237.1 \times 2988.0/(237.1^{-1.000} + (2988.0^{-1.000} - 237.1^{-1.000})\exp(-0.002t))^{-1/1.000}$	$6.7 \times 10^3\exp(-0.003t)$
$GITC^*$(g)	Eqns (2), (6)	$103.3 \times 7023.8/(103.3^{-0.5736} + (7023.8^{-0.5736} - 103.3^{-0.5736})\exp(-0.011t))^{-1/0.573}$	$395.2 + 9.0 \times 10^5(1 - \exp(-0.007t))$
RRC^*(g)	Eqns (1), (4)	$215.7\exp(0.051(1 - \exp(-0.016t))/0.016)$	3.0×10^5
$EBDM^*$(kg)	Eqns (2), (5)	$1.3 \times 60.1/(1.3^{-0.6376} + (60.1^{-0.6376} - 1.3^{-0.6376})\exp(-0.002t))^{-1/0.6376}$	$0.3\exp(0.005t)$
$EBAsh^*$ (kg)	Eqns (2), (5)	$0.2 \times 3.8/(0.2^{-0.5209} + (3.8^{-0.5209} - 0.2^{-0.5209})\exp(-0.002t))^{-1/0.5209}$	$2.9 \times 10^{-3}\exp(0.004t)$
$EBCF^*$(kg)	Eqns (2), (6)	$0.1 \times 40.2/(0.1^{-0.4488} + (40.2^{-0.4488} - 0.1^{-0.4488})\exp(-0.002t))^{-1/0.4488}$	$3.7 \times 10^{-4} + 830.0(1 - \exp(-1.2 \times 10^{-5}t))$
$EBCP^*$(kg)	Eqns (2), (5)	$0.8 \times 11.7/(0.8^{-0.96.82} + (11.7^{-0.9682} - 0.8^{-0.9682})\exp(-0.002t))^{-1/0.9682}$	$6.7 \times 10^{-2}\exp(0.003t)$
EBE^*(MJ)	Eqns (2), (6)	$22.9 \times 2280.3/(22.9^{-0.5738} + (2280.3^{-0.5738} - 22.9^{-0.5738})\exp(-0.001t))^{-1/0.5738}$	$8.3 + 1.0 \times 10^5(1 - \exp(-1.4 \times 10^{-4}t))$

$^*W$, body weight; EBW, empty body weight; GIT, gastrointestinal tract weight; $AbFat$, weight of the abdominal fat; $Trimcut$, weight of the trimmed cuts; $GITC$, fresh weight of the gastrointestinal contents; RRC, fresh weight of the ruminoreticular contents; empty body contents of dry matter ($EBDM$), ash ($EBAsh$), crude fat ($EBCF$), crude protein ($EBCP$), and energy (EBE).

Table 4. Average daily rate of retention ($\Delta\hat{y}_t/\Delta t$) of body weight (W), empty body weight (EBW), body crude protein ($EBCP$), body crude fat ($EBCF$), and body energy (EBE).

Age (days)	$\Delta W/\Delta t$*	$\Delta EBW/\Delta t$*	$\Delta EBCP/\Delta t$*	$\Delta EBCF/\Delta t$*	$\Delta EBE/\Delta t$†
	$df = 44$‡	$df = 49$‡	$df = 42$‡	$df = 43$‡	$df = 47$‡
$0 - 15$	0.134 ± 0.036	0.086 ± 0.127	0.019 ± 0.007	0.008 ± 0.003	0.784 ± 0.162
$15 - 90$	0.133 ± 0.015	0.095 ± 0.010	0.018 ± 0.003	0.016 ± 0.004	1.077 ± 0.168
$90 - 210$	0.120 ± 0.008	0.106 ± 0.007	0.015 ± 0.002	0.028 ± 0.003	1.456 ± 0.107
$210 - 365$	0.098 ± 0.008	0.093 ± 0.004	0.012 ± 0.001	0.036 ± 0.002	1.656 ± 0.084
$365 - 730$	0.064 ± 0.006	0.070 ± 0.009	0.007 ± 0.001	0.034 ± 0.003	1.605 ± 0.164
$730 - 900$	0.039 ± 0.012	0.047 ± 0.015	0.005 ± 0.002	0.025 ± 0.002	1.269 ± 0.097

*(kg.day^{-1}).

†(MJ.day^{-1}).

‡df means denominator degrees of freedom calculated as the number of observations minus the number of parameters in the model.

Table 5. Ages at the inflection point (t_i, days), predicted values at the estimated t_i for the variables $\left(\hat{Y}_{t_i},\ \text{g, kg, or MJ}\right)$ and growth rates ($d\hat{Y}_{t_i}/dt$, g, kg, or MJ.day^{-1}), and $\hat{Y}_{t_i}$ and $d\hat{Y}_{t_i}/dt$ at the estimated point of inflection for the empty body weight ($t_i = 142.9$ days) and predicted weight of the variables at $t = 900$ days of age. The acronym NA means not applicable.

Variable[†]	Model[‡]	t_i	$\hat{Y}_{t_i}$	$d\hat{Y}_{t_i}/dt$	$\hat{Y}_{t_i=142.9}$	$d\hat{Y}_{t_i=142.9}/dt$	$\hat{Y}_{t=900}$
W (kg)	Eqns (2), (5)	22.6 ± 132.0	7.7 ± 17.6	0.135 ± 0.026	23.3 ± 1.1	0.121 ± 0.018	76.0 ± 3.5
EBW (kg)	Eqns (2), (5)	142.9 ± 105.8	18.4 ± 1.0	0.101 ± 0.007	—	—	73.0 ± 3.9
$Carcass$ (kg)	Eqns (2), (5)	50.1 ± 288.3	6.2 ± 7.2	0.063 ± 0.012	12.0 ± 0.8	0.061 ± 0.006	44.2 ± 2.5
$Organs$ (g)	Eqns (1), (6)	71.0 ± 7.1	793.8 ± 26.8	7.3 ± 0.6	1285.9 ± 54.9	6.1 ± 0.3	2156.6 ± 72.3
GIT (g)	Eqns (1), (6)	77.2 ± 13.0	811.4 ± 35.1	10.5 ± 3.0	1438.9 ± 158.3	8.0 ± 0.5	2205.6 ± 95.3
$Skin$ (g)	Eqns (1), (5)	104.8 ± 15.6	1222.7 ± 56.5	5.6 ± 0.6	1435.4 ± 59.8	5.5 ± 0.5	3238.1 ± 116.6
$AbFat$ (g)	Eqns (1), (6)	347.2 ± 47.6	5374.7 ± 312.7	26.2 ± 1.1	977.1 ± 103.2	12.9 ± 1.4	13654.0 ± 600.5
$Trimcut$ (g)	Eqns (1), (6)	55.6 ± 16.7	189.5 ± 15.9	2.7 ± 0.7	385.9 ± 56.4	1.6 ± 0.3	515.1 ± 43.2
$Blood$ (g)	Eqns (2), (5)	-34.4 ± 10.5	NA	NA	1038 ± 41	4.7 ± 0.3	2673 ± 45
$GITC$ (g)	Eqns (1), (6)	76.4 ± 11.4	2556.3 ± 153.3	8.28 ± 1.52	5211.8 ± 513.7	40.8 ± 9.3	6948.8 ± 416.7
RRC (g)	Eqns (1), (4)	74.0 ± 10.4	1992.8 ± 77.7	31.5 ± 4.0	3868.7 ± 367.6	20.6 ± 1.9	5416.8 ± 211.1
$EBDM$ (kg)	Eqns (2), (5)	229.8 ± 64.7	12.2 ± 3.2	0.053 ± 0.006	7.7 ± 0.5	0.051 ± 0.004	40.5 ± 3.0
$EBAsh$ (kg)	Eqns (2), (5)	198.5 ± 81.3	0.9 ± 0.3	0.004 ± 0.001	0.7 ± 0.05	0.004 ± 0.001	3.0 ± 0.2
$EBCF$ (kg)	Eqns (2), (6)	370.3 ± 48.4	10.6 ± 1.2	0.038 ± 0.003	2.7 ± 0.5	0.028 ± 0.003	27.3 ± 2.5
$EBCP$ (kg)	Eqns (2), (5)	-25.4 ± 227.1	NA	NA	3.3 ± 0.2	0.016 ± 0.002	9.7 ± 0.6
EBE (MJ)	Eqns (2), (6)	347.1 ± 62.7	516.6 ± 30.0	1.681 ± 0.103	187.7 ± 21.5	1.450 ± 0.112	1330.6 ± 59.4

[†] W, body weight; EBW, empty body weight; GIT, gastrointestinal tract weight; $AbFat$, weight of the abdominal fat; $Trimcut$, weight of the trimmed cuts; $GITC$, fresh weight of the gastrointestinal contents; RRC, fresh weight of the ruminoreticular contents; empty body contents of dry matter ($EBDM$), ash ($EBAsh$), crude fat ($EBCF$), crude protein ($EBCP$), and energy (EBE).

[‡] Details of Eqns (1), (2), (3), (4), (5), and (6) are in the text.

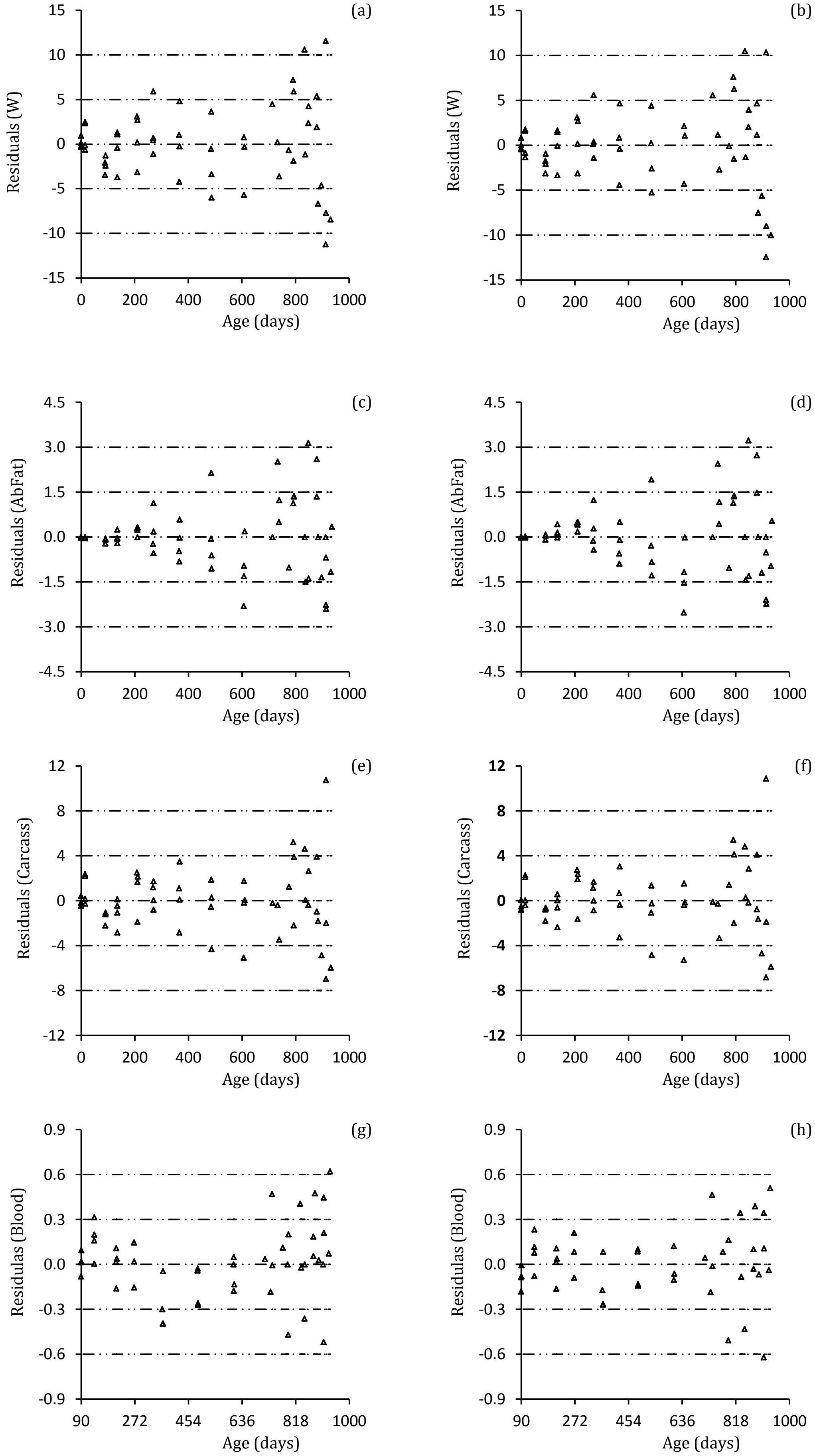
(a)
Residuals (W)
15
10
5
0
-5
-10
-15
0
200
400
600
800
1000
Age (days)
(b)
Residuals (W)
Age (days)
(c)
Residuals (AbFat)
4.5
3.0
1.5
0.0
-1.5
-3.0
-4.5
Age (days)
(d)
Residuals (AbFat)
Age (days)
(e)
Residuals (Carcass)
12
8
4
0
-4
-8
-12
Age (days)
(f)
Residuals (Carcass)
Age (days)
(g)
Residulas (Blood)
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
90
272
454
636
818
1000
Age (days)
(h)
Residulas (Blood)
Age (days)

Figure 1. Absolute residuals (Δ) for some variables plotted against the time axis (Age, days). The residual plots are based on: (a) Liveweight (W, kg) described by Eqn (3) combined with Eqn (4); (b) W described by Eqn (2) with Eqn (5); (c) Abdominal fat ($AbFat$, kg) described by Eqn (1) with Eqn (4); (d) $AbFat$ described by Eqn (1) with Eqn (6); (e) Carcass (kg) described by Eqn (3) with Eqn (4); (f) Carcass described by Eqn (2) with Eqn (5); (g) Blood (kg) described by Eqn (3) with Eqn (4); and (h) Blood described by Eqn (2) with Eqn (5). Details of equations are in the text.

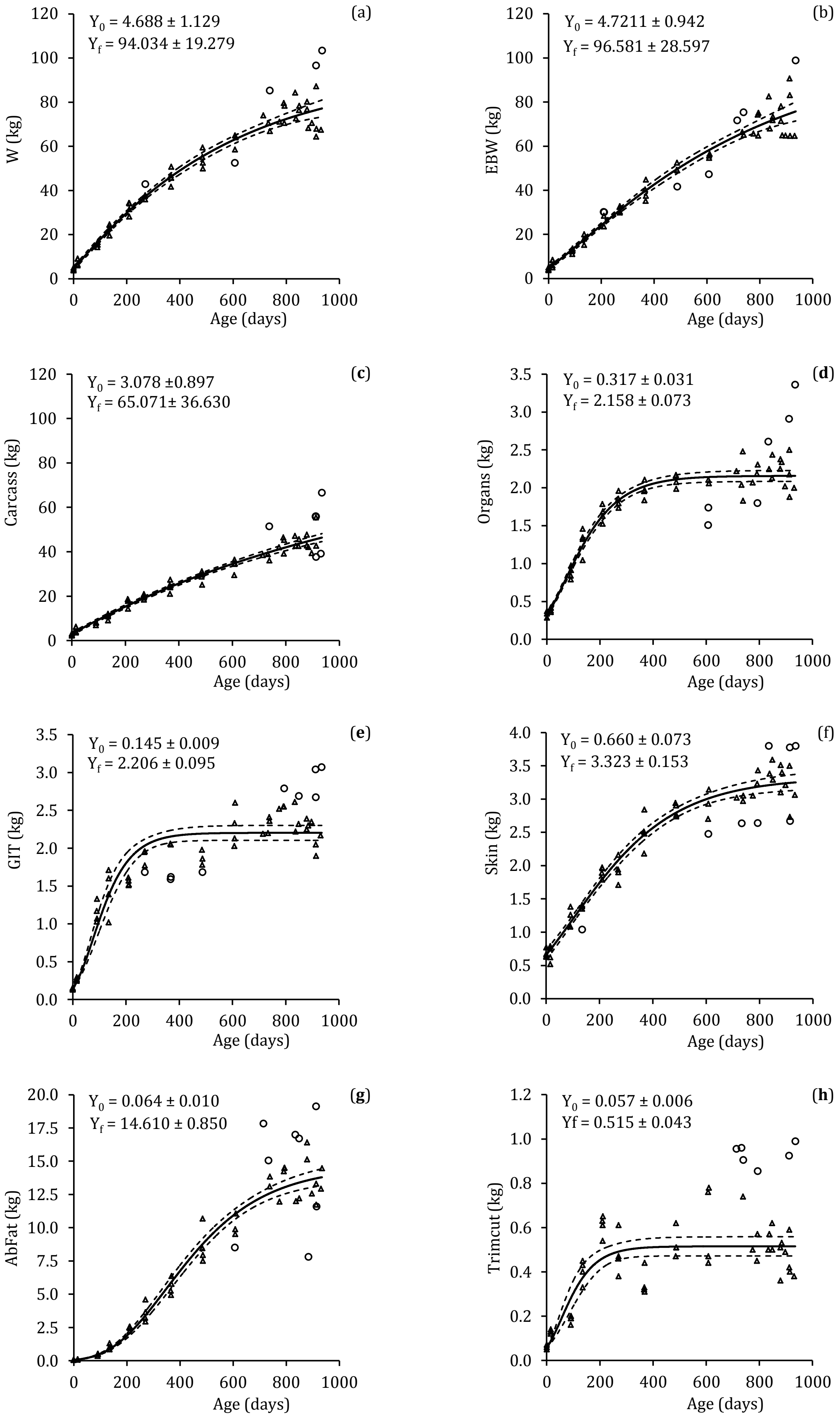
(a)
Y_0 = 4.688 ± 1.129
Y_f = 94.034 ± 19.279
W (kg)
Age (days)
(b)
Y_0 = 4.7211 ± 0.942
Y_f = 96.581 ± 28.597
EBW (kg)
Age (days)
(c)
Y_0 = 3.078 ±0.897
Y_f = 65.071± 36.630
Carcass (kg)
Age (days)
(d)
Y_0 = 0.317 ± 0.031
Y_f = 2.158 ± 0.073
Organs (kg)
Age (days)
(e)
Y_0 = 0.145 ± 0.009
Y_f = 2.206 ± 0.095
GIT (kg)
Age (days)
(f)
Y_0 = 0.660 ± 0.073
Y_f = 3.323 ± 0.153
Skin (kg)
Age (days)
(g)
Y_0 = 0.064 ± 0.010
Y_f = 14.610 ± 0.850
AbFat (kg)
Age (days)
(h)
Y_0 = 0.057 ± 0.006
Yf = 0.515 ± 0.043
Trimcut (kg)
Age (days)
0
200
400
600
800
1000

Figure 2. Observed (△), predicted (solid lines), 95% confidence interval (95%CI, dashed lines), and outlier (o) values of the growth profiles and 95%CI for the intercept and asymptotic estimates for the variables. Age (abscissa) is expressed in days (days). Dependent variables and the respective fitted models are: (a) liveweight (W, kg), Eqn (2) combined with Eqn (5); (b) empty body weight (EBW, kg), Eqn (2) with Eqn (5); (c) carcass weight ($Carcass$, kg), Eqn (2) with Eqn (5); (d) total weight of the organs ($Organs$, kg), Eqn (1) with Eqn (6); (e) weight of the gastrointestinal tract (GIT, kg), Eqn (1) with Eqn (6); (f) weight of the skin ($Skin$, kg), Eqn (1) with Eqn (5); (g) weight of the abdominal fat ($AbFat$, kg), Eqn (1) with Eqn (6); and (h) weight of the trimmed cuts ($Trimcut$, kg), Eqn (1) with Eqn (6). Details of equations are in the text.

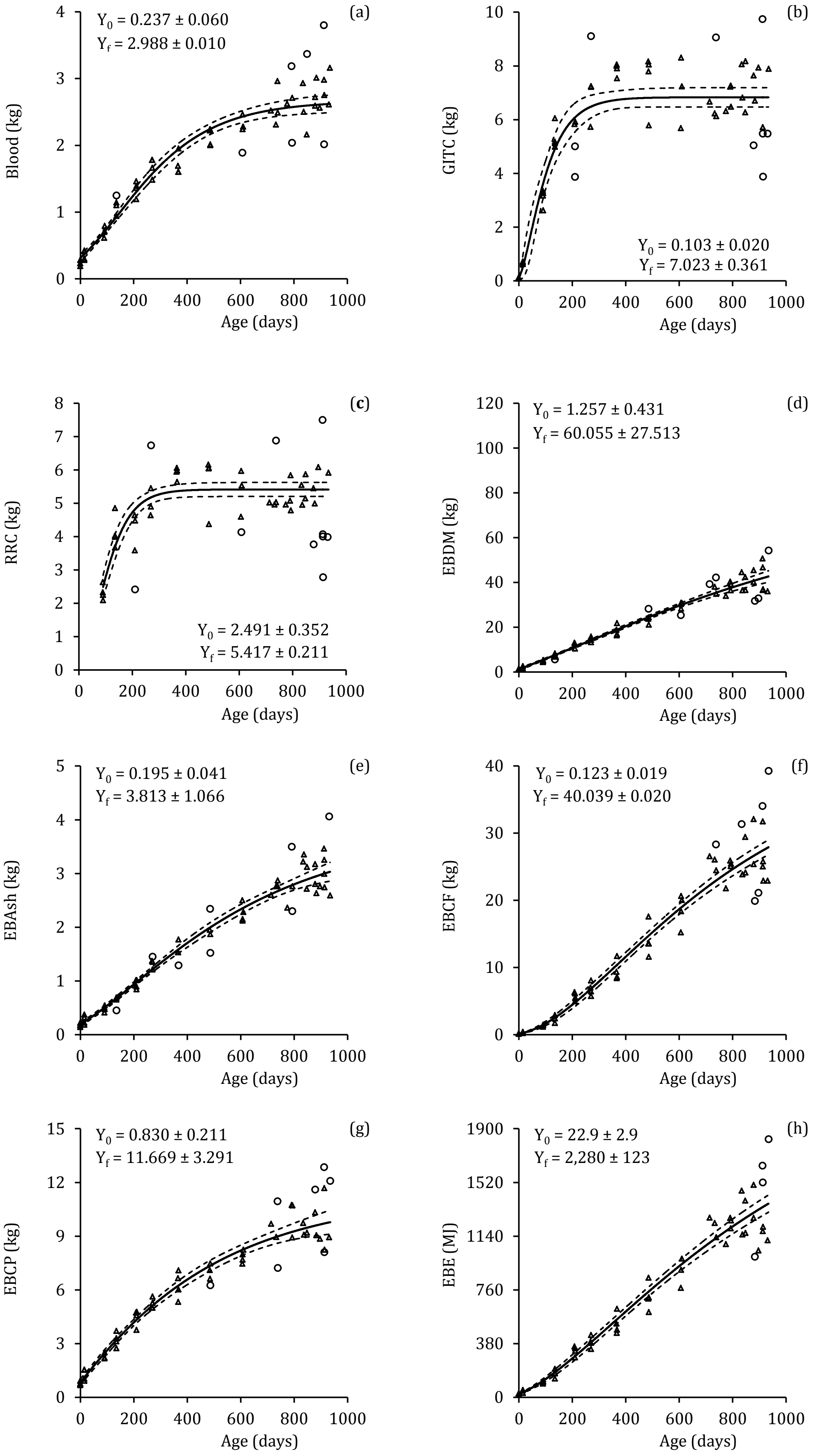
(a)
Y_0 = 0.237 ± 0.060
Y_f = 2.988 ± 0.010
Blood (kg)
0
1
2
3
4
Age (days)
0
200
400
600
800
1000
(b)
Y_0 = 0.103 ± 0.020
Y_f = 7.023 ± 0.361
GITC (kg)
0
2
4
6
8
10
Age (days)
(c)
Y_0 = 2.491 ± 0.352
Y_f = 5.417 ± 0.211
RRC (kg)
0
1
2
3
4
5
6
7
8
Age (days)
(d)
Y_0 = 1.257 ± 0.431
Y_f = 60.055 ± 27.513
EBDM (kg)
0
20
40
60
80
100
120
Age (days)
(e)
Y_0 = 0.195 ± 0.041
Y_f = 3.813 ± 1.066
EBAsh (kg)
0
1
2
3
4
5
Age (days)
(f)
Y_0 = 0.123 ± 0.019
Y_f = 40.039 ± 0.020
EBCF (kg)
0
10
20
30
40
Age (days)
(g)
Y_0 = 0.830 ± 0.211
Y_f = 11.669 ± 3.291
EBCP (kg)
0
3
6
9
12
15
Age (days)
(h)
Y_0 = 22.9 ± 2.9
Y_f = 2,280 ± 123
EBE (MJ)
0
380
760
1140
1520
1900
Age (days)

Figure 3. Observed (△), predicted (solid lines), 95% confidence interval (95%CI, dashed lines), and outlier (o) values of the growth profiles and 95%CI for the intercept and asymptotic estimates for the variables. Age (abscissa) is expressed in days (days). Dependent variables and the respective fitted models are: (a) Blood ($Blood$, kg), Eqn (2) combined with Eqn (5); (b) Gastrointestinal Tract content ($GITC$, kg), Eqn (2) with Eqn (6); (c) Ruminoreticular Content (RRC, kg), Eqn (1) with Eqn (4); (d) empty body dry matter ($EBDM$, kg), Eqn (2) with Eqn (5); (e) empty body ash ($EBAsh$, kg), Eqn (2) with Eqn (5); (f) empty body crude fat ($EBCF$, kg), Eqn (2) with Eqn (6); (g) empty body crude protein ($EBCP$, kg), Eqn (2) with Eqn (5); and empty body energy (EBE, MJ), Eqn (2) with Eqn (6). Details of equations are in the text.

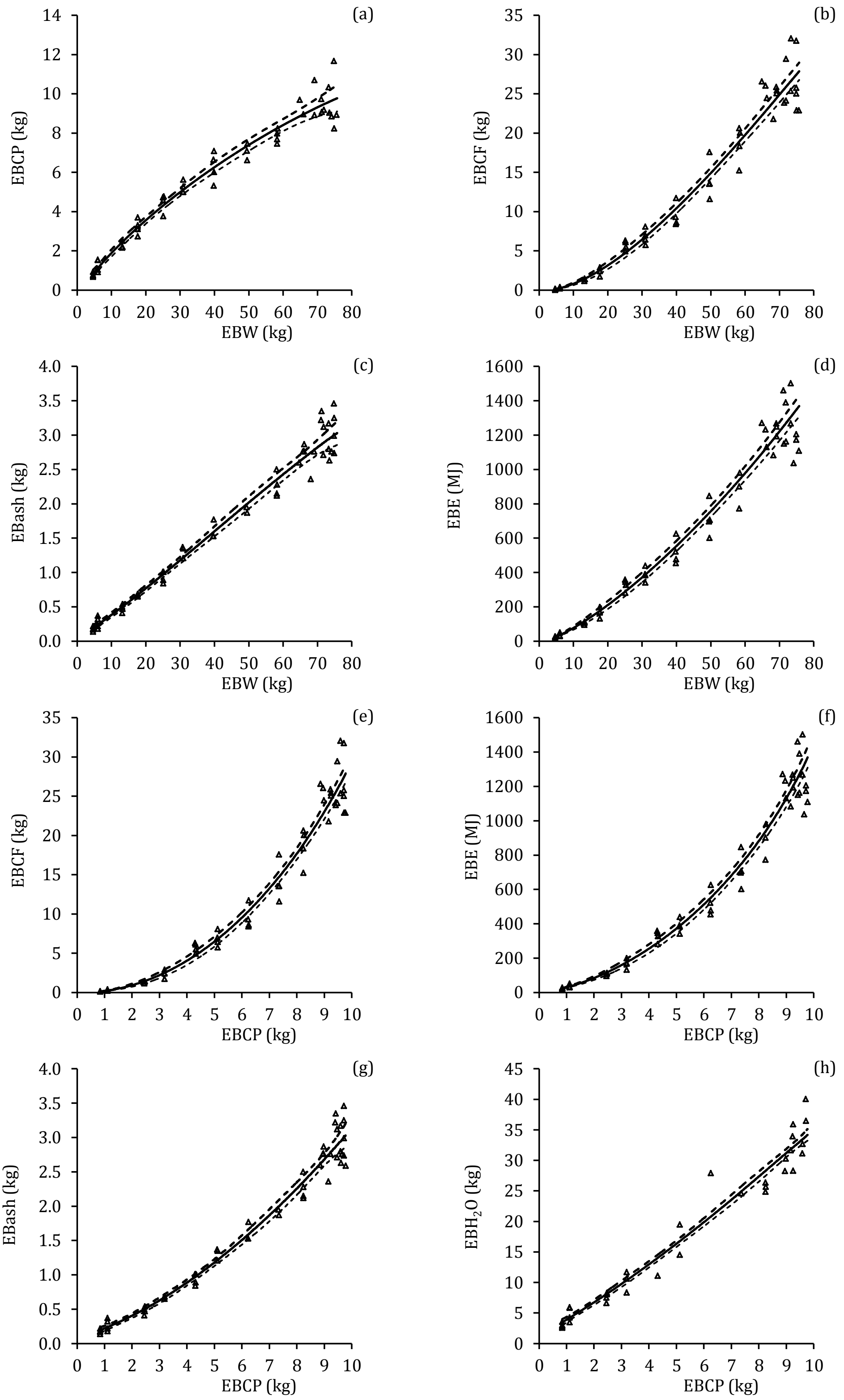
(a)
EBCP (kg)
0 2 4 6 8 10 12 14
EBW (kg)
0 10 20 30 40 50 60 70 80
(b)
EBCF (kg)
0 5 10 15 20 25 30 35
EBW (kg)
0 10 20 30 40 50 60 70 80
(c)
EBash (kg)
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
EBW (kg)
0 10 20 30 40 50 60 70 80
(d)
EBE (MJ)
0 200 400 600 800 1000 1200 1400 1600
EBW (kg)
0 10 20 30 40 50 60 70 80
(e)
EBCF (kg)
0 5 10 15 20 25 30 35
EBCP (kg)
0 1 2 3 4 5 6 7 8 9 10
(f)
EBE (MJ)
0 200 400 600 800 1000 1200 1400 1600
EBCP (kg)
0 1 2 3 4 5 6 7 8 9 10
(g)
EBash (kg)
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
EBCP (kg)
0 1 2 3 4 5 6 7 8 9 10
(h)
EBH$_2$O (kg)
0 5 10 15 20 25 30 35 40 45
EBCP (kg)
0 1 2 3 4 5 6 7 8 9 10

Figure 4. Observed (△) and predicted point (solid lines) and 95% interval (dashed lines) estimates for some variables plotted against the predicted empty body weight (EBW) and empty body crude protein ($EBCP$). On panels (a), (b), (c), and (d) are the respective plots of $EBCP$ (kg), $EBCF$ (kg), $EBAsh$ (kg), and EBE (MJ) against EBW (kg). On panels (e), (f), (g), and (h) are the respective plots of $EBCF$, EBE, $EBAsh$, and $EB\mathrm{H_2O}$ (kg) against the $EBCP$.

5. CONCLUSÕES

O modelo de richardz se ajusta a maioria dos perfis de crescimento de caprinos castrados por sua capacidade de mimetizar os modelos de brody, logistico e gompertz, dependendo da característica do perfil avaliado.

O modelo de gompertz somente é verossímel nos perfis que possuem característica sigmoide.

O modelo composto brody-gompertz deve ser avaliado com critério, principalmente quando se objetiva caracterizar um ponto de inflexão alternativo à puberdade, que ocorre normalmente no desmame de animais criados em sistema intensivo.

A determinação da estrutura de variância e covariância que melhor se ajusta a cada perfil avaliado sofre influência marcante das características de dispersão dos dados ao longo do tempo.

O crescimento das partes corporais e a composição do ganho de corpo vazio ao longo do tempo em caprinos castrados não são constantes em toda a gama de massa corporal estudada.

A fase assintótica dos perfis de crescimento não foi caracterizada para todas as variáveis analisadas, apesar do período longo de crescimento avaliado.

6. APÊNDICE

DATABASE

```
data pavesi;
input trt age anim W EBW carcass organs GIT skin AbFat Trimcut blood GITC RRC EBDM EBAsh EBCF EBCP EBE
y=w;
t=Age;
Dataline
1    0    1    27.323     4.854     3.146    0.374  0.152  0.768  0.077    0.065  0.276  0.130  0.007  1.390    0.224  0.146    0.922    18.117
1    0    2    19.454     3.579     2.270    0.287  0.141  0.626  0.052    0.050  0.194  0.080  0.004  0.999    0.141  0.096    0.670    13.523
1    0    3    22.815     4.044     2.574    0.339  0.131  0.670  0.068    0.055  0.228  0.088  0.007  1.184    0.181  0.127    0.761    16.306
1    0    4    21.323     3.680     2.308    0.293  0.153  0.640  0.055    0.055  0.200  0.113  0.005  1.109    0.173  0.109    0.728    14.068
2    15   5    29.142     5.727     3.614    0.359  0.247  0.520  0.083    0.137  0.280  0.710  0.008  1.492    0.224  0.197    0.914    18.729
2    15   6    31.635     6.191     4.047    0.380  0.260  0.620  0.086    0.128  0.300  0.615  0.030  1.614    0.182  0.189    1.034    19.362
2    15   7    50.700     8.620     6.106    0.415  0.295  0.788  0.104    0.117  0.406  0.620  0.010  2.414    0.317  0.380    1.528    25.206
2    15   8    48.989     8.797     6.260    0.420  0.270  0.752  0.118    0.129  0.423  0.680  0.035  2.480    0.370  0.332    1.536    24.271
3    91   9    108.250    14.335    8.140    0.915  1.070  1.255  0.490    0.190  0.710  2.620  2.090  4.803    0.471  1.443    2.203    69.717
3    90   10   95.222     13.080    6.915    0.790  1.165  1.085  0.350    0.155  0.605  3.165  2.315  4.414    0.405  1.140    2.155    57.718
3    91   11   113.006    15.227    8.112    0.975  1.325  1.375  0.525    0.195  0.785  3.255  2.245  5.263    0.540  1.381    2.509    70.640
3    90   20   105.074    14.595    7.910    0.840  1.025  1.075  0.500    0.185  0.700  3.340  2.625  4.720    0.495  1.367    2.194    65.010
4    135  32   171.226    21.120    10.880   1.325  1.705  1.350  0.995    0.430  1.135  4.985  3.670  7.376    0.648  2.400    3.286    108.235
4    135  36   199.832    22.935    12.065   1.460  1.600  1.410  1.295    0.445  1.095  5.115  3.990  8.274    0.689  2.879    3.704    124.749
4    135  40   131.429    18.525    9.115    1.045  1.015  1.040  0.850    0.325  0.940  5.180  4.030  5.550    0.450  1.717    2.733    81.239
4    135  43   167.445    22.965    11.505   1.345  1.385  1.385  1.015    0.400  1.250  6.050  4.845  6.787    0.678  2.409    3.110    109.226
5    211  13   327.773    32.555    18.365   1.690  1.515  1.955  2.565    0.645  1.390  5.920  4.480  12.167   1.008  5.499    4.771    195.102
5    209  16   358.531    32.645    18.630   1.785  1.610  1.885  2.505    0.625  1.360  5.825  4.635  13.020   1.005  6.306    4.730    217.719
5    210  23   281.907    26.625    14.295   1.525  1.505  1.790  2.225    0.540  1.185  5.005  3.575  10.369   0.840  4.932    3.763    175.351
5    210  26   346.490    29.865    17.850   1.630  1.565  1.970  2.460    0.610  1.455  3.865  2.415  12.424   0.888  6.097    4.567    206.737
6    270  41   384.206    36.025    19.310   1.795  1.685  1.895  3.645    0.465  1.655  7.240  4.895  14.266   1.212  6.431    5.618    221.028
6    269  45   390.865    35.427    20.395   1.855  1.945  1.935  3.215    0.455  1.777  5.730  4.635  14.443   1.365  6.974    4.991    236.099
6    270  46   439.808    40.960    20.975   1.960  1.955  2.155  4.600    0.380  1.780  9.105  6.740  15.743   1.351  8.055    5.267    265.520
6    270  47   341.504    34.150    18.430   1.735  1.770  1.705  2.935    0.605  1.480  7.210  5.445  13.206   1.454  5.718    4.991    201.991
7    368  15   625.420    48.685    27.445   2.105  2.045  2.835  6.370    0.440  1.950  7.540  5.635  21.766   1.766  11.701   7.076    356.520
7    366  18   521.690    44.696    24.961   1.955  2.060  2.505  5.265    0.315  1.690  8.000  5.940  18.795   1.529  9.318    6.644    294.881
```

```
7   368  21  477.925   44.045   24.040  1.970  1.620  2.475  5.765   0.305  1.600  7.905  5.980  16.852  1.287  8.585   6.006   278.309
7   367  42  454.329   39.990   21.070  1.835  1.590  2.180  4.945   0.330  1.595  8.050  6.060  16.276  1.525  8.391   5.324   268.456
8   485  31  697.449   53.200   28.765  2.160  1.975  2.940  8.450   0.465  2.220  8.160  6.160  23.726  1.953  13.526  7.090   401.386
8   486  37  845.421   57.640   31.235  2.170  1.780  2.895  10.675  0.620  2.235  7.785  6.040  28.284  2.336  17.574  6.614   496.513
8   487  38  601.640   47.980   25.095  1.985  1.860  2.740  7.495   0.510  2.005  8.050  6.055  21.028  1.520  11.583  6.258   349.045
8   487  39  706.533   50.810   29.680  2.075  1.685  2.755  7.945   0.510  1.995  5.775  4.365  24.413  1.866  13.539  7.456   398.353
9   610  22  980.237   61.340   34.765  2.060  2.600  3.135  11.070  0.780  2.280  7.225  5.530  30.790  2.277  20.044  8.227   549.982
9   607  24  772.606   50.540   29.500  1.505  2.025  2.695  8.515   0.760  1.890  5.675  4.585  25.419  2.496  15.221  7.454   415.313
9   608  28  996.894   62.550   36.375  2.105  2.325  2.930  9.880   0.470  2.460  8.300  5.965  30.851  2.151  20.616  7.978   565.145
9   608  14  900.705   56.305   34.445  1.745  2.125  2.475  9.530   0.440  2.235  5.400  4.135  28.224  2.117  18.348  7.677   497.916
10  714  19  1270.537  71.735   38.510  2.220  2.190  3.020  17.825  0.955  2.515  6.655  5.020  39.207  2.602  26.557  9.694   708.680
10  739  7   1130.978  64.490   36.105  1.830  2.360  3.050  13.835  0.905  2.485  6.115  5.030  34.808  2.873  24.474  7.228   644.620
10  733  30  1232.592  68.245   38.970  2.040  2.200  2.635  15.055  0.960  2.305  6.230  4.955  38.014  2.758  26.036  8.947   689.424
10  738  29  1368.970  82.830   51.495  2.480  2.405  2.970  13.090  0.735  2.960  9.065  6.885  42.243  2.766  28.315  10.948  760.037
11  793  4   1193.521  67.960   39.135  1.805  2.545  2.640  14.480  0.570  2.040  7.260  5.840  36.413  2.300  25.057  8.922   657.271
11  794  5   1249.669  75.550   45.270  2.305  2.790  3.430  14.510  0.855  2.710  6.470  4.780  39.101  2.761  25.427  10.700  685.582
11  775  49  1082.321  68.610   41.995  2.070  2.515  3.050  11.945  0.495  2.615  6.305  4.960  33.943  2.356  21.771  9.690   590.781
11  791  6   1268.331  76.980   46.480  2.185  2.545  3.225  14.240  0.445  3.185  7.220  5.065  40.228  3.502  25.880  10.737  691.457
12  848  12  1390.770  74.035   42.565  2.130  2.315  3.585  16.715  0.615  2.160  6.265  5.135  42.305  2.711  29.444  9.983   772.707
12  849  2   1162.574  75.595   45.625  2.435  2.690  3.290  12.195  0.500  3.370  8.165  5.870  36.545  3.115  24.114  9.184   659.959
12  837  34  1150.151  70.315   42.710  2.245  2.220  3.375  11.995  0.570  2.500  6.820  4.950  36.425  3.352  23.868  9.066   646.738
12  834  44  1460.480  81.605   47.175  2.615  2.610  3.800  17.000  0.500  2.925  8.055  5.545  44.517  3.216  31.367  9.734   836.748
13  897  25  1037.688  68.215   39.390  2.020  2.345  3.205  12.560  0.485  2.560  7.925  6.075  32.860  2.760  21.138  8.845   574.009
13  884  33  994.071   65.895   42.105  2.340  2.300  3.400  7.805   0.530  3.005  6.695  4.990  31.708  2.631  19.909  9.044   557.840
13  879  51  1267.600  74.425   42.825  2.375  2.250  3.505  15.140  0.355  2.585  7.640  5.450  40.217  3.169  25.346  11.603  686.424
13  879  50  1502.117  77.770   47.710  2.250  2.385  3.095  16.395  0.510  2.715  5.040  3.770  45.355  2.797  32.071  10.330  838.894
14  912  52  1638.836  93.555   55.910  2.915  3.040  3.495  19.130  0.925  3.800  9.740  7.500  50.602  3.458  34.051  12.847  911.363
14  914  48  1205.276  65.920   42.665  1.880  1.895  2.670  11.595  0.400  2.745  3.880  2.780  36.860  2.741  25.768  8.231   676.847
14  931  8   1108.670  65.245   39.105  2.000  2.165  3.060  12.930  0.375  2.610  5.115  3.990  35.983  4.055  22.893  8.931   614.285
14  913  53  1520.316  84.425   55.395  2.500  2.675  3.775  13.310  0.585  2.980  5.715  4.005  46.600  2.992  31.739  11.666  840.940
14  913  17  1173.512  62.250   37.665  2.175  2.050  2.725  11.730  0.415  2.015  5.480  4.070  36.529  3.250  25.030  8.112   671.187
14  935  3   1825.544  100.340  66.605  3.365  3.070  3.800  14.460  0.990  3.160  7.885  5.905  54.244  2.591  39.258  12.081  1050.885
;
```

```
proc mixed data=pavesi method=reml;
class trt anim;
model y=trt/ddfm=kr outp=baiano;
repeated /type=vc subject=anim group=trt;
run;
/*Gompertz model*/
proc nlmixed data=pavesi tech=newrap maxit=500;
parms
w0=1 to 15 by 1
m=.01 to .1 by .01
d=.001 to .01 by .001
s0=1000 to 40000 by 500
c=.01 to .1 by .01
/best=1;
bounds w0>0, m>0, d>0, s0>0, c>0;
v=s0*exp(c*t);
mean=w0*exp(m*(1-exp(-d*t))/d);
/*inflection point*/
ti=(1/d)*log(m/d);
meanti = w0*exp(m*(1-exp(-d*ti))/d);
estimate 'delta1' meanti;
/*Average daily rate of retention*/
Mfinal=w0*exp(m/d);
M0=w0;
estimate 'M0' M0;
estimate 'Mfinal' Mfinal;
mean=w0*exp(m*(1-exp(-d*t))/d);
mean15=w0*exp(m*(1-exp(-d*15))/d;
mean90=w0*exp(m*(1-exp(-d*90))/d;
mean210=w0*exp(m*(1-exp(-d*210))/d;
mean365=w0*exp(k2*(1-exp(-d*365))/d;
mean730=w0*exp(k2*(1-exp(-d*730))/d;
mean900=w0*exp(k2*(1-exp(-d*900))/d;
estimate 'delta1' (mean15-M0)/(15-0);
estimate 'delta2' (mean90-mean15)/(90-15);
estimate 'delta3' (mean210-mean90)/(210-90);
estimate 'delta4' (mean365-mean210)/(365-210);
estimate 'delta5' (mean730-mean365)/(730-365);
estimate 'delta6' (mean900-mean730)/(900-730);
resid=y-mean;
id resid;
model y ~ normal(mean,v);
predict mean ti out=raphael;
run;
quit;
proc print data=raphael;
var t y pred lower upper;
run;
quit;
proc gplot data=raphael;
plot y*t pred*t lower*t upper*t/frame overlay;
plot resid*t/frame overlay;
plot resid*y/frame overlay;
plot der1*t/frame overlay;
plot der2*t/frame overlay;
run;
quit;
/*Richards model*/
proc nlmixed data=pavesi tech=newrap maxit=500;
```

```
parms
Y0=150 to 350 by 50
Yf=2000 to 3500 by 100
n=-1 to 1 by .1
k=.0001 to .001 by .0001
s0=200 to 1000 by 100
c=.00001 to .0001 by .00001
sb=100000 to 200000 by 10000
/best=1;
bounds Y0>0, Yf>0, n>=-1, n<=1, k>0, s0>0, sb>0, c>0;
v=s0;
v=s0*exp(c*t);
v=s0+sb*(1-exp(-c*t));
mean=Y0*Yf/(Y0**n+(Yf**n-Y0**n)*exp(-k*t))**(1/n);
/*inflection point*/
ti=-(1/k)*log(n*y0**n/(yf**n-y0**n));
meanti=Y0*Yf/(Y0**n+(Yf**n-Y0**n)*exp(-k*ti))**(1/n);
estimate 'delta1' meanti;
/*Average daily rate of retention*/
Mfinal=Yf;
M0=Y0;
estimate 'M0' M0;
estimate 'Mfinal' Mfinal;
mean0=Y0*Yf/(Y0**n+(Yf**n-Y0**n)*exp(-k*0))**(1/n);
mean15=Y0*Yf/(Y0**n+(Yf**n-Y0**n)*exp(-k*15))**(1/n);
mean90=Y0*Yf/(Y0**n+(Yf**n-Y0**n)*exp(-k*90))**(1/n);
mean210=Y0*Yf/(Y0**n+(Yf**n-Y0**n)*exp(-k*210))**(1/n);
mean365=Y0*Yf/(Y0**n+(Yf**n-Y0**n)*exp(-k*365))**(1/n);
mean730=Y0*Yf/(Y0**n+(Yf**n-Y0**n)*exp(-k*730))**(1/n);
mean900=Y0*Yf/(Y0**n+(Yf**n-Y0**n)*exp(-k*900))**(1/n);
estimate 'delta1' (mean15-mean0)/(15-0);
estimate 'delta2' (mean90-mean15)/(90-15);
estimate 'delta3' (mean210-mean90)/(210-90);
estimate 'delta4' (mean365-mean210)/(365-210);
estimate 'delta5' (mean730-mean365)/(730-365);
estimate 'delta6' (mean900-mean730)/(900-730);
resid=y-mean;
id resid;
model y ~ normal(mean,v);
predict mean ti out=raphael;
run;
quit;
proc print data=raphael;
var t y pred lower upper;
run;
quit;
proc gplot data=raphael;
plot y*t pred*t lower*t upper*t/frame overlay;
plot resid*t/frame overlay;
plot resid*y/frame overlay;
plot der1*t/frame overlay;
plot der2*t/frame overlay;
run;
quit;
/*Brody-Gompertz model*/
proc nlmixed data=pavesi tech=newrap ;
parms
Yf1=-100 to 30 by 10
Y10=-100 to 10 by 10
```

```
k1=1 to 5 by .5
Y20=5 to 50 by 5
k2=.0001 to .001 by .0001
d=.0001 to .001 by .0001
s0=1 to 3 by .5
c=.00001 to .0001 by .00001
sb=200 to 1500 by 200
/best=1;
bounds Yf1>-101, Y10>-101, k1>0, Y20>0, k2>0, d>0, s0>0, sb>0, c>0;
v=s0;
v=s0*exp(c*t);
v=s0+sb*(1-exp(-c*t));
mean=Yf1-(Yf1-Y10)*exp(-k1*t) + Y20*exp(k2*(1-exp(-d*t))/d);
/*Average daily rate of retention*/
Mfinal=Yf1+Y20*exp(k2/d);
M0=Y10+Y20;
estimate 'M0' M0;
estimate 'Mfinal' Mfinal;
mean=Yf1-(Yf1-Y10)*exp(-k1*t) + Y20*exp(k2*(1-exp(-d*t))/d);
mean15=Yf1-(Yf1-Y10)*exp(-k1*15) + Y20*exp(k2*(1-exp(-d*15))/d);
mean90=Yf1-(Yf1-Y10)*exp(-k1*90) + Y20*exp(k2*(1-exp(-d*90))/d);
mean210=Yf1-(Yf1-Y10)*exp(-k1*210) + Y20*exp(k2*(1-exp(-d*210))/d);
mean365=Yf1-(Yf1-Y10)*exp(-k1*365) + Y20*exp(k2*(1-exp(-d*365))/d);
mean730=Yf1-(Yf1-Y10)*exp(-k1*730) + Y20*exp(k2*(1-exp(-d*730))/d);
mean900=Yf1-(Yf1-Y10)*exp(-k1*900) + Y20*exp(k2*(1-exp(-d*900))/d);
estimate 'delta1' (mean15-M0)/(15-0);
estimate 'delta2' (mean90-mean15)/(90-15);
estimate 'delta3' (mean210-mean90)/(210-90);
estimate 'delta4' (mean365-mean210)/(365-210);
estimate 'delta5' (mean730-mean365)/(730-365);
estimate 'delta6' (mean900-mean730)/(900-730);
resid=y-mean;
id resid;
model y ~ normal(mean,v);
predict mean ti out=raphael;
run;
quit;
proc print data=raphael;
var t y pred lower upper;
run;
quit;
proc gplot data=raphael;
plot y*t pred*t lower*t upper*t/frame overlay;
plot resid*t/frame overlay;
plot resid*y/frame overlay;
plot der1*t/frame overlay;
plot der2*t/frame overlay;
run;
quit;
```