UNIVERSIDADE ESTADUAL PAULISTA - UNESP
CÂMPUS DEJABOTICABAL

THE CONSTRAINING EFFECT OF FEED BULK ON THE VOLUNTARY FEED INTAKE OF POULTRY

Mariana Quintino do Nascimento
Zootecnista

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CERTIFICADO DE APROVAÇÃO

TÍTULO DA TESE: THE CONSTRAINING EFFECT OF FEED BULK ON THE VOLUNTARY FEED INTAKE OF POULTRY

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Jaboticabal, 12 de maio de 2020

DADOS CURRICULARES DO AUTOR

MARIANA QUINTINO DO NASCIMENTO – filha de João Luiz Santos do Nascimento e Anna Maria Quintino, nasceu no dia 26 de outubro de 1988, na cidade de Vitória, Espírito Santo. Em agosto de 2006 ingressou no curso de Zootecnia na Universidade Federal do Espírito Santo – Campus de Ciências Agrárias, Alegre/ES, graduando-se em agosto de 2011. No período de agosto de 2009 a julho de 2011 foi bolsista de iniciação científica voluntária (PIVIC) pelo CNPq, sob orientação do Prof. Dr. José Geraldo de Vargas Junior. Em agosto de 2011 ingressou no curso de mestrado em Ciências Veterinárias pela mesma instituição, onde obteve bolsa pela CAPES, sob orientação do Profº. Drº. José Geraldo de Vargas Junior e defendendo sua dissertação em agosto de 2013. Entre agosto de 2013 e julho de 2016 atuou como coordenadora do controle de qualidade na empresa Granvitória Alimentos Ltd, sendo responsável pelo desenvolvimento e teste de novos produtos, pela aplicação do Manual de Boas Práticas no ambiente da fábrica e pela análise bromatológica e microbiológica dos produtos finais (farinhas de origem animal). Em agosto de 2016 iniciou o curso de Doutorado em Zootecnia na Faculdade Ciências Agrárias e Veterinárias da Universidade Estadual Paulista – Campus Jaboticabal, São Paulo, onde obteve bolsa pelo CNPq, sob orientação da Profa. Dra. Nilva Kazue Sakomura, defendendo esta tese em 2020 para obtenção do título.

EPÍGRAFE

Deus,
Dai-nos a força no progresso de subir até Vós,
Dai-nos a caridade pura,
Dai-nos a fé e a razão,
Dai-nos a simplicidade que fará de nossas almas
O espelho onde refletirá um dia a Vossa Santíssima imagem.

(Prece de Cáritas)

DEDICO...

Aos meus pais, Anna Maria e João Luiz, por todo amor, dedicação, confiança nos meus maiores sonhos e por toda paciência comigo.

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Aos meus grandes amigos que conquistei ao longo dessa jornada.

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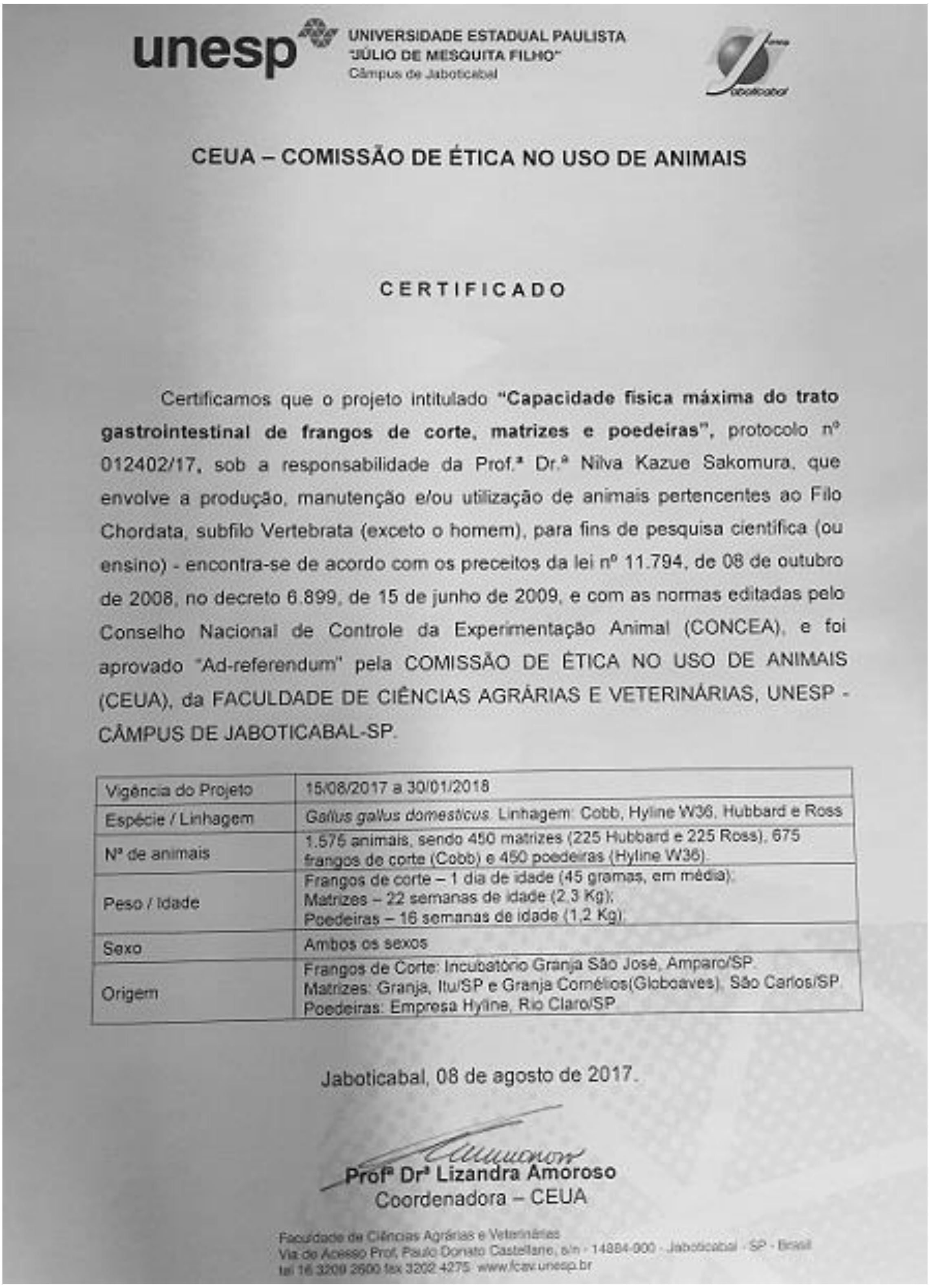
SUMÁRIO



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Câmpus de Jaboticabal

CEUA – COMISSÃO DE ÉTICA NO USO DE ANIMAIS

CERTIFICADO

Certificamos que o projeto intitulado **"Capacidade física máxima do trato gastrointestinal de frangos de corte, matrizes e poedeiras"**, protocolo nº **012402/17**, sob a responsabilidade da Prof.ª Dr.ª Nilva Kazue Sakomura, que envolve a produção, manutenção e/ou utilização de animais pertencentes ao Filo Chordata, subfilo Vertebrata (exceto o homem), para fins de pesquisa científica (ou ensino) - encontra-se de acordo com os preceitos da lei nº 11.794, de 08 de outubro de 2008, no decreto 6.899, de 15 de junho de 2009, e com as normas editadas pelo Conselho Nacional de Controle da Experimentação Animal (CONCEA), e foi aprovado "Ad-referendum" pela COMISSÃO DE ÉTICA NO USO DE ANIMAIS (CEUA), da FACULDADE DE CIÊNCIAS AGRÁRIAS E VETERINÁRIAS, UNESP - CÂMPUS DE JABOTICABAL-SP.

Vigência do Projeto	15/08/2017 a 30/01/2018
Espécie / Linhagem	*Gallus gallus domesticus*. Linhagem: Cobb, Hyline W36, Hubbard e Ross
Nº de animais	1.575 animais, sendo 450 matrizes (225 Hubbard e 225 Ross), 675 frangos de corte (Cobb) e 450 poedeiras (Hyline W36).
Peso / Idade	Frangos de corte – 1 dia de idade (45 gramas, em média); Matrizes – 22 semanas de idade (2,3 Kg); Poedeiras – 16 semanas de idade (1,2 Kg);
Sexo	Ambos os sexos
Origem	Frangos de Corte: Incubatório Granja São José, Amparo/SP. Matrizes: Granja, Itu/SP e Granja Cornélios(Globoaves), São Carlos/SP. Poedeiras: Empresa Hyline, Rio Claro/SP.

Jaboticabal, 08 de agosto de 2017.

Profª Drª Lizandra Amoroso
Coordenadora – CEUA

Faculdade de Ciências Agrárias e Veterinárias
Via de Acesso Prof. Paulo Donato Castellane, s/n - 14884-900 - Jaboticabal - SP - Brasil
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CAPACIDADE MÁXIMA DO TRATO GASTROINTESTINAL DE AVES

RESUMO - O objetivo deste estudo foi determinar a capacidade máxima de consumo, por meio da coleta de dados de consumo de ração das aves. E desta forma, ajustar equações que correlacionassem as características físicas de um alimento com a capacidade do trato gastrointestinal de frangos de corte, matrizes pesadas e poedeiras em diferentes fases de criação. Foram conduzidos 8 ensaios, sendo 4 ensaios com frango de corte, nas fases inicial, crescimento, terminação e o último para validação. Dois ensaios com matrizes pesadas e outros dois com poedeiras, nas fases de pré-postura e produção de ovo, sendo que em cada ensaio foram utilizados 225 animais. O delineamento foi inteiramente casualizado (DIC) com cinco diluentes e 5 níveis de diluição, totalizando 25 tratamentos e nove repetições contendo uma ave cada. Os tratamentos consistiram em uma dieta controle (sem inclusão de diluente) e as demais dietas com níveis graduais de cada diluente (2.5; 5; 10 e 15% para frangos de corte e poedeiras; 0; 10; 20; 30 e 40% para matrizes pesadas). Os diluentes utilizados foram a fibra de celulose, a serragem, a casca de arroz, a areia e a vermiculita. Os períodos experimentais aplicados ao estudo com frango de corte foram de 14 dias cada (1 a 14 dias; 15 a 28 dias e 29 a 45 dias), para matrizes pesadas e poedeiras foram de 28 dias cada ensaio. Nos ensaios foram mensurados o consumo diário e o peso vivo das aves. Foram realizadas análises laboratoriais que permitissem simular o comportamento físico do diluente e da ração diluída no trato gastrointestinal de cada classe animal e sua fase. Logo em seguida, utilizando a análise multivariada como ferramenta de decisão, pretendeu-se então selecionar a característica física que melhor se correlacionasse com o consumo e a partir daí estabelecer uma correlação entre estas análises físicas e a capacidade máxima do TGI do animal. Deste modo, no capítulo 2 é apresentado o estudo para frangos de corte. A seguir, no capítulo 3 foi avaliado o efeito da diluição sobre o consumo de matrizes pesadas nas fases de pré-postura e produção de ovos. No capítulo 4 estão descritos os experimentos e respectivos resultados encontrados para frangas e poedeiras em fase de produção. Por fim, no capítulo 5 é apresentada a aplicação dos resultados obtidos.

Palavras-chave - Capacidade de retenção de água, consumo máximo, diluição, trato gastrointestinal

THE CONSTRAINING EFFECT OF FEED BULK ON THE VOLUNTARY FEED INTAKE OF POULTRY

ABSTRACT - The objective of this study was to determine the maximum food intake capacity by collecting feed intake data from birds. Thus, to fit equations that correlates the physical characteristics of a food with the capacity of the gastrointestinal tract of broilers, broiler breeders and laying hens in different rearing phases. Eight trials were conducted, four trials with broiler chicken in the initial, growth, final and last for validation. Two trials with broiler breeders and two with laying in the rearing and egg - production phases, and 225 animals were used in each test. The design was completely randomized (DIC) with five diluents and 5 dilution levels, totaling 25 treatments and nine replicates containing one bird each. The treatments consisted of a control diet (without diluent inclusion) and the other diets with gradual levels of each diluent (2.5, 5, 10 and 15% for broilers and laying hens; 0, 10, 20, 30 and 40% for broiler breeders). The diluents used were cellulose fiber, sawdust, rice husk, sand and vermiculite. The experimental periods applied to the study with broiler chicken were 14 days each (1 to 14 days; 15 to 28 days and 29 to 45 days), for broiler breeders and laying hens were 28 days each trial. In the trials the daily food intake and body weight of the birds were measured. Laboratory analyzes were performed to simulate the physical behavior of diluent and diluted diets in the gastrointestinal tract of each animal category and its phase. Therefore, using multivariate analysis as a decision tool, it was then intended to select the physical characteristic that best correlated with food intake and from there to establish a correlation between these physical analyzes and the maximum capacity of the bird's TGI. Thus, chapter 2 presents the study for broilers. Chapter 3 the effect of dilution on food intake of broiler breeders in the rearing and egg-production phases was evaluated. In chapter 4, describes the experiments and their results for pullets and laying hens. Finally, in chapter 5, it is presented to apply in broiler growth model the broiler chickens' results obtained.

Keywords - Water holding capacity, maximum food intake, dilution, gastrointestinal tract.

CAPÍTULO 1 – Considerações gerais

Introduction

Knowledge of the mechanisms of regulation of food intake is important in order to provide adequate intake of nutrients and energy to birds for optimum productive performance. This subject is particularly relevant in birds, in which these mechanisms may differ between meat-type and posture strains of poultry. The regulation of voluntary feed intake occurs to keep the body's homeostasis, stimulating feed intake and increasing catabolism when the animal presents negative energy balance and inhibiting feed intake and promoting anabolism when It’s in positive energy balance. However, in addi-tion to metabolic/energetic homeostasis, there are other factors that influence feed intake, such as genetics, nutritional levels, social factors, stress, among others.

Thus, no only one theory can explain such phenomena, several theories about the main factors that regulate feed intake are the chemical factors circulating levels of glucose, amino acids, fatty acids and ions and physical filling of the gastrointestinal tract, the most discussed in the literature. What will be discussed in this study is the maximum filling of the gastrointestinal tract. The physical filling of the gastrointestinal tract in poultry seems to be the main control factor of the food intake, mainly in broilers, be-cause the current strains have been selected for ravenous feed intake of diet (Ferket & Gernat, 2006). Newcombe & Summers, (1985) related that the observed maximum volume of feed consumed by the broiler when fed the 300 g cellulose/kg diet, was 14% greater than its corresponding intake on the basal diet, whereas the equivalent change for the Leghorn was about 44%.

In the trials that were performed in this work, a balanced diet will be diluted in gradual proportions of different diluents as a means of characterizing dietary properties that reflect this restriction in food intake. As the proportion of diluent increases, the concentration of all essential nutrients decreases. As a result, the animal will increase its food intake to satisfy its nutritional needs (MRAZ et al., 1957). This raises two questions:

a) What is the response on daily food intake and growth rate, and production increasing dilutions of a food?

b) What is the maximum volume of food that the animal can consume?

The purpose of this tese was to answer these questions by measuring the total gastrointestinal capacity in certain stages of the animal and to determine which measure most accurately describes the physical characteristic of the food, measured by the maximum volume that can be consumed by the animal.

In this way, the maximum production capacity of the production birds was determined, which provided more accurate food intake values by minimizing the effects of the environment, diet and genotype on daily food intake.

The results to be obtained contributed to the formulation of more precise diets, based not only on nutritional requirements, but also on the physical capacity of the bird.

The broiler growth model (Growth and Production Model) is based on the principle proposed by Emmans (1981) that the bird tends to consume sufficient amount of feed to satisfy its genetic growth potential, considering the capacity of the digestive tract and the limitations of the environment. However, in order to estimate the maximum food intake of a medium bird, the model considers only the total dietary fiber as a factor influencing food intake, not taking into account the physical characteristics and other chemical characteristics of the diet that can directly influence consumption, such as volume, density, crude fiber contents, neutral detergent fiber and acid detergent fiber. The results generated in the present work was applied to the AVINESP, with the main objective of predicting the maximum capacity of food intake with greater accuracy and consequent improvement in poultry performance. In addition, understanding how these restrictions affect intake may complement management, feeding, and genetic selection strategies in poultry production.

Based on the results to be obtained in the present project, we intend to generate a mathematical model that correlates the physical characteristics of a food with the maximum capacity of food intake of different birds of production in different phases.

Literature review

Modeling of food intake

Emmans (1981) proposed that an animal consumes the feed to reach its genetic potential by satisfying its need for maintenance and growth. The genetic potential for birds is defined by their production of meat or eggs. To reach this potential, defined by its genotype, the bird must consume sufficient quantities of the nutrients it needs, by ingestion of the food provided. There are factors that may prevent the animal from consuming enough nutrients, these include food volume, room temperature, nutrient excess, and bird health (EMMANS AND OLDHAM, 1988). In this way, the processes of food intake are described in figure 2.1.

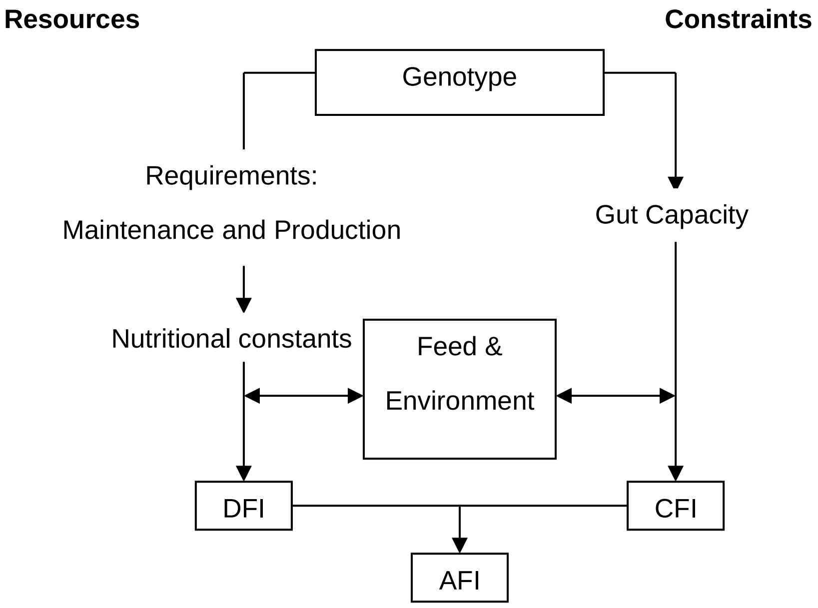

Figure 2.1. Scheme proposed by Emmans and Oldham (1988) explain the regulation of food intake in poultry, where DFI is desired feed intake, AFI is actual feed inatke, and CFI is constrained feed intake.

In the absence of restrictions, the bird has an ability to ingest sufficient nutrients to meet these requirements. If these are satisfied the animal will have achieved a Desire Feed Intake (DFI), expressed by the equation:

DFI = RL/FCON (g/day) [Eq.1]

Where RF = requirement for the first limiting (g/day) and FCON= concentration of the first nutrient or limiting energy in the diet (g/g).

If the physical capacity of the digestive tract limits food intake of diet supplied, the intake will be restricted (Constrained Feed Intake - CFI), as shown in Figure 2.1. Thus, actual food intake (AFI) can be determined by considering the physical and environmental constraints on dietary intake, hence the AFI defines bird performance. The AFI should be accurately estimated to maximize animal performance in a specific diet and environment. For this, the requirements must be known, and the diet must be formulated to meet these requirements. The actual feed intake of an animal in a thermoneutral environment should be calculated based on energy and protein.

If $DFI_{ENERGY} > DFI_{PROTEIN}$ so $AFI = DFI_{ENERGY}$ (g/day) [Eq.2]
or if $DFI_{PROTEIN} > DFI_{ENERGY}$ so $AFI = DFI_{PROTEIN}$ (g/day) [Eq.3]

Already on a perfectly balanced diet:

$$AFI = DFI_{ENERGY} = DFI_{PROTEIN} \quad \text{[Eq.4]}$$

Factors that could restrict food intake

In a thermoneutral environment, by providing a diet that meets exactly the needs of a bird, the bird would be able to ingest enough food to meet its needs and thus reach the potential defined by its genotype. However, this situation rarely occurs in practice, since the diet is not always perfect, and there are environmental restrictions. The actual intake of the diet will set the performance of the bird, so it should be expected to maximize performance in a specific environment. For this, the requirements of the bird must be known, and the diets must be formulated in order to meet all the requirements, however, the restrictions must be considered.

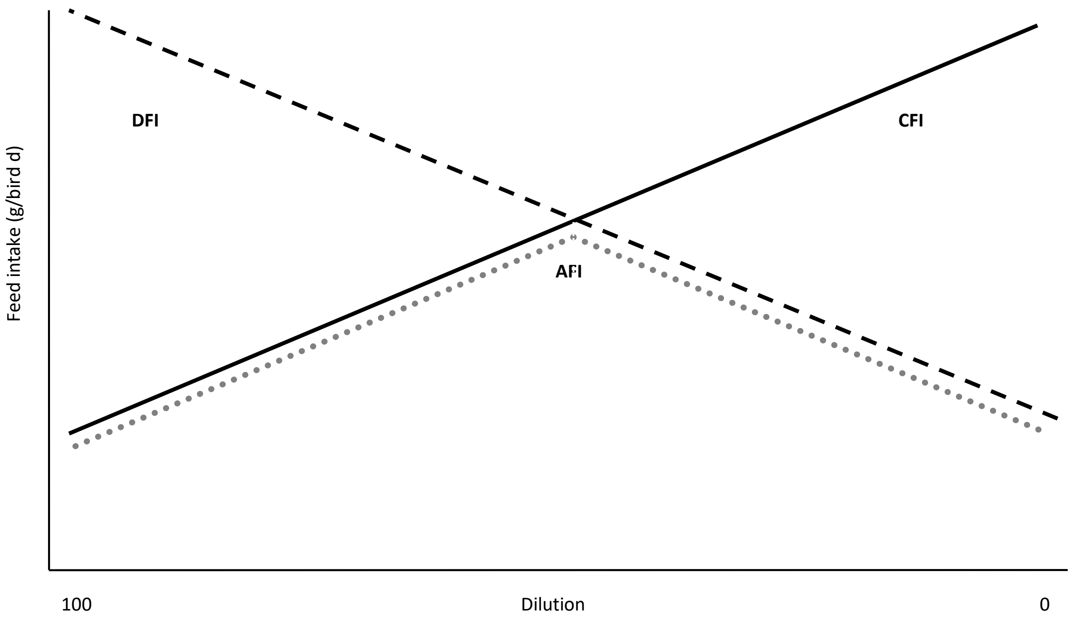

Figure 2.2 Proposed relationship between the desired feed intake (DFI, dotted line), constrained feed intake (CFI, solid line) and actual intake (AFI, broken line) as feed is diluted with an inert filler (MOORE, 2004).

Figure 2.2 represents the effect of diet dilution on animal food intake. It is possible to verify that in a dilution of 100% of the diet, with inert material, DFI (broken line) is only served with a high food intake and as this dilution decreases (more concentrated diet) the food intake necessary to meet the DFI decreases proportionally (decreasing linear behavior), since the bird needs to eat less and less of the diet to satisfy its needs. The CFI (solid line) presents an inverse (linear increasing) behaviour to DFI. In diets with higher dilutions, feed consumption will be lower, since the bird will not be able to ingest the necessary amount by limiting the digestive tract. Food intake shows a gradual increase in CFI as dietary dilution decreases, and this will impose less restriction on the consumption of the animal. The AFI (dotted line) shows an increase up to a maximum point (point of intersection between the DFI and the CFI) of food intake followed by fall. Therefore, as the dilution of the diet is increased, the food intake increases proportionally up to a maximum point, this represents the maximum consumption capacity of the bird. This breaking point is directly influenced by the physical capacity of the digestive tract. An animal cannot reach its DFI if the volume of the diet is greater than the capacity of the bird's digestive tract or if the environment also imposes certain restrictions on the desired consumption (EMMANS, 1981; COLE AND CHADD, 1989)

Kyriazakis and Emmans (1995) describes the effect of food on voluntary intake, and its results have been used to date to determine the relationship between the nutrient density of a diet (using water retention capacity) and intestinal capacity. The model implements a restriction on volume and density (BULKDN) using the function proposed by Emmans (1981)

$$BULKDN = 0.1*digOM + (1 - water-ash-digOM) *(5+fform) \qquad [Eq.5]$$

Where, digOM is the digestible organic matter, the ash is the ash content as a proportion of the feed, the water is the moisture content as a proportion of the diet and fform is the physical form of the food (pellets = 0.0; crumbles = 0.2 ; meal = 0.5).

Emmans (1981) proposed three types of restrictions that could influence feed food intake:

I. Ambient temperature: can limit the heat loss of the animal by restricting food intake.

II. Gastrointestinal capacity: may not allow sufficient food intake due to the amount needed to meet the genetic potential or the volume of the diet.

III. And the presence of toxins in the feed.

Thus, according to Emmans (1987) the CFI can be calculated as:

$$CFI= (90*Diet\ Protein^{1.0})/ BULKDN \qquad (g/day) \qquad [Eq.6]$$

Relation between food intake with food volume and density

The gastrointestinal tract of the bird adapted to many changes due to the intensive genetic improvement to obtain more productive animals. A cutting chicken, for example, consumes approximately 10% of its live weight daily, its digestive tract must be able to withstand this amount of food to meet its high nutritional requirements (SVIHUS, 2014). Thus, the components of the gastrointestinal tract that have undergone the most adaptations in the bird to improve the digestion of the food are the proventriculus, the gizzard, the small intestine and the colon (MARSDEN AND

MORRIS, 1986). From this information, Jorgensen et al. (1996) observed that broiler chickens can adapt to fiber-rich diets, increasing the size of the gastrointestinal tract and increasing the length of the small intestine. These authors also observed that changes in the size of the tract influenced the animal's maintenance requirements due to the relationship between an animal's requirement and its metabolic weight. When a highly concentrated diet is diluted with an inert, bulky ingredient (lower density), it is possible to assume that the bird will increase its food intake so that nutrient demand continues to be met, and its performance remains unchanged. According to Emmans (1981), the animal has a potential rate of performance (genetic potential), this in turn will have a direct influence on food consumption in order that the bird can ingest the amount of nutrient enough so that this potential rate of performance is achieved. In a situation in which the animal consumes a diet that is gradually diluted, the point of maximum consumption will be reached, followed by drop in consumption and consequent reduction in performance. Defining this critical point is the main objective of this work. So that maximum food consumption can be predicted to ensure that the bird will be able to ingest the amount of feed needed to meet the demand for nutrients and energy.

Physical capacity of gastrointestinal tract

The gastrointestinal tract (GIT) of the bird is responsible for the digestion and absorption of nutrients from the diet. The most obvious restriction that the GIT's ability can impose is the physical limitation on the amount of food it can carry. Factors affecting the intestinal capacity, body extension and the emptying rate are important to provide an adequate measurement of this restriction. According to Wolford and Polin (1973) distension of the intestine plays a major role in the regulation of food intake. This can be attributed to the physical factors within the duodenum that appear to inhibit gastric motility and, therefore, decrease the bird's food intake (RICHARDSON, 1972).

The amount of a more nutritionally diluted diet that a bird can consume depends on its physical capacity and the physical density of the feed. Based on this, Tsaras et al. (1998) found that, in pigs, the maximum feed capacity in volume and density is directly proportional to the live weight of the animals. Savory (1980) also observed that the density of food affects the time the birds take to ingest the food.

This same author reported that by changing the density of the feed, the food consumption is affected. Thus, according to Emmans (1981), birds fed a diluted diet consumed more than birds with an undiluted feed. Therefore, if food consumption is limited by the volume and density of the diet, the actual food intake is delineated by volume intake rather than *ad libitum* feed.

The animal can reach its maximum capacity of ingestion when there is some nutritional deficiency in the diet or it is diluted to the point of taking the animal to consume more to try to meet its requirements or if the environment presents temperatures lower to the range of comfort causing the bird uses as a tool the production of heat from the digestion process in order to maintain its constant temperature. Thus, when there is nutritional deficiency of the diet or it is diluted, it is important to consider which is the first most limiting nutrient of the diet, since it determines if the animal can reach its rate of growth potential (protein deposition) or not. It may be possible for the animal to consume enough protein to reach its potential, yet it can not get enough energy. In this case, energy is the first most limiting factor and second is the physical limitation of the treatment that prevents it from consuming enough of the diluted diet to supply the first limitant (in this case, energy). And at this point it is possible to observe the point of consumption drop and subsequent fall in animal performance. The animal first directs energy to its maintenance, so once the maintenance is satisfied, the remaining energy will be allocated for growth (protein deposition - dPr), however if there is insufficient energy for dPr then the efficiency with which the protein is deposited will be influenced negatively. The change in efficiency depends on energy intake (CAMPBELL AND TAVERNER, 1988) or, more specifically, on the energy: protein ratio, as demonstrated by Kyriazakis and Emmans (1995).

This hypothesis was confirmed by Gous et al. (2012). This author states that birds of any age try to maintain the body's protein: lipid ratio, determined by its genetic potential, by long-term regulatory mechanisms. According to this theory, which was first proposed by Emmans (1981), when an animal has more body lipids than its genetically determined protein: lipid ratio, the extra amount of lipid will be used as the source of energy as soon as possible. These findings are consistent with the hypothesis that there is a desired body lipid content that the bird tries to maintain. In this way, to define the maximum consumption capacity can contribute to the definition of more efficient food programs, which among other factors already mentioned, can contribute to the improvement of the carcass quality of the production birds.

References

CAMPBELL, RG. AND TAVERNER, M.R 1988. Genotype and sex effects on the relationship between energy intake and protein deposition in growing pigs. Journal of Animal Science 66:676.

CAPREZ A, ARRIGONI E, AMADO R, NEUKOM H. 1986. Influence of different types of thermal treatment on the chemical composition and physical properties of wheat bran. Journal Cereal Science 4:233-239.

COLE, D.J.A. AND CHADD, SA 1989. Voluntary food intake of growing pigs. In: The Voluntary Food Intake of Pigs. Eds. Forbes, J.M., Varley, M.A. & Lawrence, T.L.J., Animal Production Occasional Publication No. 13, London. p. 61.

EMMANS, G.C. (1981) A model of the growth and food intake of ad libitum fed animals, particularly poultry. In: Computers in Animal Production, Occasional Publication No. 5, pp 103-110.

EMMANS, G.C. (1987) Growth, body compositon and food intake. World's Poultry Science. 43, 208-227.

EMMANS, G. C. AND OLDHAM, J. D. (1988) Modelling of growth and nutrition in different species. In: Korver, S. and Van Arendonk, J. A. M. (eds.) Modelling of livestock production systems. Academic Publishers, Amsterdam: Kluwer, pp. 13-21.

FERGUSON, N.S. Title: Basic Concepts describing animal growth and feed intake. In: Eds Gous, R.M., Morris, T.R. and Fisher, C. Mechanistic modelling in pig & poultry production. CAB International 2006, p 22.

GOMEZ-ORDONEZ E, JIMENEZ-ESCRIG A, RUPEREZ P. 2010. Dietary fibre and physicochemical properties of several edible seaweeds from the northwestern Spanish coast. Food Research International. 43:2289–2294.

GOUS, R., EMMANS, G. C. AND FISHER, C. (2012) The performance of broilers on a feed depends on the feed protein content given previously. South African Journal of Animal Science 42, 63-73.

JØRGENSEN, H., ZHAO, X., KNUDSEN, K., & EGGUM, B. (1996). The influence of dietary fibre source and level on the development of the gastrointestinal tract, digestibility, and energy metabolism in broiler chickens. British Journal of Nutrition, 75(3), 379-395. doi:10.1079/BJN19960141.

KYRIAZAKIS, I. AND EMMANS, G.C. 1995. The voluntary feed intake of pigs given feeds based on wheat bran, dried citrus pulp and grass meal, in relation to measurements of feed bulk. British Journal of Nutrition 73:615.

MARSDEN, A. AND MORRIS, T.R. (1986) Quantitative review of the effects of environmental temperature on feed intake, egg output and energy balance in laying pullets. British Poultry Science. 28, 693-704.

MRAZ, F.R., BOUCHER, R.V. AND MCCARTNEY, M.G. (1957) The influence of energy:volume ratio on growth response in chickens. Poultry Science. 36, 1217-1221.

MOORMAN WFB, MOON NJ, WORTHINGTON RE. 1983. Physical properties of dietary fiber and binding of mutagens. Journal of Food Science. 48:1010-1011.

Moore, M.L. The constraining effect of feed bulk on the voluntary feed intake of laying hens. 2004. 113f. Dissertação (Mestrado) - University of KwaZulu-Natal Pietermaritzburg. 2004.

POLIN, D. AND WOLFORD, J.H. (1973) Factors influencing food intake and caloric balance in chickens. Federation Proceedings. Federation of American Societies for Experimental Biology. 32, 1720-1726.

RICHARDSON, A.J. (1972) The effect of duodenal constriction on food intake and water intake of Brown Leghorn cockerels. British Poultry Science. 13, 175-177.

SAVORY, C.J. (1980) Meal occurrence in Japenese Quail in relation to particle size and nutrient density. Animal Behaviour. 28, 160-171.

SAKOMURA, N.K., ROSTAGNO, H.S. 2016. Métodos de pesquisa em nutrição de monogástricos. 2ªed. Jaboticabal:Funep, 2016. p.262.:il.,retrs.

SUZUKI T, OSHUGI Y, YOSHIEM Y, SHIRAI T, HIRANO T. 1996. Dietary fibre content, water holding capacity and binding capacity of seaweeds. Journal Fishery Science 62:445-446.

SILVA, D.J.; QUEIROZ, A.C. Análises de alimentos (métodos químicos e biológicos). 3.ed. Viçosa, MG: Editora UFV, 2002. 235p.

SVIHUS, B., 2014. Function of the digestive system. The Journal of Applied Poultry Research 23, 306-314.

TSARAS, L.N., KYRIAZAKIS, I. AND EMMANS, G.C. (1998) The prediction of the voluntary feed intake of pigs on poor quality foods. Animal Science. 66, 713-723.

WANG, J.C., KINSELLA, J.E. 1976. Functional properties of novel protein: alfafa leaf protein. Journal of Food Science. 41, 286-290.

YASUTMASU K, SAWADA K, MORITAKA S, NFISAKI M, TODA J, WADA T, ISHI K. 1972. Whipping and emulsifying properties of soybean products. Chemical and Biological Technologies in Agriculture. 36:719–737.

CAPÍTULO 2 - Prediction of maximum scaled feed intake in broiler chickens based on physical properties of bulky feeds

Abstract - A trial was conducted to investigate the capacity of broilers chickens to consume bulky feeds during three stages of growth. These phases were from 1 to 15 d, 16 to 30 d and from 31 to 45 d. A basal feed was serially diluted (0, 2.5, 5.0, 10 or 15 %) with one of five diluents (cellulose fibre, sawdust, rice husk, sand or vermiculite) to produce 25 feeds which were supplied on an a*d libitum* basis to the birds in each phase. Cobb 500® strain chicks were used, and, within each phase, each feed was given to nine individually-caged birds, 225 in total, distributed in a completely randomised design. Intake increased initially, and then declined, as the proportion of each diluent increased. The intakes of feeds that limited intake were directly proportional to metabolic body weight and so a scaled feed intake, expressed as g/BW$^{0.67}$ per day, was calculated. There were large effects of feed type on intake, in the short term, with consumption of a bulky feed leading to higher intakes. It was concluded the WHC content of the feeds could be appropriate measurement of 'bulk' responsible for limiting intake and could be used to predict maximum feed intake capacities of broiler chickens fed bulky diets.

Keywords: Bulk capacity, water holding capacity, fibre, gastrointestinal tract, modelling

Introduction

The accurate prediction of feed intake in broiler chickens is a critical starting point for the simulation of growth and changes in body composition (Emmans, 1987). Whereas the calculation of food intake required to enable a bird to grow at its potential is relatively straightforward, it is not possible for the bird to consume this 'desired food intake' under all circumstances. The two most important factors constraining such intake are the inability to lose sufficient the heat generated by the bird into the environment and gut capacity (Emmans, 1987). The ability to predict gastrointestinal capacity would increase the accuracy with which the constraining effect of bulky or low-density feeds could be assessed.

As the nutrient density of a feed is reduced (or bulkiness is increased) or the environmental temperature decreased, the bird will attempt to consume more of this feed to meet its nutrient requirements for potential growth (Mraz, 1956; 1957; Emmans 1987; Tsaras *et al.*, 1998). If environmental temperature is not limiting, feed intake will reach a maximum when the physiological limit of gut capacity has been reached. Attempts have been made to define this gut capacity in terms of both physical and chemical characteristics of the feed, and the most successful measure has been water-holding capacity (WHC) (Kyriazakis and Emmans, 1995; Tsaras *et al.*, 1998; Whittemore *et al.*, 2001).

Changes in gut capacity will take place as the bird grows, and acclimatisation to bulky feeds has been shown to occur (Tsaras *et al.*, 1995). These changes must be accommodated if the constraining effect of bulk capacity are to be accurately predicted. Some scaled measure of the size of the bird is required to take account of the growth of the organs involved: Kyriazakis and Emmans (1995) and Tsaras *et al.* (1998) scaled intake directly to body weight (g/kg), but Schmidt-Nielsen (1984) suggested that the 2/3 exponent of body weight was best because it represents a sphere. Both of these measures were evaluated in the present trial.

Thus, the hypothesis for the current trial was that some physical measure of a feed can enable the constraining effect of feed bulk on voluntary feed intake to be predicted. The aim was to investigate the capacity of broiler chickens for different bulky feeds during three phases of growth, from 1 to 15 d, 16 to 30 d and 31 to 45 d of age.

Material and methods

This study was approved by the Ethics Committee on Animal Use of the Faculty of Agriculture and Veterinary Sciences, UNESP, Jaboticabal (nº 012402/17) and was conducted in the Laboratory of Poultry Science of the Faculty of Agriculture and Veterinary Sciences, Jaboticabal, São Paulo, Brazil.

Animals and housing

Two trials were conducted. In both, Cobb 500 strain broilers were used (225 broilers x three phases in trial 1, and 400 in trial 2). In trial 1 the birds were housed in individual cages with each cage supplied with a metal feeder and one nipple drinker, whereas in trial 2 they were housed in floor pens, with 20 birds per pen, and with each pen containing one tube feeder and six nipples drinkers. All birds were given free and continuous access to feed and water. The temperature, humidity and ventilation in each experimental facility was controlled, with artificial heating used during the starter phase. The ambient temperature was gradually reduced from 32 to 21°C during the first 21 d of the trial and was then maintained at that temperature. Lighting was supplied for 12 h each day. A tray was placed underneath each trough so that feed spillage could be collected and measured.

Basal feed and diluents used

In trial 1*,* three basal feeds were formulated (Table 1), one for each phase (0–15 d, 16–30 d and 31–45 d, respectively) to provide adequate levels of all essential nutrients (Rostagno *et al.* 2011). Five bulky ingredients, with varying physical and chemical properties, were chosen as diluents: cellulose fibre (C), rice husk (R), sawdust (S), sand (SA) or vermiculite (V). The composition and the chemical analysis of the three basal feeds is given in the Table 1. Five dilution levels were used with each diluent, namely, 0, 2.5, 5.0, 10 and 15 %, hereafter referred to as proportions (0, 0.025, 0.05, 0.10 and 0.15).

Table 1. The composition and chemical analysis (g/kg, as is basis) of basal feeds used in the two trials

Ingredient	Trial 1 Starter (1-15 d)	 Grower (16 – 30 d)	 Finisher (31 – 45 d)	Trial 2 Starter (1 – 21 d)	 Finisher (22 – 43 d)
Corn	499	562	658	483	545
Soybean meal 45%	371	262	261	400	366
Soy Protein Concentrate	0.00	0.00	0.00	30.0	0.00
Gluten meal 60%	45.6	40.0	0.00	0.00	0.00
Soy oil	29.8	30.0	46.7	39.7	53.4
Peanut Bran	0.00	24.4	0.00	0.00	0.00
Hydrolysed feather meal	0.00	20.0	0.00	0.00	0.00
Dicalcium phosphate 22%	19.9	17.3	11.5	19.9	15.2
Limestone	11.1	10.4	7.88	9.80	8.30
Salt	3.91	4.00	4.61	2.70	1.50
TrypAMINO®	5.00	0.39	0.00	0.00	0.00
MetAMINO®	3.12	10.0	2.37	4.20	2.80
Biolys®	4.94	9.92	1.99	1.30	0.40
ThrAMINO®	1.17	1.95	1.36	5.40	5.00
ValAMINO®	0.12	0.07	0.62	0.00	0.00
Sodium bicarbonate	2.00	1.44	0.00	0.00	0.00
Potassium carbonate	0.00	1.00	0.00	0.00	0.00
BHT	0.50	0.50	0.50	0.00	0.00
Coxistac[3]	0.50	0.50	0.50	0.50	0.50
Choline chloride 60%	1.00	1.00	1.00	1.50	0.50
Premix Vitamin [1]	1.50	1.50	1.50	1.00	1.00
Premix mineral [2]	1.50	1.50	1.50	1.00	1.00
Nutrient composition (g/kg) calculated					
Crude Protein	253	243	195	245	212
Metabolisable energy (MJ/kg)	12.6	13.0	13.6	12.6	13.2
Digestible Lysine	13.2	12.2	11.3	14.3	11.5
Digestible Met+Cys	9.53	8.76	8.26	10.6	8.4
Digestible Methionine	6.56	5.94	5.55	7.36	5.63
Digestible Threonine	8.61	7.91	7.35	9.41	7.56

Digestible Tryptophan	2.40	2.30	1.90	2.82	2.41
Calcium	9.20	8.41	6.63	10.1	8.22
Phosphorus	4.70	4.01	3.54	4.82	3.84

[1] Amount/kg of diet: Mn = 150.000 mg. Fe = 100.000 mg. Zn = 100.000 mg. Cu= 16.000 mg. I = 1.500 mg. [2] Amount/kg of diet: Folic acid = 1000 mg. Pantothenic acid = 15.000 mg. Niacin = 40.000 mg. Biotin = 60 mg. vit B1 = 1.800 mg. vit. B12 = 12.000 mg. vit. B2 = 6.000 mg. vit. B6 = 2.800 mg. vit D3 = 2.000.000 UI. vit E = 15.000 mg. vit. K3 = 1.800 mg. Se = 300 mg. [3] Coxistac 12% with sodium salinomycin

In trial 2, two basal feeds were formulated on the same basis as before (Table 1), one for each phase (0–21 d and 22–43 d). In this case just one bulky ingredient, rice husk (R), was used at five dilutions: 0, 0.10, 0.20, 0.30 and 0.40.

The physical and chemical properties of feeds and the diluents, representing ‘bulkiness’, were measured. In the first trial analysis included dry matter (DM), crude protein (CP), neutral detergent fibre (NDF) and acid detergent fibre (ADF) (Van Soest 1963), ether extract (EE), ash (A) and crude fibre (CF), bulk density (BD) (Wang and Kinsella 1976), water-holding capacity by centrifugation (WHC) (Kyriazakis and Emmans, 1995), cation-exchange capacity (CEC) (Moorman, Moon, and Worthington 1983), oil holding capacity (OHC) (Caprez *et al.* 1986) and faecal organic matter (FOM), which reflected the indigestible organic matter content of each ingredient. In the second trial only WHC and crude fibre were used as measures of bulkiness.

All feeds were pelleted and then crumbled prior to their being fed. Broilers destined for the second and third phases were fed a high-quality basal feed until they had reached their respective starting ages.

Experimental design

Trial 1. Each of the 225 birds at one-day-old (Cobb 500), with uniform body weight, was assigned at random to one of the 25 treatments (five diluents x five levels of inclusion), there being nine replications of each treatment. The mean body weight of the group at the start of each phase was 46 ± 0.4 g, 581 ± 2.6 g, and 1690 ± 90 g, respectively.

Trial 2. For each phase, 400 Cobb 500 broiler chickens were housed in groups of 20 birds per pen, with each of the five treatments being replicated four times. The mean body weight of the group at one-day-old at the start of each phase was 46 ± 0.2 g and 816 ± 9.5 g, respectively.

Management

To avoid spillage by birds in trial 1, small amounts of feed were allocated to each bird from a weighed amount on six occasions each day whilst ensuring that feed was available at all times. Feed remaining in the trough was weighed back at the same time each morning, and any feed spilled into the tray below the feeder was measured at the same time. If either the feed in the trough or that spilled in the tray was wet this was oven-dried before being weighed. In trial 2 a tray was placed under each feeder to collect any feed spillage. All animals were weighed weekly in the morning.

Statistical analysis

In Trial 1 data were subjected to analysis of variance using RStudio© version 3.6.3 to calculate the mean food intake and body weight gain for each treatment. To evaluate which physical characteristic of the feed had the highest correlation with mean daily food intake scaled to metabolic body weight (scaled food intake, SFI, $g/BW^{0.67}$/day), multivariate exploratory techniques were used. In order to build a set of variables that were less numerous than the original but adequately summarised the information contained in the original variables, principal component analysis (PCA) was chosen to determine the variables that had the greatest influence on maximum SFI. The model to predict maximum bulk capacity was then developed making use of the most appropriate physical measurement of feed bulk and SFI.

To ascertain whether the broilers adapted to the different diluents over time, quadratic equations were fitted to SFI (g/kg body $weight^{0.67}$/day) over each of the three successive 5 d periods during each of the three phases of growth, to enable the calculation of the rate of dilution that maximised food intake. If the maximum intake in each succeeding 5 d period corresponded to a greater dilution of the basal feed, this indicated that the broilers were adapting to the given diluent. The same procedure was used in Trial 2, where three, 7 d periods were applied.

Quadratic equations were then fitted to the mean SFI for each phase, and the corresponding WHC of the feed at the rate of dilution that maximised SFI (SFI_{max}) was calculated for each diluent in each phase of the trial. These variables (SFI_{max} and the corresponding WHC) were multiplied together and then averaged to produce a constant that would enable the SFI_{max} to be calculated for any WHC. An appropriate equation was then derived that would predict SFI_{max} for any given WHC.

Results

The feed characteristics measured in the first trial negatively related to bulkiness were moisture and CP content, fat, and density (a unit weight of feed yields less volume as density increases). Those positively related to bulkiness were fibre content (CF, ADF and NDF) and WHC (Tables 1 and 2).

Table 2. The measured bulk characteristics of the basal feeds (B) and diluents used in the trials, including mean water-holding capacity (WHC), density (D), cation-exchange capacity (CEC), oil holding capacity (OHC), faecal organic matter (FOM), crude fibre (CF) , acid detergent fibre (ADF), neutral detergent fibre (NDF) and standard error of mean (SEM) of corresponding characteristic

Basal Feed, diluents and inert ingredients	WHC g/g	SEM	D g/ml	SEM	CEC meq/g	SEM	OHC g/g	SEM	CF %	SEM	FOM %	SEM	ADF %	SEM	NDF %	SEM
B: 1 – 15 d	2.43	0.60	0.72	0.03	29.0	0.84	0.87	0.2	2.56	0.2	18.6	1.2	3.14	0.22	17.8	0.28
B: 16 – 30 d	2.52	0.82	0.74	0.04	32.0	0.91	0.98	0.3	2.17	0.12	17.4	0.59	4.99	0.18	23.5	0.25
B: 31 – 45 d	2.38	0.41	0.72	0.13	30.0	0.93	0.98	0.3	2.18	0.01	15.8	0.34	3.12	0.02	18.9	1.02
Cellulose fibre	7.82	0.16	0.40	0.02	113	0.53	0.34	0.7	16.2	0.4	83.0	0.88	59.1	0.07	76.2	0.44
Sawdust	6.42	0.3	0.25	0.04	99.0	0.44	0.80	0.11	70.0	0.03	83.0	0.33	39.3	0.3	54.0	0.20
Rice Husk	2.30	0.13	0.30	0.04	70.0	0.34	0.65	0.20	40.0	0.3	83.0	0.41	58.5	0.02	79.5	0.05
Sand	2.80	0.3	1.45	0.03	$2x10^{-4}$	0.24	*	*	*	*	0.00	*	*	*	*	*
Vermiculite	8.28	0.08	0.15	0.06	$3x10^{-4}$	0.23	*	*	*	*	0.00	*	*	*	*	*

* Cannot be analyzed and calculated

The PCA identified Dimension 1 as explaining 59 % of the variation in SFI (Figure 1) and, within this dimension, 35 % of the variation was explained by WHC. As a result, WHC was chosen as the physical characteristic of the feed that best represented the bulkiness of the feed. Positively correlated variables (WHC and CEC) were grouped together, whilst negatively correlated variables (OHC and BD) were positioned on opposite sides of the plot origin. The distance between variables and the origin measured the quality of the variables on the factor map. Variables that were far from the origin are well represented on the factor map. Based on the above, WHC was chosen as the variable most likely to represent the bulkiness of a feed.

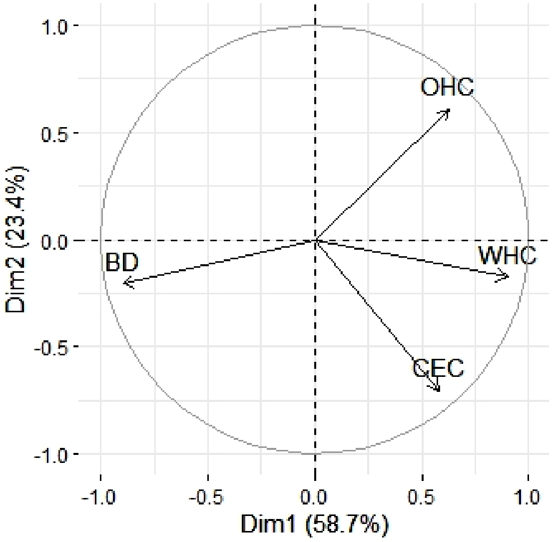

Figure 1. Variable correlation plots, where WHC is water holding capacity, CEC is cation exchange capacity, OHC is Oil holding capacity and BD is Bulk density.

Daily food intake increased with rate of dilution, reaching a peak and then decreasing as the dilution rate increased further (Table 3). In a few instances body-weight gain and feed conversion efficiency (FCE, g gain/kg feed consumed; Table 3) decreased as the basal feed was progressively diluted ($P<0.001$). These exceptions were all in the first phase, and included cellulose fibre, sawdust and vermiculite.

Table 3. Mean body weight gain, feed conversion efficiency (FCE), food intake and scaled food intake (SFI, g feed//kg BW$^{0.67}$/d) of broilers given access to a basal feed increasingly diluted with one of five diluents or inert ingredients, during three phases of growth. Trial 1.

		Rate of dilution (proportion)				
Phase		0.0	0.025	0.05	0.10	0.15
		Cellulose Fibre				
1 - 15d	Weight gain (g/d)	27.1	28.4	25.5	19.1	17.9
	FCE (g gain/kg intake)	912	942	936	719	706
	Food intake (g/d)	27.7	30.9	27.5	27.3	25.2
	SFI (g feed/kg$^{0.67}$/d)	83.4	90.9	91.4	83.4	75.2
16 – 30 d	Weight gain (g/d)	59.3	54.3	42.7	41.8	41.6
	FCE (g gain/kg intake)	764	679	649	555	531
	Food intake (g/d)	83.8	86.1	84.5	75.3	73.6
	SFI (g feed/kg$^{0.67}$/d)	138	142	162	136	113
31 – 45 d	Weight gain (g/d)	65.8	64.1	59.5	58.1	49.0
	FCE (g gain/kg intake)	376	345	341	289	206
	Food intake (g/d)	80.0	87.8	82.6	82.7	75.5
	SFI (g feed/kg$^{0.67}$/d)	125	127	139	124	123
		Sawdust				
1 – 15 d	Weight gain (g/d)	27.8	28.2	22.8	22.7	22.5
	FCE (g gain/kg intake)	917	861	836	777	670
	Food intake (g/d)	24.3	34.0	29.6	25.4	25.2
	SFI (g feed/kg$^{0.67}$/d)	86.0	97.7	95.9	79.0	71.1
16 – 30 d	Weight gain (g/d)	53.0	45.1	39.4	48.6	46.7
	FCE (g gain/kg intake)	718	666	616	598	573
	Food intake (g/d)	80.3	87.8	83.2	83.8	73.1

	SFI (g feed/kg$^{0.67}$/d)	141	154	162	132	117
31 – 45 d	Weight gain (g/d)	62.3	61.3	61.1	60.7	51.1
	FCE (g gain/kg intake)	319	285	308	277	251
	Food intake (g/d)	87.0	88.2	83.3	81.2	77.9
	SFI (g feed/kg$^{0.67}$/d)	126	130	144	129	122
			Rice Husk			
1 – 15 d	Weight gain (g/d)	25.9	25.1	24.5	23.9	22.3
	FCE (g gain/kg intake)	885	766	724	722	708
	Food intake (g/d)	29.5	32.9	31.7	30.7	24.9
	SFI (g feed/kg$^{0.67}$/d)	78.4	91.7	101	99.2	80.5
16 – 30 d	Weight gain (g/d)	54.9	54.1	53.7	51.2	47.8
	FCE (g gain/kg intake)	645	638	636	630	611
	Food intake (g/d)	91.9	95.3	94.7	87.3	87.0
	SFI (g feed/kg$^{0.67}$/d)	144	157	160	135	114
31 – 45 d	Weight gain (g/d)	75.8	63.8	63.1	62.2	57.0
	FCE (g gain/kg intake)	322	313	321	277	282
	Food intake (g/d)	85.1	88.1	84.7	83.9	80.9
	SFI (g feed/kg$^{0.67}$/d)	117	126	142	127	121
			Sand			
1 – 15 d	Weight gain (g/d)	28.0	27.6	25.8	25.5	25.4
	FCE (g gain/kg intake)	893	744	745	740	723
	Food intake (g/d)	32.1	37.2	34.8	33.5	31.2
	SFI (g feed/kg$^{0.67}$/d)	90.9	125	108	105	89.5
16 – 30 d	Weight gain (g/d)	53.1	44.7	44.9	43.8	37.1
	FCE (g gain/kg intake)	803	577	569	559	450
	Food intake (g/d)	73.3	91.3	91.2	84.6	84.1

	SFI (g feed/kg$^{0.67}$/d)	143	151	160	168	112
31 – 45 d	Weight gain (g/d)	63.3	61.1	60.5	59.4	55.4
	FCE (g gain/kg intake)	307	239	292	285	157
	Food intake (g/d)	86.6	89.5	91.8	87.3	86.8
	SFI (g feed/kg$^{0.67}$/d)	125	130	137	143	123
				Vermiculite		
1 – 15 d	Weight gain (g/d)	27.0	27.5	26.2	18.7	17.7
	FCE (g gain/kg intake)	808	820	770	635	633
	Food intake (g/d)	31.4	32.2	30.3	26.3	26.3
	SFI (g feed/kg$^{0.67}$/d)	79.5	91.9	97.1	99.6	79.6
16 – 30 d	Weight gain (g/d)	58.0	56.6	42.2	38.1	44.8
	FCE (g gain/kg intake)	776	697	519	512	533
	Food intake (g/d)	80.5	87.9	84.6	80.2	75.6
	SFI (g feed/kg$^{0.67}$/d)	147	154	169	201	94.9
31 – 45 d	Weight gain (g/d)	65.2	63.4	61.0	55.6	53.2
	FCE (g gain/kg intake)	334	320	282	276	267
	Food intake (g/d)	84.8	87.4	88.2	82.0	53.9
	SFI (g feed/kg$^{0.67}$/d)	124	125	135	147	128

Data in Table 4 addressed the issue of whether broilers adapted when exposed to different diluents over a period of time. The rates of dilution in each 5-d period corresponding to the highest food intake measured during that period were identified by fitting quadratic equations to the data. In only two cases, both involving sand as a diluent, was there any indication that the birds might have been capable of higher gut capacity with increasing exposure to the diluent.

Table 4. The rates of dilution (%) of feed, over three phases of growth and using five diluents, that maximised scaled food intake (g/kg body weight$^{0.67}$) over each of three successive five-day periods and over the entire 15 d period, together with the corresponding water holding capacity (WHC) of the feed that maximised food intake over 15 d. Trial 1.

		Phase	
Period	1 -15 d	16 – 30 d	31 – 45 d
		Rate of dilution (%)	
		Cellulose Fibre	
0 - 5 d	6.35	3.13	6.54
6 - 10 d	4.76	6.21	5.18
11 - 15 d	2.73	5.78	8.16
0 - 15 d	5.30	5.50	6.30
WHC[1]	2.72	2.82	2.73
		Sawdust	
0 - 5 d	2.74	6.40	5.53
6 - 10 d	4.46	2.90	7.25
11 - 15 d	*	3.71	4.57
0 - 15 d	7.59	4.21	7.55
WHC[1]	2.66	2.65	2.62
		Rice Husk	
0 - 5 d	8.52	6.43	6.05
6 - 10 d	6.71	4.58	7.39
11 - 15 d	8.41	3.96	7.07
0 - 15 d	6.44	6.48	7.72
WHC[1]	2.53	2.62	2.51
		Vermiculite	
0 - 5 d	7.72	7.19	7.68
6 - 10 d	7.19	5.96	8.76
11 - 15 d	7.39	6.89	6.53
0 - 15 d	3.74	4.56	6.57
WHC[1]	2.58	2.70	2.65
		Sand	
0 - 5 d	3.06	7.32	7.36

6 - 10 d	8.17	5.29	8.03
11 - 15 d	10.2	6.21	12.6
0 - 15 d	7.55	6.79	8.9
WHC[1]	2.89	2.93	2.92

[1] Water holding capacity of the feed that maximised food intake in each phase

* Maximum point cannot be calculated. Linear food intake behaviour

The mean rate of dilution over each 15-d period at which feed intake was maximised in each phase is shown in Table 4, together with the corresponding WHC of that feed mixture. These maxima were achieved, in general, when WHC was between 2.51 and 2.93 g water/g feed. Thus, based on the proximity observed between the estimated values for WHC, a parallelism analysis was performed in order to compare the coefficients generated for the equations, and to determine whether or not there would be significant differences between them. The hypothesis that all coefficients were equal was accepted ($P>0.458$). Consequently, only one equation was generated to explain the behaviour for the scaled food intake maxima.

The resultant polynomial equation, when WHC was regressed against the SFImax of all phases combined (Figure 2) was:

$$\text{SFImax } (\text{g/kg}^{0.67}\text{/d}) = 369 - 116 \cdot \text{WHC} + 12.0 \cdot \text{WHC}^2 \qquad \text{[Equation 1]}$$

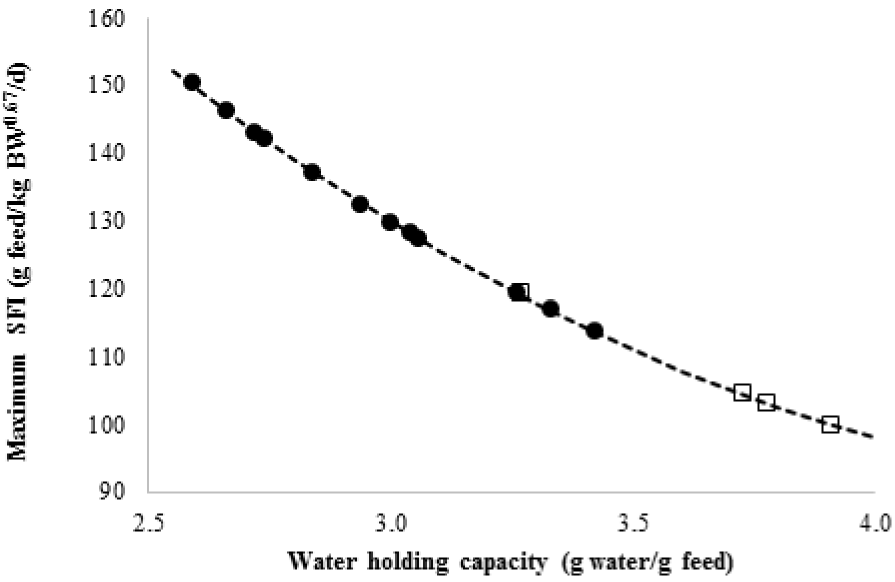

Figure 2. Maximum scaled feed intakes (SFImax, g/kg body weight0.67 /d) over the range of water- holding capacities (WHC, g water/g dry feed) of feeds used in Trials 1 (●) and 2 (□). SFImax (g/kg0.67 /d) = 369.4 – 115.7*WHC + 11.96*WHC^2. Confidence interval of 95%: 137 ≤ σ^2 ≤ 155

In the second trial, using just rice husks as a diluent, in both periods (0 – 21 and 22 – 43 d) both food intake and SFI increased as the feed was diluted to a maximum rate of dilution of 0.3 after which intake declined (Table 5). In both periods body weight gain was sustained only to a rate of dilution of 0.1 whereafter it declined, and FCE declined throughout the range of dilutions applied. The mean rate of dilution that maximised SFI, of 33 %, was the same for both periods, the corresponding WHC being 3.42 g/g (Table 6).

Table 5. Mean daily feed intake, body weight gain and feed conversion efficiency (FCE) of broiler chicken given access to a basal feed increasingly diluted with rice husk, during two phases of growth. Trial 2.

Rate of dilution (proportion)

	0.0	0.1	0.2	0.3	0.4
1 – 21 d					
Feed Intake (g/d)	48.7	52.7	55.7	65.3	57.1
Weight gain (g/d)	37.5	37.8	33.5	30.5	32.6
FCE (g gain/kg intake)	770	719	602	464	572
SFI (g feed/kg$^{0.67}$/d)	99.2	109	119	139	122
22 – 43 d					
Feed Intake (g/d)	148	156	165	201	173
Weight gain (g/d)	87.0	89.2	82.5	52.4	41.2
FCE (g gain/kg intake)	587	571	498	260	235
SFI (g feed/kg$^{0.67}$/d)	103	108	121	147	130

Table 6. The rates of dilution (%) of feed, over two phases of growth and using rice hulls as a diluent, that maximised scaled food intake (g/kg body weight$^{0.67}$) over each of three successive seven-day periods and over the entire 21 d period, together with the corresponding water holding capacity (WHC) of the feed that maximised food intake over 21 d. Trial 2.

Period	Phase	
	1 -21 d	22 – 43 d
	Rate of dilution (%)	
0 - 7 d	23.7	28.9
8 - 14 d	35.2	*
15 - 21 d	34.7	37.4
0 -21 d	31.9	33.5
WHC[1]	3.40	3.44

[1] Water holding capacity of the feed that maximised food intake in each phase

* Maximum point cannot be calculated. Linear food intake behaviour

Discussion

When predicting feed intake in broilers using the theory of Emmans (1987), there were at least two possible constraints preventing the bird from consuming its desired food intake, these being the inability to release sufficient heat to the environment and the bulkiness of the food being consumed. The current trial was designed to devise a method by which the bulkiness of the feed could be measured, such that the constraining effect of gut capacity on intake at different stages of growth could be predicted.

Mraz *et al.* (1957), Owen and Ridgman (1967) and Kyriazakis and Emmans (1995) demonstrated that, when a highly digestible feed was progressively diluted with one of greater ‘bulk’, feed intake increased initially at a rate such that the intake of essential nutrients and energy would remain roughly constant, with performance being unaffected. Beyond a certain point, intake of feed and performance would be reduced as the dilution proceeds further. The critical point has been assumed to reflect the capacity of the animal for consuming ‘bulk’. The effects of increasing bulky diluents on feed intake and performance from the current trial are shown in Tables 3 and 4. The increase in intake of bulky feeds in line with higher inclusion of the inert fillers confirmed previous theories (Emmans 1987; 1989) that birds increase feed intake to compensate for more indigestible material, in an attempt to acquire sufficient of the essential nutrients to achieve their growth potential.

Five bulky ingredients with varying physical and chemical properties were chosen as diluents (Table 2) to emulate the types of fibre and non-fibre sources likely to be encountered when formulating feed for broiler chickens. Not all fibre sources behave in the same way in the gastrointestinal tract: insoluble non-starch polysaccharides (NSP) such as cellulose and xylans behave like sponges, resulting in considerable bulking properties, whereas soluble NSP’s form gels and contribute to the viscosity of the contents of the gastrointestinal tract. The high retention of water that is observed between fibre and certain materials like silicates, can act as a limiting factor in various parts of the gastrointestinal tract (Bertin *et al.,* 1988).

To determine which of the physical or chemical properties of the various diluents most accurately defined gut capacity in broilers, use was made of PCA, a statistical procedure that converts a set of observations of correlated variables into a set of values of linearly uncorrelated variables called principal components (Pearson, 1901). The first principal component accounts for as much of the variability in the data as possible, and each succeeding component in turn has the highest variance possible whilst remaining orthogonal to the preceding components. The resulting vectors form an uncorrelated orthogonal basis set (Zee Ma, 2014). Whilst it is known that chemical components, such as ME, crude protein and crude fibre, influence food intake (Owen and Ridgman, 1967; Sibbald, 1975; Shelton *et al.*, 2005; Ndou *et al.*, 2013) PCA excluded them, as their content did not relate to the maximum intake measured by the broilers in this trial. Similarly, dry matter (Lehmann, 1941; Whittemore, 1995) and undigested organic matter (Roan 1991) have been suggested as being related to maximum feed intake, but these were additionally excluded by the PCA for the same reason.

Because of the high correlation between WHC and crude fibre (Figure 3), and because WHC has previously been shown to correlate well with bulk capacity (Kyriazakis and Emmans, 1995), crude fibre was excluded from the PCA in favour of WHC.

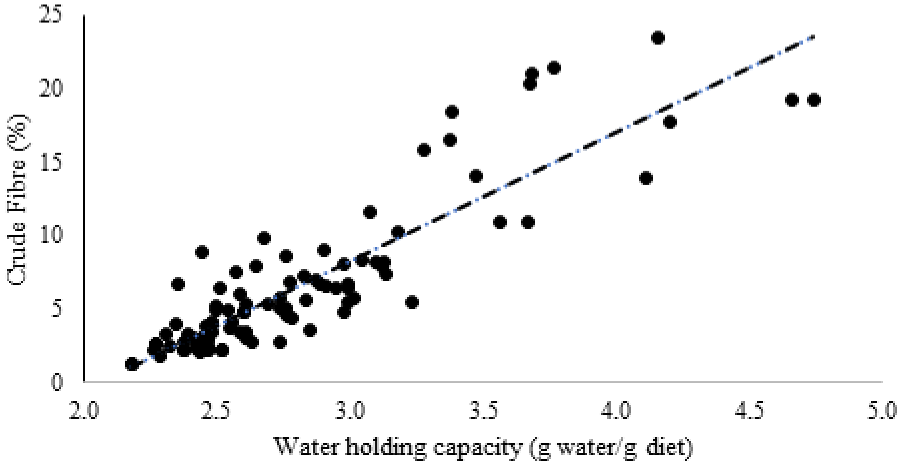

Figure 3. Correlation between dietary crude fibre content and water holding capacity. Pearson's correlation 0.89. Crude fibre = 8.77*WHC – 18.06 (R^2 0.78)

In previous studies Kyriazakis and Emmans, (1995), Tsaras *et al.* (1998) and Whittemore *et al.* (2003) reported that the maximum capacity for food bulk in pigs was directly proportional to body weight. However, Heusner (1982) suggested that the exponent 0.67 should be used when relating energy to mass, on the grounds that standard metabolic rate depends on the organism's surface to volume ratio, thus $BW^{0.67}$ describes the area of the body as a sphere. In Trial 1, the difference in maximum SFI in each of the three periods differed by approximately 60 g/g $BW^{1.0}$ but by less than half this amount when scaled to $BW^{0.67}$ (Schmidt-Nielsen, 1984). Maximum capacity for food bulk was, therefore, not proportional to body weight, but considerably more closely related to $BW^{0.67}$ and, as a result, this scalar was used in the prediction of bulk capacity.

Contrary to the report by Kyriazakis and Emmans (1995) with pigs, the broilers in these trials showed no adaptation to bulky feeds over time. In a previous study (Savory 1992) it was reported that the weight and volume of the whole intestine, and particular sections, tended to increase in animals fed bulky foods. It was assumed that these changes were the direct effect of adaptation to increased intestinal fill and the involvement of parts of the intestine in the digestion of fibres. In the present trial, the level of dilution resulting in maximum intake during each of the three consecutive 5 d periods in each phase remained the same for all diluents, other than sand. Had the birds adapted to the diluents, the level of dilution resulting in maximum intake would have increased as time progressed, but this occurred only with sand, and only in Phases 1 and 3. In these cases, the rate of dilution increased from 3 to 10% in Phase 1, and from 7.4 to 12.6% in Phase 3 (Table 4). Sand and rice husk have the lowest WHC of all the diluents used in the trial, but no adaptation to rice husk was evident, thus, some property other than WHC would appear to be involved in enabling broilers to adapt to a diluent, such as sand. In the experiments reported by Owen and Ridgman (1968) and Kyriazakis and Emmans (1995), where pigs adapted to bulky feeds, the authors used the food consumed during the previous 7 d of their experiment as the measure of gut capacity. However, in the current experiment, because no adaptation was evident, the mean intake over the 15-d period (and 21 d in Trial 2) was used.

By fitting polynomial regressions to the mean scaled feed intakes at each level of dilution, it was possible to determine the dilution rate that maximised SFI, and, from this, the corresponding WHC was calculated. It is interesting to note that the dilution level that maximised food intake was not the same as that which maximised SFI (Table 3). In most cases in Trial 1, the maximum feed intake occurred when the basal feed was diluted by 0.025, whereas maximum SFI occurred at higher dilutions than this, usually around 0.062. In Trial 2, the differences were not as evident, with the rate of dilution that maximised both food intake and SFI being close to 0.3.

These mean levels of dilution at which SFI was maximised, or bulk capacity realised, were considerably lower than that reported by Leeson *et al.* (1996), where finishing broilers (aged 35–49 d) doubled their intake of feed when this was diluted 1:1 with oat hulls and sand. The difference in the results between these trials is substantial. A large part of the difference was explained by the fact that the most diluted feed used by Leeson *et al.* (1996) had a WHC of 3.15 g/g, which was equivalent to the feeds in the present trials that were diluted by 0.22. This demonstrated the importance of using an appropriate measure of bulkiness in feed when determining the maximum intake of bulk by a broiler at different stages of growth.

Accuracy in estimating the maximum bulk capacity of a broiler has a considerable impact when optimising the nutrient density of feeds for broilers. Fisher *et al.* (1974) made the point that energy levels (i.e. nutrient density) should be defined in economic terms, such that, when formulating feeds for broilers, the nutrient density chosen should be that which optimises returns. In order to achieve this it is necessary to be able to predict the food intake and performance of broilers on feeds of different nutrient density, and a simulation program (EFG Software, 2019) is available that is capable of doing so. Given an optimum ratio between the essential amino acids and energy within each phase of the growing period, this program can optimise the nutrient density in each of the feeds in the programme by maximising the objective function over the entire growth period. As Fisher *et al.* (1974) have shown, optimum nutrient density depends on such factors as sex, the ratio between input and output costs, and mixing and transport costs. However, if the constraining effect of feed bulk is not accurately assessed, the predicted optimal nutrient density may be too low to enable the broilers to consume sufficient nutrients to grow as expected. Hence, the difference in the maximum levels of dilution that would enable broilers to grow to the same level as on the undiluted feed between that published by Leeson *et al.* (1996) and the present results, needs further investigation.

In the summary of papers dealing with nutrient density up to 1974, which were mainly conducted on slower-growing, egg-type genotypes, Fisher *et al.* (1974) calculated that feed intake would continue to increase linearly at low nutrient densities, and that the rate of increase could be calculated as 1.595 g/kJ ME. An increase in feed intake of 0.30 would, in this case, have resulted by halving the nutrient density.

There are no corroborating reports in the literature for broilers doubling intake when the basal feed is diluted by 0.5 with an inert diluent, as reported by Leeson *et al.* (1996). Pettersson and Razdan (1993) showed that an inclusion rate of 0.023 of sugar beet pulp in broiler feeds increased food intake and weight gain, but that these were reduced at dilution levels of 0.046 and 0.092. Similarly, Jiménez-Moreno *et al.* (2013) and Mateos *et al.* (2012) demonstrated that pea hulls, oat hulls and sugar beet pulp all improved performance when added to a basal feed at a rate of 0.025, but at levels higher than this (0.05 and 0.075) feed intake and growth rate were reduced. In a number of unreported studies in South Africa (Gous, personal communication) feed intake increased only marginally (0.05) when nutrient density, as measured by the energy content of the feed, decreased to 0.88 of the control. These reports supported the evidence from trial 1 reported here, where feed intake was higher in birds (compared to those fed the basal feed) in only two instances (sawdust in phase 1 and sand in phase 2) when the feed was diluted to 0.8 of the control. However, the results of trial 2 suggested that broilers are capable of compensating for dilution of up to 0.3 by consuming an additional 0.35 of feed, with the maximum SFI conforming to the same relationship with WHC, as found in trial 1. However, instead of remaining the same as for the undiluted feed groups, growth rate on the 0.3 diluted feed decreased by 20% and 40% in the two phases of the trial (Table 5), so the birds could not be regarded as having compensated for feed dilution. Attaining weight gains similar to that seen for broilers on the undiluted feed was achieved only in birds fed the 0.10 dilution, which related more closely to the results of the first trial.

Table 5. Mean daily feed intake, body weight gain and feed conversion efficiency (FCE) of broiler chicken given access to a basal feed increasingly diluted with rice husk, during two phases of growth. Trial 2.

	Rate of dilution (proportion)				
	0.0	0.1	0.2	0.3	0.4
1 – 21 d					
Feed Intake (g/d)	48.7	52.7	55.7	65.3	57.1
Weight gain (g/d)	37.5	37.8	33.5	30.5	32.6
FCE (g gain/kg intake)	770	719	602	464	572
SFI (g feed/kg$^{0.67}$/d)	99.2	109	119	139	122
22 – 43 d					
Feed Intake (g/d)	148	156	165	201	173
Weight gain (g/d)	87.0	89.2	82.5	52.4	41.2
FCE (g gain/kg intake)	587	571	498	260	235
SFI (g feed/kg$^{0.67}$/d)	103	108	121	147	130

The results suggested that the gut capacity of modern broiler genotypes may be only marginally extended when the nutrient density of a given feed is diluted. Depending on the WHC of the diluent used, scaled feed intake will be maximised at a rate of dilution of 0.15 to 0.20, a maximum occurring when WHC is around 2.6 g/g.

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References

Bertin, Chantal, Xavier Rouau, and Jean-François Thibault. 1988. “Structure and Properties of Sugar Beet Fibres.” *Journal of the Science of Food and Agriculture* 44 (1): 15–29. https://doi.org/10.1002/jsfa.2740440104.

Caprez, Andrea, Eva Arrigoni, Renato Amadò, and Hans Neukom. 1986. “Influence of Different Types of Thermal Treatment on the Chemical Composition and Physical Properties of Wheat Bran.” *Journal of Cereal Science* 4 (3): 233–39. https://doi.org/10.1016/S0733-5210(86)80025-X.

EFG Software. 2019. “EFG Software.” http://www.efgsoftware.net/.

Emmans, G. C. 1987. “Growth, Body Composition and Feed Intake.” *World’s Poultry Science Journal* 43 (3): 208–27. https://doi.org/10.1079/WPS19870014.

Emmans, G.C. 1989. “The Growth of Turkeys.” *Recent Advances in Turkey Science*. http://ci.nii.ac.jp/naid/10018625017/en/.

Fisher, C., Wilson, B. J., Morris, T. R., and Freeman, B. M. (1974). Energy requirements of poultry. *Energy Requirements of Poultry. British Poultry Science Ltd, Edinburgh, UK*, 151-184.

Heusner, A. A. 1982. “Energy Metabolism and Body Size II. Dimensional Analysis and Energetic Non-Similarity.” *Respiration Physiology* 48 (1): 13–25. https://doi.org/10.1016/0034-5687(82)90047-0.

Jiménez-Moreno, E., M. Frikha, A. De Coca-Sinova, R. P. Lázaro, and G. G. Mateos. 2013. “Oat Hulls and Sugar Beet Pulp in Diets for Broilers. 2. Effects on the Development of the Gastrointestinal Tract and on the Structure of the Jejunal Mucosa.” *Animal Feed Science and Technology* 182 (1–4): 44–52. https://doi.org/10.1016/j.anifeedsci.2013.03.012.

Kyriazakis, I, and G C Emmans. 1995. “The Voluntary Feed Intake of Pigs given Feeds Based on Wheat Bran, Dried Citrus Pulp and Grass Meal, in Relation to Measurements of Feed Bulk.” *The British Journal of Nutrition* 73 (2): 191–207. https://doi.org/10.1079/BJN19950023.

Leeson, S., L. Caston, and J. D. Summers. 1996. “Broiler Response to Energy or

Energy and Protein Dilution in the Finisher Diet.” *Poultry Science* 75 (4): 522–28. https://doi.org/10.3382/ps.0750522.

Lehmann, F. (1941). Die Lehre von Ballast (The lesson of ballast). Zeitschrvr fir Tierernahrung und Futtermittelkunde 5, 15S173.

Mateos, G.G., E. Jiménez-Moreno, M.P. Serrano, and R.P. Lázaro. 2012. “Poultry Response to High Levels of Dietary Fiber Sources Varying in Physical and Chemical Characteristics.” *Journal of Applied Poultry Research* 21 (1): 156–74. https://doi.org/10.3382/japr.2011-00477.

Moorman, W. F. B., NANCY J. Moon, and R. E. Worthington. 1983. “Physical Properties of Dietary Fiber and Binding of Mutagens.” *Journal of Food Science* 48 (3): 1010–11. https://doi.org/10.1111/j.1365-2621.1983.tb14959.x.

Mraz, F.R., R.v. Boucher and M.G. McCartney. 1956. The influence of dietary productive energy and fibre on growth response in chickens. Poultry Science 35 (6): 1335-40. https://doi.org/10.3382/ps.0351335

Mraz, F. R., R. V. Boucher, and M. G. McCartney. 1957. “The Influence of the Energy: Volume Ratio on Growth Response in Chickens.” *Poultry Science* 36 (6): 1217–21. https://doi.org/10.3382/ps.0361217.

Ndou, S. P., R. M. Gous, and M. Chimonyo. 2013. “Prediction of Scaled Feed Intake in Weaner Pigs Using Physico-Chemical Properties of Fibrous Feeds.” *British Journal of Nutrition* 110 (4): 774–80. https://doi.org/10.1017/S0007114512005624.

Owen, J. B., and W. J. Ridgman. 1967. “The Effect of Dietary Energy Content on the Voluntary Intake of Pigs.” *Animal Production* 9 (01): 107–13. https://doi.org/10.1017/S0003356100038320.

———. 1968. “Further Studies of the Effect of Dietary Energy Content on the Voluntary Intake of Pigs.” *Animal Production* 10 (01): 85–91. https://doi.org/10.1017/S0003356100025976.

Pearson K. 1901. “Pearson, K. 1901. On Lines and Planes of Closest Fit to Systems of Points in Space.” *Philosophical Magazine* 2: 559–72.

Pettersson, D., and A. Razdan. 1993. “Effects of Increasing Levels of Sugar-Beet Pulp in Broiler Chicken Diets on Nutrient Digestion and Serum Lipids.” *British Journal of Nutrition* 70 (1): 127–37. https://doi.org/10.1079/bjn19930110.

Roan, Shii-wen. 1991. “Bio-Economic Models for the Simulation of the Production and Management of the Growing Pigs and Sows By.”

Rostagno, Horacio, L F T Albino, Juarez Donzele, P C Gomes, R F DE Oliveira, D C Lopes, A S Ferreira, S L DE Toledo Barreto, and R F Euclides. 2011. *Tabelas Brasileiras Para Aves e Suínos: Composição de Alimentos e Exigências Nutricionais*. *Composição de Alimentos e Exigências Nutricionais*.

Savory, C. J. 1992. “Gastrointestinal Morphology and Absorption of Monosaccharides in Fowls Conditioned to Different Types and Levels of Dietary Fibre.” *British Journal of Nutrition* 67 (1): 77–89. https://doi.org/10.1079/bjn19920010.

Schmidt-Nielsen, Knut. 1984. *Scaling, Why Is Animal Size so Important?* Cambridge University Press. https://books.google.com.br/books?hl=pt-BRandlr=andid=8WkjD3L_avQCandoi=fndandpg=PR11anddq=animals+scale+laws++allometric+andots=oTg8dphPUKandsig=1DcFm3NdxGXYjnAku9xc1ThoNME#v=onepageandqandf=true.

Shelton, J. L., D. W. Dean, L. L. Southern, and T. D. Bidner. 2005. “Effect of Protein and Energy Sources and Bulk Density of Diets on Growth Performance of Chicks.” *Poultry Science* 84 (10): 1547–54. https://doi.org/10.1093/ps/84.10.1547.

Sibbald, I. R. 1975. “The Effect of Level of Feed Intake on Metabolizable Energy Values Measured with Adult Roosters.” *Poultry Science* 54 (6): 1990–97. https://doi.org/10.3382/ps.0541990.

Tsaras, L. N., I. Kyriazakis, and G. C. Emmans. 1998. “The Prediction of the Voluntary Food Intake of Pigs on Poor Quality Foods.” *Animal Science* 66 (3): 713–23. https://doi.org/10.1017/S1357729800009292.

Van Soest, Peter J Van. 1963. “Collaborative Study of Acid-Detergent Fiber and Lignin.”

Wang, J. C., and J. E. Kinsella. 1976. “FUNCTIONAL PROPERTIES OF NOVEL PROTEINS: ALFALFA LEAF PROTEIN.” *Journal of Food Science* 41 (2): 286–92.

https://doi.org/10.1111/j.1365-2621.1976.tb00602.x.

Whittemore, Colin T. 1995. "Modelling the Requirement of the Young Growing Pig for Dietary Protein." *Agricultural Systems* 47 (4): 415–25. https://doi.org/10.1016/0308-521X(95)92107-H.

Whittemore, E. C., I. Kyriazakis, G.C. Emmans, and B.J. Tolkamp. 2001. "Tests of Two Theories of Food Intake Using Growing Pigs 1. The Effect of Ambient Temperature on the Intake of Foods of Differing Bulk Content." *Animal Science* 72 (2): 351–60. https://doi.org/10.1017/s1357729800055855.

Whittemore, E.C., G. C. Emmans, and I. Kyriazakis. 2003. "The Relationship between Live Weight and the Intake of Bulky Foods in Pigs." *Animal Science* 76 (01): 89–100. https://doi.org/10.1017/S1357729800053352.

Zee Ma, Y. 2014. "Appendix_Tutorial on PCA." *Technical Report*, no. February 2014. https://doi.org/10.13140/2.1.1593.1684.

CAPÍTULO 3 - Bulk capacity of broiler breeder hens

Abstract - Two trials were conducted to measure the bulk capacity of broiler breeders just prior to the onset of lay and in the laying phase. Birds were given *ad libitum* access to one of 20 feeds that were made by progressively diluting (0.10, 0.20, 0.30, 0.40) a high-quality basal feed, formulated to meet the requirement for all essential nutrients, with one of five diluents, namely, cellulose fibre, rice husk, sand, vermiculite and sawdust. The undiluted basal feed was also included in the design. Each feed treatment was randomly assigned to nine individually-caged breeders of *Ross®* strain, totalling 189 birds per trial. Physical analyses were performed on each diluent and feed, including density, crude-, acid detergent- and neutral detergent-fibre content, water-holding capacity (WHC), cation-exchange capacity, and oil holding capacity. In most cases feed intake increased and then declined as the proportion of each diluent in the mixture was increased. Intake increased linearly when rice hulls and sand were used as diluents. Feed intake, scaled to body weight$^{0.67}$, was used as the response variable to minimize the effect of body weight between birds. It was concluded that WHC is the most appropriate measure of feed bulk to be used to define the gut capacity of broiler breeders. Maximum scaled feed intake (SFI_{max}) in broiler breeders can be estimated as $240 – 56.1WHC + 4.34WHC^2$ g/kg$^{0.67}$ /d.

Keywords: bulk capacity, diluted feed, gastrointestinal tract, physical characteristics, voluntary feed intake

Introduction

When broiler breeders are fed *ad libitum* they become obese and suffer a high incidence of lameness, thermal discomfort, high mortality due to skeletal disorders and heart failure (Katanbaf et al., 1989; Sandilands et al., 2006), and reduced disease resistance (Han and Smyth 1972; Hocking et al., 1996). The production of hatching eggs is reduced due in part to an increased incidence of multiple ovulations in females (Hocking et al., 1987; Waddington et al., 1989), poor egg shell quality (Robinson et al., 1993) and reduced fertility in males (Hocking and Duff 1989). For these reasons the daily ration of food allocated to commercial broiler breeders is restricted throughout the life of the bird, and this is achieved in most instances using quantitative feed restriction practices. Qualitative restriction has also been used (Enting et al., 2007; Lee et al., 1971; Tolkamp et al., 2005) but with less success than with quantitative restriction. The principle on which qualitative restriction works in reducing food intake is that with the addition of high levels of low-density raw materials into the feed, the gut capacity of the broiler breeder would be reached and intake would thereby be restricted. The rate at which feed has to be diluted with inert or low-nutrient ingredients to achieve a desired rate of feed restriction depends on the bulkiness of the raw materials used, and although research has been conducted to measure the gut capacity of pigs (Kyriazakis and Emmans 1995; Tsaras et al., 1998a,b; Whittemore et al., 2001) and broilers (Nascimento et al., 2020) no such research has been conducted with broiler breeders.

Field experiments suggest that when low ME diets are fed in the rearing period flock uniformity is improved, reproductive tract development is delayed and early egg size is increased. However, because of the increased intake of feed on such diets, the cost of feeding is usually prohibitively high (Lee et al., 1971). Low density breeder diets during lay showed an increase in egg and day-old chick weight, an improvement in offspring growth rate and a reduction in progeny mortality (Enting et al., 2007). To ensure that voluntary food intake is restricted with the use of low-density fillers it would be useful to be able to predict the gut capacity of breeders at different stages of growth and during lay such that an appropriate dilution rate is maintained. It is also of importance to ascertain whether breeders adapt to these low-density diets, which would necessitate having to increase the rate of dilution to maintain the same level of restricted growth. There is merit therefore in being able to predict the gut capacity of broiler breeders during growth and reproduction.

The mechanism by which low density diets reduce growth rate is that as the nutrient density of a feed is reduced (or bulkiness increased) or the environmental temperature decreased, the bird will attempt to consume more of this feed to meet its nutrient requirements for potential growth (Mraz et al., 1956; 1957; Emmans 1981; Tsaras et al., 1998b). If the environmental temperature is not limiting, food intake will reach a maximum when the physiological limit of gut capacity has been reached. If nutrient density is reduced further, food intake will be insufficient to meet the requirement for growth or reproductive performance which will decline in relation to potential. The most successful measure of gut capacity has been the water-holding capacity (WHC) of the feed (Kyriazakis and Emmans 1995; Tsaras et al., 1998b; Whittemore et al., 2001; Nascimento et al., 2020).

The advantages of using low density diets in the laying period are not necessarily due to their ability to restrict food intake. Because the daily amount of food allocated to breeders in lay is restricted quantitatively, it is possible to meet the daily amino acid and energy requirements of the hens by feeding small amounts of a high density feed or larger amounts of a low density feed, the decision of which course of action to follow being based on the relative costs of the raw materials available. When low density ingredients are available at a relatively low cost there would be an advantage in feeding relatively more of a low nutrient density feed, this having the added benefit of, amongst others, improving uniformity in the flock, as mentioned above (Enting et al., 2007). However, if nutrient density is reduced beyond a critical point, breeders would be unable to consume sufficient of the feed and egg production would be compromised, so it is of value to be able to predict the nutrient density at which the expected feed intake would be constrained by gut capacity. This would differ depending on the physical properties of the raw materials used in the formulation, thus a general equation that makes use of a reliable measure of bulkiness is needed to predict when the expected feed intake would be constrained by gut capacity.

A model that predicts the food intake required by broiler breeders to meet their amino acid and energy requirements for potential egg output was developed by Gous and Nonis (2010) and the other one by Sakomura et al. (2019), both being based on the theory of food intake regulation by Emmans (1981) and the egg production model of Johnston and Gous (2006). This model considers the genetic potential egg output and body composition of the bird, the nutrient composition of the feed, the environmental temperature, and lipid deposition and utilisation (Nonis and Gous 2012). The potential constraints of high temperature and gut capacity were not considered in the model as no data are available that enable these constraints to be modelled. Consequently, the actual food intake by breeders under different circumstances cannot be predicted by this model.

Thus, the objectives of this trial were to measure the gut capacity of broiler breeder females prior to, and during lay; to confirm our previous findings (Nascimento et al., 2020) that the water-holding capacity (WHC) of a feed best describes the relationship between feed bulk and intake; and to produce an equation to predict gastrointestinal capacity of a broiler breeder using this measure of feed bulk.

Material and methods

All the animal care procedures were approved by the institutional Animal Care and Use Committee of the Faculty of Agriculture and Veterinary Sciences, UNESP, Jaboticabal, São Paulo, Brazil (nº 012402/17).

Birds, husbandry and experimental design

Four hundred Ross 308 breeder pullets, obtained from a local commercial facility at 15 weeks of age (body weight 1.80 ± 0.20 kg), were housed individually in cages with raised wire floors each equipped with a feeder and nipple drinker. The research facility was environmentally controlled which allowed the temperature, humidity and lighting recommendations in the Ross 308 Parent Stock Management Manual (2018) to be implemented.

Two trials were conducted on these birds, the first commencing at 20 weeks, prior to the onset of laying, and the second at 32 weeks after the commencement of lay. Different birds were used in the two trials. At the start of each of the two phases, 189 breeder pullets were weighed and assigned to individual cages to which 21 treatments were randomly assigned, with nine replicates per treatment. In the first phase the average initial body weight was 2.59 ± 0.20 kg, and in the second, 2.62 ± 0.27 kg. From 15 to 20 weeks all birds were fed restricted amounts of feed daily according to the Ross 308 guidelines. Broiler breeders destined for the second trial were fed restricted amounts of feed daily for a further 12 weeks. During each experimental period water and feed was provided *ad libitum.* The lighting programme was set at 8 L: 16 D in the first assay but this was changed to 16L: 8D for the second period.

Experimental feeds and diluents

A basal feed (mash form) was formulated for each phase (Table 1) which was fed alone or diluted with one of five diluents (cellulose fibre, rice husk, sand, vermiculite and sawdust) at four inclusion levels (0.10, 0.20, 0.30 and 0.40) making up the 21 experimental feeds. The basals were formulated to meet or exceed nutritional recommendations described by the strain guidelines (Ross 308 Parent Stock Management Manual, 2018).

Table 1. Composition and chemical analysis (g/kg) of the two basal diets used in the experiment

Ingredients	**Rearing**	**Egg-laying**
Corn	640	585
Soybean meal (450 g/kg)	216	193
Wheat bran	80.0	65.0
Hydrolysed feather meal	0.00	11.8
Gluten meal (600 g/kg)	0.00	3.00
Soy oil	9.70	27.7
Dicalcium phosphate (220 g/kg)	24.5	19.1
Limestone	21.8	85.7
Salt	4.32	4.61
MetAMINO®	0.80	1.41
Biolys®	0.00	0.40
Potassium chloride	0.00	1.20
BHT	0.10	0.10
Choline chloride (600 g/kg)	0.80	0.80
Premix Vitamin [1]	1.00	1.00
Premix mineral [2]	1.00	1.00
Nutritional composition (g/kg) calculated		
Crude Protein[3]	170	160
Metabolizable energy (MJ/kg)	12.1	11.9
Digestible Lysine	7.09	6.60
Digestible Met + Cys	5.38	5.60
Digestible Methionine	3.06	3.50
Calcium	14.9	30.0
Available Phosphorus	4.50	0.45

[1] Content/kg of product: folic acid 2.4 mg; pantothenic acid 30 g; biotin 160 mg; butylated hydroxytoluene 100 mg; niacin 84 g; selenium 6.0 g; β carotene 12 g; Vit B1 5.0 g; Vit B2 1.30 g; pantothenic acid 7.0 g; Vit B12 36 mg; cholecalciferol 125 g; α tocopherol 25 g; Vit K3 4.0 g

[2] Content/kg diet: Mn 150 g; Zn 140 g; Fe 90 g; Cu 15 g; I 15 mg.

[3] Analyzed crude protein: 170 g/kg for rearing feed and 162 g/kg for egg-laying feed; Analyzed ether extract: 22.6 g/kg for rearing feed and 54.0 g/kg for egg-laying feed.

Chemical composition and bulk characteristics of the 21 feeds used in each assay were performed in the Animal Nutrition Laboratory at the Faculty of Agriculture and Veterinary Sciences, Jaboticabal, São Paulo, Brazil. Chemical analysis of feeds and diluents were performed according to AOAC (2005) procedures. Samples were ground in an analytical mill (IKA A11) and analyzed for nitrogen (Foss Kjeltec8400, method 2001.11), ash (method 942.05), ether extract (method 920.39), and moisture (method 920.39). Protein content was calculated by multiplying the nitrogen content by 6.25. Fat was determined by Ankom XT15 Ex-tractor (ANKOM Technology, Macedon, NY) using petroleum ether as solvent. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) contents were determined using ANKOM Fibre Analyser (Ankom, Macedon, NY, USA), according to Van Soest et al. (1991) and Van Soest (1963), respectively. Neutral detergent fibre was determined using heat stable α-amylase (Sigma A3306; Sigma Chemical Co., St. Louis, MO, USA). The analyses to determine bulkiness of the diets were density (D; Wang and Kinsella 1976), water-holding capacity (WHC; Kyriazakis and Emmans 1995), cation-exchange capacity (CEC; Moorman et al., 1983), and oil holding capacity (OHC; Caprez et al., 1986).

Management and performance measurements

Each experimental assay lasted 30 days during which feed intake was determined daily and all birds were weighed at 5-d intervals. In order to avoid feed spillage, feed was allocated to each bird six times a day. Spilled feed was collected daily, dried, weighed and discarded. For data analysis, each assay was divided into six periods of five days each (Owen and Ridgman 1968; Kyriazakis and Emmans 1995).

Statistical analysis

The response variables evaluated were feed intake, body weight gain and egg output. The statistical assumptions were checked for normality and heteroscedasticity, then each response variable was submitted to analysis of variance with 5% of probability using RStudio© to calculate the means for each treatment.

Before determining the maximum intake on each diluent it was necessary to determine whether feed intake increased with each succeeding 5-d period to ascertain whether the birds had demonstrated an inclination to adapt to the bulky feeds. The decision to split each phase into shorter periods (5 d) was based on experiments reported by Owen and Ridgman (1968) and Kyriazakis and Emmans (1995) indicating that pigs required about 7 d to adapt to bulky feeds. For each diluent, and for each level of inclusion of the diluent, linear or quadratic equations were fitted to the scaled feed intakes (SFI, g/kg $BW^{0.67}$ /d) measured during each of the six successive 5-d periods to identify trends over time. In the absence of any trend the mean SFI over all six periods would be used as the measure of feed intake for that diluent at the given dilution rate.

A linear or quadratic regression was then fitted to define the point of maximum SFI for each diluent. The most appropriate physical measurement of feed bulk was then determined (the physical property that had the highest correlation with SFI) with the use of Principle Component Analysis (PCA). An equation was then developed that would predict the maximum SFI for any given value of the appropriate physical property of a feed.

A parallelism test was applied to test coefficients of equations, the hypothesis being that all coefficients were equal between the pre-laying and laying phases.

Results

Feed characteristics

The chemical and physical properties of the basal feeds and diluents offered in the trials are given in Tables 1 and 2. Moisture, lipid and CP content, CEC, OHC and density were negatively related to bulkiness, whereas fibre content (CF, ADF and NDF) and WHC were positively related.

Table 2. The measured bulk characteristics of the basal feeds (B) and diluents used in the trials, including mean water-holding capacity (WHC), density (D), cation-exchange capacity (CEC), oil holding capacity (OHC), crude fibre (CF) , acid detergent fibre (ADF), neutral detergent fibre (NDF) and standard error of mean (SEM) of corresponding characteristic

Diluent	WHC	SEM	D	SEM	CEC	SEM	OHC	SEM	CF	SEM	ADF	SEM	NDF	SEM
	g/g		g/ml		meq/g diet		g oil/g feed		g/kg		g/kg		g/kg	
B – Pre-laying phase	2.60	0.74	0.80	0.07	0.033	0.91	0.91	0.33	41.3	0.22	51.0	0.31	149	0.18
B – Laying phase	2.47	0.62	0.87	0.05	0.032	0.67	0.97	0.28	26.7	0.26	424	0.24	503	0.14
Cellulose Fibre	7.95	0.16	0.40	0.02	0.113	0.53	0.34	0.7	162	0.4	591	0.07	762	0.44
Sawdust	6.50	0.3	0.25	0.04	0.099	0.44	0.80	0.11	700	0.03	393	0.3	540	0.20
Rice Husk	5.50	0.13	0.30	0.04	0.070	0.34	0.65	0.20	400	0.3	585	0.02	795	0.05
Sand	4.00	0.3	1.45	0.03	2x10^{-4}	0.24	*	*	*	*	*	*	*	*
Vermiculite	8.50	0.08	0.15	0.06	3x10^{-4}	0.23	*	*	*	*	*	*	*	*

* Cannot be analyzed and calculated

According to the results of the PCA, dimension 1 explained 0.59 of the variation in SFI (Fig. 1) and within this dimension 0.40 of the variation was explained by WHC, which was used thereafter as the most reliable physical measure of feed bulk.

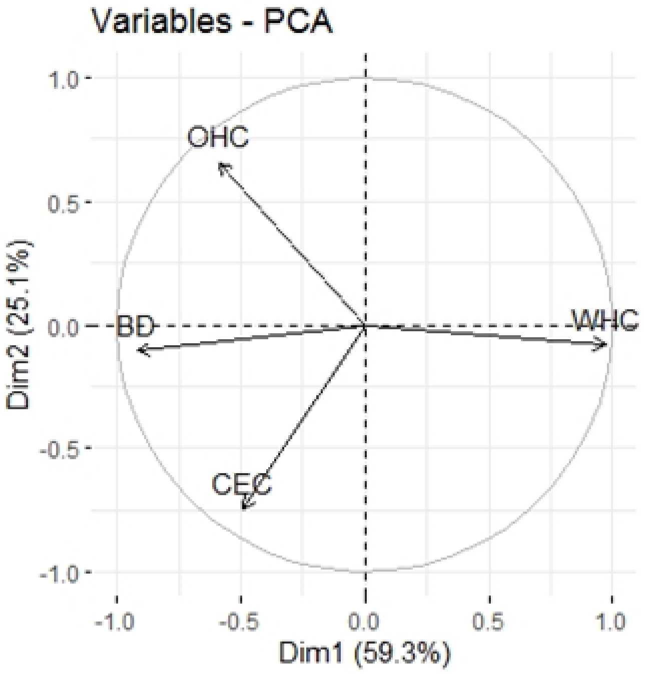

Figure 1. Variable correlation plots, where WHC is water holding capacity, CEC is cation exchange capacity, OHC is oil holding capacity and BD is bulk density

Response over time

When the mean SFI for each of the six five-day periods was regressed against time, for each level of inclusion of each diluent, the slope was in all cases zero, i.e. there was no change in SFI to indicate that the birds were adapting to the bulky feed. The mean over the six five-day periods was used therefore to calculate the mean SFI for each rate of dilution of each diluent.

Responses to diluents

Mean daily feed intakes, SFI and either mean daily body weight gain (pre-laying phase) or egg output (laying phase) for the five dilutions of each diluent are given in Table 3. In the rearing phase the response in feed intake to an increase in the rate of dilution was linear in all cases, increasing when sand was used as the diluent and decreasing linearly with cellulose fibre, rice husk, vermiculite and sawdust. Similarly, SFI decreased linearly with increasing cellulose fibre dilution, and increased with rice husk and sand. Only in the case of vermiculite and sawdust was there an increase in SFI followed by a decline as the rate of dilution was increased, the breakpoint being reached at a SFI of 91.9

and 94.5 g feed/kg$^{0.67}$/d, respectively. In all cases, body weight gain decreased with the rate of dilution.

Table 3. Scaled feed intake, body weight gain and egg output of broilers breeders given access to either a basal or a diluted feed in rearing and laying phases

Feed	**0.0**	**0.10**	**0.20**	**0.30**	**0.40**
Pre-laying phase					
Celulose Fibre					
Feed intake (g/d)	355	331	278	257	232
Scaled feed intake (g feed/kg$^{0.67}$/d)	90.9	87.0	80.0	80.0	70.6
Body weight gain (g/d)	59.2	47.7	32.7	22.6	13.8
Rice Husk					
Feed intake (g/d)	355	352	355	343	331
Scaled feed intake (g feed/kg$^{0.67}$/d)	90.9	97.3	102	103	108
Body weight gain (g/d)	59.2	50.6	48.8	45.8	29.7
Sand					
Feed intake (g/d)	355	380	397	403	464
Scaled feed intake (g feed/kg$^{0.67}$/d)	90.9	102	115	118	143
Body weight gain (g/d)	59.2	53.8	49.7	49.4	48.3
Vermiculite					
Feed intake (g/d)	355	334	306	270	209
Scaled feed intake (g feed/kg$^{0.67}$/d)	90.9	91.9	88.7	83.9	70.1
Body weight gain (g/d)	59.2	48.2	37.4	21.5	0.7
Sawdust					
Feed intake (g/d)	355	340	309	261	232
Scaled feed intake (g feed/kg$^{0.67}$/d)	90.9	94.5	90.5	82.5	74.7
Body weight gain (g/d)	59.2	51.5	39.5	22.5	12.0
Laying phase					
Celulose Fibre					

Feed intake (g/d)	198	195	180	163	137
Scaled feed intake (g feed/kg$^{0.67}$/d)	73.5	75.6	74.3	69.8	57.4
Egg output (g/d)	51.2	53.7	54.0	47.9	30.1
Rice Husk					
Feed intake (g/d)	198	203	219	240	240
Scaled feed intake (g feed/kg$^{0.67}$/d)	73.5	75.5	83.1	94.1	95.5
Egg output (g/d)	51.2	52.6	50.2	50.8	51.9
Sand					
Feed intake (g/d)	198	240	248	282	304
Scaled feed intake (g feed/kg$^{0.67}$/d)	73.5	86.0	90.2	103	111
Egg output (g/d)	51.2	54.9	53.6	51.6	55.1
Vermiculite					
Feed intake (g/d)	198	218	200	175	155
Scaled feed intake (g feed/kg$^{0.67}$/d)	73.5	83.5	81.8	76.5	68.1
Egg output (g/d)	51.2	49.8	53.5	50.0	41.0
Sawdust					
Feed intake (g/d)	198	206	195	188	171
Scaled feed intake (g feed/kg$^{0.67}$/d)	73.5	77.8	77.3	78.3	72.8
Egg output (g/d)	51.2	46.7	45.6	50.5	46.3

In the laying phase, only vermiculite and sawdust resulted in a curvilinear response in feed intake, with cellulose fibre causing a linear decrease, and rice husk and sand a linear increase in both feed intake and SFI. Cellulose fibre, vermiculite and sawdust produced a curvilinear response to SFI, with the maximum being 75.5, 83.5 and 78.3 g feed/kg$^{0.67}$/d, respectively (Table 3).

Egg output was maintained in most cases on all but the highest dilutions, with decreases evident when cellulose, vermiculite and sawdust were included at a dilution rate of 0.4. Sawdust as a diluent resulted in poorer performance throughout the range of dilutions used (Table 3).

Maximum SFI and WHC

The maximum feed intake attained, and rate of dilution of feed that maximised SFI, when breeders in both the pre-laying and laying phases were given feeds diluted with cellulose, vermiculite or sawdust are given in Table 4, together with the corresponding WHC of the feed that maximised SFI in each period. Intakes of feeds diluted with rice hulls and sand are not included in this table as food intake by birds given feeds diluted with these diluents increased linearly over the range of dilutions applied, suggesting that the maximum intake had not been reached even at the highest dilution. The data related to the use of these two diluents were therefore not used in the calculation of the WHC that maximises SFI. The WHC of feeds that maximized feed intake and SFI (SFI_{max}) were from 3.0 to 3.3 and 3.2 to 3.6 g/g, respectively for both periods.

Table 4. The maximum feed intake (FI_{max}) and the rate of dilution (%) of feed that maximised scaled food intake (SFI_{max}, g/kg body weight$^{0.67}$), together with the corresponding water holding capacity (WHC) of the feed that maximised SFI, in both the pre-laying and laying phases

	Pre-laying period			Laying period		
Diluent[1]	FI_{max} g	Rate of dilution that maximised SFI	WHC at SFI_{max} (g water/g feed)	FI_{max} g	Rate of dilution that maximised SFI	WHC at SFI_{max} (g water/g feed)
Cellulose	58.8	0.0	3.0	48.3	11.6	3.2
Vermiculite	62.1	9.49	3.3	52.9	17.2	3.6
Sawdust	62.5	9.82	3.0	49.9	19.4	3.3

[1] Intakes and WHC of feeds diluted with rice hulls and sand are not included in this Table. See text for explanation.

The parallelism test, applied to test coefficients of equations and the hypothesis that all coefficients were equal between the two phases of the trial, was accepted ($P > 0.412$) attesting that there was no difference in SFI_{max} between periods. As a result, a polynomial equation was fitted to the combined data from both phases, with SFI_{max} being a function of WHC of the feed (Fig. 2), as follows:

$$\text{SFImax (g/kg}^{0.67}\text{ per d)} = 4.34\ \text{WHC}^2 - 56.1\ \text{WHC} + 240 \qquad \textbf{[Equation 1]}$$

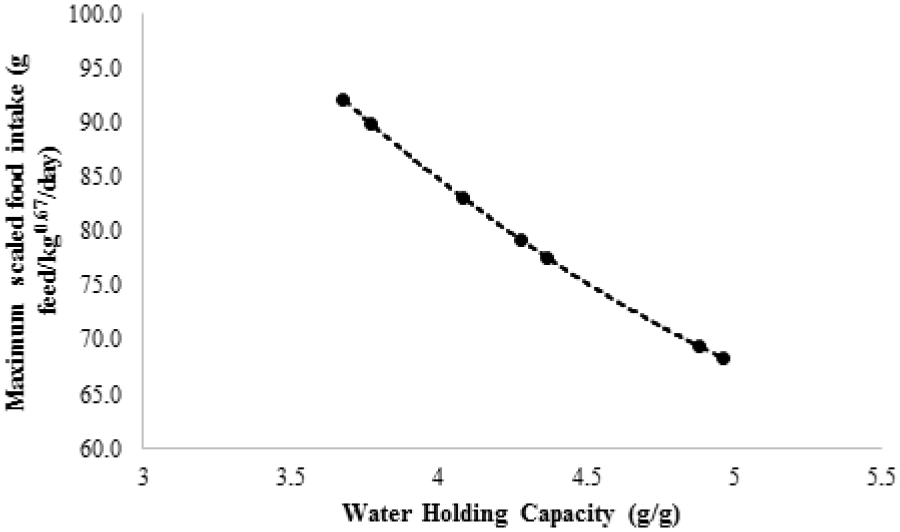

Figure 2. The maximum scaled feed intake (SFImax; g/kg 0.67 per d) on the seven experimental feeds v. their water- holding capacity (g water/g feed). SFImax (g/kg $^{0.67}$ per d) = 4.34WHC^2 – 56.06WHC + 239.54

Discussion

The increased intake of bulky feeds with the rate of inclusion of the diluent confirmed the theory (Mraz et al., 1956; 1957; Emmans 1981) that birds increase feed intake to compensate for an increase in indigestible material content so that they may consume sufficient nutrients to achieve their potential performance. It was assumed that birds receiving the control diet would demonstrate the lowest feed intake and that this would increase with the rate of inclusion of the diluent to a maximum, this being the bulk capacity of the bird. SFI was maximised when cellulose, vermiculite and sawdust were used as diluents at rates below the maximum, but when feeds were progressively diluted with sand and rice husk, SFI increased linearly in both phases, suggesting that gut capacity is greater than that achieved with a rate of dilution of 0.4 when these diluents are used. As a consequence, these two diluents were not used to calculate the WHC that maximised SFI.

The important question of whether broiler breeders adapt to low density feeds when subjected to such feeds over time was addressed in the trials by measuring intake over six successive periods of five days. No systematic change in intake was discernible over the 30 -d period in either the pre-laying or laying phases, this being the case also with growing broilers (Nascimento et al., 2020). Were broiler breeders able to adapt to low density feeds over time it would mean that the feeds would need to be systematically further-diluted over time in order to obtain the same degree of restriction of the essential nutrients in the feed. It appears that this difficult management strategy is not necessary.

Because of the decline in SFI at the higher rates of dilution, body weight gain in the pre-laying period and egg production in the laying period both declined in most instances. In the case of cellulose, vermiculite and sawdust this decline was particularly severe in the growing period, but due to the increased intakes on the highest dilutions with rice hulls and sand, laying performance was unaffected. The decline in performance in the above cases was the result of the increase in SFI being insufficient to compensate for those rates of dilution. A decline in growth rate during rearing would be favoured by broiler breeder managers, and thus feeds with a WHC greater than that which defines gut capacity would need to be applied if qualitative restriction were to be used to reduce growth rate. Conversely, feeds for breeders in lay should not exceed this critical WHC as these would result in a reduction in rate of laying. In both cases, therefore, it is essential to take account of gut capacity as defined by WHC, in one case to ensure that feed intake and hence growth rate is constrained, whereas in the other case, when ingredient costs favour low density feeds during lay, the gut capacity of the breeder hen should not be exceeded as this would reduce laying performance.

In our previous paper (Nascimento et al., 2020) we used PCA as a decision tool to select the physical characteristic of a feed that best described its ‘bulkiness’. As in the previous paper, PCA analysis indicated that, among the 'bulk' characteristics measured, neither density, OHC nor CEC accurately predict maximum feed intake. Once again, WHC proved to be the most appropriate measure for defining the bulk capacity of broilers, enabling the constraining effects of bulk on voluntary feed intake to be defined (Fig. 2). WHC has been found to be a sufficient descriptor of bulk across different materials for pigs also (Kyriazakis and Emmans 1995; Tsaras et al., 1998b; Ndou et al., 2013a,b).

By fitting polynomial regressions to the mean SFI's as a function of dilution rate it was possible to estimate the level of dilution, and from this the corresponding WHC, that maximised SFI. This technique was used in our previous study (Nascimento et al., 2020) following that by Kyriazakis and Emmans (1995), Ndou et al. (2013a), Ndou et al. (2013b) and Bakare et al. (2013) in which similar results regarding SFI and WHC were observed. WHC measures the ability of the feed to hold water; thus, a diet with a high WHC would increase the distension of the gastrointestinal tract. As in our previous trial, a quadratic equation (Fig. 2) was used to predict the maximum gastrointestinal capacity as a function of WHC, and consequently when gastrointestinal capacity would constrain SFI.

As shown by the results, an increase in WHC of the feed will lead to a decrease in SFI because the capacity of the gastrointestinal tract for feed is being filled with water molecules being held within the diluent matrix, thus initiating swelling. SFI was dependent not only on the inclusion level of each diluent source, but also on the WHC of the feeding material used. Using only the three sources of bulk (cellulose fibre, vermiculite and sawdust) that achieved a break-point when regressed against WHC, the maximum gastrointestinal capacity was found to be 83.9 g/kg$^{0.67}$ per day. This suggests that feeds containing a WHC equal to or greater than 4.06 g water/g feed will constrain voluntary feed intake.

To demonstrate the practical application of the equation produced in this study, three feeds of increasing nutrient density were formulated, the WHC was calculated and the maximum amount of each feed that could be consumed by broiler breeders in the first phase of lay (from 5 % production to 245 d of age) was predicted using equation 1. The composition of the undiluted feed for this period of lay was based on the guidelines recommended by Aviagen (2016). The two additional feeds were formulated to contain 0.9 and 0.8 times the nutritional levels of the reference feed such that the feed intakes necessary to meet the daily nutrient requirements of a 2.7 kg broiler breeder would have been 160, 176 and 192 g, respectively. The WHC calculated for the three feeds was 2.68, 3.62 and 4.18 g/g, respectively, which would have allowed maximum daily feed intakes per hen of 234, 181 and 157 g, respectively. Breeder hens given feeds 1 and 2, at a daily allocation of 160 and 176 g, respectively, would have had their requirements met at those allocations, but hens on the most diluted feed would not have been able to consume sufficient of the feed offered and egg production would have been compromised. This equation therefore appears to produce plausible results and would thus be of value to nutritionists investigating the use of low-density diets for broiler breeders.

It is of considerable interest that the same equation may be applied to broiler breeders in both the pre-laying and laying stages, lending credibility to the scaling of body weight used here. In our previous paper on bulk capacity of growing broilers (Nascimento et al., 2020) three age groups of broiler were used, varying from a mean body weight of 46 to 1690 g, and a common scaling factor was successfully used in that case also. Although the equations for predicting SFI_{max} differed, mainly as a result of the range of body weights used in the two trials, nevertheless the SFI_{max} predicted for broilers and for broiler breeders on a feed with a WHC of 4.0 differed by only 8 g for a 0.5 kg bird and 28 g for a 3.5 kg bird. It can be concluded that the gut capacity of broilers and broiler breeders can successfully be predicted from the WHC of the feed and the body weight of the bird using the equation described in this paper.

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References

AOAC. 2005. “Official Methods of Analysis of AOAC INTERNATIONAL,” no. February: 1–96.

AVIAGEN. 2016. “ROSS 308 parent stock: Nutrition specifications.” Retrieved on 15 May 2020 from http\\Ross308-PS-NS-2016-EN.pdf.

BAKARE, A. G., S. P. NDOU, and M. CHIMONYO. 2013. “Influence of physicochemical properties of fibrous diets on behavioural reactions of individually housed pigs.” *Livestock Science* 157 (2–3): 527–34. https://doi.org/10.1016/j.livsci.2013.08.021.

CAPREZ, A., E. ARRIGONI, R. AMADÒ, and H. NEUKOM. 1986. “Influence of different types of thermal treatment on the chemical composition and physical properties of wheat bran.” *Journal of Cereal Science* 4 (3): 233–39. https://doi.org/10.1016/S0733-5210(86)80025-X.

EMMANS, G C. 1981. “A model of the growth and feed intake of ad libitum fed animals, particularly poultry.” In *Computers Animal Production*, edited by G.M.; Whittemore Hillyer C.T.; Gunn, R.G, 106–10. Edinburgh: British Society of Animal Production.

ENTING, H, W.J.A. BOERSMA, J.B.W.J. CORNELISSEN, S.C.L. VAN WINDEN, M.W.A. VERSTEGEN, and P.J. VAN DER AAR. 2007. “The effect of low-density broiler breeder diets on performance and immune status of their offspring.” *Poultry Science* 86 (2): 282–90. https://doi.org/https://doi.org/10.1093/ps/86.2.282.

GOUS, R.M., and M.K. NONIS. 2010. “Modelling egg production and nutrient responses in broiler breeder hens.” *The Journal of Agricultural Science* 148 (03): 287–301. https://doi.org/doi:10.1017/S0021859610000183.

HAN, P. F.-S., and J. R. SMYTH. 1972. “The influence of restricted feed intake on the response of chickens to Marek’s disease.” *Poultry Science* 51 (3): 986–91. https://doi.org/10.3382/ps.0510986.

HOCKING, P.M., and S.R.I. DUFF. 1989. “Musculo-skeletal lesions in adult male broiler breeder fowls and their relationships with body weight and fertility at 60 weeks of age.” *British Poultry Science* 30 (4): 777–84. https://doi.org/10.1080/00071668908417203.

HOCKING, P.M., M.H. MAXWELL, and M.A. MITCHELL. 1996. “Relationships between the degree of food restriction and welfare indices in broiler breeder females.” *British Poultry Science* 37 (2): 263–78. https://doi.org/10.1080/00071669608417858.

HOCKING, P.M., M.A. WALKER, D. WADDINGTON, and A. B. GILBERT. 1987. “Observations on the size of the follicular hierarchy in the turkey hen and a case of arrested follicular growth.” *British Poultry Science* 28 (4): 755–57. https://doi.org/10.1080/00071668708417014.

JOHNSTON, S.A., and R. M. GOUS. 2006. “Modelling Egg Production in Laying Hens.” In *Mechanistic Modelling in Pig and Poultry Production*, edited by T.R. MORRIS, C. FISHER and R. M. GOUS, 188–208. Wallingford: CABI Publishing.

KATANBAF, M.N., E.A. DUNNINGTON, and P.B. SIEGEL. 1989. “Restricted feeding in early and late-feathering chickens.: 1. growth and physiological responses.” *Poultry Science* 68 (3): 344–51. https://doi.org/https://doi.org/10.3382/ps.0680344.

KYRIAZAKIS, I, and G C EMMANS. 1995. “The voluntary feed intake of pigs given feeds based on wheat bran, dried citrus pulp and grass meal, in relation to measurements of feed bulk.” *The British Journal of Nutrition* 73 (2): 191–207. https://doi.org/10.1079/BJN19950023.

LEE, P.J.W., A.L. GULLIVER, and T.R. MORRIS. 1971. “Restricted feeding of broiler breeder pullets during the rearing period and its effect on productivity and breeding.” *British Poultry Science* 12 (4): 499–510. https://doi.org/10.1080/00071667108415905.

MOORMAN, W.F.B., N.J. MOON, and R.E. WORTHINGTON. 1983. “Physical properties of dietary fiber and binding of mutagens.” *Journal of Food Science* 48 (3): 1010–11. https://doi.org/10.1111/j.1365-2621.1983.tb14959.x.

MRAZ, F.R., R. v. BOUCHER, and M.G. MCCARTNEY. 1956. “The influence of dietary productive energy and fiber on growth response in chickens.” *Poultry Science* 35 (6): 1335–40. https://doi.org/10.3382/ps.0351335.

MRAZ, F.R., R. v. BOUCHER, and M.G. MCCARTNEY. 1957. “The influence of the energy: volume ratio on growth response in chickens.” *Poultry Science* 36 (6): 1217–21. https://doi.org/10.3382/ps.0361217.

NASCIMENTO, M., R.M. GOUS, M. REIS, J. B. FERNANDES, and N. K. SAKOMURA. 2020. "Prediction of maximum scaled feed intake in broiler chickens based on physical properties of bulky feeds." *British Poultry Science*.

NDOU, S. P., R. M. GOUS, and M. CHIMONYO. 2013a. "Prediction of scaled feed intake in weaner pigs using physico-chemical properties of fibrous feeds." *British Journal of Nutrition* 110 (4): 774–80. https://doi.org/10.1017/S0007114512005624.

NDOU, S.P., A.G. BAKARE, and M. CHIMONYO. 2013b. "Prediction of voluntary feed intake from physicochemical properties of bulky feeds in finishing pigs." *Livestock Science* 155 (2–3): 277–84. https://doi.org/10.1016/j.livsci.2013.04.012.

NONIS, M.K., and R.M. GOUS. 2012. "Broiler breeders utilise body lipid as an energy source." *South African Journal of Animal Science* 41 (4): 369–78. https://doi.org/http://dx.doi.org/10.4314/sajas.v42i4.5.

OWEN, J. B., and W. J. RIDGMAN. 1968. "Further studies of the effect of dietary energy content on the voluntary intake of pigs." *Animal Production* 10 (01): 85–91. https://doi.org/10.1017/S0003356100025976.

ROBINSON, F.E., J.L. WILSON, M.W. YU, G.M. FASENKO, and R.T. HARDIN. 1993. "The relationship between body weight and reproductive efficiency in meat-type chickens." *Poultry Science* 72 (5): 912–22. https://doi.org/10.3382/ps.0720912.

SANDILANDS, V., B. J. TOLKAMP, C. J. SAVORY, and I. KYRIAZAKIS. 2006. "Behaviour and welfare of broiler breeders fed qualitatively restricted diets during rearing: are there viable alternatives to quantitative restriction?" *Applied Animal Behaviour Science* 96 (1): 53–67. https://doi.org/https://doi.org/10.1016/j.applanim.2005.04.017.

SAKOMURA, N. K., M. P. REIS, N. T. FERREIRA, AND R. M. GOUS. 2019. "Modeling egg production as a means of optimizing dietary nutrient contents for laying hens." *Animal Frontiers* 9 (2): 45-51. https://doi.org/10.1093/af/vfz010.

TOLKAMP, B. J., V. SANDILANDS, and I. KYRIAZAKIS. 2005. "Effects of qualitative feed restriction during rearing on the performance of broiler breeders during rearing and lay." *Poultry Science* 84 (8): 1286–93. https://doi.org/https://doi.org/10.1093/ps/84.8.1286.

TSARAS, L.N., I. KYRIAZAKIS, and G.C. EMMANS. 1998a. "The prediction of the voluntary food intake of pigs on poor quality foods." *Animal Science* 66 (3): 713–23. https://doi.org/10.1017/S1357729800009292.

TSARAS, L.N., I. KYRIAZAKIS, and G.C. EMMANS. 1998b. "The prediction of the voluntary food intake of pigs on poor quality foods." *Animal Science* 66 (03): 713–23. https://doi.org/10.1017/S1357729800009292.

VAN SOEST, P.J. 1963. "Collaborative study of acid-detergent fiber and lignin."

VAN SOEST, P.J., J.B. ROBERTSON, and B.A. LEWIS. 1991. "Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition." *Journal of Dairy Science* 74 (10): 3583–97. https://doi.org/10.3168/JDS.S0022-0302(91)78551-2.

WADDINGTON, D., P.M. HOCKING, M.A. WALKER, and A.B. GILBERT. 1989. "Control of the development of the ovarian follicular hierarchy in broiler breeder pullets by food restriction during rearing." *British Poultry Science* 30 (1): 161–73. https://doi.org/10.1080/00071668908417134.

WANG, J. C., and J. E. KINSELLA. 1976. "Functional properties of novel proteins: alfalfa leaf protein." *Journal of Food Science* 41 (2): 286–92. https://doi.org/10.1111/j.1365-2621.1976.tb00602.x.

WHITTEMORE, E. C., I. KYRIAZAKIS, G.C. EMMANS, and B.J. TOLKAMP. 2001. "Tests of two theories of food intake using growing pigs 1. the effect of ambient temperature on the intake of foods of differing bulk content." *Animal Science* 72 (2): 351–60. https://doi.org/10.1017/s1357729800055855.

CAPÍTULO 4 - Prediction of scaled feed intake in pullets and laying hens based on physical properties of bulky feeds

Abstract - Two trials were carried out to investigate the food intake capacity for bulky feeds, in pullets and laying hens. The first goal was to identify the physical characteristic of diets more correlated to feed bulkiness, which might be used to predict maximum food intake; The second goal was to investigate the maximum food intake of pullets and laying hens, given bulky foods, coming up with an equation that could be used to predict the maximum intake, based on feed traits. For each trial, twenty-five treatments were randomly distributed into 225 experimental units, with nine replicates of one bird each. The treatments were set in five diluents (cellulose fibre, rice husk, sand, vermiculite and sawdust) and five dilution levels (0.000, 0.025, 0.050, 0.100, 0.150). The *ad libitum* intake was measured daily and expressed in function of metabolic body weight (g/BW$^{0.67}$ per day). The food intake initially increased, and then declined, as inclusion of diluent increase. There were large effects of feed changes on intake, in the short term, birds experienced higher intakes of bulk feed. WHC of feeds was more appropriate as a measure of bulk capacity. The equation to predict the maximum food intake capacity of pullets and laying hens recommended was: $SFImax\ (g/kg^{0.67}/d) = 212.12 – 74.0*WHC + 8.58*WHC^2$

Keywords: water holding capacity, gastrointestinal tract; maximum food intake;

Introduction

Food intake of laying hens may vary according to strain used. Although it is generally accepted that gastrointestinal tract's ability to consume feed from modern strains is not in according to its energy needs. Results related that food intake capacity of the strains used was not the factor that limited food intake. Laying hens that were fed diets diluted by up to 30% were able to increase their food intake by up to 30%, resulting in an energy intake similar to that of laying hens fed on undiluted diets (Van der Meulen et al., 2008). However, when the energy content of the feed of these birds was decreased, a decrease in mortality was observed due to the decrease in behavior of feather pecking and significantly improved conditions of feathers (Van der Lee et al., 2001). Laying hens that were fed diluted diets compensated with a higher food intake, resulting in similar energy intake, compared to birds fed a standard energy diet. Dilution levels of up to 30%, adding 30% sand to a control diet, have been fully offset by a higher food intake (Van der Meulen et al., 2008). Some studies also suggest that addition of NSP to laying hens diets may reduce behavior of feather pecking and, consequently, cannibalism (Aerni, El-Lethey, and Wechsler 2000; El-Lethey et al. 2000; Hetland, Choct, and Svihus 2004; Hartini et al. 2002). Birds fed with diluted diets, mainly rich in insoluble NSP, spent more time feeding and seemed calmer than those fed diets with low NSP (Hetland, Choct, and Svihus 2004).

In addition, the growth period of pullets must have nutritional objectives that aim production of healthy birds, with an ideal body weight, ready to produce at the expected age. Generally, a variable number of diets are used in feeding programs for pullets, differing in reduction of nutrient levels as the bird grows. Thus, it is possible to add fibrous or inert ingredients to the diets offered to these birds, as a strategy to maintain the low energy density of the diet, avoiding excessive weight gain, development of the gastrintestinal tract and consequent feeding efficiency during the growth phase of the birds (Mateos et al., 2012).

The modelling, using biological principles and mathematics, is a tool that has a potential to contribute and create many scenarios for decision-making. Nevertheless, model building requires, as a first step, a satisfactory theory to describe the behaviour of the system to be simulated. Hence, in many senses a model is a theory. In fact, the basic theory and model that drives this study was proposed by Emmans (1981). This model shows how their three components - the animal, the diet and the environment are interconnected.

In this way, we hypothesize that physical limitation of the gastrointestinal tract (GIT) is a constrain factor, which may prevent the laying hen to consume feed as desired and grow/produce at his potential. The importance of such results is useful for poultry nutritionists and modelers, because enable to predict if the animal will consume sufficient amount of the feed offered. Initially, the Edinburgh Growth Model (Emmans, 1981) assumes dietary density as the characteristic that impact maximum capacity of the GIT; however, several studies suggests that water-holding capacity (WHC) of the diet would be a better measure to relate the feed with the maximum capacity of the GIT (S. P. Ndou, Gous, & Chimonyo, 2013; Saymore P. Ndou, Bakare, & Chimonyo, 2013a; Emma C. Whittemore, Emmans, & Kyriazakis, 2003). The objective of this study was to identify the physic properties of a given feed that describe the relationship between the feed bulk and the scaled feed intake (SFI) and predict maximum gastrointestinal capacity of a laying hen.

Materials and methods

This study was approved by the Ethics Committee on Animal Use of the Faculty of Agriculture and Veterinary Sciences, UNESP, Jaboticabal (nº 012402/17).

Birds, husbandry and experimental design

Two trials were carried out, first study with pullets (14 to 16 weeks of age) and other with laying hens (26 to 30 weeks of age). For each trial, two hundred and twenty-five birds, Hy-line W36 strain were housed into individual cages. Pullets had a mean body weight of 1.2 kg ±0.077 kg and laying hens had a mean body weight of 1.42 kg ±0.066 kg. All birds were weighed and then assigned to experimental treatment groups. Nine individual replicates were randomly assigned to each of 25 treatments for the 4-week assay. Poultry house had a controlled lighting and ventilation system, with a water supply with nipples in individual cages and the feed was offered *ad libitum* using a feeder placed outside of each cage. The lighting programme used for pullet group was a 12-hour light program and in last week of experiment (18th week) 13 hours of light and in production phase was used a lighting programme with increasing artificial light (15 minutes per week), starting with 15 light hours until reaching 16 light hours in the last week of experiment.

Management

Food intake was daily measured. All animals were weighed weekly and fed five times a day to minimize spillage, which was low and measured. Underneath each trough a tray was placed, where feed waste was collected. Feed refusals were daily weighed; wet feed-waste was oven-dry and measured also. Egg data collecting during the experiment was include daily egg production, egg weight (also daily and calculated egg mass). Each experiment lasted four weeks.

Diets

Two basal diets (BD) were formulated (table 1), one feed for each trial, according to nutritional requirement. These diets were diluted with five diluents (cellulose fibre, rice husk, sawdust, sand and vermiculite) which were included at crescent levels (0.000, 0.025, 0.050, 0.100, 0.150) to obtain bulky feeds (D). Each diluent was included in BD, as follow: D1 = (1 BD + 0 of diluent); D2 = (0.975 BD + 0.025 of diluent); D3 = (0.95 BD + 0.05 of diluent); D4 = (0.9 BD + 0.10 of diluent) and D5 = (0.85 BD + 0.15 of diluent).

Table 1. The composition, chemical analysis (g/kg fresh weight) and 'bulk' characteristics

Ingredients (g/kg)	Pullets	Laying hens
Corn	506.34	364.99
Soybean meal 45%	146.66	196.59
Wheat bran	100.00	----
Gluten meal 60%	----	112.93
Soy oil	5.00	37.14
Dicalcium phosphate 22%	111.54	162.86
Limestone	121.31	108.73
Salt	5.00	3.00
MetAMINO®	----	3.30
L-Lisina HCl®	----	1.83
ThreAMINO®	----	1.38
Sodium bicarbonate	----	2.95
BHT	0.5	0.50
Choline chloride 60%	1.00	1.00
Premix Vitamin [1]	1.50	1.50
Premix mineral [2]	1.50	1.50
Total	1.000	1.000
Nutritional composition calculated		
Crude Protein[3]	156.00	180.00
Metabolizable energy (kcal/kg)	2900	2900
Digestible Lysine	8.35	9.00
Digestible Met+Cis	6.85	8.83
Digestible Methionine	3.75	4.87
Calcium	22.00	47.72
Available Phosphorus	4.40	3.82
Crude Fiber	25.60	12.30
Neutral Detergent fiber	256.00	151.60
Acid Detergent fiber	35.80	24.60
Water holding capacity (g water/g diet)	3.27	3.18
Density (g diet/ml)	0.75	0.75
Oil holding capacity (g oil/g diet)	0.87	0.85
Cation Exchange capacity (meq/mg feed)	0.035	0.034

[1] kg of product: folic acid 2400.000 mg; pantothenic acid 30.00 g; biotin 160.00 mg; butylated hydroxytoluene 100.00 mg; niacin 84.00 g; selenium 600.00 mg; Vit A 20000000,0 UI. Vit B1 5000.00 mg; Vit B12 36000.00 mcg; Vit B2 1300 g; Vit B6 7000,00 mg; Vit D3 5000000,00 UI; Vit E 37500,00 UI; Vit K3 4000,00 mg; Mn 150,00 g; Zn 140,00 g; Fe 90,00 g; Cu 15 g; I 15,00 mg.

[3] Analyzed crude protein: 158.8 g/kg for pullets feed and 179.8 g/kg for laying hen feed; Analyzed ethereal extract: 26.5 g/kg for pullets feed and 28.3 g/kg for laying hen feed.

Feeds were offered in a mash form. Chemical analysis of feeds and diluents were performed according to AOAC, (2005). Samples were ground in an analytical mill (IKA A11) and analysed for nitrogen (Foss Kjeltec8400, method 2001.11), ash (method 942.05), ether extract (method 920.39), and moisture (method 920.39). Protein content was calculated by multiplying the nitrogen content by 6.25. Fat was determined by Ankom XT15 Extractor (ANKOM Technology, Macedon, NY) using petroleum ether as solvent. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) contents were determined in ANKOM Fibre Analyser (Ankom, Macedon, NY, USA), according to Van Soest et al. (1991) and Van Soest (1973), respectively. Neutral detergent fibre was determined using heat stable α-amylase (Sigma A3306; Sigma Chemical Co., St. Louis, MO, USA). The analyses to determine bulkiness of the diets were density (D; Wang & Kinsella., 1976), water-holding capacity (WHC; Kyriazakis & Emmans., 1995), cation-exchange capacity (CEC; Moorman, Moon, & Worthington., 1983), and Oil holding capacity (OHC; Caprez et al., 1986).

Statistical analysis

Each trial was divided in four sub-periods of seven days, and the weekly food intake was related with weekly metabolic body weight ($kg^{0.67}$), obtaining scaled food intake (SFI; g of feed / $kg^{0.67}$ of body weight) as a mean to standardize the food intake from laying hens of distinct size. The data were submitted to analysis of variance with 5% of significance. The correlation of physical analysis (density, WHC, CEC, and OHC) with SFI was evaluated by multivariate exploratory techniques using RStudio©. A quadratic equation, with SFI as the dependent variable and a physic analysis (higher correlation with SFI) set as the independent variable, was fitted for each period of 7 days, to obtain the inflection point, i.e. the maximum SFI.

In order to analyze whether the birds were adapted to the diets or not, the parallelism test was applied using GenStat 12th Edition©, comparing the coefficients obtained for each quadratic equation.

Results

Food characteristics

Among the analysis performed on feed, the ones negatively related to bulkiness were moisture (R^2 - 0.97), crude protein (R^2 - 0.90), and fat (R^2 - 0.93). Fibre content (in terms of CF, ADF and NDF) and WHC were positively related to bulkiness (tables 1 and 2). The principal component analysis (PCA) estimate that a Dimension 1 explains 0.363 of the variation in SFI (Figure 1) and, within this dimension, 0.565 of the variation was explained by WHC. Hence, WHC was chosen as the physical characteristic of the feed that is more related with maximum food intake capacity.

Table 2. The measured bulk characteristics of the basal feeds (B) and diluents used in the trials, including mean water-holding capacity (WHC), density (D), cation-exchange capacity (CEC), oil holding capacity (OHC), crude fibre (CF) and standard error of mean (SEM) of corresponding characteristic

Diluent	WHC	SEM	D	SEM	CEC	SEM	OHC	SEM	CF	SEM
	g/g		g/ml		meq/g diet		g oil/g feed		g/kg	
B – Pre-laying phase	3.27	0.55	0.75	0.02	0.04	0.22	0.87	0.15	256	0.41
B – Laying phase	3.18	0.39	0.75	0.02	0.03	0.41	0.85	0.62	123	0.56
Cellulose Fibre	7.95	0.16	0.40	0.02	0.113	0.53	0.34	0.7	162	0.4
Sawdust	6.50	0.3	0.25	0.04	0.099	0.44	0.80	0.11	700	0.03
Rice Husk	5.50	0.13	0.30	0.04	0.070	0.34	0.65	0.20	400	0.3
Sand	4.00	0.3	1.45	0.03	$2x10^{-4}$	0.24	*	*	*	*
Vermiculite	8.50	0.08	0.15	0.06	$3x10^{-4}$	0.23	*	*	*	*

* Cannot be analyzed and calculated

The relationships between variables can be observed in figure 1. Negatively correlated variables (OHC and D) are positioned on opposite sides of the plot origin (opposed quadrants). The distance between variables and origin measures the quality of the variables on the vector map. In other words, variables that are away from the origin are well represented on the vector map, as WHC.

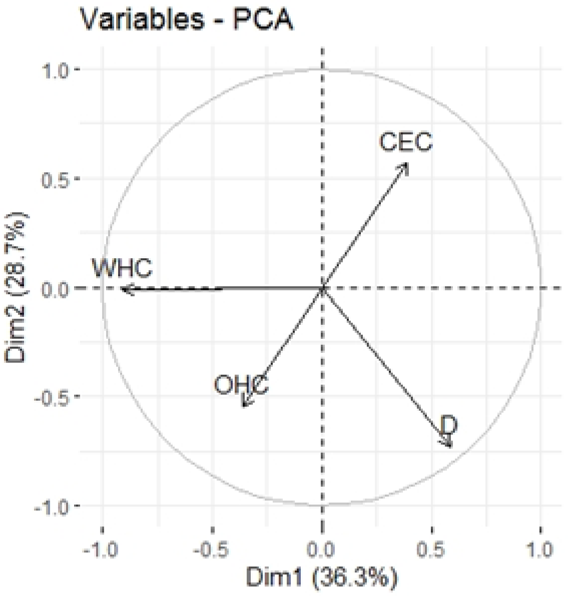

Figure 1. Variable correlation plots, where WHC is water holding capacity, CEC is cation exchange capacity, OHC is oil holding capacity and D is density.

Bulk capacity of different diluents

Maximum SFI were at intermediate dilution levels, 0.05 and 0.10 of dilution, for all diluents (table 3). Nevertheless, the response of laying hens consuming diluted diets was not the same among diluents; consequently, the maximum food intake changes according to the WHC of the feed. The hens were able to eat more when the diet was diluted with inert ingredients (sand and vermiculite). When the diets were diluted with fibrous ingredients, the hens were able to eat less, and the breaking point was at lower dilutions. Moreover, the rate of decrease in SFI was not the same between diluents.

Table 3. The scaled food intake, body weight gain of pullets and egg output of laying hens given access to either a basal or a diluted feed observed in pre-laying and laying phases

Feed	Dilution rate				
	0.0	0.025	0.05	0.10	0.15
Pullets – From 14 to 16 weeks of age					
Celulose Fiber					
Scaled food intake (g feed/kg$^{0.67}$/d)	50.23	53.75	57.35	56.00	53.27
Body weight gain (g/d)	7.34	7.26	2.04	0.488	-0.121
Rice Husk					
Scaled food intake (g feed/kg$^{0.67}$/d)	51.46	56.67	60.78	57.38	55.35
Body weight gain (g/d)	7.13	6.07	4.12	3.28	1.57
Sand					
Scaled food intake (g feed/kg$^{0.67}$/d)	50.31	53.33	57.31	59.61	55.76
Body weight gain (g/d)	6.48	6.30	5.57	5.34	4.29
Vermiculite					
Scaled food intake (g feed/kg$^{0.67}$/d)	51.86	53.96	55.09	56.18	49.42
Body weight gain (g/d)	7.67	5.58	4.89	1.93	1.00
Sawdust					
Scaled food intake (g feed/kg$^{0.67}$/d)	52.62	54.60	63.72	54.33	46.50
Body weight gain (g/d)	6.53	4.40	3.05	2.78	0.768
Laying hens - From 26 to 30 weeks of age					
Celulose Fiber					
Scaled food intake (g feed/kg$^{0.67}$/d)	75.59	77.34	83.14	81.63	76.94
Egg Output (g/bird d)	55.88	56.49	58.60	58.08	50.23
Rice Husk					
Scaled food intake (g feed/kg$^{0.67}$/d)	78.88	79.50	84.50	91.92	85.57
Egg Output (g/bird d)	58.46	58.09	59.75	59.13	56.96
Sand					
Scaled food intake (g feed/kg$^{0.67}$/d)	78.63	80.55	84.42	87.09	85.95
Egg Output (g/bird d)	58.88	59.70	60.00	59.29	58.88
Vermiculite					
Scaled food intake (g feed/kg$^{0.67}$/d)	75.68	78.86	89.54	88.56	81.64
Egg Output (g/bird d)	56.74	56.68	57.60	58.55	56.36
Sawdust					
Scaled food intake (g feed/kg$^{0.67}$/d)	80.43	89.13	85.02	82.13	78.92

Egg Output (g/bird d)	57.96	56.99	56.96	57.25	56.23

The daily body weight gain of pullets (table 3) decreased as BD was progressively diluted, however, this response was not the same for laying hens when egg output was evaluated. Egg output increased with the first levels of dilution, followed by a reduction with the increase of dilution (table 3). Besides that, the results presented were as expected, since as the dilution rate of the diets increased, scaled food intake increased to a maximum and fell after.

Progressive dilution of BD had not different effects on food intake between each 7 days, neither between trials (pullet and laying phase – table 4).

Table 4. The rates of dilution (%) of feed that maximised scaled food intake when using five diluents over four successive seven-day periods during two phases of growth, together with the overall mean for each phase, and the corresponding water holding capacity (WHC) of the feed that maximised scaled food intake

	Phase	
Period	**Pullets**	**Laying hens**
	From 14 to 16 weeks of age	From 26 to 30 weeks of age
	Cellulose Fiber	
0 - 7 d	5.57	6.08
8 - 14 d	13.30	7.05
15 - 21 d	8.84	10.00
22 – 28 d	8.81	10.75
Mean (0-28 d)	8.33	8.03
WHC[1]	2.74	2.64
	Rice Husk	
0 - 7 d	6.42	10.58
8 - 14 d	10.49	12.71
15 - 21 d	8.07	9.19
22 – 28 d	7.44	10.14
Mean (0-28 d)	8.16	10.37
WHC[1]	2.61	2.63
	Sand	
0 - 7 d	7.29	9.71
8 - 14 d	8.86	12.30
15 - 21 d	12.19	10.44
22 – 28 d	*	13.56
Mean (0-28 d)	9.41	11.47
WHC[1]	2.57	2.39
	Sawdust	
0 - 7 d	5.49	5.65
8 - 14 d	5.83	5.74
15 - 21 d	6.58	5.76
22 – 28 d	10.94	4.01
Mean (0-28 d)	6.25	5.69
WHC[1]	2.38	2.37
	Vermiculite	
0 - 7 d	6.01	8.42
8 - 14 d	6.13	8.69
15 - 21 d	*	8.46
22 – 28 d	8.84	9.47
Mean (0-28 d)	6.93	8.66
WHC[1]	2.7	2.73

1 Water holding capacity of the feed that maximised food intake in each phase; * Linear effect, maximum point cannot be calculated

The maximum dilution points observed were very close. Maximum dilution was achieved when diet had a WHC between 2.38 and 2.74 g water/g feed (table 4). A parallelism test was applied to test coefficients of equations and the hypothesis that all coefficients were equal was accepted ($P > 0.598$) attesting that the birds did not adapt to diets, and there was no difference on maximum SFI (SFI_{max}) between ages. As a result, polynomial equation was fitted combining data from both trials, using the SFI_{max} as of break point in function of correspondent WHC (Figure 2), as follows:

$$SFI_{max}\ (g/kg^{0.67}\ /d) = 212.12 - 74.0*WHC + 8.58*WHC^2 \qquad [Eq. 1]$$

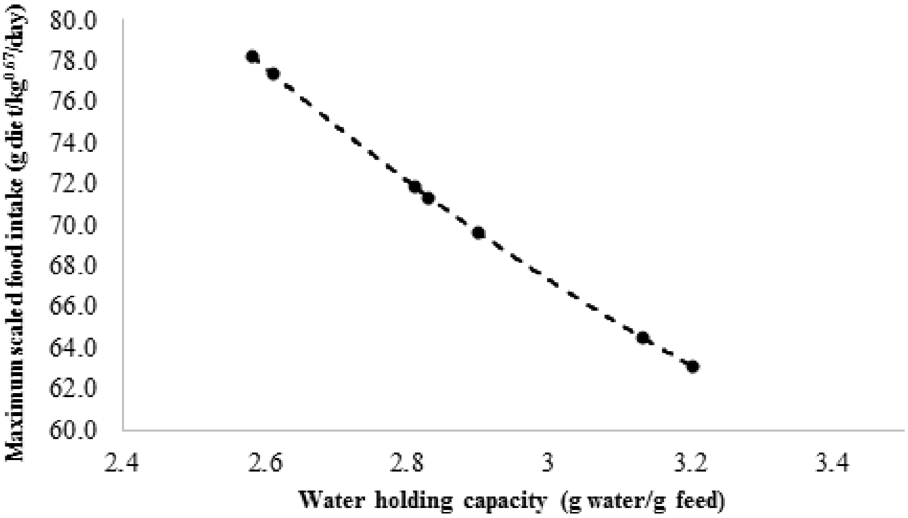

Figure 2. The maximum scaled food intake (SFImax; g/kg body weight per d) on the experimental feeds v. their water-holding capacity (g water/g dry feed) to pullets and laying hens. SFImax (g/kg0.67 per d) = 212.12 – 74.0*WHC + 8.58*WHC²

Discussion

The changes on food intake according to the first limiting component of the feed (energy or amino acids), have being proved as a valid theory (Emmans, 1981b; Johnston & Gous, 2006). A desired food intake (dFI) seems to fit very well on such theory, however, the food intake observed might be constrained by some factors. For growing birds, some of the constraining factors that probably may prevent them to reach the dFI is the heat production and the maximum capacity of intestine (Emmans & Kyriazakis, 1997). For laying hens, the same constraining factors might be involved (Johnston & Gous, 2007). In this sense, the first objective of this study was to identify physical factors of diet that is correlated with food intake, and could be an indicative of feed ‘bulkiness’, allowing to use it to predict maximum intake of feed. The results obtained herein is in agreement with literature, in which the WHC was the physical trait that had more influence on food intake (Kyriazakis & Emmans, 1995; S. P. Ndou, Gous, & Chimonyo, 2013; Saymore P. Ndou, Bakare, & Chimonyo, 2013).

In fact, the WHC of the feed implies in the amount of water can be retained, being reasonable to infer that ingredients with higher values of WHC may increase the volume of such feed in the gastrointestinal tract. The results of this study confirm the findings observed for other animal species (Kyriazakis & Emmans, 1995). In this study, the food intake increased together with the increase of WHC, until a point when the WHC was too high and then the feed intake decreased.

Despite the studies on this subject, from our knowledge there is no literature that uses PCA to investigate a physical characteristic of the feed, in order to decide which, one is more related to ‘bulkiness’. The PCA demonstrates that, among the 'bulk' characteristics measured, neither OHC, density, nor CEC could be used to predict food intake better than WHC (Figure 1). This result supports the findings of Kyriazakis & Emmans, (1995), who attribute the limitation in food intake due to higher WHC of the feed. Furthermore, the authors increased crude fibre of the feed as a strategy to increasing WHC. The fibre, and more specifically non-starch polysaccharides, have capacity of holding water, swelling and forming a mixture with high water content (Robertson & Eastwood, 1981). However, our findings demonstrated that some characteristics of inert diluents such as vermiculite also increases the value of WHC and affect the food intake.

The advantages in use WHC is to allow the prediction of the maximum amount of feed that could be consumed, if the proper relation with food intake is performed. In this sense, it is necessary to describe the relation between WHC and food intake. In addition, the food intake is related to body weight (Whittemore et al., 2003), and as demonstrated by Heusner (1982), the metabolic body weight (kg$^{0.67}$) describes the metabolic rate according to the animal surface. Thus, relation between food intake and metabolic weight was used to calculate SFI (g of feed / kg$^{0.67}$), reducing the differences of food intake related to distinct body sizes between animals.

Another instance that should be investigated in experiments with similar design is the capacity of birds to adapt to bulky feeds. Such ability was demonstrated for swine (Kyriazakis & Emmans,1990, 1995); as a consequence, one equation is not sufficient to estimate the maximum food intake. From reasonable reasons, one can presume that birds fed with higher levels of dilutions needs a period to adjust their GITs, allowing the scaled intakes to increase. In the present study, one quadratic equation was adjusted for each seven days period, predicting SFI in function of WHC. The parallelism analyses, for each diluent, demonstrate that the coefficients from the quadratic equation did not change over the seven-days period ($P>0.05$). Indicating that, neither pullets nor laying hens, adapted to bulky feeds. Nevertheless, it is a common practice among nutritionists increase the fibre of feed for pullets around 15 weeks of age, with the objective to increase the GIT capacity for the laying phase, avoiding a reduction on egg production due to a constrained food intake. Results of pulltes demonstrates only a tendency of acclimatization, demonstrating agreement with the results observed by Van der Meulen et al., (2006) who diluted 0.30 diets and birds were able to adapt and compensate for food intake, increasing their intake by approximately 0.3. And suggesting further studies on this issue.

To predict maximum food intake, WHC was the selected variable and the food intake was scaled to metabolic body weight, which allows the use of this information on more complex models, such as the Avinesp Model (Hauschild, Sakomura, & da Silva, 2015), increasing the liability of the outputs. Once the WHC of the feed is known, the equation adjusted (figure 2) can be applied to estimate the maximum SFI for that particular feed, helping to decide if a change on feed formula is necessary. Under these considerations, it can be concluded that WHC content is a physic measure of feed bulky that can be used to predict SFI in pullets and laying hens from 14 to 30 weeks-old. This physical property provides the threshold value, marking the breaking point were food intake is reduced due to gut fill, when a diet can hold approximately 2.5 g of water per g of feed for pullets and laying hens.

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References

AERNI, V., H. EL-LETHEY, AND B. WECHSLER. 2000. “Effect of Foraging Material and Food Form on Feather Pecking in Laying Hens.” *British Poultry Science* 41 (1): 16–21. https://doi.org/10.1080/00071660086349.

AOAC. 2005. *Official Methods of Analysis of AOAC INTERNATIONAL*. (February), 1–96.

CAPREZ, A., ARRIGONI, E., AMADÒ, R., & NEUKOM, H. 1986. Influence of different types of thermal treatment on the chemical composition and physical properties of wheat bran. *Journal of Cereal Science*, *4*(3), 233–239. https://doi.org/10.1016/S0733-5210(86)80025-X

EL-LETHEY, H., V. AERNI, T. W. JUNGI, AND B. WECHSLER. 2000. “Stress and Feather Pecking in Laying Hens in Relation to Housing Conditions.” *British Poultry Science* 41 (1): 22–28. https://doi.org/10.1080/00071660086358.

EMMANS, G. C. 1981a. 3.3 A model of the Growth and Feed Intake of *Ad Libitum* Fed Animals, Particularly Poultry. *BSAP Occasional Publication*, *5*, 103–110. https://doi.org/10.1017/S0263967X00003761

EMMANS, G. C. 1981b. A model of the growth and feed intake of ad libitum fed animals, particularly poultry. In G. M. . W. Hillyer C.T.; Gunn, R.G (Ed.), *Computers Animal Production* (pp. 106–110). Edinburgh: British Society of Animal Production.

EMMANS, G. C., & KYRIAZAKIS, I. 1997. Models of pig growth: problems and proposed solutions. *Livestock Production Science*, *51*(1–3), 119–129.

FERKET, P. R., & GERNAT, A. G. 2006. Factors That Affect Feed Intake of Meat Birds: A Review. *International Journal of Poultry Science*, *5*(10), 905–911. https://doi.org/10.3923/ijps.2006.905.911

HARTINI, S., M. CHOCT, G. HINCH, A. KOCHER, AND J. V. NOLAN. 2002. “Effects of Light Intensity during Rearing and Beak Trimming and Dietary Fiber Sources on Mortality, Egg Production, and Performance of ISA Brown Laying Hens.” *Journal of Applied Poultry Research* 11 (1): 104–10. https://doi.org/10.1093/japr/11.1.104.

HAUSCHILD, L., SAKOMURA, N. K., & DA SILVA, E. 2015. AvinespModel: Predicting Poultry Growth, Energy and Amino Acid Requirements. In N. K. Sakomura, R. M. Gous, I. Kyriazakis, & L. Hauschild (Eds.), *Nutritional modelling for pigs and poultry* (p. 304). Wallingford, Oxon.: CAB International.

HETLAND, H., M. CHOCT, AND B. SVIHUS. 2004. "Role of Insoluble Non-Starch Polysaccharides in Poultry Nutrition." *World's Poultry Science Journal* 60 (4): 415–22. https://doi.org/10.1079/wps200325.

JOHNSTON, S. A., & GOUS, R. M. 2006. Modelling egg production in laying hens. In T. R. M. and C. F. R. M. GOUS (Ed.), *Mechanistic modelling in pig and poultry production* (pp. 188–208). Wallingford: CABI Publishing.

JOHNSTON, S. A., & GOUS, R. M. 2007. A mechanistic, stochastic, population model of egg production. *British Poultry Science*, *48*(2), 224–232.

KYRIAZAKIS, I., & EMMANS, G. C. 1990. The immediate effects of abrupt diet composition changes in young pigs. *British Journal of Nutrition*, *64*(03), 619. https://doi.org/10.1079/BJN19900065

KYRIAZAKIS, I., & EMMANS, G. C. 1995. The voluntary feed intake of pigs given feeds based on wheat bran, dried citrus pulp and grass meal, in relation to measurements of feed bulk. *The British Journal of Nutrition*, *73*(2), 191–207. https://doi.org/10.1079/BJN19950023

MATEOS, G. G., E. JIMÉNEZ-MORENO, M. P. SERRANO, AND R. P. LÁZARO. 2012. "Poultry Response to High Levels of Dietary Fiber Sources Varying in Physical and Chemical Characteristics." *Journal of Applied Poultry Research* 21 (1): 156–74. https://doi.org/10.3382/japr.2011-00477.

MOORMAN, W. F. B., MOON, N. J., & WORTHINGTON, R. E. 1983. Physical Properties of Dietary Fiber and Binding of Mutagens. *Journal of Food Science*, *48*(3), 1010–1011. https://doi.org/10.1111/j.1365-2621.1983.tb14959.x

NDOU, S. P., GOUS, R. M., & CHIMONYO, M. 2013. Prediction of scaled feed intake in weaner pigs using physico-chemical properties of fibrous feeds. *British Journal of Nutrition*, *110*(4), 774–780. https://doi.org/10.1017/S0007114512005624

NDOU, SAYMORE P., BAKARE, A. G., & CHIMONYO, M. 2013. Prediction of voluntary feed intake from physicochemical properties of bulky feeds in finishing pigs. *Livestock Science*, *155*(2–3), 277–284. https://doi.org/10.1016/j.livsci.2013.04.012

NEWCOMBE, M., & SUMMERS, J. D. (1985). Effect of Increasing Cellulose in Diets Fed as Crumbles or Mash on the Food Intake and Weight Gains of Broiler and Leghorn Chicks. *British Poultry Science*, *26*(1), 35–42. https://doi.org/10.1080/00071668508416784

ROBERTSON, J. A., & EASTWOOD, M. A. (1981). An examination of factors which may affect the water holding capacity of dietary fibre. *Br J Nutr*, *45*(1), 83–88. https://doi.org/10.1079/BJN19810079

VAN DER MEULEN J, C. KWAKERNAAK, C.A. KAN. 2008. Sand intake by laying hens and its effect on egg production parameters. *Journal of Animal Physiology and Animal Nutrition* (Berl). Aug; 92(4), 426-431. https://doi.org/10.1111/j.1439-0396.2007.00732.x.

VAN DER LEE, A. G., HEMKE, G., & KWAKKEL, R. P. 2001. Low density diets improve plumage condition in non-debeaked layers. *In Proceedings* of the 13th European Symposium on Poultry Nutrition . : 13th European Symposium on Poultry Nutrition (WPSA)., Blankenberge, Belgium, 2001 (pp. 244-245).

WANG, J. C., & KINSELLA, J. E. (1976). FUNCTIONAL PROPERTIES OF NOVEL PROTEINS: ALFALFA LEAF PROTEIN. *Journal of Food Science*, *41*(2), 286–292. https://doi.org/10.1111/j.1365-2621.1976.tb00602.x

WHITTEMORE, E. C., EMMANS, G. C., & KYRIAZAKIS, I. (2003). The relationship between live weight and the intake of bulky foods in pigs. *Animal Science*, *76*(01), 89–100. https://doi.org/10.1017/S1357729800053352

CAPÍTULO 5 – Considerações finais

O desempenho das aves de produção (frangos de corte, poedeiras e matrizes pesadas), tem melhorado de forma rápida nos últimos 30 anos devido à genética, nutrição e ambiente controlado. Observa-se que este crescimento veio atrelado à um aumento na deposição de gordura na carcaça destes animais prejudicando funções reprodutivas, no caso das fêmeas, mortalidade e doenças metabólicas. Estes problemas são observados em aves que são submetidas a um programa de alimentação não restritivo, isto é, que possuem o consumo de ração a vontade. Desta forma, programas de restrição alimentar têm sido utilizados, de forma bem ampla e difundida para matrizes pesadas para reduzir os problemas gerados pelo excesso de consumo. Contudo, tem-se considerado estes programas alimentares retritivos como uma estratégia nutricional para frangos de corte e poedeiras também, uma vez que a aplicação para estas categorias de aves de produção pode trazer benefícios para o desempenho destas aves.

A restrição alimentar pode se dar de duas formas, a qualitativa, quando se diminui a densidade nutricional da dieta (diluição com alimentos fibrosos), e a quantitativa, quando se restrige a quantidade de alimento consumido. Há diversos relatos na literatura que observaram que a restrição qualitativa pode trazer, além dos benefícios para o desempenho destes animais, melhora do bem-estar destas aves, uma vez que possuem um comportamento alimentar bastante agressivo, principalmente frangos de corte e matrizes pesadas.

Contudo, a adição de fibra nas dietas sempre foi tratada pelos nutricionistas como um ponto negativo para o desempenho de aves e suínos. Existe uma literatura muito bem estabelecida que traz resultados de efeitos deletérios do uso de fibras. Há relatos que dietas típicas Européias (aquelas a base de trigo, cevada e centeio) para frangos de corte interferem de froma negativa no padrão digestivo destes animais. De acordo com trabalhos que abrodam esta questão, o uso de polissacarídeos não amiláceos (PNA) dos cereais apresentam atividade antinutritiva quando presentes em dietas de frangos de corte, sendo que os altos níveis de pentosanas no centeio e β-glucanos na cevada são responsáveis pelo baixo valor nutricional desses cereais, caracterizando estas dietas como pobres nutricionalmente. Ainda de acordo com estes estudos, inúmeras variedades de trigo podem variar consideravelmente em sua densidade nutricional, com alguns podendo apresentar valores de energia metabolizável aparente muito baixo (EMA < 3000 kcal/kg), sendo que esta variação foi relacionada de forma direta à variação nos níveis dos PNA solúveis em água (PNAs) que são predominante nas pentosanas. Com base nisso, ficou-se muito bem estabelecido que dietas que incluíam uma maior concentração de ingredientes fibrosos poderiam causar diminuição da digestibilidade e prejuízos ao desempenho animal dependendo da concentração de PNA que determinada dieta apresentava.

Para que a opção por um programa alimentar restritivo qualitativo possa trazer reais benefícios é necessário que o nutricionista leve em consideração que a dieta terá um volume muito maior pela presença da alimentos mais fibrosos em sua composição. Além disso, esta dieta volumosa terá características físico-químicas, e principalmente físicas, bem diferentes daquelas observadas em dietas mais praticadas no sistema de alimentação à vontade. Claramente, quando se opta por dietas mais diluídas, espera-se que haja uma menor densidade nutricional desta ração, e, consequentemente, o animal precise comer uma quantidade maior para atender o primeiro limitante daquela dieta, podendo ser energia ou qualquer outro nutriente como aminoácido, por exemplo.

Como ponto central de discussão deste trabalho, observou-se que as características físicas de dietas deste tipo podem limitar o consumo ao ponto de causar prejuízos ao desempenho destes animais. Desta forma, dentre as características físicas estudadas (capacidade de troca catiônica, densidade, capacidade de retenção de óleo e capacidade de retenção de água), a característica física de maior impacto no consumo, tanto de frangos de corte, poedeiras como no de matrizes pesadas é a capacidade de retenção de água (CRA). Observou-se que esta característica está diretamente ligada à fibra bruta, e seu aumento se dá de forma proporcional ao aumento da fibra da dieta. A capacidade de retenção de água mostrou-se capaz de limitar o consumo das aves estudadas, uma vez que esta característica causava, no animal, a distenção do trato gastrintestinal ainda que ele não tivesse atendido sua necessidade nutricional do primeiro limitante, para dietas com CRA muito elevada (acima de 3,0 g de água/g de ração), e isso pode ser observado porque os animais tiveram seu desempenho prejudicado. Diante do exposto torna-se importante que se conheça quais são os níveis aceitáveis e limites de CRA para cada categoria animal, a fim de que programas de alimentação restritivos qualitativos possam trazer seus benefícios e sem causar prejuízos ao desempenho destas aves.