LES DEFIS DE LA TECHNOLOGIE DE L'ALIMENT EN NUTRITION VOLAILLE PERTINENCE ET ENJEUX POUR REPONDRE AUX ATTENTES INDUSTRIELLES ET SOCIETALES

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RÉSUMÉ

Les défis de la technologie de l'aliment en nutrition volaille pertinence et enjeux pour répondre aux attentes industrielles et sociétales

Au cours des dernières années, des innovations technologiques sont apparues en nutrition avicole : l'alimentation humide, le broyage grossier, l'utilisation de nouveaux critères décrivant les propriétés physiques de l'aliment ou encore le déploiement de la spectroscopie par proche infrarouge sur les lignes de production. Ces innovations influencent le comportement alimentaire et la physiologie digestive des volailles. En ce sens, elles peuvent permettre aux filières avicoles œufs et chair d'améliorer les performances zootechniques mais aussi de réduire l'impact environnemental et l'utilisation des antibiotiques, répondant ainsi à un double enjeu industriel et sociétal. A l'heure actuelle, ces innovations restent néanmoins cantonnées à une utilisation expérimentale. Leur utilisation à l'échelle industrielle requiert une meilleure connaissance du comportement alimentaire des volailles: la technologie de l'aliment doit servir à soutenir le développement intestinal des oiseaux.

ABSTRACT

The feed technology challenge in poultry nutrition. Relevance and concerns in addressing industrial and societal expectations

Numerous feed technology innovations have been communicated over the last years in poultry nutrition: wet feeding, coarse grinding, use of novel criteria describing the physical properties of the feed and on-line near infrared reflectance spectroscopy. Such innovations influence both the feeding behavior and the digestive physiology of poultry. Hence, they may help egg and poultry meat producers to improve zootechnical performance while reducing environmental impact and antibiotics use, thereby addressing both industrial and societal concerns. Nowadays, the use of such innovations remains, however, experimental. Industrial upscaling of such innovations requires a better understanding of the feeding behavior of poultry: feed technology should be fully committed to support the gut development of birds.

INTRODUCTION

Poultry production is facing a challenging future. Production efficiency needs to be further improved to fulfill the growing global demand for human-edible protein sources (Mottet and Tempio, 2017) while being under societal scrutiny in western societies (e.g. environmental impact of poultry production and antibiotics use; Smith, 2011).

Visual and olfactory cues influence the feeding behavior of poultry (Picard et al., 2000). The digestive tract of birds allows, in addition, the sensing of nutrients and structural properties of the feed in the beak and beyond, thereby affecting feed intake, digestive physiology and growth performance of poultry (Niknafs and Roura, 2018). Feed particle size, degree of processing and feed form are, therefore, key aspects for the efficiency of broiler and laying hen farming.

The purpose of the present paper is threefold. Firstly, to describe the specific objectives of broiler and layer production regarding feed intake management and nutrient digestibility. Secondly, to illustrate how such specific objective may be addressed by alternative feed technology such as wet or coarse feeding. Thirdly, to illustrate how alternative feed technology processes may help to address societal and industrial concerns.

1. IMPROVING PERFORMANCE IN BROILER AND LAYER PRODUCTION THROUGH FEED TECHNOLOGY

1.1. Specific objectives of broiler and layer productions

Feed intake capacity is the main driver of growth performance of poultry and seems to reach a biological limit in broilers (Tallentire et al., 2018). Broilers may also face a suboptimal digestion of several nutrients such as starch as a result of a too fast passage of digesta through the gastro-intestinal tract (Svihus, 2011). A challenge of broiler nutrition is, therefore, to keep steady or increase nutrient intake of birds without compromising nutrient digestibility.

Conversely, one of the main challenges in layer nutrition is to match nutrient intake and requirement on a day-to-day basis and to manage egg production and egg weight.

Changes in feed technology at different levels (Figure 1) may help to meet the specific objectives of broiler and layer production, as highlighted below.

Figure 1. Scientific developments related to feed technology and poultry nutrition occurring at different levels

Coarse grinding	Wet feeding	Reflux
Pre-pelleting WW	Post-pelleting WW	Gizzard activity
On-line NIR-S		

NIR-S: Near infrared reflectance spectrometry; WW: whole wheat

1.2. Improving feed intake by increasing feed moisture content

The most prominent factors affecting feed intake are related to gut distension and digesta passage rate (Scott, 2007). Initial moisture content of the feed may influence hydration rate of the bolus in the crop. This phenomenon is known to influence particle size reduction in the gizzard, a digestion step that is thought to set the pace of digestion in birds, as reviewed by Rodrigues and Choct (2018).

In practical poultry nutrition, initial moisture content of the feed can be influenced by the addition of water to ground ingredients prior pelleting. Dilution of the diet without re-formulation with 2 to 4% water has, however little to no impact on the feed intake of broilers and turkeys (unpublished MiXscience data). Such dilution decreased the final dry matter content of the feed (-1,5 and 3 %; respectively) and improved pellet durability (+ 2 pts; irrespective of the level of water added).

Dilution rates far larger than 4 % can be achieved experimentally by soaking the feed. Such wet feeding has been reported to improve dry mater intake in both broilers and layers (e.g. Khoa, 2007; Elling-Staats et al., 2015; Dijkslag et al, submitted). Scott (2007) speculated that variation in feed intake was due to hydration rate of the grain after examining the relationship between wheat type and feed moisture on growth performance of broilers (Table 1).

Wet feeding may prove useful therefore as a strategy to further increase feed intake of broilers and potentially of layers at the onset of lay. Implementation of such systems in commercial poultry enterprises requires, however, the development of new feeding systems to reach water:feed ratio larger than 1. Such systems could be inspired from those commonly used in swine production facilities.

1.3. Improving nutrient digestibility with coarse diets

For decades, the feed industry has been driven by the concept that fine grinding enables digestive secretions to access substrate easily, thereby improving digestibility (Kwakkel and Moquet, 2013). Counter-intuitively, feeding a more structural – coarser - diet may results in even greater nutrient digestibility (Abdollahi et al., 2016). Coarse diets stimulate the grinding activity of the gizzard, digestive enzymes secretion and specific avian retrograde peristaltic contractions that are also known as reflux (Svihus, 2011).

Three sites of intensive reflux are documented in birds (Duke, 1994). The gastro-duodenal reflux (2 to 4 cycles per min) occurs between the proventriculus and proximal duodenum. The duodenal and upper ileal reflux (about 4 times per hour) increases intestinal retention time. Finally, colonic reflux transfers urinary nitrogen to the cloaca via the colon particularly when a diet is limiting in protein (Karasawa, 1999). Such mechanisms contribute to nutrient digestibility (Svihus, 2011). The existence of an ileo-cecal reflux remains putative. The latter may facilitate the conversion of urinary nitrogen (N) into microbial protein and the subsequent absorption of microbial amino acids in the ileum (Kwakkel and Moquet, 2014). Such N-recycling mechanism would contribute greatly to the N-efficiency of birds.

As said before, coarse diets stimulate contractions in the gut and thereby may enhance absorption rates. Feeding whole grains is an effective way to increase the coarseness of a diet. Commonly used methods have been described as pre- or post-pelleting inclusion of whole grain (Singh et al., 2014). Pre-pelleting inclusion means that whole grains are bound to a balanced complementary part in one pellet. In a post-pelleting system, whole wheat is mixed with the balanced complementary part. Achieving good durability indexes may be challenging in pre-pelleting systems (Elling-Staats et al., 2017), whilst post-pelleting systems may result in lower flock homogeneity as a result of dietary selection. To avoid particle selection thereby ingesting an unbalanced diet in the post-pelleting system can be avoided by feeding a larger pellet that includes the whole grain. Results from our lab illustrate that in a choice feeding experiment young birds do not prefer automatically small pellets and it may indicate that we have to increase pellet size with the age of birds (Figure 2).

Next to feeding whole grain, coarse grinding is another method to increase the coarseness of poultry diets. Such method is, however, associated with inconsistent results. This may be due to differences in milling methods used or in differences in feed presentation across studies (Kilburn and Edwards, 2001). Indeed, different grinding methods including roller mills, hammer mills, multi-cracker systems and multi-stage grinding combined with sieving actions are currently used. The roller mill tends to produce materials having a more uniform particle size distribution (PSD) and consumes less energy, whilst hammer mills have a great grinding capacity for a wide variety of ingredients, even fiber rich (Thomas et al., 2018). The multicracker system, a grinding system using two contra-revolving rows of discs, was considered saving energy and ensure grinding capacity (Thomas et al., 2012). Since the advantages of different grinding method vary, multi-stage grinding, combining different grinding methods, might result in a desired particle size distribution. In most studies, coarse grinding is solely applied to the cereal fraction. Interestingly, results from our lab illustrate that coarse grinding of protein-rich by products such as rapeseed meal may further improve nutrient digestibility (Klein et al., 2019).

As in pre-pelleting inclusion of whole wheat, the use of coarser particles in pellets may lead to a poorer pellet quality in terms of its durability that may adversely affect feed intake in broilers. It was formerly described, that birds may distinguish between high and low energy diets and prefer high energy diets (Bouvarel et al., 2009). The distance between roller and die and hole diameter/die thickness of the pellet press therefore may both have a relevant role in establishing a pellet that contains coarsely ground or whole grains while maintaining a good physical quality as measured by pellet durability and hardness indexes.

Such considerations illustrate, again, that feed presentation is crucial for maximizing feed intake of poultry. This holds true especially for fast-growing broilers, which seems to avoid low-durability pellets (Elling-Staats et al., 2017). At the same time, such modern broilers tend to refuse eating hard pellets (Moquet, 2018; personal observations). Feed producers have, therefore, to adjust constantly their process to find a balance between low hardness and high durability to reach the “marshmallow” pellet that maximizes the feed intake of commercial broiler flocks.

Concerning layers, offering a mash with a wide range of particle sizes may result in segregation in the feed through and nutrient asynchrony, e.g. for starch (Ruhnke et al., 2015). Segregation may also lead to particle selection and will affect the hens ability to meet their daily nutrient requirements. Especially nutrients contained in smaller particles, e.g. vitamins were observed to be insufficiently consumed by the hens (Tang et al., 2006).

A large part of variation in feed intake remains, however, unexplained (Scott, 2007). In other words, feeding behavior of birds may change unexpectedly despite the feed complying with the quality indicators measured by the industry, e.g. dry sieving, hardness or durability. Novel quality indicators are therefore needed to better predict the feeding behavior of birds and, especially, broilers.

The effect of variation in feed particle sizes and diet uniformity on bird performance is not fully understood (Amerah et al., 2007). This may be due to the way we measure and express PSD. Current methods of particle size determination include dry/wet sieving, laser diffraction, microscope, and static/dynamic image analysis. According to the ASAE standard (2008), after sieving and weighing, PSD can be approximated by using a logarithmic calculation and expressed as geometric mean diameter (GMD or D_{50}) and geometric standard deviation (GSD). The choice of sieves at sieving, however, largely determines the results. Additional particle characteristics can be measured by diffraction and image analysis (Fang et al., 2019). These quick methods result in novel PSD criteria such as the median volume distribution (D_{50}), the 'Sauter diameter' (a surface weighted mean diameter), the 'de Brouckere diameter' (a volume weighted mean diameter) and the span of the size distribution (Fang et al., 2019). Such novel PSD criteria may be useful in improving our understanding of feeding behavior of poultry.

The physical characteristics of pellets are commonly evaluated using durability tests (e.g. Holmen test or Pfost's tumbling can test) and hardness tests. The latter indicates the breaking strength of pellets. Birds, however, resort to palpation rather than breaking when assessing a novel food source (Picard et al., 2000). Hence, measuring novel physical characteristics of the feed such as the modulus of elasticity, e.g. with an Instron device, may provide additional insights into the feeding behavior of poultry. The strong effect of physical properties of the diet on the feeding behavior of poultry highlights the importance of quality measurement systems in the feed mill. With regards to the latter, interesting developments are provided by near infrared reflectance spectroscopy (NIR-S) techniques.

1.4. Matching precisely the requirement and supply of nutrients with online quality measurement

The current NIR-S use in the modern feed mill covers the control of ingredient analysis between laboratories, of ingredient origins and of nutrient levels of ingredients (e.g. work of Doret-Auberteau et al., 2019). In addition, current data derived from NIR-S also comprises the prediction of digestibility (van Barneveld et al., 2018), the presence of undesirable substances such as phytate phosphorus (Tahir et al., 2012), wheat endosperm hardness (Rose et al., 2001) and e.g. heat damage of soybean meal (T. Hulshof, 2017, pers. comm.). NIR-S may, therefore, provide additional data to predict the chemico-physical characteristics of raw materials and compound feeds and help better prediction of the growth performance of poultry (Owens et al., 2009).

Notably, NIR-S may allow the control of in-line, real time accuracy of formulation to be carried out in the feed mill. The use of NIR-S in the production line the so-called 'in-line feed formulation', can be installed in the transportation line of ingredients before the dosing process takes place as described by Penz (2017). Such system allows the immediate reading of nutrient values of ingredient, consequent formulation and dosing. Precision and accuracy of NIR-S is sufficient to evaluate nutrient levels upon reception (e.g. Doret-Auberteau et al., 2019), but currently, online use of NIR is seldom and still a proposal.

Such system operates, however, under two prerequisites. Firstly, NIR-S evaluation of ingredients has to be accurate. Secondly, all processes down-stream such as agglomeration (e.g. pelleting) must be well controlled to avoid damages of nutrients (e.g. amino acids such as lysine; Fernandez and Parsons (1996) or heat-sensitive additives (e.g. enzymes).

The use of 'in-line feed formulation' may prove especially useful in layer nutrition, wherein nutrient provision must be tightly matched to requirements to prevent overfeeding and where levels of specific nutrients are commonly used to manage egg weight. Overall, recent developments in feed technology, e.g. wet feeding, coarse feeding, novel quality criteria or NIR-S, have the potency to further improve the performance of both broiler and layer production. Beyond the economical scope, such development may also help addressing societal concerns.

2. ROLE OF FEED TECHNOLOGY IN ADRESSING SOCIETAL CONCERNS

2.1. Minimizing environmental impact

The use of cereals and oilseeds by-products such as dried distillers grains or rapeseed meal in poultry diets may be limited by the variability of nutrient levels and digestibility of such ingredients. Variability is attributable to the ingredient origin (plant genetics, environment, harvest and storage conditions), the production process and composition of the solubles added (Batal and Dale, 2006).

Use of NIR-S may provide a quicker evaluation of nutrient levels of ingredients (Doret-Auberteau et al., 2019) as well as their digestibility (van Barneveld et al., 2018). Hence, NIR-S may facilitate the use of cereals and oilseeds by-products, thereby reducing the use of human-edible raw material in poultry nutrition. Next to reducing feed/food competition, NIR-S may also allow to formulate diets that minimize both over-formulation and excretion of non-digestible materials. Collectively, such effects are prone to reduce the environmental impact of poultry production. Minimizing the non-digestible nitrogen fraction in poultry diets may, in addition, contribute to gut health and thereby reduce the use of antibiotics in poultry farming.

2.2. Reduced use of antibiotics

Proteins that escape the ileum undigested may serve as substrate for proteolytic fermentation substrates that are detrimental for the health of birds (Apajalahti and Vienola, 2016). As NIR-S may provide immediate digestibility values for single AA, it also allows to formulate diets that are low in undigestible protein. Besides, feeding coarse diets has been shown to affect gut health and microbiota composition in a manner that is considered to be positive for the broilers' health (Qaisrani, 2014). Finally, wet feeding seems to improve the functionality of the foregut (Scott, 2007) and a healthy crop is considered to be important in reducing antibiotic use in poultry (Classen, 2016).

2.3. Beak trimming

The study of Persyn et al. (2004) indicated that beak-trimmed hens spent significantly more time with eating (3.3 vs 2.0 h/d) with a slower bout size as compared with their non-trimmed beak counterparts. Shorter time intervals spent on eating with hens having intact beaks may have detrimental effects on feather pecking behavior. Previous research indicated that a longer eating time partly prevented feather pecking behavior (van Krimpen et al., 2009). Novel feed technologies presented in this paper may improve the feed intake of birds (Tables 1 and 2). It is hitherto unclear whether such technologies will affect the occurrence of feather pecking behavior in hens having intact beaks.

CONCLUSIONS

Changes in feed technology at factory level (e.g. use of coarser diets, on line NIR-S or novel feed quality criteria) and at farm level (e.g. use of wet feeding) may help to reach higher performance for both layer and broilers. Such changes can, in addition, help the poultry industry to address several societal concerns, to move forward to a more sustainable poultry production.

Poultry nutritionists may, however, face some dilemma when applying novel feed technologies. The use of coarser diets may, for instance, reduce pellet quality while the use of water sanitized with peroxide or chlorine in wet feeding systems may compromise vitamin stability. Additional research is therefore warranted to fully exploit the potential of novel feed technologies, starting with a better understanding of the feeding behavior of poultry species (Table 2).

Table 1. Effects of wheat type and wet/dry feeding on broiler performance (0-21 d; Scott, 2007).

	Feed intake g/bird/d	Body weight 21d	Feed conversion ratio, 0-21 d	Feed:water ratio 0-21 d
Total (144 cages)	41.4 ± 4.1	637 ± 57.7	1.57 ± 0.142	0.52 ± 0.074
Wheat type (significance)	**	NS	**	NS
Durum	37.5	638	1.42	0.53
Hard red spring	45.3	636	1.72	0.53
Dry vs wet (1.2g water:1g feed)	**	**	**	NS
Dry	35.7	591	1.47	0.52
Wet	47.2	682	1.67	0.51
Wheat type x Dry/wet	**	NS	**	NS
Durum x dry	34.1 d	591	1.40 c	0.54
Durum x wet	40.9 b	685	1.44 c	0.52
Hard red spring x dry	37.2 c	592	1.55 b	0.51
Hard red spring x wet	53.4 a	679	1.89 a	0.49

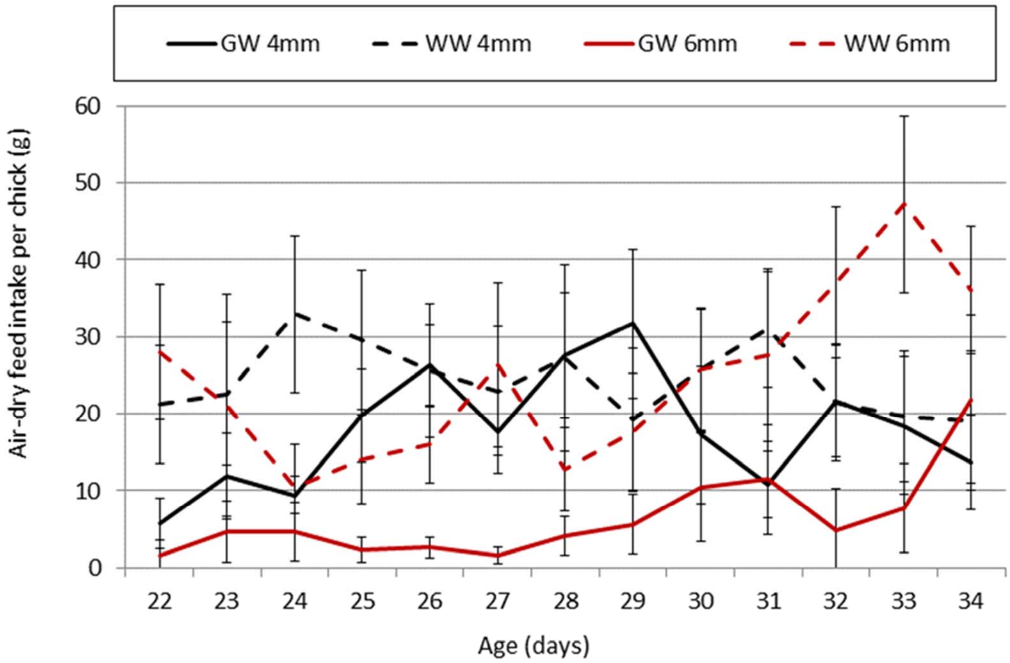
,, a-d, NS* *Significance at P<0.05, P<0.01, not significant, respectively*

Table 2. Expected benefits and current limitations associated with the use of novel feed technologies to poultry nutrition.

Technology	Production	Expected benefits					Current limitations
		Animal & Industrial			Societal		
		↗ Gut health	↗ Feed intake	↘ Feed conversion ratio	↘ Carbon footprint	↘ Antibiotics use	
Wet feeding	Broiler	x	x		x	x	Microbial overgrowth if water is untreated; Vitamin stability if water is treated with peroxide or chlorine
Coarse diets	Broiler Layer	x	x	x	x	x	Reduced pellet quality
Novel quality criteria, e.g. elasticity	Broiler Layer		x		x		Poor understanding of feeding behavior
NIR-S	Broiler Layer	x		x	x	x	Accuracy of NIR-S equations, control of downstream process to avoid damages to nutrients

NIR-S: Near infrared reflectance spectroscopy

Figure 2. Feed intake of broilers (22-34 d) choice-fed pellets (4 or 6 mm diameter) with either ground wheat (GW) or whole wheat (WW).



REFERENCE LIST

Abdollahi MR, Ravindran V, Amerah AM, 2016. J Anim Physiol Anim Nutr, 100 (5): 929-37.
Amerah AM, Ravindran V, Lentle RG, Thomas DG, 2007. W. Poult. Sci. J., 63, 439-455.
Apajalahti K, Vienola K, 2016. Anim. Feed Sci. Technol., 221, 323-330.
Bouvarel I, Chagneau AM, Lecuelle S, Lescoat P, Ferreira G, Duvaux-Ponter C and Leterrier C, 2009. Appl. Anim. Behav. Sci., 118 (1-2):62-68.
Carré B, 2000. INRA Prod. Anim., 13 (2), 131-136.
Doret-Aubertot M, Faivre JF, Nolwenn B, Stéphanie K, Anne-Marie J, 2019. Proceedings 13th JRAPFG, Tours, 20/21 March 2019.
Duke GE 1994. Proc. 21st Annual Carolina Poultry Nutrition Conference, 7-8 December 1994. Charlotte, North Carolina, USA, 46-51.
Classen HL, Apajalahti ., Svihus B, Choct M, 2016. W. Poult. J., 72 (3), 459-472.
Elling-Staats M, Akinloye KA Loeffen J, Dijkslag A, Kwakkel RP, 2015. Proc. 20th Eur. Symp. Poult. Nutr.. 27-28 August 2015, Prague, Czech Republic, 213.
Elling-Staats M, van Loon J, Raaijmakers MMP, van der Poel AFB., Kwakkel RP, 2017. Proc. 21th Eur. Symp. Poult. Nutr.. 05-11 August 2017, Salou/Vila-Seca, Spain, 217-221.
Fang L, Thomas M, Hendriks WH, van der Poel AFB, 2019. Anim. Feed Sci. Technol., submitted.
Fernandez SR, and Parsons CM, 1996. Poult. Sci. 75:224-231
Karasawa Y, 1999. J. Exp. Zool. 283, 418-425.
Khoa M., 2007. PhD Thesis dissertation, Wageningen University, The Netherlands, 141 p.
Kilburn, J, Edwards, Jr, H, 2001. Br. Poult. Sci., 42, 484-492.
Klein S, Thoraval Y, Mathiaud A, Mansuy E, 2019. Proc. 11th JRAPFG, Tours, 25-26 March 2015.
Kwakkel RP, Moquet PCA, 2013. Proc. Curso de Especialización FEDNA. Madrid, Spain. 103-110.
Mottet A, and Tempio G 2017. W. Poult. Sci. J., 73, 245-256.
Niknafs S, and Roura E. 2018. Nutr. Res. Rev., 31:2, 256-266.
Owens, B, McCann, MEE, McCracken, KJ, Park, RS, 2009. Br. Poultr.Sci., 50, 1, 103-122.
Penz AM, 2017. Proc. 21st Eur. Symp. Poult. Nutr, Salou/Vila-seca, Spain, 144-147.
Persyn KE, Xin H,, Nettyleton D, Ikeguchi A, Gates, RS, 2004. ASEA, 47 (2), 591-596.
Picard M, Le Fur C, Melcion JP, Bouchot C, 2000. INRA Prod. Anim., 13 (2), 117-130.

Ruhnke I, Röhe I, Krämer C, Goodarzi Boroojeni F, Knorr F, Mader A, Schulze E, Hafeez A, Neumann K, Löwe R, Zentek J, 2015. Poultr. Sci., 94: 692-699.

Qaisrani SN, Moquet PCA, van Krimpen MM, Kwakkel RP, Verstegen MWA, Hendriks WH, 2014. Poult. Sci., 93 (12), 3053-3064.

Rodrigues I and Choct M 2018. Poultr. Sci., 97:9, 3188-3206.

Rose SP, Tucker LA, Kettlewell PS, Collier JDA, 2001. J. Chem. Sci., 34, 181-190.

Scott T, 2007. Proc.16th Eur. Symp. Poult. Nutr., 26-30 August, Strasbourg, France. 447-454.

Singh Y Amerah AM, Ravindran V, 2014. Anim. Feed Sci. Technol., 190, 1-18.

Smith JA 2011. Poult. Sci. 90:2670-2678.

Svihus B, 2011. Anim. Prod. Sci., 51, 583-589.

Tahir M, Shim MY, Ward NE, Westerhaus O, Pesti GM, 2012. Poult. Sci., 91, 2540-2547.

Tallentire CW, Leinonen I and Kyriazakis I, 2018. Sci. Rep., 8, 1168-1178.

Tang P, Patterson PH, Puri VM, 2006. J. Appl. Poult. Res., 15: 564-573.

Thomas M, Vrij M, Zandstra T, van der Poel AFB, 2012. Anim. Feed Sci. Technol., 175, 182-192.

Thomas M, Hendriks WH, van der Poel AFB., 2018. Anim. Feed Sci. Technol., 240, 11-21.

Van Barneveld RJ, Graham H, Diffey, 2018. Anim. Prod. Sci., 58, 709-718.

Van Krimpen, MM, Kwakkel, RP, van der Peet-Schwering, CMC, den Hartog, LA, Verstegen, MWA, 2009. Poult. Sci., 88 (4), 759–773.