RECENT ADVANCES IN ENERGY AND PROTEIN EVALUATION OF POULTRY AND PIG FEEDS

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Introduction

The cost of feed is the most important cost in pig or poultry (meat, egg, etc.) production (#60-70%); the energy component represents the greatest proportion (>80%) of that cost; while protein and minerals (phosphorus mainly) supplies in feed are much less expensive but crucial for performance of animals and levels of wastes and potential pollutions in the environment. Therefore, it is important to estimate precisely the nutritional value (energy, protein, phosphorus) of feeds, either for least-cost formulation purposes (i.e. ingredients) or for adapting feed supply to energy and nutrient requirements of animals (i.e. complete feeds). In addition, in the general context of increased prices of ingredients and increased demand of human food and industry usage (biofuels, etc.), new and alternative feed ingredients and also new technologies (enzymes, for instance) will be used. Such changes must be quantified precisely in terms of nutritional values in order to obtain a representative hierarchy between feeds. Accurate, easy-to-use, ethically acceptable and cheap methods for such evaluations should also be proposed. The objectives of this paper are then to present the most recent methods and concepts for estimating the energy and protein values in both pig and poultry feeds. Some gaps, uncertainties and perspectives on this topic will also be given.

Energy evaluation

Not all gross energy (GE) of a feed is available for meeting the requirements of animals since variable proportions of GE are lost in excreta (faeces and urine), as fermentation gases (methane, hydrogen) and as heat (or heat increment; HI). The digestible energy (DE) content of a feed (in pigs) is equal to its GE content minus faecal energy losses, the latter ones being directly related to the levels of dietary fibre in the feed in both pigs and poultries. The metabolizable (ME) content of a feed corresponds to the difference between the DE content and energy losses in urine and gases. Urinary energy is directly dependent on dietary N content. Most of the energy lost in gases is due to methane production, which typically is very small in growing pigs and poultry; therefore, most ME values in literature and tables for growing pigs and poultry ignore energy losses as methane. As illustrated by Le Goff et al. (2002), methane energy losses should be considered in adult pigs. Unlike protein and amino acids evaluation (see below), most energy values do not consider energy losses related to the gut activity (i.e. endogenous losses) and DE and ME values are then apparent values (ADE, AME). In the case of poultry, it is common to consider that digestible N is totally excreted as uric acid and then the ME values are adjusted/corrected for a zero N balance (MEn), even though that option is unrealistic, not based on sound arguments and not representative of the vast majority of the consumed poultry feed. In pig feeds, ME values as measured in growing animals (i.e. with a positive N balance) are used and adjusted or standardized (MEs) for realistic and practical N balance values (50% of digestible N, for instance; Noblet et al., 2004). That standardization is particularly important for high crude protein (CP) ingredients (oil meals, etc.).

Energy digestibility increases with body weight (BW) increase in pigs (Noblet et al., 1994; 2013) with the highest difference between adult pigs (i.e. reproductive sows) and young growing pigs (Le Goff and Noblet, 2001). Similar but smaller variations of energy digestibility with BW are observed in poultry (broiler and adult rooster, for instance) but, in that latter case, differences are also observed between poultry species (Cozannet et al., 2010). The practical consequences of these variations is that DE (pigs) or ME (pigs and poultry) values should vary with BW or physiological stage in pigs and between species in poultry. That is implemented in most feeding tables for pigs (Sauvant et al., 2004; EvaPig software; FEDNA, 2010; Brazilian tables, 2011) with one value applicable to piglets and growing pigs and one value for reproductive sows; some non-public tables have even proposed 3 or 4 values for the different stages of production. Unfortunately, this concept which has important technical and economic consequences for the nutrition of (pregnant) sows has not been implemented in the recent NRC (2012) feeding tables. In the case of poultry species, most feeding tables provide only one ME value, either obtained in adult rooster or in growing broiler; the concept and the methodologies for measuring this ME value (apparent ME, AME; true ME, TME; Sibbald, 1982; Bourdillon et al., 1990) may also differ between sources; the correction for a zero N balance is usually applied. Despite this variability in concepts between tables, most recent editions of feeding tables (Sauvant et al., 2004; Brazilian tables, 2011) propose AME or AMEn values obtained in growing broilers, which is representative of the feed consumed in practical situations. From that point of view, the tables based on the TME concept (NRC, 1994) should be used with caution.

The efficiency of utilization (k) of ME for net energy (NE) varies with the type of production (maintenance, growth, protein gain, fat gain, etc.) and the composition of the feed. The variations with feed composition are due to low k values for ME provided by protein and dietary fibre and higher values for starch and fat, justifying the superiority of a NE system for evaluating the energy content of a feed and a better prediction of the animals performance. In the case of growing pigs, Noblet et al. (1994) obtained k values of 60, 60, 82 and 90% for ME provided by protein, dietary fibre, starch and fat, respectively; they also proposed NE prediction equations that are applicable at any stage of production for both ingredients and compound feeds (Noblet and van Milgen, 2004). A similar ranking of k values of nutrients is suggested for poultry (Carré et al., 2014) but the extent of the differences between nutrients would be smaller and these data require further confirmation. Consequently, for poultry feeds, the NE concept is not yet used in feeding tables and in practical formulation while most recent feeding tables for pigs and formulation are based on the NE concept (Sauvant et al., 2004; FEDNA, 2010; Brazilian tables, 2011; NRC, 2012) and most important countries and industries in the pig sector have moved (or are moving) their energy evaluation systems from DE or ME to NE. This transition is favoured by the high variety of ingredients available for pig feeds with subsequent variable k values and the high constraints for low N content in pig feeds. Further details on the methodologies, justifications and difficulties related to the NE concept in pigs and poultry have been given by Pirgozliev and Rose (1989), Noblet and van Milgen (2004) and Noblet (2015).

More and more technologies such as pelleting or extrusion or the supplementation with enzymes are used in the preparation of pig and poultry feeds. These technologies have usually a positive effect on nutrients and energy digestibility of feeds (Le Gall et al., 2009; Noblet and van Milgen, 2014) and their costs should be compared with the improvements in nutritional value. Unfortunately, these effects are documented for only a few ingredients and, unfortunately, they are not additive. Consequently, these effects are not yet considered in feeding tables and, quite rarely, in formulation.

In conclusion, the energy value of feeds for pigs is usually based on the NE concept with at least 2 values, one for piglets and growing-finishing pigs and one for reproductive sows. Mean values for most ingredients used in pig feeds are proposed in feeding tables (Sauvant et al., 2004). However, the ingredients used on a day to day basis may differ from those proposed in feeding tables. It is then important to adjust or correct their energy value for the actual composition. Using the EvaPig software is an option for such adjustments. However, the best adjustment in terms of accuracy, cost, rapidity, etc. will come from the near infra-red spectroscopy (NIRS) methods that will represent a major progress when compared to wet chemistry or *in vitro* techniques (Bastianelli et al., 2014). That should be an important area of research for practical applications. The further inclusion of the effects of technologies (pelleting, enzymes, etc.) on energy value in such NIRS techniques represents an additional challenge. Most challenges and perspectives listed for energy value of pig feeds apply also to poultry feeds; in addition, the differentiation between poultry species should be considered and further research is required to demonstrate and document the interest of a NE system for broilers feeds.

Protein evaluation

It is now widely accepted that the total amino acids (AA) content of feeds is an insufficient predictor of the protein value for pigs and the nutritional availability of AA is highly preferred. The reference technique for measuring the bioavailability of AA is the growth assay, in which the processes of digestion, absorption and metabolic utilization are considered together. However, practically and routinely, only the digestion stage is quantified and based on the digestibility of amino acids at the end of the ileum (or ileal digestibility) since only AA absorbed before the end of the ileum are usable for protein synthesis. That is measured in cecectomized birds (Payne et al., 1971) or pigs fitted with an ileo-rectal anastomosis or an ileal cannula (Laplace et al., 1994). But, apparent ileal digestibility values obtained from the total collection of amino acids at the end of the small intestine ignore the origin - endogenous or exogenous - of the undigested nitrogen (N) or AA that appear at the end of the small intestine. In fact, it has been shown that losses of N or AA at ileal level include a basal or endogenous loss that is independent on dietary protein content and more related to dry matter intake; the rest of ileal AA loss corresponds to the undigested AA of the feed (and some specific AA losses due, for instance, to antinutritional factors). It is then preferable to subtract this basal loss from the total N or AA ileal loss in order to consider only what is related to the dietary protein fraction of the feed; the basal endogenous loss is usually estimated by feeding a protein-free diet or simply estimated from literature data (Noblet et al., 2004). The "true" or "standardized" digestibility (SID) of AA is then calculated and this value is constant whatever the dietary N or AA levels. In addition, the standardized digestibilities of AA of ingredients are additive. Despite differences in the methods for feeding the birds (force-feeding vs. etc.) or the pigs during the digestibility trials, for the surgery preparation (anastomosis vs cannula vs etc.) or for the collection of excreta (total vs marker vs slaughter vs. etc.), there is now a general consensus for using SID values of AA for estimating the protein value of poultry or pig feeds (Stein et al., 2007); however, attention should be paid to the techniques when combining and compiling data of different origins. Anyway, most recent feeding tables are based on this SID concept for estimating the protein value of pig or poultry feeds (Sauvant et al., 2004; FEDNA, 2010; Brazilian tables, 2011).

As for DE but to a smaller extent, SID values of AA may be unable to estimate the availability of AA (or "true" protein value) in some ingredients or compound feeds. This question has been raised a long time ago, at least for pigs (Batterham et al., 1990), and usually in the case of feeds that have been heat-treated or heat damaged. In that case, some AA (lysine, arginine) are apparently absorbed but not in a form that can be used for later protein synthesis. That point has become more critical with 1/ the increased production of heat treated co-products such as DDGS in animal feeds and 2/ the fact that the most damaged AA is lysine (Cozannet et al., 2010) that is usually the 1st limiting AA in most diets. Methods for differentiating the different forms of lysine and/or their ability to be absorbed and used for protein synthesis are welcome; as for energy evaluation, NIRS techniques should be suitable for rapid and cheap evaluations.

In practice, it is then highly recommended to use SID values to estimate the protein value of a feed and to meet the requirements that correspond then to the sum of requirements for "maintenance" (or basal loss) and for protein deposition. Unlike energy, there is no evidence for using different protein values in growing-finishing pigs and reproductive sows. Similarly, the available data do not allow the use of different protein values in the different poultry species or stages of production. As for energy, the impact of technologies (pelleting, heat treatment, enzymes, etc.) is insufficiently documented for taking into account their effects on the protein value and subsequent formulation. More knowledge on this topic is welcome. Finally, the digestible AA contents in the feed materials considered in the feeding tables are fixed values that do not apply systematically to the same ingredient with a different chemical composition. However, it can be considered that the amino acid composition of the proteins of a given ingredient is constant and so are the SID values of AA.

In conclusion, the change from total AA content to SID AA level has led to a better estimate of the "true" protein value of feeds for monogastric animals; this change offers possibilities for reductions of the safety margins in feed formulation. Uncertainties remain about the effects of technological treatments (particle size, heat, enzymes, etc.) and anti-nutritional factors on ileal digestibility and/or ileal loss of amino acids. Improvements in methods of evaluation are also recommended in order to save time and costs induced by *in vivo* measurements and amino acids analyses. NIRS approaches based on important *in vivo* data base for calibration are welcome.

Conclusions and perspectives

This short review indicates that NE is a better predictor than DE or ME of the "true" energy value of poultry or pig feeds. In pigs, NE systems should be implemented for getting a reliable prediction of performance of animals, especially when quite numerous and variable ingredients are available. The system proposed by Noblet et al. (1994) implemented in feeding tables by Sauvant et al. (2004) or in the EvaPig software (www.evapig.com) has been used internationally. In the case of poultry, literature is less clear with no convincing advantage of a NE system over a ME system for predicting the performance of broilers; further investigations are necessary to evaluate the potential interest of a NE system for poultry. Whatever the energy system, most attention should be paid to the accurate estimation of DE or ME values, which are the most important factors of variation of the energy value of poultry or pig feeds. The lack of comprehensive information on the effects of technology (e.g., pelleting, extrusion, enzymes addition) or about the differences in digestion between poultry species or physiological stages (growing vs. adult, etc.) is a major limiting factor for getting accurate estimates of energy values for pigs or poultry. Improvements in energy evaluation will also come from proposals for rapid and non-invasive prediction methods such as *in vitro* or NIRS methods. Most conclusions and perspectives on energy also apply to protein but the factors of variation such as BW or even technologies have smaller or negligible impacts with a clear consensus on the SID concept. The specific situation of lysine in heat treated ingredients deserves some attention. Overall, the improvements in energy and protein evaluation of feeds will contribute to a precision nutrition approach; even most of the challenge for precision nutrition will concern the animal's requirements side with its high variability within a pen, a herd, etc.

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