Metabolic utilization of energy in monogastric animals and its implementation in net energy systems

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Abstract

The evaluation of the energy content of feeds for monogastric animals has been most commonly based on their DE or ME contents. However, the closest estimate of the 'true' energy value of a feed should be its NE content, which takes into account differences in metabolic utilization of ME of nutrients. This review considers first some methodological aspects of NE determination with emphasis on the impact of feeding level on fasting heat production and subsequent calculation of NE value. Experimental data indicate that the NE/ME ratio varies greatly with the chemical composition of diets and nutrients (fat>starch>protein=fibre) and NE systems are then better in predicting the performance of monogastric animals. However, literature data also suggest that the impact of moving to a NE system would be more important and therefore more justified for pigs and veal calves than for poultries. In any case, the accuracy of the NE value is highly dependent on the accuracy of measuring DE or ME values or the content of digestible nutrients.

Introduction

The cost of feed is the most important cost of meat production from monogastric animals (~60%) and energy represents the greatest proportion of this cost. Therefore, it is important to estimate precisely the energy value of feeds, either for least-cost formulation or for adapting feed supply to the energy requirements of animals. Evaluation of the energy content of feed for monogastric animals has been most commonly based on the DE or ME contents. However, the closest estimate of the 'true' energy value of a feed should be the NE content, which accounts for differences in metabolic utilization of ME of nutrients for maintenance and production. In addition, NE is the only system in which energy requirements and diet energy values are expressed on a basis that is theoretically independent of the feed characteristics. In several parts of the world, NE systems have been implemented, especially for pigs. However, NE systems are used very little for poultry or veal calves. The objective of this review paper is to consider recent contributions regarding the efficiency with which ME is used in pigs, poultry and veal calves while focussing on growing animals. More complete information can be obtained in recent reviews (Pirgozliev and Rose, 1999; Noblet and van Milgen, 2004; Noblet, 2006). It should be kept in mind that the ultimate energy value of a feed for any monogastric animal depends on the chemical composition of the feed, animal factors such as body weight, physiological stage or species, and technological factors such as particle size, pelletting, extrusion or the addition of enzymes that affect primarily the digestion of nutrients and energy. This latter aspect of feed energy evaluation will not be considered in the current review (Noblet and Le Goff, 2001; Noblet and van Milgen, 2004).

Methodological aspects

Not all gross energy (GE) of a feed is available for meeting the requirements of animals since variable proportions of GE are lost in faeces, in urine, as fermentation gases (i.e. methane, hydrogen) and as heat increment (HI). The DE content of a feed corresponds to its GE content minus faecal energy losses after digestion in the digestive tract. Even though related to digestion, energy losses as gas and heat originating from hindgut fermentation are not considered in the calculation of DE. The ME content of a feed corresponds to the difference between the DE content and energy losses in urine and gases. Most of the energy lost in gases is due to methane production, which is negligible in poultry and milk-fed veal calves, very small in growing pigs (<0.5% of GE) and significant (1-3% of GE intake) in adult sows (Le Goff *et al.*, 2002) or veal calves receiving solid feed in addition to milk (3-9% of GE from solid feed, Labussière *et al.*, 2009a). Most ME values reported in the literature and in feeding tables for monogastric animals ignore energy losses as methane.

Net energy is defined as the ME content minus HI associated with feed utilization (i.e. the energy cost of ingestion, digestion, and metabolic utilization of ME) and the energy cost corresponding to a 'normal' level of physical activity (Figure 1). The NE/ME ratio (or k) corresponds to the efficiency of ME utilization for NE. The NE/ME ratio also corresponds to 1-(HI/ME). However, the HI/ME ratio of a given feed is not constant over a large range of ME intakes for a given animal and depends on several physiological factors. For instance, the HI is lower for ME supplied below the maintenance energy requirement than for ME supplied above maintenance (Noblet *et al.*, 1993; 1994a,b; Birkett and de Lange, 2001). The HI is also lower when ME is used for fat deposition compared with protein deposition (Noblet *et al.*, 1999). As the proportion of fat deposition typically increases more rapidly than the protein deposition with increasing ME intake, the HI/ME should, at least theoretically, be lower at higher levels of ME intake. Therefore, to compare different feeds for HI or the efficiency of ME utilization, it is necessary to calculate these values under similar conditions, at protein and amino acid supplies meeting the requirement and/or a constant composition of the gain and/or at a given physiological stage.

For a growing animal, NE intake is calculated as the sum of retained energy (RE) at a given production feeding level and the fasting heat production at zero activity (FHP) (Noblet *et al.*, 1994a). This NE value and the corresponding k value then correspond to a combined utilization of energy for meeting requirements for maintenance and growth. The RE is either measured by the comparative slaughter technique or, more frequently, calculated as the difference between ME intake and HP estimated by calorimetry. The FHP is either measured directly in fasting animals or obtained from literature data. It can also be calculated by extrapolating HP measured at different feeding levels to zero ME intake (Figure 2; FHPr). However, the latter method, even though it has been widely used in the past, has important limitations. First, it consists of extrapolating HP measured at feed intake levels typically

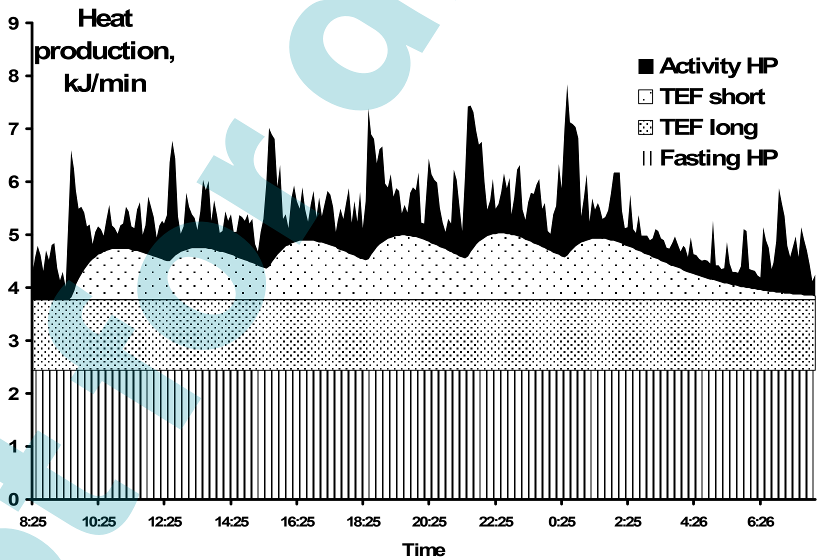

Figure 1. Dynamics of components of heat production in a group of broilers (1 kg BW) fed six meals per day. Measurements were obtained by indirect calorimetry both in the fed and fasting state (INRA data; HP: heat production; TEF: thermic effect of feed).

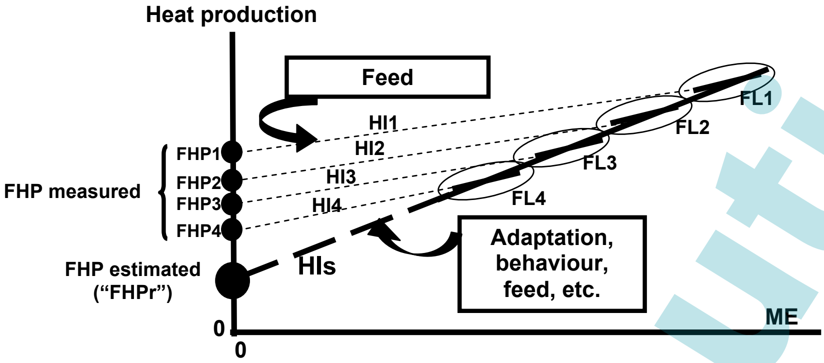

Figure 2. Schematic representation of the effect of feeding level (FLi) on heat production and fasting heat production (FHP) in monogastric animals; each FHPi corresponds to the FHP measured on animals receiving the FLi during the immediate previous period; FHPr (s for statistical) is obtained from the regression between HP and ME and calculated as HP at zero ME intake and the slope is the 'statistical' heat increment (HIs); the slope between FHPi and HPi corresponds to measured heat increment (HIm) (adapted from Koong et al.*, 1982, De Lange* et al.*, 2007 and Labussière* et al.*, 2009b).*

ranging between 60 to 100% of *ad libitum* to HP at zero feed intake, with subsequent inaccuracies in the slope and intercept. Second and more importantly, the measured FHP is not constant and is affected by the feeding level prior to fasting, especially in growing animals (Koong *et al.*, 1982; De Lange *et al.*, 2006; Labussière *et al.*, 2008a, 2010). Apparently, the animal adapts its basal energy expenditure to the level of feed intake and/or growth. The latter authors observed that FHPr was markedly lower than measured FHP with subsequent lower values for NE and k value, and a higher HI (Figure 2). They also observed that HI, calculated as HP minus the measured FHP and expressed per unit of ME, is constant for different feeding levels. Furthermore, the degree of adaptation of FHP and HP to feeding level also depends on animal characteristics such as the genotype (Renaudeau *et al.*, 2007). These observations question the use of FHPr as an estimate of FHP for calculating NE values. The direct measurement of FHP according to indirect calorimetry methods immediately after a fed period is highly preferable. If it is not possible to obtain these measurements, literature values of FHP can be used as an alternative. The HP also depends on climatic factors with an increased HP and reduced RE if the animals are kept below thermoneutrality. It is therefore recommended to keep the animals above thermoneutrality to avoid bias in estimating NE and k.

From a practical point of view and to avoid bias in the calculation of NE for different feeds, it is necessary to carry out energy balance measurements in similar animals (i.e. same sex, same breed and in the same body-weight range), to keep these animals within their thermoneutral zone, to minimize variation in behaviour, and to feed the animals at about the same feed intake level with balanced diets so that the animals can express their growth potential. Under these circumstances, an erroneous estimate of FHP will affect the absolute NE value, but not the ranking between feeds. This also means that NE should not be measured in animals fed ingredients for which the chemical characteristics are very different from those of a complete balanced diet.

While measurements of DE and, to a lesser extent, of ME are relatively easy and can be undertaken on a large number of feeds at a reasonable cost, the actual measurement of NE is far more complex and expensive. The best alternative is then to use reliable NE prediction equations established from measurements carried out under similar and standardized conditions. In our laboratory and for pigs, we proposed prediction equations to estimate the NE value of ingredients and complete diets based on DE or ME content, combined with information on chemical characteristics (Noblet *et al.*, 1994a).

Different predictors (i.e. independent variables) can be used originating from measured chemical composition, existing feeding tables or digestibility trials.

Heat production can be measured directly through direct calorimetry, estimated from gas exchanges through indirect calorimetry or calculated as the difference between ME intake and energy gain obtained by the comparative slaughter technique. The latter technique can easily be used in small animals such as poultry, but is much more difficult to perform in large animals. The most commonly used method is indirect calorimetry, which consists of measuring oxygen consumption, and carbon dioxide and methane production. These measurements, combined with the urinary energy production, are then used to calculate HP (Brouwer, 1965). This method also allows measurements over a short period of time (i.e. a few days) with possibilities of combination of measurements at different feeding levels (including fasting) on the same animal without adaptation. Modelling methods can be implemented to partition the total HP between different components, which can be used in the further interpretation of energy balance data (Van Milgen *et al.*, 1997; Figure 1).

In conclusion, the NE value of a feed and the corresponding k value should be evaluated according to standardized and adequate methods. The values are dependent on assumptions (FHP), conditions of measurement (e.g. climate, activity.) and the composition of the energy gain. This means that data on NE and k available in the literature should be interpreted with caution and may not be directly comparable.

Utilization of ME in pigs

Over the last 50 years, several experiments have been carried out by different laboratories to quantify the effect of diet and animal factors on HI or k in pigs (see the review of Noblet, 2006). The most recent and complete study was carried out by INRA with measurements on 61 diets (Noblet *et al.*, 1994a; Noblet, 2006). From their trials and other results, these authors showed that the maintenance energy requirement and FHP in 30-100 kg growing pigs are proportional to $BW^{0.60}$, and not to the commonly used metabolic BW ($BW^{0.75}$) (Noblet *et al.*, 1999). The FHP at thermoneutrality and zero activity averaged 750 kJ/kg $BW^{0.60}$/d and this value was confirmed in later studies under similar conditions (Van Milgen *et al.*, 2001a; Le Bellego *et al.*, 2001; De Lange *et al.*, 2006). On this basis, the efficiency of utilizing ME for NE in growing pigs (k_g) averaged 74% for the 61 diets, but it varied with the chemical composition of the diet (g/kg DM) according to the following equation (Noblet *et al.*, 1994a):

$$k_g = 74.7 + 0.036 \times EE + 0.009 \times Starch - 0.023 \times CP - 0.026 \times ADF \ (RSD = 1.2)^1.$$

A similar equation was proposed for adult sows fed at maintenance energy level (Noblet *et al.*, 1993). The variation in k_g is due to differences in efficiencies of ME utilization between nutrients, with the highest values for fat (~90%) and starch (~82%), and the lowest values (~60%) for dietary fibre (DF) and CP (Noblet *et al.*, 1994a). These values were confirmed experimentally later in our laboratory (Van Milgen *et al.*, 2001a) and are similar to those provided by the Rostock group in fattening pigs (Schiemann *et al.*, 1972). Measurements conducted in pigs having different BW and composition of BW gain suggested that the efficiency of ME for NE was little affected by the composition of BW gain, at least under practical conditions (Noblet *et al.*, 1994b). Similarly, the ranking between nutrients for their efficiencies was similar in adult sows fed at maintenance level and in growing pigs. Finally, the heat increment of using dietary protein for either protein retention or lipid retention appeared to be similar (Van Milgen *et al.*, 2001a), which means that the NE value of dietary CP does not depend on its final utilization.

[1] EE: ether extract, CP: crude protein; ADF: Acid Detergent Fiber.

Utilization of ME in poultry

As for pigs, several trials or theoretical assumptions over the last 70 years have been carried out to quantify the utilization of ME (or digestible nutrients) for NE in poultry (see the review of Pirgozliev and Rose, 1999). Some studies were carried out with unbalanced diets with makes the interpretation of results more difficult. The most comprehensive series of measurements were conducted more than 60 years ago in USA by Fraps (1946) and later by the Rostock group (Schiemann *et al.*, 1972), mainly focussing on feed ingredients. These studies mostly focused on starch, DF and CP with little variation in fat content of diets or feedstuffs. A recent study of Carré *et al.* (2002) was conducted on complete feeds (n=28) fed to 3-5 wk old broilers while varying the nutrient composition of the diets. The comparative slaughter technique was used to quantify energy retention and NE was calculated using a FHP value (500 kJ/ kg $BW^{0.60}$/d) measured in respiration chambers (Van Milgen *et al.*, 2001b). Later studies carried out at INRA suggested that FHP in 0.5 to 3.0 kg broilers was proportional to $BW^{0.70}$ and FHP was estimated at 445 kJ/ kg $BW^{0.70}$/d (Warpechowski *et al.*, unpublished data).

In several literature studies, efficiencies of DE or ME for NE for maintenance and growth (or fattening) in poultry have been quantified, and some of these values are listed in Table 1. As for pigs, the lowest efficiency is observed for CP and the highest for fat. However, the difference between the most extreme values (i.e. CP and EE) appears to be somewhat lower in poultry (65 to 85%) than in pigs (60 to 90%). Another major difference between poultry and pig concerns dietary fibre, which is not digested in poultry (Carré *et al.*, 1990). Consequently, no efficiency value for fibre exists (nor is needed) for poultry. The efficiency values reported by Schiemann *et al.* (1972) were obtained in adult fattening birds which deposited only fat with a subsequent higher average efficiency. From that point of view, the study of Carré *et al.* (2002) is probably more representative of modern broilers production.

An alternative approach to study the effect of diet on the efficiency of ME utilization for NE was tested in recent trials conducted at INRA (Noblet *et al.*, 2007; 2009). The approach consisted in preparing diets focussing in each trial on one specific nutrient (in exchange for starch). The effects of CP, EE and DF contents were evaluated and measurements were made in respiration chambers in group-housed, growing broilers between 3 and 7 weeks of age offered feed *ad libitum*. The summary of these results is presented in Table 2. The most surprising result of these trials is the absence of an effect of dietary CP on HP, HI and NE/ME in broilers. A study conducted simultaneously in pigs and broilers confirmed this major difference between these species (Noblet *et al.*, 2003; Table 4). Table 2 also indicates that the replacement of starch by fat did not result in a significant increase in the NE/ME ratio of the diet, which contrasts with results reported in Table 1. Finally, the presence of high levels of (undigestible) NDF in broilers diets did not change the HP and the NE/ME ratio of the diet. The latter was even numerically higher with the high DF diet. Overall and unlike pigs, these studies suggest that changes in diet composition have little effect on the efficiency of using ME for NE in broilers. The extrapolation of this conclusion obtained on compound feeds to ingredients that differ widely from the composition of a standard diet would need further studies.

Table 1. Efficiencies of ME from digestible nutrients for NE in poultry (%).

Reference	Production[1]	Crude protein	Ether extract	Starch + sugars	Diet
Schiemann *et al.*, 1972	M + fattening	61	84	75	73[2]
De Groote, 1974	M + growth	60	90	75	74[2]
Carré *et al.*, 2002	M + growth	68	84	77	76

[1] M: maintenance.
[2] Assuming that 25, 20 and 55% of ME is provided as CP, EE and carbohydrates.

Table 2. Effect of replacing starch by protein, fat or fibre on heat production and efficiency of using ME for NE in broilers: compilation of INRA data.[1]

Trial	Diets	kJ/kg $BW^{0.70}$/d			NE/ME %
		ME	HP	AHP	
1	18.0% CP	1,609	853	146	75.1
	22.7% CP	1,609	846	153	74.8
2	2.8% EE	1,873	904	141	75.0
	9.7% EE	1,877	901	152	75.7
3	9.5% NDF	1,503	912	170	71.3
	17.7% NDF	1,521	923	175	72.3

[1] Measurements carried out in groups of broilers weighing on average 1.4 kg; the indirect calorimetry method in respiration chambers was used; AHP: Activity heat production; complementary details by Noblet *et al*. (2007) for trial 1 and Noblet *et al.* (2009) for trial 2; trial 3: unpublished data. In trials 1 and 2, the variation in CP or EE content was created by replacement for starch; in trial 3, the increased NDF level resulted from dilution by dietary fibre provided by wheat bran, maize bran and soybean hulls. In trial 1, data have been adjusted for a similar ME intake while observed values are given for trials 2 and 3. None of the differences between treatments within each trial were significant (P>0.05).

Utilization of ME in veal calves

Veal calves commonly behave as monogastric animals with 90% or more of their daily GE provided by milk replacer and not fermented in the rumen. Although some trials on energy metabolism have been conducted in the 70s to 90s, these were not designed specifically to study energy utilization. In two recent experiments (Labussière *et al.*, 2008b; 2009b) conducted with 60-260 kg BW calves receiving milk replacers differing in CP content and at different feeding levels, measured values of FHP (Van Milgen *et al.*, 1997; Figure 1) were proportional to $BW^{0.85}$ and FHP increased with increasing feed intake (+0.28 kJ/kJ additional ME intake, Labussière *et al.*, 2008a). The k value of ME from milk replacer averaged 85% and was not affected by BW (or age) of the animals, composition of BW gain or level of energy intake. The greater k value observed in veal calves compared with those observed in pigs and poultry may be due to the direct deposition of dietary fat as body fat (Van den Borne *et al.*, 2007) and the high digestibility of nutrients, resulting in lower relative weight of the digestive tract and a lower energy cost of digesta transit. In a third trial conducted with calves receiving milk replacer and solid feeds, the efficiency of using ME from solid feed (i.e. a mixture of starch, dietary fibre and protein) varied between 68 to 76% (Labussière *et al.*, 2009a). These values are close to those obtained in pigs and reflect the combined utilization of intestinally digested and ruminally fermented energy in these feeds. Therefore, the use of a NE system to evaluate feedstuffs in veal calves is important when using liquid milk replacers and solid feeds simultaneously.

Comparative utilization of ME in monogastric animals

Except for veal calves that are fed almost exclusively with milk replacers, monogastric animals are usually fed with diets containing cereals, and protein-rich and fat-rich ingredients. These diets have a similar 'profile', even though differences may exist in the protein, fat, starch and dietary fibre content. To compare the efficiency of ME utilization between species, results obtained from our laboratory were compiled and average values are given in Table 3. It is remarkable that the HI (expressed as a % of ME) of 'standard' diets is very similar for growing pigs, broilers and turkeys. As mentioned previously and probably due to differences in diet composition (high fat) and diet structure (liquid and highly digestible), the HI was markedly lower in milk-fed veal calves. It is also remarkable

Table 3. Heat increment (HI) and activity heat production (AHP) in monogastric animals offered feed close to ad libitum *intake.*[1]

Animal category	Feed	HI % ME	AHP % ME	Reference
Growing pig	Standard	25	8-10	Noblet *et al.*, 1994a; Van Milgen *et al.*, 2001a
Growing broiler	Standard	25	8-10	Noblet *et al.*, 2009
Growing turkey	Standard	24	8-14	Rivera-Torres *et al.*, 2010
Veal calf	Milk	16	8-10	Labussière *et al.*, 2009b
	Milk + solid feed	20	8-10	Labussière *et al.*, 2009a

[1] According to the same method described in Figure 1 and for animals kept in cages with moderate physical activity; AHP is a component of HI and has been evaluated according to the information provided by force sensors placed below the metabolism cage (Van Milgen *et al.*, 1997).

that the average and 'minimal' cost of physical activity was similar between species represented about 10% of the ME intake. The estimated cost of activity is minimal because the animals were housed in metabolism cages and the cost of physical activity in a production setting may depend on housing conditions, physiological stage and the feeding level. This result also means that the NE value of feeds for pigs or poultry corresponds to that obtained under conditions of 'minimal' level of activity. An increase in physical activity must be considered as an additional energy requirement.

As the HI of standard compound feeds was similar between pigs and poultry, one may be tempted to use results obtained in one species for another species. Very few comparisons between species of animals fed the same diet have been conducted. However, the example given in Table 4 for growing pigs and broilers fed diets differing in protein content discourages the use of efficiency values across species. In other words, it is not possible to calculate NE values of feeds for different species according to common equations, at least not for pigs and poultry. If a common system can be used for different birds remains to be confirmed.

Table 4. Efficiency of using energy from crude protein in growing pigs and broilers (adapted from Noblet et al.*, 2003).*[1]

Species	Pigs		Broilers	
Dietary protein level	Normal	Low	Normal	Low
Body weight, kg	57.6	57.2	1.47	1.46
Energy balance, kJ/kg $BW^{0.60}$/d				
ME intake	2,564	2,566	1,626	1,642
Heat production	$1,402^{a}$	$1,346^{b}$	862	861
Fasting heat production	735	731	446	456
Heat increment[2]	667^{a}	614^{b}	417	404
NE/ME (×100)	73.9^{a}	75.9^{b}	74.8	75.0

[1] The reduction in dietary CP content consisted of replacing soybean protein concentrate by maize starch with supplementation of amino acids to meet the requirements.
[2] Sum of TEF and AHP (see Figure 1).

Net energy systems

An energy system corresponds to a method of predicting the energy value of compound feeds and ingredients for a given type of animals. It combines a mode of expression with a calculation method. Most NE systems are based on the utilization of ME for maintenance and for growth or fattening and are based on prediction equations taking into account either digestible nutrients or DE (or ME) and some chemical characteristics (see reviews of Pirgozliev and Rose, 1999 for poultry and Noblet, 2006 for pigs). Some systems have been established from measurements on animals (Schiemann *et al.*, 1972; Noblet *et al.*, 1994a; Carré *et al.*, 2002) while others have been proposed based on literature data, biochemical information, and/or theoretical assumptions (Emmans, 1994; Boisen and Verstegen, 1998). An adequate system to express energy values and requirement is important as it typically serves as a reference for express requirements and values for other nutrients (e.g. protein, amino acids, minerals, etc.).

The system proposed for pigs by Noblet *et al.* (1994a) and further developed and validated in subsequent studies (Noblet and van Milgen, 2004, Noblet, 2006) proposes NE prediction equations that are applicable to ingredients and compound feeds and different stages of pig production (Noblet, 2006). As mentioned previously, the efficiency of ME for NE differs widely between nutrients in pigs. Under the assumption that NE represents the best estimate of the 'true' energy value of feeds, the energy values of protein-rich or fibrous feeds will be overestimated when expressed on a DE or ME basis, while fat or starch sources will be underestimated in DE and ME systems (Table 4). Unfortunately, there is no general agreement on prediction equations or systems that can be implemented in poultry nutrition. According to the NE/ME ratios provided by Carré *et al.* (2002) for broilers, the result of moving from ME to NE for estimating the energy value of feeds should be similar to what is observed in pigs (Table 5), but to a smaller extent. However, our experimental results (Table 2) failed to confirm this. There is currently not enough information available to propose a NE system for other monogastric animals, such as veal calves.

It is important to point out that specific and accurate DE (or ME) values or digestible nutrient contents should be used when calculating NE values. For instance, energy digestibility differs between growing pigs and adult sows, with subsequent different NE values of feeds for both stages (Le Goff and Noblet, 2001). In fact, reliable information on digestibility of energy or of nutrients is the most limiting factor for predicting energy values of feeds for pigs or poultry. The lack of comprehensive information on the effects of technology (e.g. pelletting, extrusion, enzyme addition) or about differences in digestion between poultry strains or species, or between physiological stages (e.g. growing vs. adult.) is a major limiting factor for getting accurate estimates of energy values for monogastric animals, irrespective of the energy system used.

Table 5. Relative DE, ME and NE values of ingredients for growing pigs.[1]

	DE	ME	NE	NE/ME, %
Animal fat	243	252	300	90
Corn	103	105	112	80
Wheat	101	102	106	78
Reference diet	100	100	100	75
Pea	101	100	98	73
Wheat bran	68	67	63	71
Soybean meal	107	102	82	60

[1] From Sauvant *et al.* (2004). Within each system, values are expressed as percentages of the energy value of a diet containing 68% wheat, 16% soybean meal, 2.5% fat, 5% wheat bran, 5% peas and 4% minerals and vitamins.

Finally, moving from a DE or ME system to a NE system will affect the ranking of ingredients. This will have technical and economical consequences if the choice of feed ingredients is important and variable over time. This variety in ingredients available for monogastric animals feeds is likely to increase in the near future (e.g. more by-products) due to the competition for feed resources between human nutrition, industry, biofuels and animal nutrition. The use of a NE system would then be even more justified. Furthermore, it has been demonstrated that, at least in pigs, NE systems are better capable to predict performance of (growing) animals than are DE or ME systems (Noblet, 2006). Again, this advantage of NE systems is likely to increase when the chemical composition of diets becomes more variable (e.g. low protein, high dietary fibre).

Conclusion

This review indicates that NE is a better predictor than DE or ME of the 'true' energy value of poultry or pig feeds. Available information for pigs indicates an obvious interest of formulating on a NE basis, and NE systems should be implemented in pig production for getting a reliable prediction of performance. For poultry, the conclusions are less clear and convincing with no demonstrated advantage of a NE system over a ME system for predicting performance. Further investigations are necessary to evaluate the potential interest of a NE system for poultry. The use of two different types of feeds in veal calves (i.e. milk replacer and solid feed) should encourage the development of a NE system. Finally, even though NE is the final objective in energy evaluation of feeds, 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 feeds for monogastric animals.

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