Comparative interests and limits of metabolizable energy and net energy for evaluating poultry and pig feeds

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COMPARATIVE INTERESTS AND LIMITS OF METABOLIZABLE ENERGY AND NET ENERGY FOR EVALUATING POULTRY AND PIG FEEDS

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Summary

The evaluation of the energy content of pig or poultry feeds 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 some methodological aspects of NE determination. Experimental data in pigs indicate that the NE/ME ratio varies greatly with the chemical composition of diets and nutrient, with ratios for fat (90%) and starch (80%) that are higher than for protein and dietary fibre (60%). This has marked consequences on the relative energy values of ingredients according to the energy system that is used. The NE system is also better in predicting the performance of pigs. With regard to poultry, the ranking between nutrients for NE/ME is similar to what is observed in pigs but with smaller differences between nutrients. However, complementary data are required to propose a convincing and functional NE system for poultry. In any case, the accuracy of the NE value is highly dependent on the accuracy of DE or ME values or digestible nutrient contents that are used as predictors of NE values. Overall, there is an obvious advantage in using NE systems for pigs while further investigations are required for implementing a reliable NE system for poultry.

Introduction

The cost of feed is the most important cost of pig or broiler meat production (#60-70%) and the energy component represents the greatest proportion. Therefore, it is important to estimate precisely the energy value of feeds, either for least-cost formulation purposes or for adapting feed supply to energy requirements of animals. Evaluation of energy content of pig or poultry feeds was firstly and most commonly based on their DE or ME contents (only ME for poultry). However, the closest estimate of the "true" energy value of a feed corresponds to its NE content which takes into account differences in metabolic utilization of ME between nutrients. In addition, in a NE system, energy requirements and diet energy values are expressed on a same basis which should theoretically be independent of the feed characteristics. The objectives of this paper are then to present 1/ the available energy systems for pig feeds with emphasis given to NE systems and 2/ the corresponding available data on energy utilization in poultry (broilers). An overview of the methodological aspects of energy evaluation of pig and poultry feeds will introduce the topics.

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 excreta (faeces and urine in pigs), as fermentation gases (i.e., methane, hydrogen) and as heat (or heat increment, HI). The DE content of a feed (in pigs) is equal to its GE content minus faecal energy losses after digestion in the digestive tract. The ME content of a feed corresponds to the difference between the DE content and energy losses in urine and gases in pigs; for poultry, it is simply the difference between feed gross energy and energy losses in excreta and fermentation gases. Most of the energy lost in gases is due to methane production, which typically is very small in growing pigs and poultry and most ME values in literature and tables for growing pigs and poultry ignore energy losses as methane. As illustrated later on, it is not the case in adult pigs (Le Goff et al., 2002). In addition and unlike amino acids evaluation, 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. Finally, in the case of poultry, it is still rather common to consider that digestible N is totally excreted as uric acid and then to adjust the ME values for a zero N balance, even though that situation is unrealistic.

Net energy is defined as the ME content minus HI associated with feed utilization (i.e., energy cost of ingestion and digestion and HI related to metabolic utilization of ME) and the energy cost corresponding to a "normal" level of physical activity. However, the HI of a given feed (as % of ME) depends on several physiological/animal factors and may not be constant over a large range of ME intakes for a given animal. For instance, the HI tends to be lower below than above maintenance energy supply (Noblet et al., 1993; 1994a; 1994b) or when ME is used for fat deposition compared with protein deposition (Noblet et al., 1999). Therefore, for comparing different feeds for their HI or the efficiencies of ME utilization, it is necessary to calculate these values under similar conditions (e.g., feeding levels), at protein and amino acid supplies meeting the requirement and/or constant composition of the gain and/or at a given physiological stage.

While DE (pig) and ME (pig, poultry) contents are rather easy to measure, NE is more complex to evaluate, especially the so-called HI which corresponds to the rate of increase of heat production (HP) per unit of ME intake increase. In practice, the HI is calculated as the difference between HP in a "standard" fed state and HP in a fasting state (FHP) and related to the ME intake in the fed state. For a growing animal, the NE intake is then calculated as the sum of retained energy (RE) at this "standard" feeding level and fasting heat production at zero activity (FHP) (Noblet et al., 1994a; Noblet and van Milgen, 2004; 2013). The corresponding NE value or the efficiency of ME for NE (k as NE/ME) then correspond to a combined utilization of energy for meeting requirements for maintenance and for growth. Different methods are used in order to measure either HP (indirect calorimetry in respiration chambers, for instance; and RE equals ME intake minus HP) or energy gain (comparative slaughter method, for instance). The indirect calorimetry method is the most used, especially for large animals, since it allows measurements over a short period of time (i.e. a few days) and it is far more flexible and informative in order, for instance, to partition the total HP between different components (van Milgen et al., 1997). The value of FHP can be calculated by extrapolating HP measured at different feeding levels to zero ME intake. However, this method, even though it has been widely used in the past and is still used nowadays, has important limitations, mainly because the growing animal adapts its FHP to its feeding/energy level prior to fasting (Labussière et al., 2011) and questions severely the use and meaning of extrapolated HP at zero ME intake for getting an estimate of FHP. Consequently, direct measurements of FHP according to appropriate methods are highly preferable (Noblet et al., 1994a; 2015). In practice, the use of literature measurements of FHP is an alternative solution. Finally, the mode of expression of FHP is also quite critical. In brief and for being practical, it is now accepted that FHP averages 750 kJ per kg $BW^{0.60}$ in growing pigs (Barea et al., 2010) and 450 kJ per kg $BW^{0.70}$ in broilers (Noblet et al., 2015).

From a practical point of view and to avoid bias in the calculation of NE for a series of feeds, it is necessary to carry out energy balance measurements in similar animals (i.e., same sex, same breed and the same body-weight range), to keep these animals in a temperature-controlled environment within their thermoneutral zone, to minimize variation in behaviour, and to feed the animals at the same energy level with balanced diets so that the animals can express their production/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 a single ingredient for which the chemical characteristics are usually quite different from those of a complete balanced diet.

Measurements of DE and ME are easy to implement and can be undertaken on a large number of feeds at a reasonable cost. On the other hand, the measurement of NE is more complex and expensive and cannot then be implemented routinely, either for complete feeds or ingredients. The alternative is to keep measuring DE or ME contents and to use literature NE prediction equations that were obtained from experiments carried out under strict and standardized conditions with DE or ME values as predictors of NE. As illustrated later, the situation is rather operational for pigs; it would not be the case for broilers or poultry.

Energy utilization in pigs

For most pig diets, the digestibility coefficient of energy (DCe) varies between 70 and 90% but the variation is larger for feed ingredients (10 to 100%). Most of the variation of DCe is related to the presence of dietary fiber (DF) which is less digestible than other nutrients (#50% vs 80-100% for starch, sugars, fat or protein) and which also reduces the apparent fecal digestibility of other dietary nutrients such as crude protein and fat. Consequently, DCe is linearly and negatively related to the DF content of the feed (Le Goff and Noblet, 2001; table 1). The coefficients relating DCe to DF are such that DF essentially dilutes the diet, at least in growing pigs (table 1). In other terms, even though DF is partly digested by the young growing pig, it provides very little DE to the animal. Digestibility of energy can be modified by technological treatments. Pelleting, for instance, increases the energy digestibility of feeds by about 1% (Le Gall et al., 2009). However, the improvement is more important for some ingredients such as full fat rapeseed or (high oil) corn for which pelleting improves the digestibility of fat with subsequent marked differences in their DE value between mash and pellet forms (Noblet, 2006).

Table 1. Effect of diet composition (g/kg DM) on energy digestibility (DCe, %), ME:DE coefficient (%) and efficiency of utilization of ME for NE of mixed diets for growth (k_g, %)[a]

	Equation	RSD	Source[b]
1	DCe = 98.3 - 0.090 x NDF	2.0	1
2	DCe = 96.7 - 0.064 x NDF	2.2	1
3	ME/DE = 100.3 - 0.021 x CP	0.5	1
4	k_g = 74.7 + 0.036 x EE + 0.009 x ST - 0.023 x CP - 0.026 x ADF	1.2	2

[a] CP: crude protein, NDF: Neutral Detergent Fibre, EE: ether extract, ST: starch, ADF: Acid Detergent Fibre; RSD: Residual standard deviation.

[b] 1: Le Goff and Noblet, 2001 (n=77 diets; equations 1 and 3 in 60 kg growing pigs and equation 2 in adult sows, respectively); 2: Noblet et al., 1994a (n=61 diets; 45 kg pigs).

Energy digestibility is also affected by animal factors. In growing pigs, DCe increases with increasing BW (Noblet, 2006; Noblet et al., 2013) and the largest effect of BW is observed when adult sows either pregnant or lactating and (close to) ad libitum growing pigs are compared (Le Goff and Noblet, 2001; Le Gall et al., 2009). The difference due to BW increase is the most pronounced for high fiber diets or ingredients. The negative effect of DF on DCe is then lower in adult pigs than in growing pigs (table 1). In the case of adult sows and "60 kg" growing pigs, the DE value is 1.8, 4.2, 6.0, 10.3 and 16.6% higher in sows for wheat, corn, soybean meal, wheat bran and corn gluten feed, respectively (Sauvant et al., 2004). This improvement of energy digestibility with BW is mainly related to an improved digestive utilization of DF (Noblet and Le Goff, 2001). Little information concerning comparative digestibility in piglets and growing pigs is available. Considering that piglets are usually fed low-fiber diets for which the effect of BW is minimized, piglets can, from a practical point of view, be considered as growing pigs concerning the digestive utilization of energy.

The ME content of a feed for pigs is the difference between DE and energy losses in urine and gases (methane). In growing pigs, average energy loss in methane is equivalent to 0.4% of DE intake and is 2-3 times this amount in adult sows. Energy loss in urine represents a variable percentage of DE since urinary energy depends greatly on the urinary nitrogen excretion. At a given stage of production, urinary nitrogen excretion is mainly related to the (digestible) protein content of the diet (table 1). On average, it represents about 4% of the DE value. However, this mean value cannot be applied to single feed ingredients. The most appropriate solution is to estimate urinary energy (kJ/kg feed DM) from urinary nitrogen (g/kg feed DM) according to the following equation (in growing pigs):

Urinary energy = 192 + 31 x urinary nitrogen

with urinary nitrogen representing 50% of digestible nitrogen or 40% of total nitrogen (Noblet et al. 2004).

Net energy is defined as ME minus heat increment associated with metabolic utilization of ME and to the energy cost of ingestion, digestion and some physical activity. The NE content, as a percentage of ME content (k) corresponds to the efficiency of utilization of ME for NE. In the studies of Noblet et al. (1994a) conducted on 61 diets fed to growing pigs, the variations in k were due to differences in efficiencies of ME utilization between nutrients with the highest values for fat (~90%) and starch (~82%) and the lowest (~60%) for DF and crude protein; k as obtained in growing pigs is then directly dependent on diet chemical composition (table 1) with positive effects of starch and fat on k and negative effects of DF and protein. Additional measurements conducted in pigs which differed for their BW and the composition of BW gain suggest that the efficiency of ME for NE is little affected by the composition of BW gain, at least under most practical conditions (Noblet et al., 1994b). Similarly, the ranking between nutrients for efficiencies is similar in adult sows fed at maintenance level and in growing pigs (Noblet et al., 1993). Finally, the heat increment associated with protein utilization, either retained as protein or catabolized, is constant (van Milgen et al., 2001) which means that the NE value of dietary CP is not dependent on its final utilization (deposition *vs*. deamination).

Table 2. Equations for prediction of NE in feeds for growing pigs (NEg; 61 diets; MJ/kg dry matter and % of DM; adapted from Noblet et al., 1994a)

N°	Equation[a]
5	NEg2 = 0.121 DCP + 0.350 DEE + 0.143 ST + 0.119 SU + 0.086 DRes
6	NEg4 = 0.703 DE - 0.041 CP + 0.066 EE - 0.041 CF + 0.020 ST
7	NEg7 = 0.730 x ME - 0.028 x CP + 0.055 x EE - 0.041 x CF + 0.015 x ST

[a] CP: crude protein, EE: ether extract, ST: starch, DCP: digestible CP, DEE: digestible EE, DRes: digestible residue (i.e., difference between digestible organic matter and other digestible nutrients considered in the equation).

The NE measurements conducted on 61 diets by Noblet et al. (1994a) were used to establish prediction equations relating dietary NE to predictors such as DE or ME and chemical indicators or digestible nutrients; the most practical ones have been used for the establishment of the INRA & AFZ feeding tables (Sauvant et al., 2004) or the EvaPig software (www.evapig.com); they are listed in table 2. Comparable equations have been produced by Schiemann et al. (1972) and further adapted in the Dutch feeding tables (CVB).

Energy systems for pig feeds

Apart from direct measurement on pigs, the DE and ME values of raw materials can be obtained from feeding tables (Sauvant et al., 2004; EvaPig; NRC, 2012). The utilization of these tabulated values should be restricted to ingredients having chemical characteristics similar or close to those in the tables. But, practically, the chemical composition and therefore the energy value of most raw materials differ from those listed in the feeding tables. It is then advised to correct the energy value for differences in chemical composition between ingredients proposed in the tables and those actually available for least-cost formulation; the EvaPig tool has been proposed for such a purpose (www.evapig.com). As illustrated in the previous section, DCe is affected by BW of the animals. It is therefore appropriate to use DE and ME values adapted to each BW class. However, from a practical point of view, it is suggested to use two values, one for "60 kg" pigs which can be applied to piglets and growing-finishing pigs and one for adult pigs applicable to both pregnant and lactating sows. The INRA & AFZ feeding tables propose such a differentiation (Sauvant et al., 2004) and the re-calculation of both energy values according to the chemical characteristics of ingredients is possible from the EvaPig software (www.evapig.com). Finally, a rather frequent difficulty in feed evaluation consists in estimating the energy value of compound feeds when their ingredients composition is unknown. The best solution is then to use prediction equations based on chemical criteria (Le Goff and Noblet, 2001; EvaPig) or estimates from near infrared or *in vitro* methods (Noblet and Jaguelin-Peyraud, 2007).

All published NE systems for pigs combine the utilization of ME for maintenance and for growth or for fattening. The system proposed by Noblet et al. (1994a) and applied in the INRA & AFZ feeding tables (Sauvant et al., 2004) is based on NE measurements on 61 diets and the NE prediction equations that have been generated from these measurements (table 2) are applicable to ingredients and compound feeds and at any stage of pig production (Noblet, 2006). It is important to point out that different DE values or digestible nutrient contents should be used in growing-finishing pigs and adult sows with two subsequent sets of NE values. Similarly, reliable information on digestibility of energy or of nutrients is absolutely necessary for an accurate prediction of NE content of pig feeds. In fact, this information represents the most limiting factor for predicting energy values of pig feeds. From that point of view, the lack of comprehensive information on effects of technology (pelleting, extrusion, enzymes addition, etc.) is a major limiting factor for getting accurate estimates of energy values for swine whatever the system used.

Assuming that NE represents the best estimate of the "true" energy value of feeds and according to differences in efficiencies of nutrients ME for NE, the energy value of protein-rich or fibrous feeds is overestimated when expressed on a DE (or ME) basis. On the other hand, fat or starch sources are underestimated in DE and ME systems (Table 3). With regard to NE for pigs, several systems have been proposed over the last 40-50 years. The INRA proposal (Noblet et al., 1994a; 2004) is probably the most advanced system which has been validated by calorimetry measurements (Noblet and van Milgen, 2013) and growth trials (table 4).

As previously mentioned, it is extremely important to use the same energy system for expressing the diet energy values and the animal energy requirements. From that point of view, the only energy system in which the requirements are the most independent on diet characteristics should be the NE system. This is illustrated by several growth trials conducted with variable dietary fat or CP levels that show that the energy cost of growth or the daily energy requirement are independent on diet composition when expressed on a NE basis. On the other hand, on DE or ME bases, the energy cost is increased when CP content is increased or decreased when fat content is increased (Table 4). In other terms, relative to the NE system, the DE and ME systems are less able to predict the performance of growing pigs and reproductive sows.

Table 3. Relative DE, ME and NE values of ingredients for growing pigs[a]

	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
Soybean (full-fat)	116	113	108	72
Wheat bran	68	67	63	71
Soybean meal	107	102	82	60

[a] 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.

Table 4. Performance of growing-finishing pigs according to energy system and diet characteristics [a]

Energy system	DE	ME	NE
Trial 1: Added fat (%)			
0	***100***	***100***	***100***
2	100	100	100
4	99	99	100
6	98	98	100
Trial 2: crude protein content (30-100 kg)			
Normal	***100***	***100***	***100***
Low	96	97	100
Trial 3: crude protein content (90-120 kg)			
Normal	***100***	***100***	***100***
Low	97	98	100

[a] Energy requirements (or energy cost of BW gain) for similar daily BW gain and composition of BW gain; values are expressed relative to the energy requirement (or energy cost of BW gain) in the control treatment (considered as 100; values in bold characters); from Noblet (2006), Wu et al. (2007) and unpublished data.

Most energy recommendations for pigs were obtained according to DE and ME estimates for feeds and conclusions were expressed as DE or ME values. These recommendations were obtained with rather conventional feeds, i.e. cereals-soybean meal based diets whose efficiency of ME utilization in growing pigs is close to 74%. It is then proposed to estimate the NE recommendations (diet energy density, daily energy requirements, components of energy requirements, etc.) as DE or ME requirements multiplied by 0.71 or 0.74, respectively. This proposal is applicable at any stage of pig production, including pregnant or lactating sows, since NE value is calculated for any stage from one single set of equations obtained in growing pigs (Table 2). However, DE or ME or digestible nutrients may differ between stages of production, i.e. growing-finishing pigs *vs* reproductive adult sows, with subsequent different NE values.

Energy utilization and energy systems in poultry

Numerous studies have concerned the digestibility (in fact metabolizability) of energy in broilers or poultry. As for pigs, the main factor of variation of energy metabolizability is the DF content with even more pronounced effects since DF is almost undigested by broilers and the contribution of DF to ME supply is then even slightly negative. The recent paper of Carré et al. (2013) on 28 diets illustrates these observations. In addition, the (apparent) ME value of poultry feeds is frequently corrected for a zero N balance, assuming then that all absorbed amino acids are deaminated; even such a correction eliminates the differences between ingredients due to their different CP contents, it is not representative of the reality for growing broilers, turkeys, etc. and even laying hens that retain 50% or more of the N that is absorbed. Therefore, this correction is questionable.

With regard to NE, several trials or theoretical assumptions over the last 70 years have been carried out to quantify the utilization of ME and its digestible nutrients for NE in poultry (review of Pirgozliev and Rose, 1999). Some studies were performed on ingredients or unbalanced diets with subsequent limitations in the interpretation of the results (cf. methodological section). The most comprehensive series of measurements were conducted in USA by Fraps (1946) and by the Rostock group (Schiemann et al., 1972), mainly focussing on feed ingredients. Unfortunately, most attention in these studies was focused on starch, DF and CP with little variability in fat content of diets or feedstuffs. A recent study of Carré et al. (2014) was conducted on quite variable complete feeds (n=28; 18.0 to 29.8 % CP, 5.6 to 12.3 % fat, 27.4 to 45.9 % enzymatic starch and 8.1 to 20.6 % NDF; expressed relative to DM) fed to 3 to 5 wk old broilers. The comparative slaughter method was used to quantify energy retention and NE was calculated according to a FHP value (500 kJ/ kg $BW^{0.60}$/d) measured in respiration chambers in comparable birds. A small concern in that study originates from an unexplained trial effect that has been included for interpreting the data and may have biased the final results.

As for pigs, literature values on poultry indicate that the lowest efficiency is observed for CP and the highest for fat (table 5). However, the difference between the most extreme values (i.e., CP and EE) appears to be lower in poultry (65 and 85%) than in pigs (60 and 90%). In addition, the values from Schiemann et al. (1972) were obtained in adult fattening birds which are in a physiologically different stage. From that point of view, the study of Carré et al. (2014) is probably more representative of modern broiler production. Preliminary results obtained in Australia (Barekatain et al., 2014) or in the USA (Cerrate Fernandez et al., 2012; Cerrate et al., 2013) on a limited number of diets would confirm these literature data. In addition, the data of Cerrate et al. (2013) indicate efficiencies of ME for NE in broilers that are remarkably close to those obtained in pigs (Sauvant et al., 2004) for a few typical ingredients used in pigs and broilers diets.

An alternative approach to study the effect of diet on the efficiency of ME for NE was tested in trials conducted at INRA (Noblet et al., 2003; 2007; 2009). The approach consisted in preparing diets focussing each time on one specific nutrient (in exchange for starch). The effects of CP, EE and DF contents were evaluated and the trials were conducted in respiration chambers on group housed and *ad libitum* fed growing broilers over the 3rd to the 6th week of age. The methodology allowed to quantify the HP related to physical activity of the birds and potential differences between diets due to changes in their behaviour. The most important results are presented in Table 6.

Table 5. Efficiency of ME utilization of digestible nutrients for NE in poultry (%)

Reference	Production[1]	CP	EE	CHO	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., 2014	M + growth	68	85	78	76

[1] M: maintenance; CP: crude protein; EE: ether extract; CHO: carbohydrates

[2] Assuming that 25, 20 and 55% of ME is provided as CP, EE and CHO

Table 6. Effect of diet composition on heat production and efficiency of ME for NE in broilers: compilation of INRA data[1]

		kJ/kg $BW^{0.70}$/d			NE/ME
Trial	Diets	ME	HP	AHP	%
1	18% CP	1609	853	146	75.1
	22.7% CP	1609	846	153	74.8
2	2.8% EE	1739	884	127	74.3[2]
	9.7% EE	1728	875	143	75.5[2]
3	9.5% NDF	1503	912	170	71.3
	17.7% NDF	1521	923	175	72.3

[1] Measurements carried out in groups of broilers weighing 1.3 to 1.5 kg BW on average for each trial (5 to 8 measurements per diet); 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 is associated with an inverse variation in starch content; in trial 3, the increased NDF level corresponds to a 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).

[2] Values adjusted for the same level of physical activity with the 2 diets

Table 7. Comparative effect of dietary crude protein on energy utilisation 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[2], kJ/kg $BW^{0.60}$					
ME intake	2564	2566	1626	1642	
Heat production	1402[a]	1346[b]	862	861	Fasting
heat production	735	731	446	456	Heat in-
crement	667[a]	614[b]	417	404	
NE/ME (x100)	73.9[a]	75.9[b]	74.8	75.0	

[1] The reduction of dietary CP consists in a replacement of protein from soybean protein concentrate by maize starch with supplementation of amino acids in order to meet the requirements.

[2] Energy balance data should be preferably expressed per kg $BW^{0.70}$ in broilers (Noblet et al., 2015)

The most surprising result of these trials is the absence of effect of dietary CP on HP and NE/ME in broilers; a parallel study conducted in both pigs and broilers confirmed this major difference between pigs and poultry (Noblet et al., 2003; Table 7). Table 6 also indicates that the replacement of starch by fat increased numerically the NE/ME ratio as it can be expected from similar trials in pigs (van Milgen et al., 2001) but this variation was not significant. Finally, the presence of high levels of undigested DF in broilers diets did not significantly change the HP and the NE/ME ratio of the diet. This latter result does not confirm the hypotheses of Emmans (1994) who suggested attributing an energy cost to undigested organic matter for its excretion in order to calculate the so-called "effective" energy. Overall and unlike our previous results on pigs or the preliminary results of Cerrate et al. (2013) in broilers, our studies indicate that major changes in diet composition do not affect markedly the efficiency of ME for NE in broilers. This result also means that the hierarchy between diets or ingredients for poultry would not be markedly affected by the energy system (ME vs. NE). Overall, additional studies conducted with adequately designed diets and discriminating methodologies and statistics are urgently required to solve these discrepancies between studies and to answer the question: is a NE system justified for poultry?

The NE equations from digestible nutrients contents proposed by Carré et al. (2014) represent a new and reliable basis for implementing a NE system in broilers feeds. Their evaluation on other NE data, either complete feeds or ingredients, is required. In a validation exercise conducted by Pirgozliev and Rose (1999), the NE value of a series of feedstuffs as measured by Fraps (1946) was compared to the values calculated according to different NE prediction equations. None of the literature NE systems for poultry was able to accurately predict the NE values measured on the feedstuffs; the biggest discrepancy was observed with the system proposed by Emmans (1994). This exercise might be repeated with the equations proposed by Carré et al. (2014). One may also question the values proposed by Fraps (1946)! Finally, to our knowledge, there is no clear and convincing study conducted on broilers for illustrating the relationship between their performance and the energy intake, either as ME or NE. Again, the preliminary results of Cerrate et al. (2013) suggest that BW gain is better predicted by NE intake than by ME intake; they deserve a confirmation.

Conclusions and perspectives

This review indicates that NE is a better predictor than DE or ME of the "true" energy value of poultry or pig feeds. In pigs, the interest of formulating on a NE basis is obvious and 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. (1994a) and implemented in feeding tables by Sauvant et al. (2004) or in the EvaPig software (www.evapig.com) has been widely 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. For achieving that, most attention should be focused on the impact of dietary fat and protein levels with potential consequences on the relative energy value of fat- or protein-rich ingredients and results in least-cost formulation. Finally, even though NE is the final objective in energy evaluation of feeds, 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, irrespective of the energy system used. Improvements in energy evaluation will also come from proposals for rapid and non-invasive prediction methods such as in vitro or NIR methods (Bastianelli et al., 2015). Finally, even it has not been considered in detail in this review, the change from DE or ME systems to a NE system is usually associated with a shift in diet composition with lower crude protein contents and slightly higher fat levels and therefore different profiles of ingredients used in the diets.

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