Estimation of energy value of feeds for pigs

DIGESTIBLE, METABOLISABLE AND NET ENERGY VALUES OF FEED INGREDIENTS FOR PIGS CAN BE ESTIMATED BY DIFFERENT METHODS. WE PRESENT THE REFERENCE METHODS USED IN THE PREPARATION OF THE INRA AND AFZ FEED TABLES AND, MORE IMPORTANTLY, SIMPLIFIED METHODS TO BE USED FOR INGREDIENTS DIFFERING FROM THOSE PRESENTED IN THESE TABLES OR ABSENT FROM THEM. BY JEAN NOBLET AND GILLES TRAN

In 2002 and 2004, INRA and AFZ published tables of feed composition and nutritive values for the major farm species (Sauvant *et al.*, 2002 ; Sauvant *et al.*, 2004a and 2004b). These tables draw from a large pool of data from INRA, the French Feed Database and the literature. For the pig, the INRA-AFZ tables provide new values of digestible energy (DE), metabolisable energy (ME) and net energy (NE), as well as digestibility coefficients for several nutrients, including amino acids.

A lot of effort was put into the estimation of reliable NE values, as it is now agreed that NE content is the best assessment of the "true" energy value for pigs. As a companion article to the INRA-AFZ tables, the objective of this paper and of the associated spreadsheet (freely available on–line: http://www.inapg.inra.fr/dsa/afz/tables/energy_pig.htm) is to provide users with practical methods – reference methods or simplified ones – to estimate energy values for pigs. The spreadsheet contains all the equations and coefficients necessary to calculate the energy values using the simplified methods.

ESTIMATION OF GROSS ENERGY

The first step in the calculation of the energy value of a feed material is to estimate its gross energy (GE) content, either by measuring it directly with a bomb calorimeter, or by using equations based on its chemical composition. The INRA-AFZ tables provide equations that are either generic or specific to a group of ingredients, based on their common botanical or anatomical origin. The generic equations can be used to predict the gross energy of feeds not listed in the tables when the specific equations do not apply.

ESTIMATION OF ENERGY AND NUTRIENT DIGESTIBILITY

The second step consists of estimating the digestibility of the energy (Ed, %) and of the main components (nitrogen, fat, organic matter). DE is calculated as GE x Ed / 100. The value of Ed is influenced by several factors other than chemical composition, notably technological treatments and pig live weight. The effect of processing could not be quantified due to the lack of available data, so the table values correspond to ingredients in meal form (except for rapeseed where the values are given for the pelleted seeds).

The effect of live weight is simplified by using two physiological stages: the growing pig at 50-70 kg live weight, representative of piglets and up to 150 kg fast-growing pigs; and the adult sow, representative of empty, gestating or lactating sows (Le Goff and Noblet 2001a, b).

REFERENCE CALCULATION METHODS FOR THE GROWING PIG

Energy: in the INRA-AFZ tables, Ed was calculated using equations derived from INRA and literature data and based on one or two chemical parameters. Data from feed materials sharing common characteristics, such as their botanical or anatomical origins, were pooled to obtain specific equations. This approach is illustrated in *Figure 1* for maize products (Noblet and Le Goff, 2000).

Equations were established usually taking crude fibre, NDF or ADF as predictors. Since several comparable equations were available for the same (group of) ingredient(s), Ed values were often calculated as weighted averages of the estimates given by these equations. Another method consisted of predicting directly the DE content of the ingredient from its chemical composition, using the following equation (Le Goff and Noblet 2001a, b and Noblet, unpub-

FIGURE 1- EFFECT OF THE NDF CONTENT OF MAIZE-BASED PRODUCTS ON THE DIGESTIBILITY OF ENERGY IN THE GROWING AND IN THE ADULT SOW

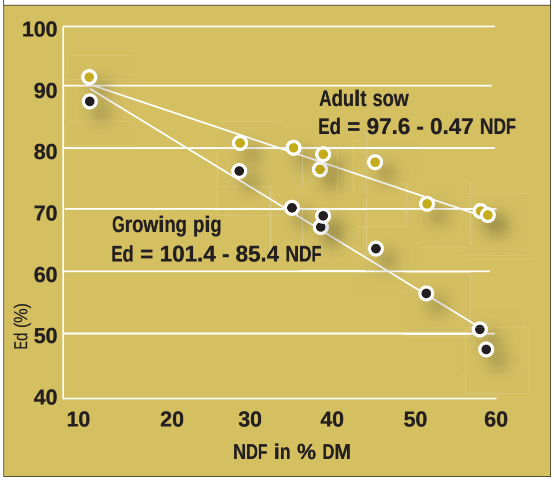
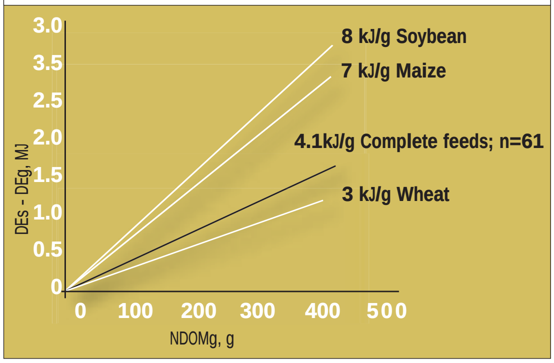


FIGURE 2 - RELATIONSHIP BETWEEN THE DIFFERENCE IN DE CONTENT BETWEEN THE ADULT SOW AND THE GROWING PIG AND THE NON DIGESTIBLE ORGANIC MATTER CONTENT IN THE GROWING PIG.



Jean Noblet (jean.noblet@rennes.inra.fr) is the head of the INRA-Agrocampus Research Unit on Pigs in France.

Gilles Tran (tran@inapg.fr) is the project manager for the AFZ's French Feed Database.

This paper is adapted from: Noblet J., Bontems V., Tran G., 2003. Estimation de la valeur énergétique des aliments pour le porc. INRA Prod. Anim., 16, 197-210.

The authors would like to thank Ajinomoto Eurolysine for its financial support in the adaptation and translation of this paper into English

lished): DE = 0.225 CP +0.317 EE + 0.172 Starch + 0.032 NDF + 0.163 Residue (RSD = 0.35). DE is expressed in MJ/kg of dry matter. All nutrients are expressed as a % of dry matter. "Residue" is the difference between organic matter and the other predictors in the equation. When equations were not applicable, literature averages were used. All the equations are presented in the spreadsheet.

Nitrogen: equations to predict nitrogen digestibility (Nd, %) were established using the same methods as for Ed.

Starch and sugars: these nutrients were assumed to be to be 100 % digestible.

Fat: digestibility data for fat sources are scarce, sometimes inconsistent with each other and above all imprecise for low-fat (< 5 % fat) ingredients. For such materials, the digestible fat content (DEE) was calculated using the following equation (Le Goff and Noblet, 2001a, b):

DEE = 0.82 EE – 0.02 NDF – 0.7 (RSD = 0.33); where DEE, EE and NDF are expressed as % DM. This equation tends to give very low (or even negative) values for fat digestibility when used on low-fat ingredients.

Cell walls: there are few reliable or comprehensive data for cell wall digestibility, so these values could only be estimated indirectly. For this purpose, organic matter digestibility (OMd, %) was estimated from Ed using one of the following equations (Noblet, unpublished):

OMd = 7.0 + 0.955 Ed – 0.05 DCP – 0.03 DEE (RSD = 0.4);

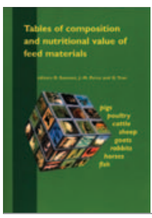
OMd = 7.9 + 0.915 Ed + 0.031 [Starch + Sugars] (RSD = 0.4).

Ed is expressed as %, digestible crude protein (DCP), digestible fat (DEE), starch and sugars are expressed as a % of dry matter. The quantity of digestible organic matter (DOM, g or %) was then estimated.

The difference between organic matter and the sum of crude protein, fat, starch and sugars, that we called "Residue" (Res), was used as an estimate for cell walls. The digestible residue DRes is calculated as follows:

DRes= DOM – DCP – DEE – Starch – Sugars ➣

Digestibility of oils and other high-fat ingredients: EEd, Ed and OMd have been considered to be equal to 85% for both the growing pig and the adult sow. This figure is a literature average and does not take into account the probable (but small) differences due to the variations in fatty acid unsaturation. However, it is not applicable to ingredients rich in free fatty acids, such as acid oils, as their EEd and Ed have been shown to be much lower than this average value (Jorgensen and Fernandez, 2000).



Tables of composition and nutritional value of feed materials for pigs, poultry, cattle, sheep, goats, rabbits, horses, fish. Editors: D. Sauvant, J.-M. Perez and G. Tran. Available in French *www.inra.fr*, English *www.wageningenacademic.com* and Spanish *www.mundiprensa.com.* This book by INRA and AFZ presents the chemical composition and nutritional values of more than 100 feed materials used in the principal farm species. The values of chemical composition were obtained using data collected by the AFZ's French Feed Database from the laboratories of feed companies and R&D organisations. The nutritional values result principally from experimental work performed by INRA and its partners. Important nutritional characteristics have been introduced, including net energy for pigs (growing pigs and sows), amino acid digestibility, mineral availability and starch degradability for ruminants.

TABLE 1 - SIMPLIFIED METHOD OF ESTIMATION OF ENERGY VALUES OF FEED MATERIAL FOR PIGS

GE, MJ/kg DM	Equation (generic or by feed material)
Edg, %	Equation (by feed material) or average value
DEg, MJ/kg DM	GE x Edg / 100
DEs/DEg, %	100 + (a / 100) (100 – Ash) (100 – b Edg)/Deg
DEs	DEg x (DEs/DEg)/100
MEg/DEg or MEs/DEs, %	Coefficients (by feed material)
MEg, MJ/kg DM	DEg x (MEg/DEg) / 100
MEs, MJ/kg DM	DEs x (MEs/DEs) / 100
NEg/MEg or NEs/MEs, %	Coefficients (by feed material)
NEg, MJ/kg DM	MEg x (NEg/MEg) / 100
NEs, MJ/kg DM	MEs x (NEs/MEs) / 100

TABLE 2 - EQUATIONS AND COEFFICIENTS FOR THE WHEAT BRAN (VALUES IN MJ/KG DM, % DM OR % WHERE RELEVANT)

GE = 17.6 + 0.0617 CP + 0.2193 EE +0.0387 CF - 0.1867 Ash
Edg = ((96.68 - 3.792 CF) + (99.39 - 0.921 NDF) + (98.2 - 4.01 CF)) / 3
This is the average of 3 equations: in this case, 2 are based on CF and 1
is based on NDF.
These individual equations can be used instead.
Edg = 96.38 – 3.792 CF
Edg = 99.39 – 0.921 NDF
Edg = 98.2 – 4.01 CF
Ndg = 89.72-2.379 CF
MEg/DEg % = 94.8
NEg/MEg % = 70.8
MEs/DEs % = 93.6
NEs/MEs % = 70.6
DEs/DEg % = 100+(3/100)(100-Ash)(100-1.068Edg)/DEg
a = 3 kJ/g
b = 1.068

Digestibility of synthetic amino acids: their energy content was assumed to be 100% digestible and the DE is therefore identical to the gross energy of the pure amino acid.

REFERENCE CALCULATION METHODS FOR THE ADULT SOW

As the digestibility of energy is higher for the adult sow than for the growing pig, two distinct energy values were used. This difference is related to the botanical nature and quantity of cell walls (Le Goff and Noblet 2001a, b). However, due to the lack of data, Ed for the sow could not be calculated by regression, as for growing pigs. It was also possible to calculate the DE content for the sow from the DE measured or estimated in the growing pig, but only for a few groups of feed materials (wheat, maize, soybean; Noblet and Le Goff 2000 and Le Goff and Noblet 2001a, b); using the same equation for all the ingredients would have led to erroneous corrections.

Further analysis of the data used in Le Goff and Noblet's publications (2001a, b) shows that the difference in DE content between the sow and the growing pig is proportional to the indigestible organic matter content for the growing pig (NDOMg):

DEs - DEg (MJ) = (a / 1000) x NDOMg (g); where a = 4.2 kJ/g or 1 kcal/g on average.

This increase is associated with an additional supply of 0.195 g of DOM, made up of 0.058 g DCP and 0.137 g DRes. A comparison of digestibility measurements in the sow and growing pig shows that the DE increase depends on the ingredients (*Figure 2*) and that the use of NDOMg in the sow depends on the botanical origin of the ingredient, as also illustrated in *Figure 1*.

Values for the "a" coefficient, ranging from 0 to 8.4, were derived from INRA data (Noblet et al., data partially published). Differences in DE, DOM, DCP and DRes content between the sow and the growing pig were calculated from the NDOMg content using the same data. It was assumed that the ratio of 0.195 g of DOM per 4.2 kJ and the repartition of the surplus DOM between DCP and DRes in the adult sow were constant whatever the value of "a". The DE, DOM, DCP, DRes in the adult sow are obtained by adding the calculated differences to the DE, DOM, DCP, DRes estimated in the growing pig.

SIMPLIFIED ESTIMATION OF DE IN THE ADULT SOW

The DEs/DEg ratio is not constant when the chemical composition of an ingredient differs from the one in the tables. The "a" coefficient is specific to a group of feed materials and the estimation of NDOMg is necessary for the Ed calculation in sows. However, in order to simplify the calculations, it can be assumed that the variations in chemical composition of an ingredient do not modify the "b" ratio between OMd and Ed in the growing pig, with OMdg = b x Edg. Therefore: DEs - DEg = (a/1000) x OM x 10 (100 – b Edg) / 100 = a (100–Ash) (100 – b Edg) / 10000; and DEs / DEg, % = 100 + (a / 100) (100 – Ash) x (100 – b Edg) / DEg; with OM and Ash in % of dry matter and Edg in %. DEg is expressed in MJ/kg of dry matter. Values of a and b are listed in the spreadsheet.

ESTIMATION OF METABOLISABLE ENERGY

Reference calculation method: The third step in the estimation of pig energy values is the calculation of the ME as the difference between DE and the energy lost in urine (Euri) and in gas (methane; Egas). Euri depends on the quantity of nitrogen measured in the urine (Nuri) according to the following equations (Noblet, unpublished):

Growing pig: Euri = 0.19 + 0.031 Nuri (RSD = 13);

Adult sow: Euri = 0.22 + 0.031 Nuri (RSD = 13).

Euri is expressed in MJ/kg of ingested dry matter and Nuri in g/kg of ingested dry matter.

The quantity of nitrogen excreted in urine is directly proportional to the difference between the daily supply and the capacity of the pig to incorporate nitrogen into protein. For most stages of pig production, when the supply of protein is balanced for amino acids and corresponds to animal requirements, close to 50% of the digestible nitrogen is retained and the quantity of nitrogen found in the urine thus represents 50% of the digestible nitrogen. This assumption was applied to each feed material and for the level of digestible crude protein estimated according to the methods described above.

The quantity of energy lost as gas (Egas) was calculated using the quantity of fermented cell walls. This was considered to be equal to the DRes value obtained in the nutrient digestibility method. Egas was estimated from a compilation of the data obtained in respiration chambers (Le Goff, 2001): 0.67 and 0.32 kJ per g of DRes in the growing pig and the adult sow, respectively. For feed materials without cell walls or crude protein, such as fats, ME values thus obtained are very close to DE, as confirmed by animal experiments. For synthetic amino acids, that are usually a limiting factor for nitrogen retention, the retention coefficient for the nitrogen supplied by these amino acids is, in practice, higher than that for protein and was assumed to be 65%.

Simplified method

The ME/DE ratio of a feed material, for an average rate of protein catabolism, is assumed to be constant when its chemical composition changes within reasonable limits. It is then possible to simplify the estimation of ME content of feed materials by calculating it as DE x (ME/DE). Values for ME/DE are listed in the spreadsheet.

NET ENERGY ESTIMATION

Reference calculation methods. The last step is the calculation of Net Energy (NE), using equations proposed by Noblet *et al* (1994a), which are applicable to both the growing pig and the adult sow (Noblet *et al*

References

Jaguelin-Peyraud and Noblet (2003). Journées Rech. Porcine en France 35: 75-82.

Jorgensen and Fernandez (2000). Acta Agric. Scand., Section A, 50, 129-136.

Le Goff (2001). Thèse de Doctorat de l'Ecole Nationale Supérieure Agronomique de Rennes.

Le Goff and Noblet (2001a). J. Anim. Sci., 79, 2418-2427.

Le Goff and Noblet (2001b). Journées Rech. Porcine en France 33: 211-220.

Noblet and Perez (1993). J. Anim. Sci. 71: 3389-3398.

Noblet et al. (1994a). J. Anim. Sci., 72, 344-354.

Noblet et al. (1994b). Journées Rech. Porcine en France, 26, 235-250.

Noblet and Le Goff (2000). Journées Rech. Porcine en France, 32, 177-184.

Sauvant et al. (2002). Tables de composition et de valeur nutritive des matières premières destinées aux animaux d'élevage: porcs, volailles, bovins, ovins, caprins, lapins, chevaux, poissons. INRA Editions et AFZ, Paris.

Sauvant et al. (2004a). Tables of composition and nutritive value of feed material: pigs, poultry, cattle, sheep, goats, rabbits, horses, fish. Wageningen Academic Publishers, The Netherlands, INRA Editions and AFZ, Paris, France.

Sauvant et al. (2004b). Tablas de composición y de valor nutritivo de las materias primas destinadas a los animales de interés ganadero: cerdos, aves, bovinos, ovinos, caprinos, conejos, caballos, peces. Ediciones Mundi Prensa, Madrid, Spain.

1994b):

NE2 = 0.121 DCP + 0.350 DEE + 0.143 Starch + 0.119 Sugars + 0.086 DRes (RSD = 0.25);

NE4 = 0.703 DE + 0.066 EE + 0.020 Starch – 0.041 CP – 0.041 CF (RSD = 0.18);

NE7 = 0.730 ME + 0.055 EE + 0.015 Starch – 0.028 CP – 0.041 CF (RSD = 0.17).

Where NE, ME and DE are expressed in MJ/kg dry matter. The chemical constituents are expressed as a % of dry matter.

In the INRA-AFZ tables, the NE value is, for most feed materials, the average of the three NE values obtained using the above equations. For oils, fats and maize starch, only NE2 was used. For synthetic amino acids, it was assumed that the efficiency of ME utilisation was 85% for the fraction fixed in body protein (65% of DE) and 60% for the fraction which was deaminated (35% of DE).

Simplified method

Like the ME/DE ratio, the NE/ME ratio for a given ingredient does not vary much with the chemical composition. The NE can then be calculated as ME x (NE/ME). Values for NE/ME are listed in the spreadsheet.

COMPLETE FEEDS

When the exact formula of a complete feed is known, its energy value can be calculated from the energy values of its ingredients, since these values are additive. When the formula is unknown, its energy value can be estimated from equations based on chemical composition only (Noblet and Perez 1993 ; Le Goff and Noblet 2001a, b) or combining chemical composition and in vitro digestibility (Jaguelin-Peyraud and Noblet 2003). These equations, particularly those relying on chemical composition only, should not be used for feed ingredients. In any case, these estimations are merely indicative of the real values.

SUMMARY

The reference calculation methods were used for the data presented in the INRA-AFZ tables. However, the entire process is relatively complex for routine use. For this reason, the simplified methods, using the equations and coefficients from the linked spreadsheet, have been proposed and they can be used to estimate energy values for feeds with a chemical composition different from those in the tables, or absent from the tables. Whenever possible, one should select a feed material in the INRA-AFZ tables close to the target ingredient from a botanical or anatomical point of view. The simplified process is summarised in *Table 1*. *Table 2* presents the equations and coefficients, using wheat bran as an example. <-