FACTORS AFFECTING NET ENERGY VALUES OF DIETS FED TO GROUP HOUSED AND AD LIBITUM FED GROWING PIGS

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1.- SUMMARY

A newly constructed indirect calorimetry unit makes it possible to determine net energy of diets fed to group housed pigs that are allowed ad libitum access to feed. A number of experiments have been completed in the facility and results have demonstrated that diet crude protein level has less impact on net energy values than previously thought. It is also apparent that the net energy of soybean meal is greater than previously estimated, which may be related to a more efficient amino acid metabolism in modern lean genotypes of pigs compared with older genotypes. The processing procedures used to prepare diets for pigs greatly influence the net energy of diets and the particle size of feed ingredients as well as effects of pelleting should be considered in estimating the energy value of feed ingredients when included in diets for group housed pigs. In conclusion, there are a number of factors that influence the net energy of diets fed to group housed pigs and research in coming years will address some of the gaps in current knowledge about determination of net energy.

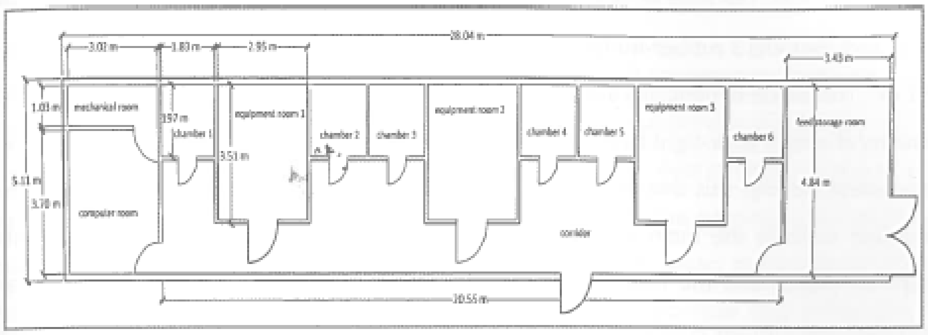
2.- INTRODUCTION

Energy is the most expensive component of diets for pigs and energy concentration in diets plays an important economical role in the swine industry (Kil et al., 2013; Noblet et al., 2022). Therefore, energy requirements by pigs need to be determined with accuracy and need to be met in diet formulation. To estimate energy contributions from feed ingredients, the chemical composition needs to be known. Analysis of gross energy indicates the total amount of energy that a feed ingredient or a mixed diet contains, the digestible energy (**DE**) value shows the amount of energy that is absorbed by the animal, and the metabolizable energy (**ME**) indicates the amount of energy that is metabolized (Kil et al., 2013). Systems based on DE and ME have been widely used in the feed industry. However, net energy (**NE**) of feed ingredients and diets may be more accurate because values for NE include the energy that was lost in the form of heat (Noblet and van Milgen, 2004; Li et al., 2018; Noblet et al., 2022). The most commonly used technique to determine NE is based on indirect calorimetry due to the lower complexity and greater accuracy of this procedure compared with other techniques such as the direct calorimetry method (Blaxter, 1989) or the comparative slaughter procedure (Kil et al., 2013). Net energy values have mostly been determined using individually housed pigs, but because pigs on commercial farms are usually housed in groups, it is believed that NE values from pigs housed in groups may be more accurate. Likewise, commercially fed pigs are usually allowed ad libitum access to feed, whereas pigs in research to determine NE of diets often are restricted in their feed intake, which will impact the energy value that is calculated. The University of Illinois at Urbana-Champaign has, therefore, constructed a facility to determine NE in diets and feed ingredients fed to group-housed pigs that are allowed ad libitum access to feed. The objective of the current contribution is to briefly describe this facility and to detail results of some recent experiments conducted to determine factors that may impact the NE of diets.

3.- BRIEF DESCRIPTION OF THE ILLINOIS SWINE CALORIMETER UNIT

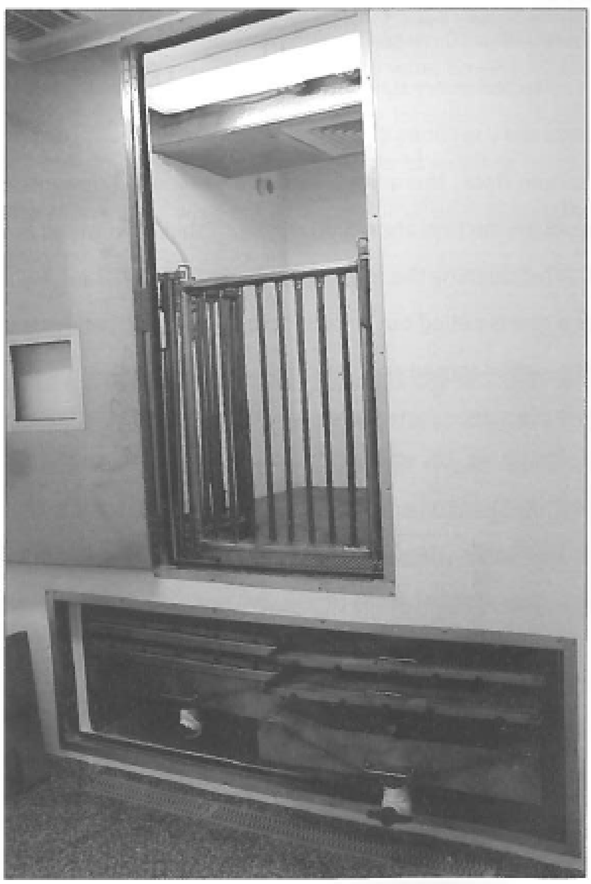
The Illinois Swine Calorimeter Unit is a wood framed construction (28.04 × 5.11 m) that is placed on a steel chassis, with oriented strand board walls, a wood truss roof, and a plywood floor. All surfaces on the inside are coated with sprayed-on plastic for water-tightness. Inside, the unit consists of a feed storage room, an access corridor, 3 equipment rooms, 6 calorimetry chambers, a computer room, and a mechanical room (Figure 1). All rooms are connected by the access corridor and all electronic equipment is connected to the master computer in the computer room. The master computer monitors the operational quality of all equipment and monitors the well-being of the animals.

Figure 1. Layout of the swine calorimeter unit at the University of Illinois



Each of the 6 calorimeter chambers is composed of a main section for animals and a secondary section to collect feces and urine (Figure 2).

Figure 2. Calorimeter chamber with the fecal screens and urine collection pans under the slatted floors



The main section has a volume of 6.5 m^3. The inside dimensions are 1.83 × 1.97 m and the height is 1.8 m. The door of the main chamber is air-tight, has a gasketed surface, is side-hinged, and contains 3 rubber-metal handles for closing. The secondary section has a volume of 3.1 m^3. The inside dimensions are 1.83 × 1.97 m, and the height is 0.86 m. The door of the secondary chamber is air-tight by means of a gasketed surface and has 8 rubber-metal handles for complete closing; this door can be removed to allow collection of feces and urine. The ceiling and walls in the main chambers are constructed from a wood-coated frame with sprayed-on plastic and the floors are galvanized steel modular slotted T-bar floors. An air supply duct and diffuser is located in the ceiling of each chamber, and an air-outlet is located in the side of each chamber to provide the air exchange needed. The chamber contains a stainless steel wet-dry feeder with a capacity of 30 kg. An auxiliary drinker is available in each chamber to ensure free access to water.

The secondary chamber has 4 flat stainless steel wire mesh screens that are placed in parallel and in two rows with a 10 cm separation between screens to avoid sample loss during collection. Feces are collected every day within the 1-hour opening period. During this time, both the main and secondary sections of the chambers are opened. To remove the feces that are present on the screen floor, the animal allocation section is opened, the screens in the upper row in the secondary section are pulled out from their mounting, and the feces on the screen are collected. After cleaning the upper screens and placing them back under the slatted floor, the lower screen row is pulled out to collect the remaining fecal material that may have been voided while the upper screen row was pulled out for collection of feces. The 2 urine pans are placed below the screens and have a total capacity of 100 L. The pans are equipped with a manual valve, which allows for collection of urine from the access corridor. During collection days, valves are opened once per day to collect the urine in plastic buckets. Once the pans are empty, the valve is closed and urine will be captured in the pans. To avoid nitrogen loss from the urine, 125 ml of 6N HCl are placed in the urine pans every day.

All air handling equipment for the chambers is located in the 3 equipment rooms. The equipment includes systems to control temperature and relative humidity inside the chambers, a system for the fresh air supply to the chambers, and systems to analyze air samples for oxygen (**O_2**), methane (**CH_4**), and carbon dioxide (**CO_2**). Because temperature and humidity in each chamber is individually controlled, different temperature and humidity conditions can be maintained in each chamber.

Each of the 3 gas analyzer systems analyzes air from 2 calorimeter chambers using a multiplexer and provides readings of O_2, CO_2, and CH_4 from a subsample of air collected from the chamber return duct. Pumps funnel the air from the return duct to the multiplexer and a sample from the fresh air supply duct is also collected. Before the air stream enters the gas analyzers, it passes through the humidity sensor, which detects water molecules by infrared spectroscopy, generating relative humidity values. The air subsample first enters the CO_2 analyzer, then the CH_4 analyzer, and finally the O_2 analyzer. The gas analyzers provide readings in percentage units.

In conclusion, the Illinois Swine Calorimeter Unit contains systems and equipment that control environmental conditions to maintain temperature and humidity in the comfort zone for animals and thereby limit energy losses in form of heat used for thermoregulation. The floor space allowance in each chamber is equivalent to what is used in commercial conditions, and the ad libitum feeding and drinking supply are intended to maintain normal animal growth. The unit is also equipped with the instruments needed to detect changes in the concentration of gases, which are used to calculate animal heat production and net energy of diets or feed ingredients.

4.- IMPACT OF PROTEIN, LIPIDS, AND CARBOHYDRATES ON NET ENERGY OF DIETS

The three nutrient classes that furnish energy to diets are protein, lipids, and carbohydrates and the levels of each of these three classes of nutrients will, therefore, influence the NE of diets although each class of nutrients differently influence NE. Crude protein contains approximately 5.7 kcal per gram, but if used for energy, the amino acids in the protein need to be deaminated and only the carbon skeleton is used for energy by the body. However, the deamination process itself costs energy and therefore, the NE of using protein for fat is only around 4 kcal per gram (Blaxter, 1989). By using feed-grade crystalline amino acids it is, however, possible to reduce the amount of crude protein in diets and provide a more balanced amino acid supply than if soybean meal is used to supply the majority of the amino acids. Theoretically, this will reduce the amount of excess amino acids that need to be deaminated, and the energy lost via the deamination process, therefore, will be reduced. As a consequence, it has been suggested that diets with low concentration of crude protein have greater NE compared with diets with greater crude protein. However, this perception is based on theoretical calculations and experiments with individually housed pigs, but in a few experiments with group housed pigs where diets based on crystalline amino acids were compared with diets without crystalline amino acids and with more SBM, it was not possible to demonstrate a difference in NE (Muñoz, 2020). Likewise, in a recent experiment with 6 different inclusion rates of crystalline amino acids and corresponding reductions in crude protein, no differences in NE among diets were observed (Table 1).

Table 1. Impact of diet crude protein level on digestible energy (DE), metabolizable energy (ME) and net energy (NE) of group housed pigs allowed ad libitum access to feed and water[1]

Item	Diet crude protein, %:							Contrast *P*-value	
	18.0	13.6	13.1	12.9	11.3	11.5	SEM	Linear	Quadratic
DE in diet, kcal/kg	3,384	3,337	3,335	3,339	3,324	3,330	12	0.381	0.932
ME in diet, kcal/kg	3,310	3,272	3,269	3,273	3,266	3,271	10	0.891	0.909
NE in diet, kcal/kg	2,646	2,605	2,663	2,631	2,665	2,634	47	0.559	0.392

[1] All diets were based on corn and soybean meal, but as dietary crude protein was reduced, inclusion of soybean meal was also reduced, and inclusion of crystalline amino acids increased to maintain the same concentrations of standardized ileal digestible amino acids.

It therefore appears that the hypothesis that low crude protein diets fortified with crystalline amino acids have increased NE compared with diets with greater concentrations of crude protein is not always true when diets are fed to group housed pigs. In agreement with this, results of recent research with both individually housed pigs and group housed pigs indicated that the concentration of NE in soybean meal is greater than previously thought (Table 2), which may further indicate that modern type genotypes of pigs that have a high lean deposition have a greater ability to utilize protein than previously thought.

Lipids have a greater energy value than crude protein or carbohydrates and will furnish around 9.5 kcal per gram. In addition, extracted lipids such as soybean oil or corn oil have high digestibility and therefore a high digestible energy (**DE**) and metabolizable energy (**ME**). There is also a low heat increment associated with metabolism of lipids and some fatty acids may be directly deposited in the body after absorption, which results in a high NE of lipids (Noblet et al., 2001; Kil et al., 2011). There are, however, at this point no data from group housed pigs to document the exact NE value of lipids and more work in this area, therefore, is needed.

Table 2. Estimated values for digestible energy (DE), metabolizable energy (ME), and net energy (NE) in soybean meal, kcal per kg dry matter.

Item	DE	ME	NE
NRC, 2012	4,021	3,660	2,319
Sotak Peper, 2015[1]	4,261	4,044	2,467
Li et al., 2017[2]	4,185	3,848	2,710
Univ. IL, 2023[3]	-	-	2,516

[1] Values for DE and ME were measured in individually housed pigs and represent an average of 22 sources of soybean meal. The NE was calculated from ME (Noblet et al., 1994).
[2] Values determined in individually housed pigs; NE was determined via indirect calorimetry.
[3] Unpublished values from Univ. IL; NE was determined via indirect calorimetry in group housed pigs that were allowed free access to feed.

Carbohydrates in diets can be in the form of sugars, oligosaccharides, starch, or fiber. All carbohydrates contain around 4 kcal per gram, but due to low digestibility, fiber has a lower DE and ME than sugar and starch. The heat increment associated with fermentation of fiber is also greater than the heat increment associated with other nutrients and as a consequence, the NE of fiber is less than that of other nutrients. Therefore, NE values of diets or ingredients high in fiber are typically less than of diets or ingredients low in fiber (NRC, 2012; Table 3).

Table 3. Impact of diet fiber concentration from wheat middlings on digestible energy (DE), metabolizable energy (ME) and net energy (NE) of group housed pigs allowed ad libitum access to feed and water[1]

Item	Wheat middlings, %		SEM	*P*-value
	0	33		
DE in diet, kcal/kg	3,317	3,072	31	<0.001
ME in diet, kcal/kg	3,252	2,981	37	<0.001
NE in diet, kcal/kg	2,539	2,273	32	<0.001

[1] The control diet was based on corn and soybean meal and 2% soybean oil.

5.- PLACEMENT OF WATER SOURCE DOES NOT IMPACT NET ENERGY OF THE DIET

Growing-finishing pigs that are allowed ad libitum access to feed typically have access to either a dry feeder and a water nipple outside the feeder or a wet-dry feeder where the water is placed inside the feeder, giving the pigs the opportunity to mix feed and water as they eat. Sometimes the wet-dry feeder is combined with an outside water nipple as well. In terms of impacting the energy efficiency of consumed feed, there is no impact on the placement of the water nipple and DE, ME, and NE are not different if pigs have access to a dry feeder and an outside water nipple or a wet-dry feeder with a water source inside the feeder or a combination of a wet-dry feeder and a water nipple outside the feeder (Table 4).

Table 4. Impact of water nipple placement on digestible energy (DE), metabolizable energy (ME) and net energy (NE) of group housed pigs allowed ad libitum access to feed and water[1]

Item	Watering option			SEM	*P*-value
	Dry feeder[2]	Wet-dry feeder[2]	Combined[2]		
DE in diet, kcal/kg	3,589	3,577	3,579	13	0.653
ME in diet, kcal/kg	3,471	3,467	3,455	11	0.558
NE in diet, kcal/kg	2,576	2,563	2,575	63	0.983

[1] Pigs were fed a corn-soybean meal based diet with 2% soybean oil.
[2] A water nipple was placed outside the feeder for pigs offered access to the dry feeder and insider the feeder for pigs offered access to the wet-dry feeder. Pigs offered the combined option had a water nipple in the feeder as well as a second nipple outside the feeder.

6.- IMPACT OF FEED PROCESSING ON NET ENERGY OF DIETS

Feed is usually processed before being fed to pigs and this processing may impact the energy value of the diets. As an example, DE and ME is increased as feed particle size of corn or other ingredients is reduced (Rojas and Stein, 2015), which results in increased growth performance of pigs (Lancheros et al., 2020). Likewise, extrusion of feed ingredients increases DE and ME of diets and results in increased growth performance (Rojas et al., 2016; Lancheros et al., 2020; Rodriguez et al., 2020). Recently it was also documented that a reduction in particle size increased NE of field peas when fed to group housed growing pigs (Table 5; Ibagon, 2023).

Table 5. Influence of particle size of field peas on digestible energy (DE), metabolizable energy (ME), and net energy (NE) in field peas, kcal per kg dry matter[1]

Particle size	DE	ME	NE
678 microns	3,586	3,440	2,412
457 microns	3,814	3,751	3,031
265 microns	3,805	3,690	2,971

[1] Field peas were grown and processed in the United States and contained approximately 19% crude protein and 40% starch (89% dry matter basis).

Likewise, in a recent experiment, pigs were fed diets where corn was ground to 700, 500, or 300 microns, and incorporated into a conventional corn-soybean meal diet. Diets were either fed in a meal form or after pelleting at 88.5ºC (Lee et al., 2023). In agreement with results of previous experiments, DE and ME increased as particle size of corn was reduced and the same was the case for NE with the greatest value for the diet containing corn ground to 300 microns. However, regardless of particle size of corn, DE, ME, and NE were greater in the pelleted diets than in the meal diets, and the optimum particle size of corn in pelleted diets appeared to be around 500 microns (Table 6). Based on these results it appears that feed processing in terms of particle size, extrusion, and pelleting independently and in combination can increase the energy value of diets and prediction equations to determine NE of feed ingredients need to take the level of feed processing into account.

Table 6. Impact of particle size reduction and pelleting on digestible energy (DE), metabolizable energy (ME) and net energy (NE) of group housed pigs allowed ad libitum access to feed and water[1]

Item Diet form:	Meal			Pellet				Contrast *P*-value		
Corn particle size, microns:	700	500	300	700	500	300	SEM[2]	Diet form	Particle size[3]	Interaction
DE in diet, kcal/kg	3,459	3,477	3,560	3,599	3,667	3,633	18	< 0.001	< 0.001	< 0.001
ME in diet, kcal/kg	3,385	3,402	3,488	3,535	3,596	3,559	18	< 0.001	< 0.001	< 0.001
NE in diet, kcal/kg	2,735	2,739	2,838	2,857	2,957	2,926	60	< 0.001	0.015	0.004

[1] All diets were based on corn and soybean meal and 1.50% soybean oil.

7.- CONCLUSIONS

Because energy production is affected by interaction among pigs and because commercial pigs are always kept in groups, it is believed that determining NE of diets is best accomplished using group housed pigs. Likewise, the level of feed intake influences energy digestibility and because commercial pigs are usually allowed ad libitum access to feed, NE values should also be determined in pigs allowed ad libitum access to feed. A facility to determine NE of group housed pigs that are allowed ad libitum access to feed and water was recently constructed at the University of Illinois and it is, therefore, now possible to determine NE in group housed pigs. Initial results from work with group housed pigs have demonstrated that modern genotypes of pigs seem to be less impacted by diet crude protein level than older genotypes and the NE of soybean meal appears to be greater than previously estimated. There is however a negative impact on NE of including high fiber ingredients in diets but the placement of water source within the calorimeter chamber does not influence energy digestibility or NE of diets. The possibility of using feed processing to increase NE of diets has also been demonstrated and reduction of particle size in meal diets as well as in pelleted diets results in increased NE, but pelleted diets have greater NE than meal diets. Thus, there are a number of factors that impact the NE of diets fed to growing pigs and future research is needed to generate values that can be used to establish a NE system based on group housed pigs.

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