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Relevance of 'genetics of environmental sustainability' in pig breeding

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Introduction

In a perfect ecosystem humans can eat animal products without disturbing sustainability. Civilization interrupted this system, and livestock production is part of it. Livestock *breeding* can slightly reduce the disruption but cannot solve the full issue. The aim of this contribution is to help the session discussion at WCGALP 2026, exploring genetic solutions across livestock production species. Our objective is to describe the relevance of selection in commercial pig breeding on CO_2 and Nitrogen traits.

CO_2 as such

CO_2 emissions in pigs are directly related to feed efficiency, that is to feed production and to manure. A reduction of fat deposition, of maintenance by increased growth rate, of mortality, and an increase of reproductive performance and of better valued cuts are relevant for economy and for feed efficiency and, hence, for reducing CO_2 emissions. A farrow-to-finish farm-based approach targets total energy efficiency (TEF): the weight of animals sold over total feed energy that entered into the farm. When the focus of farm profitability changes from short-term profit (as in current breeding goals) to medium-term profit including the price of CO_2 credits, two things may happen. First, this just adds to the price of feed which does not change the ranking of traits. Second, the breeding goal traits with the strongest correlations to TEF (i.e. growth rate, feed intake and mortality of growing-finishing pigs) become more important so that they merit more focus in the breeding goal. In dam lines, with their current focus on reproductive performance, complete focus on minimization of CO_2 emissions may result in breeding goals correlated to the current ones by +0.6 (Knap, 2022). Therefore, including costs of carbon emissions might change the relative positions of the causes for the losses but will not change the general direction as indicated by feed efficiency.

Protein and Nitrogen

In pigs and other monogastric species, the main source of CO_2-equivalents is nitrogen dioxide (N_2O) excretion. Hence pig breeding for low CO_2-equivalents should focus on nitrogen and on its main derivative, protein.

Basics. Nine Amino Acids (AAs) cannot be synthesized by the mammalian body and need to be part of the ingredients of the diet or added. The AA composition of plant protein differs from the ideal AA pattern for human nutrition; animal protein fits the human needs much better. Protein must be ingested, broken down to di- and tripeptides and AAs, and transferred through the gut barrier into the blood flow. There are several sources of inefficiency in this process. First, nitrogen digestibility varies from 67 to 83 % across typical pig diets; this is mainly caused by characteristics of the feed ingredients, but it also varies among animals with a heritability of 0.27-0.54 (higher when the feed contains more fibre; Déru *et al.,* 2020). Second, obligatory AA oxidation lowers the net efficiency of metabolization of digested nitrogen to 84-95 % (higher when the animal's protein deposition potential is higher); this is due to body protein

turnover, maintenance of gut epithelium and skin, the use of AAs as precursors of adrenalin, creatinine and serotonin, and the use of AAs not as components of protein but as regulators of protein synthesis (Millward *et al.,* 1990). Hence the utilization efficiency of ingested protein with the ideal AA composition would range from 56 to 79 %, and indeed Remus et al. (2020) achieved Nitrogen Utilization Efficiencies (NUE) up to 65 % with precision feeding in laboratory conditions. When feed protein composition is unbalanced, part of it cannot be used for body protein synthesis and these excess AAs are broken down, resulting in nitrogen being excreted as urea in the urine. Kasper (2024) summarised several studies estimating average NUE between 34 and 40%. FAO (2006) mentioned NUE levels in growing pigs and sows between 17 and 30 %, lower for low-productivity systems. It follows that an increased understanding of nitrogen digestibility and metabolizability may provide further insights into more efficient usage of ingested nitrogen and how to influence it by pig breeding.

Traits and phenotypes. Similar to energy, total *nitrogen* efficiency could be the trait to be maximized. The largest amount of nitrogen excretion occurs during the growing pig finishing phase and the carcass is the end product; then it is logical to focus on these traits, at least for early implementation. Nitrogen intake can be measured using automated individual feed intake and near infrared spectroscopy to assess, if and where needed, protein content in the feed. In a research setting carcass N content can be accurately predicted using technologies such as computed tomography or dual energy x-ray absorptiometry. Thus, carcass nitrogen retention and feed intake of growing pigs in the finishing phase are phenotypes that could *tentatively* be implemented. Alternatively, fecal and urine samples can be analyzed to estimate N-losses, indirectly estimating N-content in the body. For individual animals, NUE equals nitrogen retained in the carcass over nitrogen ingested.

Genetic (co)variation. Heritability estimates of NUE up to 0.5 (Kasper, 2024) offer interesting opportunities for selection. Genetic correlations between NUE and routinely recorded traits such as Feed Conversion Ratio (FCR), Residual Feed Intake (RFI), Average Daily Gain (ADG), and Average Daily Feed Intake (ADFI) were quite variable and mostly favourable except for ADG. Kasper (2024) stated that "… when selecting for NUE it is essential to aim for stable feed intake to counter potential negative effects on nutrient deficiency, particularly under stressful situations during which reduced feed intake may exacerbate challenges". Genetic correlations were unfavourable for intramuscular fat and moisture loss but there are few estimates available (Ewaoluwabemiga *et al.,* 2023). NUE is quite dependent on feed quality (protein content and AA composition), stage of growth and on the animal's age and health. The potential for a genotype x environment or genotype x feeding interaction is one area of concern.

Role of Ad libitum or reduced protein intake on selection approaches. Reduced protein diets have resulted in reduced nitrogen excretion but have also generally reduced pig performance since in many cases the reduced protein diet was simply a reduced percentage of an adequate protein diet relatively to the net energy content. When pigs were High-Low sampled on breeding value (EBV) for protein deposition, nitrogen retention and NUE were higher in the High group on an ad libitum regime but similar in both groups on a 30% restricted regime. This suggests that EBVs for growth potential, CO_2 emission, and NUE may require phenotyping in different nutritional regimes.
An alternative approach of Mulvenna et al. (2025) created three reduced protein diets supplemented with up to three additional amino acids (Tryptophan, Valine and Isoleucine) compared to the control diet (Lysine, Methionine and Threonine supplemented to normal levels). The reduced protein diets resulted in average N intake from 40 to 112 kg live weight

being reduced by 15%, average N excretion reduced 24% but average N retention, ADG, ADFI, FCR were not affected. Similarly, Yang et al. (2023) fed pigs unrestrictedly with four diets with the same net energy content and the same lysine, methionine/cysteine and threonine content but different crude protein and fibre contents. This resulted in a wide range of daily nitrogen intake with decidedly variable responses in the relevant productivity and efficiency criteria. It follows that determination of the correct environment or feeding regimes for data recording for selection is an important issue.

Discussion

Basics. Skeletal muscle has a relatively slow protein turnover rate compared to visceral organs but because it is the main reservoir of total body protein mass it is responsible for ~50% of whole-body protein synthesis (Sarri et al. 2022). Additionally, the finishing phase of the growing period is when pigs have the largest environmental impact. Improved efficiency should however not lead to higher emissions through changes in feed composition

G×E. Where E equals feed in this specific situation. The relevant physiological processes are quite well understood. Assuming that one individual would properly represent the total population, then feeding this population would be a relatively straightforward process for which computer models exist. Genetic selection changes this individual at a rate of roughly 2% per year, which is a considerable change even after 5 years of selection. Genetic change over the past decades influenced animal leanness and protein deposition and therefore the animal's AA requirements; Knap (2024) estimated that the daily lysine requirement of gestating and lactating sows increases each year by 2% of the current mean level; the corresponding value for growing-finishing pigs is 0.6 %. Hence the optimum protein to energy ratio of the feed is changing. Feed intake is quite heavily regulated by energy intake, so the protein content of the feed must follow. Limiting protein in the feed will increase protein digestibility but still decrease protein deposition. Optimization of feed composition to fit the nutritional demands is relevant for optimized growth rate and reduced N-losses. An interesting modelling approach of integrating genetics and nutrition is by Yu et al. (2021), who estimate genetic parameters given a specified feed.

Selection for NUE. While NUE is an easily identified trait for quantifying nitrogen use efficiency it presents issues in a selection program. The usual issues of selecting on a ratio trait exist, plus the high genetic correlation with FCR. Reduced feed intake as a result of FCR selection has occurred and further reductions may not be desirable based on other important traits such as resilience, sow feed intake, etc. Thus, splitting NUE into its components is an option but careful consideration must be given to the relationship between N intake and feed intake since they are inevitably linked. Finally, traits correlated with NUE such as blood urea nitrogen may help to reduce the cost and difficulty of data recording but there is no strong candidate trait at this point. FCR and NUE do not respond equally to a change in protein supply. The same holds for a third efficiency trait, capacity utilization rate (e.g., Christiano, 1981), where the main goal is to ensure that the animal's genetic potential for production is fully supported by its nutrient intake through some combination of voluntary feed intake and feed composition. Livestock breeding will have to find a ppropriate economic weights to integrate these three approaches into a single breeding goal.

Genetics/Genomics. Selection for increased synthesis and reduced breakdown of proteins can help decrease days to market and therefore reduce energy (and CO_2) needed for maintenance. Selection for increased digestibility can help direct transfer of nutritional protein to AA's available for growth (review by Kasper (2024)). Nutritional imbalance in AA's cannot be

solved by animal genetics. Plant genetics might help in this situation. Genome Wide Association Studies for NUE are very limited in the literature. Shirali et al. (2013) identified QTL for nitrogen excretion traits on various chromosomes during the grow-finish period. Four QTL associated with nitrogen excretion were positionally associated with QTL for Residual Energy Intake (REI) suggesting that protein turnover as well as other factors such as metabolism, digestion, etc. play a role in variation in REI and efficiency of feed utilization. In cattle, emphasis is on Milk Urea Nitrogen, also in an attempt to reduce excess N-excretion. It is unclear whether GWAS results will overlap. In the recent past a transgenic pig was developed with an improved ability to digest plant phytate, which decreased the need for P-analogues considerably (e.g. Wang *et al.,* 2020).

Addressing individual needs. Animal populations are not made of clones, there are genetic differences between animals. If breeding values and birth weights are known, sorting of piglets into pen qualities can result in optimized pen feeding. Theoretically individual animal feeding based on EBV's and weight can minimize N-losses and maximize performance. Precision feeding approaches, whereby each individual is fed to its specific needs provides an opportunity to reduce GxE, but is dependent on the accuracy of the nutritional models and the characterization of the nutritional requirements at the genetic level (Dekkers, 2025).

Conclusions

In pig breeding there is little need for added selection against CO_2, because of the high emphasis on feed efficiency. On a global level this is similar for nitrogen. On a local level there can be a clear surplus (or shortage) of nitrogen. Genetic selection for increased protein deposition and increased N-efficiency will be beneficial for pork production and for sustainability but will lead to nutrition with a higher protein to energy ratio. Clear communication between nutrition and genetic change is needed to tentatively arrive at an integrated modelling approach.

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