Assessment of near-infrared spectroscopy to predict diet nutrient digestibility in pigs

K.G.Nirea[1], M. Pérez de Nanclares[1], *A.Skugor[1], N.K. Afseth[2], T.H.E. Meuwissen[1], J.Ø. Hansen[1], L.T. Mydland[1] & M. Øverland[1]*

[1] *Norwegian university of Life Sciences, Department of Animal and Aquacutural Sciences, P.O.BOX 5003, 1430 ÅS, Norway*
Kahsay.nirea@nmbu.no (Corresponding Author)
[2] *Nofima Marine AS, P.O. Box 5010, 1432 Ås, Norway*

Summary

Diet digestibility could be a better measure of feed efficiency when breeding for robust animals that are fed fiber rich diets. The challenge is that measuring digestibility for large number of animals is expensive and complex. However, Near infrared spectroscopy (NIRS) can be used to predict diet nutrient digestibility from the spectra of faeces. The objective of this study was to investigate if diet digestibility can be predicted using faecal NIRS that originate from various pig experimental data sets. Faecal samples together with detailed information on diet digestibility were obtained from four different pig experiments. Faecal spectra were analysed using faecal samples of the complete dataset. The model was calibrated using the faecal spectra and reference samples of diet digestibility. The robustness of the model was evaluated by the closeness between standard error of calibration and validation. Prediction of diet digestibility was successful as the standard error between the calibration and validation dataset was close enough. The calibration model developed to estimate the apparent total tract nutrient digestibility from faecal spectra worked well for organic matter ($R^2 = 0.94$; SEC = 5.5; SECV = 6.7), gross energy ($R^2 = 0.88$; SEC = 2.3; SECV = 2.6) and fat ($R^2 = 0.79$ SEC = 6, SECV = 6.8). However, the standard error of prediction was slightly higher than reported in other studies. Apparent total tract digestibility prediction for crude protein ($R^2 = 0.63$; SEC = 2.3; SECV = 2.7) and neutral detergent fiber ($R^2 = 0.64$, SEC = 7.7, SECV = 8.8) was moderate. We conclude that the faecal NIRS approach is feasible in pig feed efficiency studies for predicting the apparent total tract digestibility of organic matter, crude protein, gross energy and neutral detergent fiber in situations where controlled digestibility trials are not possible.

Keywords: nutrient digestibility, feed efficiency, NIRS, pig

Introduction

Improving diet digestibility improves feed efficiency because diet digestibility is one of the factors that affect feed efficiency. However, quantifying diet digestibility for large numbers of animals as is the case in breeding programs is challenging because it requires internal digestibility markers and chemical analyses which are complex and expensive to measure at a farm level (Arthur and Herd, 2008). In a digestibility trial, digestibility coefficients are often quantified by providing internal or external markers with the diet and digestibility is the proportion of chemical components that are not excreted as a form of faeces. An alternative approach to estimate digestibility based on Near-infrared reflectance spectroscopy (NIRS) was shown to be cost effective and less technically demanding

(Bastianelli et al., 2014; Schiborra et al., 2015). The advantage of NIRS technology is that it enables the chemical and physical properties of diet and faeces samples to be determined from analysis of the spectrum. Obtaining spectral information of the samples only takes a few seconds, which allows large-scale phenotyping at a farm level. Afterwards, the spectral information can be related to both the chemical composition and digestibility of faecal samples. Therefore, once a robust calibration equation is established, only faecal samples are required to assess diet digestibility potential of an animal. For predicting a fully external dataset, a robust calibration equation is necessary. One way to ensure a robust calibration equation is to include animals with a variable genetic background, diets and age groups in the calibration dataset. Therefore, the objective of this study was to assess the possibility of estimating the nutrient digestibility of diet using faecal NIRS that originate from different experiments that involve animals with a different genetic background, diets and age groups.

Material and methods

Faecal samples (198) from piglets, young pigs, and growing-finishing pigs were obtained from four experiments. The experiments were conducted at two different locations. Detailed description of the experiments is given in (Pérez de Nanclares et al., 2017). Chemical analyses of faeces and feeds allowed for the determination of apparent total tract digestibility (ATTD) coefficients for all the analysed nutrients and energy. Apparent total tract digestibility of all individual nutrients and energy was calculated according to the equation (McDonald P, 1998)

$$\text{ATTD (\% of intake)} = [\text{Intake (g)} - \text{Faecal excretion (g)}/ \text{Intake (g)}] \times 100.$$

NIR spectra recorded on the same faeces samples that were used for analysing the chemical components of the faeces. The faeces were scanned at Nofima laboratory between 400 and 2500 nm in 2-nm increments. NIRS spectra between the region of 1105 and 2450 were taken for model calibration. Derivative spectra pre-treatments were applied on the raw faeces NIRS spectra beforehand to optimize model calibration (Naes *et al*., 2002). Calibration models were obtained using partial least squares regression (Wold et al., 1984). Two types of model validation; internal cross validation and external validation were done on the complete dataset. For the external validation, the spectra dataset was randomly split into two groups, the calibration dataset, which contained 158 samples and was used for calibration and the validation dataset (40 samples). In the internal cross validation, the complete dataset was randomly split in to five groups of equal size. Cross validation was performed on five groups, by sequential calibrating on four groups and then validating on the fifth group. The statistical evaluation during model building was done on calibration and on cross validation process (R^2_{cv} and SECV for standard error of cross validation, as stated by Naes et al. (2002). Subsequently, the calibration models were applied to the external validation dataset (40 samples), leading to the determination of R^2_{val} and standard error of prediction (SEP). The slope of the regression line was used to describe the magnitude of closeness between the reference datasets and predicted values, and the bias was defined as the mean of the difference between the reference sample and predicted values (Naes et al., 2002).

Results

Calibration

Statistical parameters for apparent total tract digestibility of the diet cross validation are presented in **Table 1**. High to moderate R^2 of calibration was observed for most of the apparent total tract digestibility coefficients of the diet. The higher R^2 of calibration was observed for organic matter digestibity (dOM) (R^2 = 0.94), followed by gross energy digestibility (dGE) (R^2 = 0.88), fat digesitlbity (dFAT) (R^2 = 0.79). Moderate R^2 of calibration was observed for neutral detergent fiber digestibility (dNDF) (R^2 = 0.65) and crude protein digestibility (dCP) (R^2 = 0.63).
For all the digestibility parameters, the calibration was precise given the high standard deviation of calibration (Table 1). The mean of the calibration data sets (40 samples) was dOM (66.49 g /kg dry matter (DM)), dCP (78.26 g /kg DM), dGE (81.68 MJ /kg DM), dFAT (73.8 g/kg DM).

Table 1. NIRS calibration and cross validation statistical parameters for total tract digestibility in growing pigs.

Components	SEC[1]	R^2_{cal}[2]	SECV[3]	R^2_{CV}[4]
dOM	5.5	0.94	6.7	0.91
dCP	2.3	0.63	2.7	0.51
dGE	2.3	0.88	2.6	0.85
dFAT	6.0	0.79	6.8	0.74
dNDF	7.7	0.64	8.8	0.53

[1] Standard error of calibration
[2] Coefficient of determination of calibration
[3] Standard error of cross validation
[4] Coefficient of variation in cross validation

Validation

For all the digestibility parameters, differences between SECV and SEC was below 22%, with dOM (22%) having the largest difference and the other digestibility parameters had less than 20% difference. For the external validation, the statistical parameters such as SEP, bias and the regression coefficients between the reference and predicted values are presented in **Table 2** and the predicted and reference observations are shown in Figure 1. The bias was very low but higher than reported in the study of Bastianelli et al. (2014). Apart from FAT, the slope was always close to one and substantially not different from 1 (**Figure 1**).

Table 2. NIRS external cross validation statistical parameters for total tract digestibility in growing pigs.

Components	SEP (g/Kg DM)[a]	R^2_{val}[b]	Bias	Slope[c]
dOM	5.5	0.94	-0.6	1.02
dCP	1.9	0.63	0.03	0.81
dGE	2.5	0.87	0.2	0.79
dFAT	6.2	0.77	1.2	0.72

[a] Standard error of prediction
[b] Coefficient of determination in cross validation
[c] Characteristics of regression between predicted and measured values

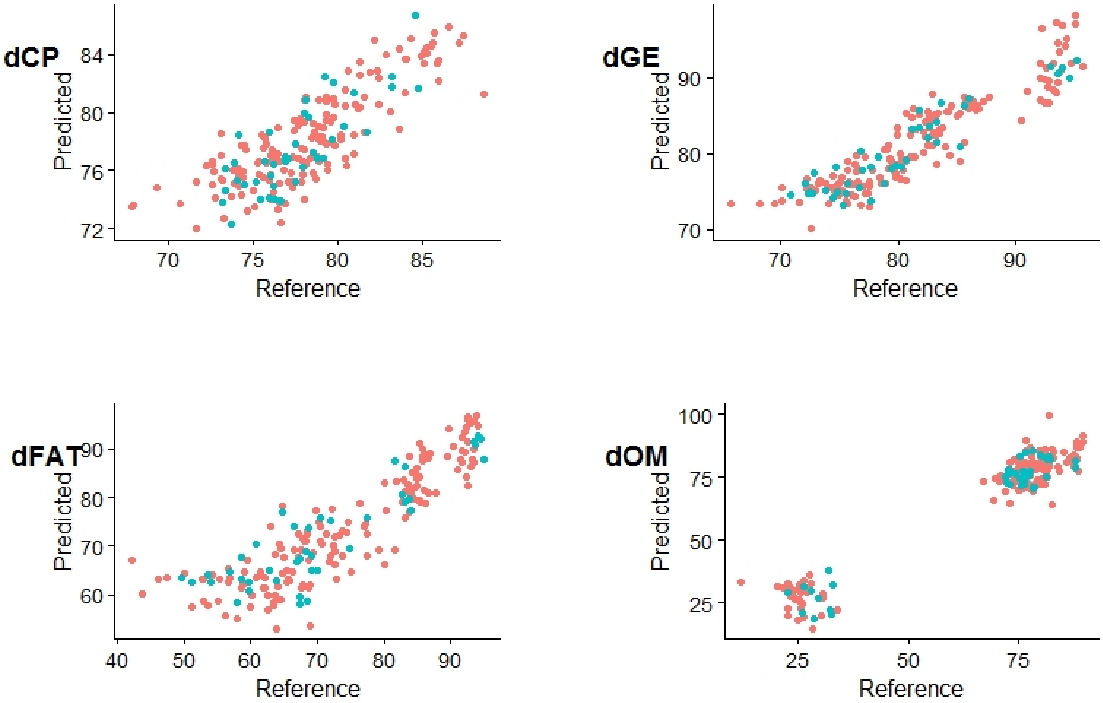

Figure 1. Fecal NIRS calibration for different digestibility parameters. The red circles show for the calibration (158 samples) dataset and green circles show for the external validation dataset (40 samples).

Discussion

The results of this study show that it is possible to successfully predict the apparent total tract digestibility of a diet using faeces NIRS scans. This is because the faecal NIRS contain information on characteristics and nutrient digestibility of the diet even though the diet has been transformed as it passes through the gastro intestinal tract of the animal. However, a robust calibration equation is required to accurately predict to a fully external dataset. In our study, the calibration was based on the complete datasets obtained mixing all the experimental trials. The animals in the calibration dataset had a variable genetic background, diets and age group. This is because a wide range of reference samples is essential for the development of accurate and robust prediction in NIRS analysis (Zijlstra et al., 2011). A robust prediction equation would enable future prediction of diet digestibility regardless of the type of feed consumed by the animal. A relatively high to moderate prediction accuracy was obtained for apparent total tract digestibility using the complete dataset. However, calibrations based on the complete datasets we used would be more essential for predicting nutrient composition. For predicting digestibility coefficients, the calibration would be based on animals that were fed the same amount of feed as reported by Bastianelli et al. (2014). This would give more emphasis on the animal factor of digestibility. Otherwise, it would be more difficult to use for genetic improvement purposes because for breeding purposes the animal factor is more essential than feed characteristics.

Diet digestibility as a measure of feed efficiency

Diet digestibility is influenced by the interaction of feed and genetics of the animal, which implies both the characteristics of the diet and the genetic potential of the animal contributes to variation in digestibility. In addition, medium to high heritability were reported for digestibility (Mignon-Grasteau et al., 2004; Mignon-Grasteau, 2010), which means one can use digestibility to select for feed efficiency. Despite this, there was no emphasis on diet digestibility in feed efficiency studies. This could be due to the fact that measuring digestibility at a farm level is very challenging and most digestibility reports have been from an experimental trial point of view. As observed from previous results and those of this study, the use of faecal NIRS scans would make it possible to measure animal specific digestibility at a farm level at a low cost and technical ease. Therefore, it is possible to use digestibility as a measure of feed efficiency in the breeding goal separately or in combination with the other existing measures of feed efficiency. However, the animals should have been fed on the same type of feed to make sure the differences in digestibility are due to the animal factor.

Most measures of feed efficiency, as in the case of residual feed intake, consider the feed energy that is turned into production and maintenance. However, digestibility can better explain how much the energy in the feed and other chemical constituents are available for all the biological activities of the animal not just for production and maintenance. On the one hand, the use of diet digestibility would be a better measure of feed efficiency as compared to the existing measures such as feed conversion ratio or residual feed intake. Conversely, digestibility alone might not determine the overall feed efficiency of the animal. The overall feed efficiency of an animal has been associated with feed intake, digestibility and the metabolic use of the absorbed energy into products (Carré et al., 2008). Therefore, a better measure of feed efficiency should be derived which accounts for the overall parameters that contribute to feed efficiency.

Conclusion

This study shows the importance of faecal NIRS as a promising tool for large-scale evaluation of diet digestibility in pig breeding programs where a controlled digestibility estimation is not possible. Our results show that it is possible to accurately predict diet digestibility using faecal NIRS with a relatively variable experimental data sets. Calibration using an experimental datasets can be accurate, but for commercial application, larger datasets may be required to obtain a more robust calibration. With the present results, it is difficult to say if the predicted diet digestibility is diet specific or animal specific. To obtain a more specific diet digestibility it is important to use methods that exploit the genetic differences of the animals. The results of this study were obtained based on a feeding trial in a controlled environment. For a more practical application, it is beneficial to examine the technology at a farm level. Diet digestibility provides a holistic approach measure of feed efficiency. Therefore, when breeding for feed efficiency it is beneficial to use digestibility as a measure of feed efficiency separately or in a combination with the existing measures of feed efficiency.

List of References

Arthur, J. P. F., and R. M. Herd, 2008. Residual feed intake in beef cattle. Revista Brasileira de Zootecnia 37:269-279.

Bastianelli, D., L. Bonnal, Y. Jaguelin-Peyraud, and J. Noblet, 2014. Predicting feed digestibility from NIRS analysis of pig faeces. Animal 9(5):781-786.

Carré, B., S. Mignon-Grasteau, and H. Juin, 2008. Breeding for feed efficiency and adaptation to feed in poultry. J. Worlds Poult Sci. 64(3):377-390.

McDonald P, E. R., Greenhalgh JFD and Morgan CA, 1998. Animal nutrition. Fifth ed. Longman Group, Edimburgh, United Kingdom.

Mignon-Grasteau, S., Juin, H., Sellier, N., Bastianelli, D., Gomez, J., Carré, B, 2010. Genetic parameters of digestibility of wheat- or corn-based diets in chickens. In: 9th World Congress on Genetics Applied to Livestock Production, Gesellschaft für Tierzuchtwissenschaften e.V (Ed) , Leipzig, Germany ,Aug 1-6, 2010, p 55.

Mignon-Grasteau, S., N. Muley, D. Bastianelli, J. Gomez, A. Peron, N. Sellier, N. Millet, J. Besnard, J. M. Hallouis, and B. Carre, 2004. Heritability of digestibilities and divergent selection for digestion ability in growing chicks fed a wheat diet. J. Poult Sci. 83(6):860-867.

Naes T, I. T., Fearn T, Davies T. 2002. Validation: A user-friendly guide to multivariate calibration and classification. NIR publications, Charlton, Chichester, UK.

Pérez de Nanclares, M., M. P. Trudeau, J. Ø. Hansen, L. T. Mydland, P. E. Urriola, G. C. Shurson, C. Piercey Åkesson, N. P. Kjos, M. Ø. Arntzen, and M. Øverland, 2017. High-fiber rapeseed co-product diet for Norwegian Landrace pigs: Effect on digestibility. J. Liv Sci. 203:1-9.

Schiborra, A., M. Bulang, A. Berk, A. Susenbeth, and E. Schlecht, 2015. Using faecal near-infrared spectroscopy (FNIRS) to estimate nutrient digestibility and chemical composition of diets and faeces of growing pigs. J. Anim Feed Sci Tech. 210:234-242.

Wold, S., A. Ruhe, H. Wold, and I. W. J. Dunn, 1984. The Collinearity Problem in Linear Regression. The Partial Least Squares (PLS) Approach to Generalized Inverses. SIAM J Sci Comput. 5 (3):735-743.

Zijlstra, R. T., M. L. Swift, L. F. Wang, T. A. Scott, and M. J. Edney, 2011. Short Communication: Near infrared reflectance, spectroscopy accurately predicts the digestible energy content of barley for pigs. Can J Anim Sci. 91(2):301-304