Trend of energy and nitrogen utilization of high fibre diets in pigs from 100 to 160 kg bodyweight

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ABSTRACT

The aim of the experiment was to investigate the ability of the heavy pig to utilize diets rich in fibre. Eight Landrace x Large White fattening barrows were fed 3 high fibre (HF) diets (on average 17.8% NDF on DM) and a traditional (C) diet (13.5% NDF) in a Latin Square design. Feeding was restricted. Each of the 4 periods included 21 days adaptation and 7 days digestibility/calorimetry. The HF diets included wheat bran (coarse or milled) or beet pulp. In periods 1, 2, 3 and 4 the eight pigs weighed, on average, 105, 124, 140 and 158 kg. Fibre digestibility (%) of HF diets increased from period 1 to period 4: 56.2, 56.6, 58.8, 62.2 for NDF and 46.0, 47.1, 49.0, 53.4 for ADF. A similar trend was registered for the digestibility of DM, OM, CP, EE and energy. Comparing the digestibility of diet C with HF diets, independently of the periods, diet C always had significantly higher digestibility (e.g. DM=87.5 vs 84.9%) except for fibre which gave similar coefficients. Methane energy losses increased significantly from period 1 to period 4 for HF diets (0.40 vs 0.59% of the intake energy, IE, P<0.05), while heat production and retained energy (% of IE), did not differ significantly between periods. Retained energy of diet C (37.1% IE) and of HF diets (35.3%) considered as the average of the four periods, were similar, confirming that the heavy pig can utilize fibre to a good extent. Considering the N balance of treatment HF, passing from period 1 to period 4 concomitantly with a lower faecal excretion a significantly greater urinary excretion was recorded: 35.7 and 51.9% of intake N in periods 1 and 4, respectively (P<0.05). Total N excretion was similar in the four periods (on average 0.98 g/BW^{0.75}). However, expressing the data as % of the intake N, total N excretion increased from period 1 (54.6%) to period 4 (68.2%) (P<0.05). As a consequence, protein deposition (N*6.25) decreased from 155 to 126 g/d from period 1 to period 4 (P<0.05). On the contrary, fat deposition increased, as expected, in the four periods: 315, 359, 374 and 394 g/d.

Key Words: Heavy pig, High fibre diets, Energy balance, Nitrogen balance.

RIASSUNTO

ANDAMENTO DELL’UTILIZZAZIONE DELL’ENERGIA E DELL’AZOTO DI DIETE A ELEVATO TENORE IN FIBRA NEL SUINO DAI 100 AI 160 KG

Scopo della ricerca è stato di indagare la capacità del suino pesante di utilizzare diete a elevato contenuto di fibra. Sono stati utilizzati 8 suini castrati Landrace x Large White, alimentati con tre diete ad alto tenore in fibra (HF, mediamente NDF 17.8% SS) e con una dieta di controllo (C, NDF 13.5% SS), inseriti in un disegno sperimentale a Quadrato Latino. L’alimentazione è stata razionata, mentre l’acqua era a volontà. Ognuno dei 4 periodi includeva 21 giorni di adattamento e 7 di digestibilità e calorimetria. Le 3 diete HF includevano crusca di frumento in scaglie o macinata e polpe di betola disidratate. Le 3 diete HF includevano crusca di frumento in scaglie o macinata e polpe di betola disidratate. Nei 4 periodi di digestibilità gli otto suini pesavano mediamente 105, 124, 140 e 158 kg. La digestibilità della fibra delle diete HF è aumentata dal periodo 1 al periodo 4: 56.2, 56.6, 58.8 e 62.2% per l’NDF e 46.0, 47.1, 49.0 e
Introduction

The quality guidelines of the Parma Ham and San Daniele Ham Consortia stipulate that pigs for ham must be slaughtered at over 9 months of age and at a body weight (BW) of 160 kg ±10%. This leads to an average daily gain of 0.6 kg. Thus, Italian heavy pig feeding must aim at maturing the animals sufficiently without excessive fattening, implying the restriction of feed and energy intake. Beet pulp and wheat bran are often used as fibrous feeds in pig feeding to reduce the risk of digestive disorders. In Italy, for fattening pigs, 8-10% in weight of wheat bran is traditionally added to the maize-based diet. Higher levels are not normally fed, because its digestibility and nutritional value, not usually determined on heavy pigs, are considered low and there is the fear that high proportions of wheat bran could decrease the energy concentration of the diet excessively. A recent study on heavy pigs conducted by our group (Crovetto et al., 2001) showed that, compared to controls, higher levels of dietary wheat bran neither increased methanogenesis nor decreased the digestibility or net energy content of the diet. However, it is documented that the ability of the pig to digest the nutrients increases while it is growing and approaching maturity also in terms of a functional gastrointestinal apparatus. This is particularly evident for the dietary fibre which can hardly be digested by the piglet, but is utilized fairly well by the adult pig (Noblet and Shi, 1994; Le Goff et al., 2002c). Most of the research on the

matter has been carried out in growing pigs up to 100 kg BW (Le Goff et al., 2003) and only few studies have been concerned with energy metabolism (Schiemann et al., 1989; Hoffmann et al., 1990; Jentsch et al., 1993; Noblet et al., 1994) and nitrogen excretion (Piva et al., 1993; Bosi et al., 1995; Crovetto et al., 1995; Martelli et al., 1995) in the heavy pig. Particularly, no experiment, to our knowledge, had been carried out in the heavy pig fed on HF diets. It seemed therefore interesting, especially in the case of Italy, to investigate the ability to utilize diets rich in fibre in the pig from 100 to 160 kg bodyweight.

Material and methods

Eight Landrace x Large White barrows of 100 kg BW were grouped into 4 pairs and fed four different diets for 28 days (21 of adaptation and 7 of digestibility) in a Latin Square design so that each animal received all dietary treatments throughout the experiment, in four consecutive periods.

Each pig was housed in a metabolism cage and placed individually in an open-circuit respiration chamber during each digestibility period to measure respiratory exchange over three 24 h cycles. Four diets were utilised: a control (C) traditional diet based on cereal with a limited inclusion of coarse wheat bran (8%) and three high fibre (HF) diets: one with 24% milled wheat bran, another with 24% coarse wheat bran, and a third one with 16% dried sugar beet pulp.
The overall compositions and analyses of the four diets, fed as dry mash, are shown in Table 1. The three HF diets were formulated to have a similar NDF content.

Industrially produced amino acids (lysine, methionine, threonine and tryptophan) were included to obtain similar amino acid availability in the ileum for all diets: 0.50% lysine, 0.18% methionine, 0.36% methionine + cystine, 0.36% threonine and 0.11% tryptophan (data calculated on values published by INRA, 1989).

The feed supply was restricted during the experiment following the normal procedure applied in the feeding of the Italian heavy pigs. The quantity of dry matter (DM) available was 7.4% of BW\(^{0.75}\) at the start of the experiment and gradually reduced to 6.1% of BW\(^{0.75}\) after the animals reached 160 kg BW. Drinking water was always available. The animals were fed at 8 am and 5 pm each day.

The procedures related to digestibility, calorimetry, nitrogen and carbon balances are described in a previous paper (Galassi et al., 2004). Samples of feeds, uneaten feed, faeces and urine were analysed chemically in accordance with the Italian Scientific Association for Animal Production recommendations (ASPA, 1980).

The data were analysed by ANOVA using the GLM procedure (SAS, 2001). The data were analysed with the following model:

\[ Y_{ijkl} = \mu + S_i + A_{ij} + T_{(t)} + P_k + e_{ijk} \]

where:
- \( Y_{ijkl} \) = dependent variable;
- \( \mu \) = general mean;
- \( S_i \) = square effect (i=1,2);
- \( A_{ij} \) = effect of animal within each square (j=1,3 for the analysis by period of diets HF; j=1,4 for the comparison of dietary treatments);
- \( T_{(t)} \) = effect of dietary treatment (t=1,2);
- \( P_k \) = effect of period (k=1,4);
- \( e_{ijk} \) = residual error.

The differences between periods were analysed by orthogonal contrasts.

### Table 1. Composition of the experimental diets.

| Diet          | C   | MB  | CB  | BP  |
|---------------|-----|-----|-----|-----|
| Maize         | %   | 69.11 | 58.01 | 58.01 | 59.29 |
| Barley        | %   | 10.00 | 10.00 | 10.00 | 10.00 |
| Wheat bran, milled | %   | 8.00  | -    | 24.00 | -    |
| Wheat bran, coarse | %   | -    | 24.00 | -    | -    |
| Beet pulp, dried | %   | -    | -    | -    | 16.00 |
| Soybean meal  | %   | 10.00 | 5.20  | 5.20  | 12.00 |
| L-Lys HCl     | %   | 0.15  | 0.22  | 0.22  | 0.12  |
| DL-Met        | %   | -    | -    | -    | 0.02  |
| L-Thr         | %   | 0.03  | 0.06  | 0.06  | 0.05  |
| L-Trp         | %   | 0.01  | 0.01  | 0.01  | 0.02  |
| CaCO3         | %   | 1.30  | 1.60  | 1.60  | 0.50  |
| Ca(H2PO4)2 hydr. | %   | 0.50  | -    | -    | 1.10  |
| NaCl          | %   | 0.40  | 0.40  | 0.40  | 0.40  |
| Vit./min. suppl. | %   | 0.50  | 0.50  | 0.50  | 0.50  |

| Dry matter    | % DM | 91.5  | 91.3  | 91.6  | 91.7  |
| Ash           | %    | 5.3   | 6.0   | 5.4   | 5.5   |
| Carbon        | %    | 43.4  | 44.8  | 44.3  | 44.2  |
| Nitrogen * 6.25 | %   | 15.0  | 14.7  | 15.0  | 14.6  |
| Ether extract  | %    | 3.0   | 3.1   | 3.0   | 2.4   |
| Crude fibre   | %    | 3.6   | 4.7   | 4.7   | 5.9   |
| NDF           | %    | 13.5  | 18.4  | 17.7  | 17.2  |
| ADF           | %    | 4.3   | 6.1   | 5.6   | 7.3   |
| ADL           | %    | 0.8   | 1.3   | 1.2   | 1.1   |
| Starch and sugars | %  | 58.4  | 51.6  | 53.9  | 51.0  |
| Gross energy  | MJ/kg DM | 18.26 | 18.33 | 18.42 | 18.12 |

C: Control; MB: Milled Bran; CB: Coarse Bran; BP: Beet Pulp.
Results and discussion

Digestibility

Considering digestibility of diets HF (Table 2) a trend of increase was registered from period 1 to period 4 for all the parameters considered (DM, OM, N, EE, CF, NDF, ADF, energy) and this increase was more evident between period 4 and the previous ones. Particularly, digestibility of OM and NDF in periods 1, 2, 3 and 4 were respectively 86.3, 86.4, 87.0, 88.5% and 56.2, 56.6, 58.8, 62.2%, with a significant difference (P<0.05) between period 4 and periods 1 and 2, as registered for energy digestibility (84.0, 84.1, 84.7, 86.5%). The data obtained are consistent with those obtained, in lighter pigs and in sows, by other researchers (Noblet and Bourdon, 1997; Le Goff et al., 2002a, 2002b, 2002c, 2003) and confirm that pigs improve their digestive efficiency as they grow (Noblet and Shi, 1994); this improvement is greater for fibre, as it can be seen from the above cited data.

Our results are consistent with those obtained, in the heavy pig, by Scipioni et al. (1993) and suggest that digestibility in the heavy pig is more similar to that of the sow than to that of the 40-80 kg BW growing pig. This is confirmed comparing our data and those obtained by Scipioni et al. (1993) in the heavy pig with those obtained in growing pigs and sows by Le Goff et al. (2003).

The data obtained in the present experiment suggest that, as already stated by Le Goff et al. (2002c), new energy values of feed (especially the fibrous ones) should be tabulated for adult pigs, being different from those referred to growing pigs.

Table 2. Apparent faecal digestibility (%) of high fibre diets (n=6) during the four trial periods.

| Period | 1   | 2   | 3   | 4   | SEM  |
|--------|-----|-----|-----|-----|------|
| Average bodyweight (kg) | 105 | 122 | 141 | 160 |      |
| Dry matter         | 84.2a | 84.1a | 84.8a | 86.5b | 0.55  |
| Organic matter     | 86.3a | 86.4a | 87.0ab | 88.5b | 0.51  |
| Carbon             | 84.5a | 85.0a | 85.5a | 87.2b | 0.53  |
| Nitrogen           | 81.8a | 82.7a | 84.5a | 84.7a | 0.76  |
| Ether extract      | 75.5a | 77.5a | 84.9a | 87.0b | 2.02  |
| Crude fibre        | 43.8 | 44.3 | 45.8 | 51.0 | 3.06  |
| NDF                | 56.2a | 56.6a | 58.8ab | 62.2b | 1.62  |
| ADF                | 46.0a | 47.1a | 49.0a | 53.4a | 3.00  |

Values in the same row with different superscripts differ significantly (P<0.05)
Energy utilization

Table 3 shows the energy utilization as related to the four consecutive periods of the experiment. Digestible energy (DE) intake on a metabolic weight basis decreased with increasing body-weight and energy digestibility increased concomitantly, as well as methane energy losses: 0.40 vs 0.59% of the intake energy (IE) in period 1 and period 4, respectively, P<0.05.

Urinary energy losses were similar in the four periods and averaged 3.2% of the IE.

Metabolisable energy (ME) resulted as having a trend similar to DE in the four periods: it decreased in terms of absolute values because of the progressively lower feed and energy intake on metabolic weight basis, but with no significant difference when expressed as metabolisability (ME/IE, %).

Heat production, as a percentage of the IE or the ME, was similar in the four periods and consistent with the data obtained by other authors (Longland et al., 1991; Noblet et al., 1998; Le Bellego et al., 2001; Le Goff et al., 2002a).

Retained energy (RE) was not significantly different between periods 1, 2, 3 and 4 (34.8, 34.6, 35.4 and 36.3% of IE, respectively).

Nitrogen balance

Faecal nitrogen excretion decreased significantly from period 1 to 4 (Table 4); this was expected since it is well documented that digestibility increases as long as the animal is growing (Fernandez et al., 1986; Shi and Noblet, 1994; Le Goff et al., 2002c).

On the contrary, urinary nitrogen excretion increased significantly as a percentage of the intake nitrogen (IN) in the same interval: 35.7 vs 51.9%, respectively, P<0.05. The higher urinary nitrogen excretion in heavier animals can be attributed both to the higher amount of absorbed nitrogen and to

Table 3. Daily energy utilization of high fibre diets (n=6) during the four trial periods. (Average BW0.75: 1=32.7, 2=36.7, 3=40.9, 4=44.9)

| Period | 1     | 2     | 3     | 4     | SEM  |
|--------|-------|-------|-------|-------|------|
| Energy Intake (EI) (kJ/BW0.75) | 1321a  | 1261a | 1194b | 1074c | 21.9 |
| Digestible energy (kJ/BW0.75) | 1110a  | 1060ab| 1011b | 929c  | 21.5 |
| % EI  | 84.0a  | 84.1a | 84.7ab| 86.5b | 0.59 |
| Urinary energy (kJ/BW0.75) | 40.1a  | 43.5a | 38.5ab| 33.4b | 2.8  |
| % EI  | 3.0    | 3.5   | 3.2   | 3.1   | 0.21 |
| Methane energy (kJ/BW0.75) | 5.3    | 6.2   | 5.8   | 6.3   | 0.58 |
| % EI  | 0.40a  | 0.49a | 0.50a | 0.59a | 0.052|
| Metabolisable energy (ME) (kJ/BW0.75) | 1065a  | 1010ab| 967a  | 890a  | 21.4 |
| % EI  | 80.6   | 80.1  | 81.0  | 82.8  | 0.67 |
| Heat production (kJ/BW0.75) | 604a   | 573a  | 543a  | 499a  | 7.5  |
| % EI  | 45.8   | 45.5  | 45.6  | 46.4  | 0.52 |
| % ME  | 56.8   | 56.7  | 56.2  | 56.2  | 0.75 |
| Retained energy (kJ/BW0.75) | 460a   | 437a  | 424ab | 390a  | 15.7 |
| % EI  | 34.8   | 34.6  | 35.4  | 36.3  | 0.81 |
| % ME  | 43.2   | 43.3  | 43.8  | 43.8  | 0.75 |

Values in the same row with different superscripts differ significantly (P<0.05)
the fact that the diet was the same throughout the experiment and that its protein content was suitable to meet the requirements of pigs of 100-120 kg, but rather in excess for heavier animals.

A rise in terms of total nitrogen excretion can be observed in higher bodyweights. As a consequence nitrogen retention decreased significantly from period 1 to 4 both when expressed in absolute values and as percentage of the IN (45.4 vs 31.7\%, \(P<0.05\)). This confirms the importance of decreasing the protein content of the diet not only during the growing period, as long as the pig is gaining weight, but also in the finishing period of fattening of the traditional Italian heavy pig.

**Protein and fat deposition**

In the four consecutive periods of the trial, considering the HF diets, the pigs gained 155, 148, 126, 126 g protein and 315, 359, 374, 394 g fat daily, respectively.

Expressing the daily gains as g/kg metabolic bodyweight, the results for periods 1 to 4 were respectively: 4.8, 3.9, 3.1, 2.9 g protein/kg BW\(^{0.75}\) (\(P<0.05\), except for the difference between periods 3 and 4) and 9.6, 9.6, 9.2, 8.8 g fat/kg BW\(^{0.75}\) (differences statistically NS).

For a more precise evaluation of the influence of fibre on the protein accretion of pigs one should also take into account the dressing percentage at slaughter, to distinguish total N deposited from the N retained in the viscera. However, this registration was not possible with the experimental design applied (Latin Square).

The fast growth rate of the pigs, despite their high bodyweights, was achieved because they were allocated to individual cages, without food competition or “waste” of energy for movement or hierarchical struggles and stress.

**Control vs High Fibre diets**

Table 5 reports digestibility, energy utilization, and N balance of the HF diets in comparison with the C diet, independently of the stage of growth.

The inclusion of fibrous ingredients in the diet decreased digestibility of the main nutrients with the exception of fibre. Although statistically significant, such a decrease is limited to 2-4 points percentage, with the highest decrease for protein probably due to a “binding” effect of the undigestible fibre on the protein content of the cell wall.
and to the fact that non-starch polysaccharides are fermented to large extent in the hindgut with an increase of the microbial protein and, consequently, of the nitrogen faecal output (Bach Knudsen and Hansen, 1991; Bach Knudsen et al., 1991).

As regards to energy utilization, it is evident that the HF diets had significantly lower DE and ME. The differences between the three HF diets are reported in a previous work of Galassi et al. (2004). No significant difference, however, was registered between C and HF diets in terms of RE.

Finally, considering the Nitrogen balance, diet C attained a significantly lower faecal N excretion but a numerically higher urinary N excretion (49.5 vs 45.7% of IN). The two aspects compensate each other and result in similar total N excretion and N retention for the two dietary treatments; this is consistent with the data obtained by other authors (Scipioni et al., 1993; Canh et al., 1997).

The higher faecal N excretion of the HF diets, as already discussed, is due mainly to the fermentable non-starch polysaccharides of the fibrous by-products, particularly beet pulp (Galassi et al., 2004) and to the consequent increase of the microbial growth in the hindgut, as reported by Bach Knudsen et al. (1991). On the other hand, this determines a demand for urea, as a source of ammonia-nitrogen for the microbial protein synthesis, from the blood to the intestinal lumen and consequently a lower nitrogen excretion with urine (Low, 1985). The property of fibre to reduce the concentration of ammonia in the colon was highlighted by Malmlof and Hakansson (1984).

Table 5. Apparent faecal digestibility, daily energy utilization and Nitrogen balance of C diet (n=8) and HF diets (n=24). (Average BW0.75: Control=38.6, High fibre=38.8)

| Diets and SEM | Control | SEM | High fibre | SEM |
|---------------|---------|-----|------------|-----|
| Digestibility: |         |     |            |     |
| Dry matter %  | 87.5a   | 0.64| 84.9b      | 0.37|
| Nitrogen      | 87.2a   | 0.71| 83.4b      | 0.41|
| Crude fibre   | 44.1    | 5.64| 46.2       | 3.25|
| NDF           | 58.0    | 3.16| 58.5       | 1.82|
| ADF           | 47.8    | 5.13| 48.9       | 2.96|
| Energy utilization: |   |   |            |     |
| Energy Intake (EI) kJ/BW0.75 | 1219 | 15.8| 1213       | 9.1 |
| Digestible energy % EI | 87.5a | 0.61| 84.8b      | 0.35|
| Metabolisable energy % | 83.4b | 0.62| 81.1b      | 0.36|
| Retained energy | 37.1    | 0.75| 35.3       | 0.43|
| Nitrogen balance: |   |   |            |     |
| Intake (NI) g/BW0.75 | 1.60 | 0.02| 1.57       | 0.012|
| Faecal % NI | 12.8a  | 0.72| 16.6b      | 0.41|
| Urinary % | 49.5    | 2.24| 45.7       | 1.29|
| Excreted % | 62.9    | 2.19| 63.0       | 1.26|
| Retained % | 37.1    | 2.19| 37.0       | 1.26|

Values in the same row with different superscripts differ significantly (P<0.05)
Conclusions

While pigs were growing, a significant increase in digestibility of all nutrients, particularly fibre fractions, was registered. Whilst RE expressed as a percentage of both intake and metabolisable energy, remained constant at increasing bodyweights.

On the contrary, retained nitrogen, expressed as percentage of the intake N, was significantly lower in heavier animals, confirming that the protein content of the diet must be strongly reduced as long as pigs are growing.

In conclusion, dietetic fibre proved to be well utilized by the heavy pig and the use of fibrous feeds in the finishing phase of heavy pigs fattening can be increased, with an NDF content of the diet higher than the 13-14% on DM, usually attained in practical conditions. However, this requires that the nutritive value of these feeds is properly determined instead of relying on published values obtained from studies on younger animals.

Part of the work was presented at the 54th Annual Meeting of the EAAP in Roma, Italy, 2003.

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