Effect of bacterial protein meal grown on natural gas on growth performance and carcass traits of pigs

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Paper received March 5, 2004; accepted May 19, 2004

ABSTRACT

Bacterial protein meal (BPM), a new protein feedstuff produced by bacteria (Methylococcus capsulatus, Alcaligenes acidovorans, Bacillus brevis and Bacillus firmus) grown on natural gas, was evaluated as a protein source for pigs. Two growth trials were conducted, one with growing-finishing pigs and one with pigs from weaning until slaughter. In Exp. 1, 18 pigs fed restrictively (26.0 and 109.4 kg initial and final weight) were used to determine the effect of dietary inclusion of BPM (0, 60, or 120 g kg⁻¹), replacing protein from soybean meal on growth performance and carcass traits. Adding 60 and 120 g kg⁻¹ BPM to diets reduced (P < 0.01) ADG and feed efficiency during the growing period, but had no effect on growth performance during the finishing or overall periods. Both levels of BPM improved amino acid and lysine utilization (P < 0.01) compared with the control. Fat firmness tended to increase with inclusion of BPM. When using orthogonal contrast, both levels of BPM tended to increase carcass meatiness. In Exp. 2, 48 pigs (11.4 and 107.2 kg initial and final weight) were used to evaluate increasing levels of BPM (0, 50, 100, or 150 g kg⁻¹) on growth performance and carcass traits from weaning at 34.5 days of age until slaughter. Bacterial protein meal reduced ADG (linear P < 0.03) during the period from weaning until five weeks post weaning and during the period from weaning until slaughter. Increasing levels of BPM tended to increase overall feed/gain. Also, BPM increased backfat firmness (linear P < 0.01), but reduced percent carcass lean (linear P < 0.05) and carcass meatiness (linear P < 0.01), and increased P2 backfat thickness and fat area in cutlet (linear P < 0.05). All levels of BPM improved amino acid and lysine utilization (linear P < 0.05) compared with the control. In conclusion, up to 120 g kg⁻¹ BPM in diets for pigs from 26 kg live weight until slaughter had no adverse effect on overall growth performance or carcass lean or fat content. Up to 150 g kg⁻¹ BPM to diets for pigs from weaning until slaughter reduced growth rates during the piglet period and increased carcass fat content due to marginal dietary lysine levels. Bacterial protein meal gave a dose dependent improvement in the utilization of total amino acids and lysine and the quality of back fat determined as fat firmness and fat color.

Key words: Bacterial protein meal, Pigs, Growth performance, Carcass traits

RIASSUNTO

PERFORMANCE DI ACCRESCIMENTO E CARATTERISTICHE DELLA CARCASSA DI SUINI ALIMENTATI CON DIETE CONTENENTI UNA FARINA PROTEICA BATTERICA CRESCIUTA SU GAS NATURALE

Una farina proteica (BPM) prodotta da batteri dei ceppi Methylococcus capsulatus, Alcaligenes acidovorans, Bacillus brevis and Bacillus firmus cresciuti su un substrato di gas naturale è stata valutata come fonte proteica per suini in accrescimento. Sono state quindi realizzate due prove di accrescimento, una in accrescimento-finissaggio e una tra lo svez-
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zamento e la macellazione. Nell'Exp. 1, 18 suini sono stati alimentati secondo razione tra i 26.0 e i 109.4 kg, per determinare l'effetto dell'inclusione nella dieta di 0, 60, o 120 g kg\(^{-1}\) di BPM in sostituzione della proteina della farina di estrazione di soia. L'inclusione di 60 e 120 g kg\(^{-1}\) di BPM ha peggiorato (P< 0.01) l'incremento ponderale giornaliero e l'indice di conversione alimentare durante la fase di accrescimento, mentre non ha determinato effetti negativi sulle performance di crescita nella fase del finisaggio o quando i due periodi della ricerca sono stati considerati complessivamente. Entrambi i livelli di BPM hanno migliorato l’utilizzazione degli aminoacidi e della lisina (P< 0.01) e la consistenza del grasso (P<0.01), nonché un aumento dello spessore del grasso dorsale (P< 0.01), cui tuttavia hanno fatto riscontro una ridotta percentuale di carne magra della carcassa (P<0.05). Tutti i dosaggi di BPM hanno migliorato l’utilizzazione degli aminoacidi e della lisina (P< 0.01) e una ridotta carnosità della stessa (P< 0.01), nonché un aumento dello spessore del grasso dorsale P2 e una maggiore incidenza del grasso nella superficie del taglio campione (P< 0.05). Tutti i dosaggi di BPM hanno migliorato l’utilizzazione degli aminoacidi e della lisina (P< 0.01) e una ridotta carnosità della stessa (P< 0.01), nonché un aumento dello spessore del grasso dorsale P2 e una maggiore incidenza del grasso nella superficie del taglio campione (P< 0.05). Tutti i dosaggi di BPM hanno migliorato l’utilizzazione degli aminoacidi e della lisina (P< 0.01) e una ridotta carnosità della stessa (P< 0.01), nonché un aumento dello spessore del grasso dorsale P2 e una maggiore incidenza del grasso nella superficie del taglio campione (P< 0.05), con sempre un effetto lineare della dose (P<0.03) l’incremento ponderale giornaliero degli animali sia nelle 5 settimane successive allo svezzamento che nell’intero periodo dallo svezzamento alla macellazione. Sempre con effetto lineare della dose si sono riscontrati anche un tendenziale peggioramento (P<0.10) e un aumento della consistenza del grasso dorsale (P< 0.01), cui tuttavia hanno fatto riscontro una ridotta percentuale di carne magra della carcassa (P< 0.05) e una ridotta carnosità della stessa (P< 0.01), nonché un aumento dello spessore del grasso dorsale P2 e una maggiore incidenza del grasso nella superficie del taglio campione (P< 0.05). Tutti i dosaggi di BPM hanno migliorato l’utilizzazione degli aminoacidi e della lisina (P< 0.05) e una ridotta carnosità della stessa (P< 0.01). Nell'Exp. 2, 48 suinetti di 11.4 kg iniziali sono stati utilizzati per valutare l'effetto sull'accentramento to e sulle caratteristiche della carcassa di dosi crescenti di BPM (0, 50, 100 or 150 g kg\(^{-1}\)) fornite dallo svezzamento, realizzato ad un’età di 34.5 d, fino alla macellazione. La farina proteica batterica ha manifestato un miglioramento “dose dipendente” nell’utilizzazione degli aminoacidi totali e della lisina oltre al macello hanno aumentato il grasso della carcassa a causa di un apporto non ottimale di lisina. La farina proteica batterica ha manifestato un miglioramento “dose dipendente” nell’utilizzazione degli aminoacidi totali e della lisina oltre ad un aumento della qualità del grasso dorsale sia dal punto di vista della consistenza che del colore.

Parole chiave: Farina proteica batterica, Suini, Performance di crescita, Caratteristiche della carcassa

Introduction

Bacterial protein meal (BPM) is a bacterial protein produced by mainly *Methylococcus capsulatus*, but also *Alcaligenes acidovorans*, *Bacillus brevis* and *Bacillus firmus*, by fermentation of natural gas (99% methane), ammonia and mineral salts (Skrede et al., 1998). The final spray-dried product is a reddish/brownish meal containing about 95% dry matter (DM), 70% crude protein (CP), 10% lipids and 7% ash. Compared to other bacterial protein sources (D'Mello, 1972, 1973; Smith and Palmer, 1976; Braude et al., 1977; Kiessling and Askbrandt, 1993), BPM is a protein source with a favorable amino acid composition (Skrede et al., 1998). Compared to fish meal, BPM has almost the same content of methionine and cystine, a higher content of tryptophan and threonine, and a somewhat lower content of lysine (Skrede et al., 1998). Previous studies have shown no impairment in performance of pigs when traditional protein sources were substituted by certain single cell proteins (Brenne, 1976; Whittemore et al., 1976; Braude et al., 1977; Hanssen and Farstad, 1980). Similar observations have been reported for chickens (D'Mello, 1972; D'Mello, 1973). In previous studies, BPM produced on natural gas has shown to improve growth performance of weanling pigs and growing-finishing pigs (Överland et al., 2001), blue foxes (Skrede and Ahlstrøm, 2002), and broiler chickens (Skrede et al., 2003).

Methane-utilizing bacteria have a high content of phospholipids consisting mainly of phosphatidylethanolamine and phosphatidylglycerol, but also minor amounts of phosphatidylcholine (PC) and cardiolipin (CL) with predominantly 16:0 and 16:1 fatty acids (Makula, 1978). A reduction in abdominal fat of broiler chicken (Skrede et al., 2003) and improvement in fat firmness and fat color scores of growing-finishing pigs (Överland et al., 2001) have been reported. This suggests that BPM may improve lean-fat ratio as well as the quality of fat from monogastric farm animals.

Limited information exists on optimal inclusion rates of BPM on growth performance and carcass traits of growing-finishing pigs. Also, no information exists on growth performance and carcass

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traits of pigs receiving BPM from weaning until slaughter. The BPM was, therefore, evaluated in diets for growing-finishing pigs as well as for pigs from weaning until slaughter. The objectives of our experiments were to 1) determine the effect of adding increasing levels of BPM up to 120 g kg⁻¹ in diets on growth performance and carcass traits of growing-finishing pigs, and 2) evaluate the effect of adding up to 150 g kg⁻¹ BPM to diets on growth performance and carcass traits of pigs from weaning until slaughter.

Material and methods

Two growth experiments (Exp. 1 and Exp. 2) were carried out to evaluate BPM as a protein source for pigs at the Experimental Farm of the Agricultural University of Norway.



Animals, allotment and housing

In Exp. 1, a total of 18 crossbreed [(Norwegian Landrace x Yorkshire) x (Norwegian Landrace x Duroc)] growing-finishing pigs from six litters were used. Average initial weight was 26.0 kg and average final weight was 109.4 kg. The experiment was conducted as a randomized complete block design. Pigs were blocked by litter and allotted by initial weight and sex to three dietary treatments with six replicates per treatment. The experimental period lasted on average 95.5 days. At feeding time, each pig was restrained in an individual feeding stall until the feed was consumed in order to obtain individual feed intake. Thus, each pig was one experimental unit. There were equal numbers of gilts and barrows in each treatment group. The experiment was split into a growing period from start until 60 kg live weight, a finishing period from 60 kg live weight until slaughter, and the overall period. The pigs were slaughtered over two weeks when they reached a commercial weight of about 105-110 kg live weight. The piglet period, the animals were housed in an environmentally controlled nursery in 2.5 m x 2.5 m pens with partially slotted concrete floors. Pigs were fed according to appetite. In the growing-finishing period, pigs were moved to an environmentally controlled growing-finishing room located in the same building. Three 8.2 m² pens, with partially slotted concrete floor, designed for individual feeding were used. At feeding time, each pig was restrained in an individual feeding stall until the feed was consumed in order to obtain individual feed intake. During both periods, the pen was the experimental unit. Saw dust was provided as bedding. Average ambient daily temperature was kept between 16.5 and 22°C.

In Exp. 2, a total of 48 [(Norwegian Landrace x Yorkshire) x (Norwegian Landrace x Duroc)] weanling pigs from six litters were used. Average initial weight was 11.4 kg and average final weight was 107.2 kg. The experimental period lasted on average 119.4 days. The experiment was conducted as a randomized complete block design. There were four dietary treatments with 12 pigs and three blocks (pens) per treatment with four pigs per pen. Pigs were allotted to the treatments on the basis of litter, initial weight, and sex. There were equal numbers of gilts and barrows in each treatment group.

Experiment 2 was divided into a piglet period from weaning at 34.5 days of age until week five of the experimental period, a growing period from week five to 12, a finishing period from week 12 to slaughter, and the overall period from weaning until slaughter. The pigs were slaughtered when they reached a commercial weight of about 105-110 kg live weight. In the piglet period, the animals were housed in an environmentally controlled nursery in 2.5 m x 2.5 m pens with partially slotted concrete floors. Pigs were fed according to appetite. In the growing-finishing period, pigs were moved to an environmentally controlled growing-finishing room located in the same building. Three 8.2 m² pens, with partially slotted concrete floor, designed for individual feeding were used. At feeding time, each pig was restrained in an individual feeding stall until the feed was consumed in order to obtain individual feed intake. During both periods, the pen was the experimental unit. Saw dust was provided as bedding. Average ambient daily temperature was kept between 22.1 and 24.4°C in the piglet period and between 16.8 and 22.8°C in the growing-finishing period.

Diets, feeding and registrations

In Exp. 1, the dietary treatments consisted of a basal diet based on barley, soybean meal (SBM) and fish meal and two test diets containing 60 or 120 g kg⁻¹ BPM. This corresponded to 24% and 48% of total dietary crude protein from BPM, respectively. The increasing levels of dietary protein from BPM were balanced by a reduction in the level of protein from SBM. Level of lysine was adjusted to 8 g FU per by using crystalline amino acids. The diets were also designed to be isoener-
getic and to contain equal levels of methionine + cysteine, and threonine.

In Exp. 2, two separate basal diets were used: one for the piglet period and one for the growing-finishing period. The dietary treatments consisted of a basal diet of barley, wheat and SBM and three test diets containing 50 g, 100 g or 150 g kg⁻¹ BPM. Increasing levels of BPM were balanced by a reduction in content of protein from SBM. During the piglet period, the level of lysine was adjusted to 8.5 g FUᵢp⁻¹ by using crystalline amino acids. During the growing-finishing period, the level of lysine was adjusted to 7.5 g FUᵢp⁻¹. The diets were also designed to be isoenergetic and to contain equal levels of methionine + cysteine, and threonine. In the growing-finishing diet, the level of crude fat in diets was kept similar by replacing soy oil in the basal diet by increasing levels of fat from BPM.

In Exp. 1 and 2, BPM was produced and supplied by Norferm AS, Stavanger, Norway. The BPM used in Exp. 1 was spray-dried to a dry meal. The BPM used in Exp. 2 was pelleted with inclusion of about 1% soy oil after spray-drying to avoid dustiness and to facilitate easy transportation and handling. The SBM was of an ordinary solvent extracted, not dehulled, commercial quality. Other feed ingredients were also obtained from commercial suppliers. Samples from BPM and SBM used in Exp. 1 and 2 were taken for chemical analyses. The diets in both Exp. 1 and 2 were made at Centre for Feed Technology, Ås, Norway. The feed was pelletized with a 3-mm die. The content of digestible lysine, threonine, methionine and cystine of the ingredients was estimated using analyzed values, except for the BPM where the declared values were used, multiplied by the apparent total tract digestibility coefficient for nitrogen (Andersen and Just, 1983). The energy value of the diets and all the ingredients was expressed according to the Danish energy evaluation system as FUᵢp and as ME (Just, 1982) based on analyzed chemical content and table values for the apparent total tract digestibility coefficient for nutrients. Diets were formulated to meet or exceed the requirements for indispensable amino acids and all other nutrients (NRC, 1998). A cumulative feed sample from each dietary treatment was taken for chemical analysis. Analyses of BPM and SBM in Exp. 1 are shown in Table 1. Composition and analyses of diets are shown in Table 2 for Exp. 1 and in Table 3 and 4 for Exp. 2.

In Exp. 1, a 7-day preliminary period adjusted pigs to experimental diets and pens while in Exp. 2, the experiment started the day of weaning. During the piglet period in Exp. 2, pigs were fed according to appetite from an automatic feeder. In Exp. 1 and during the growing-finishing period in Exp. 2, all pigs were individually fed twice per day according to a restricted Norwegian feeding scale (Øverland, 1997). Feed refusals for each pig were recorded and subtracted from the total feed intake. All pigs were given free access to water from nipple drinkers. In the growing-finishing barn, water was also provided directly in the trough during meals.

Feed consumption and pigs’ weight were recorded daily to determine average daily gain (ADG), average daily feed intake (ADFI) and feed efficiency as kg feed per kg of weight gain (feed/gain). Total amino acid utilization was determined as average daily intake of total amino acids per kg of weight gain and lysine utilization was determined as average daily intake of lysine per kg of weight gain.

Carcass characteristics

In Exp. 1 and Exp. 2, pigs were slaughtered at a commercial slaughterhouse. Carcass characteristics were measured after 1 d of chilling according to procedures described by Sundstøl (1973). Dressing percentage was determined by: (hot carcass weight/final weight) x 100. Live weight was monitored the day of slaughter. Carcass lean percentage was determined commercially on the slaughter line using a GP2Q pistol (Hennessy System Ltd., Auckland, New Zealand) to measure the depth of the longissmus dorsi and the backfat thickness at two sites (between the 10th and 11th rib, 6 cm from the midline and behind the last rib, 8 cm from the midline). The prediction of carcass lean percentage was done according to an equation from the Norwegian Meat Research Centre, Oslo, Norway. A tracing of a cross section of the cutlet behind the last rib was made on tracing paper. The total area and meat area in the cutlet were deter-
mined by planimeter (Coradi AG, Zürich, Switzerland). The fat area of the cutlet was determined by the difference between the total area and meat area. The P2 backfat thickness was measured 8 cm from the midline behind the last rib using tracing paper and a ruler.

**Chemical analysis**

In Exp. 1 and 2, DM, crude protein (Kjeldahl-N x 6.25), crude fat (HCl hydrolysis with petroleum ether extraction), crude fiber and ash of the diets, SBM and BPM were determined by standard methods (AOAC, 1990). Phosphorus and calcium content of the diets were analyzed by atomic absorption spectrophotometry according to methods described by AOAC (1990). Analyses of amino acids were carried out according to Directive 98/64/EC (OJEC 1998).

**Statistical analyses**

Statistical analysis was performed using the GLM procedure of SAS (1990) for a complete randomized block design. In Exp. 1 each pig was the experimental unit. In Exp. 2, pen average was the experimental unit. Results are presented as the least square mean (LSMEANS) for each treat-
ment, and variance is expressed as standard error of the mean (SEM).

Means were separated according to the Least Significance Difference (LSD) test. Significant difference among treatments was shown as \( P < 0.05 \), tendency for difference was defined as \( P \) between 0.05 and 10.0, while not significant differences (NS) were shown as \( P > 0.10 \). In Exp. 1, orthogonal polynomials were used to test linear responses of increased dietary levels of BPM. Orthogonal contrasts were made between the control diet and the two diets containing BPM and between the two BPM diets. Final weight was used as a covariate in the analysis of carcass weight and dressing percentage in Exp. 1. In Exp. 2, orthogonal polynomials were used to test linear and quadratic responses of increased dietary levels of BPM.

Animal Care
All pigs were cared for according to laws and regulations controlling experiments with live animals in Norway (the Animal Protection Act of December 20th, 1974, and the Animal Protection Ordinance concerning experiments with animals of January 15th, 1996).

Results and discussion

Bacterial protein meal and diets
The lower crude fat content in the BPM used in Exp. 1 compared to Exp. 2 (65 vs 120 g kg\(^{-1}\)) was a result of a lower crude fat content than the declared value of 90 g kg\(^{-1}\) in Exp. 1 and the inclusion of about 1% soy oil in the BPM after spray-drying in Exp. 2. In Exp. 1 and 2, the diets were similar in proximate content, but the content of lysine was higher in the control diet (Table 2, 3, and 4). The diets were calculated based on declared chemical content of ingredients, but chemical analysis revealed a lower lysine content in the BPM than the declared values.

Health
In Exp. 1 and 2, no health problems related to the dietary treatments were encountered during the experimental period. The pigs had a good health status. They were free from swine dysentery, scabies, and mycoplasma.

Growth performance and carcass traits
The effect of BPM on growth performance of growing-finishing pigs in Exp. 1 is shown in Table 5. Pigs fed diets containing BPM were heavier at slaughter (\( P < 0.05 \)) than the control pigs, but this was probably caused by differences in the number of days on test rather than an effect of treatment. During the growing period, BPM inclusion decreased ADG and increased feed/gain (\( P < 0.01 \)) of pigs, but BPM had no effect on ADFI. Increasing levels of BPM up to 120 g kg\(^{-1}\) did not, however, significantly affect growth performance in the finishing or the overall period.

The effect of BPM on amino acid utilization in Exp. 1 is shown in Table 6. Both levels of BPM gave a reduction in daily intake of total amino acid and lysine compared with the control (\( P < 0.001 \)). Pigs receiving both levels of BPM had better total amino acid and lysine utilization (\( P < 0.01 \)) compared with the control pigs.

The effect of BPM on carcass traits of pigs in Exp. 1 is shown in Table 7. Adding BPM to diet gave an increase in carcass weight and dressing percentage of pigs (\( P < 0.01 \)) when using orthogonal contrasts. The increase in carcass weight was associated with the differences in final weight; however, Øverland et al. (2001) also reported an increase in dressing percentage by feeding BPM compared with SBM. Conversely, Skrede et al. (2003) observed a reduction in the dressing percentage of broiler chickens with increasing levels of BPM. When using orthogonal contrasts, both levels of BPM tended (\( P < 0.07 \)) to increase carcass meatiness of pigs compared with the control. Adding 120 g kg\(^{-1}\) BPM to diets tended (\( P < 0.1 \)) to give a positive increase in fat firmness score compared with the control. Also, the 120 g kg\(^{-1}\) BPM diet tended to give a higher (\( P < 0.06 \)) firmness score and fat color score than 60 g kg\(^{-1}\) BPM diet, based on orthogonal contrasts. The improvement in fat firmness score and fat color score suggests that BPM improves the quality of backfat. This effect of BPM may be related to the characteristic fatty acid profile of the BPM lipids, predominantly 16:0 and 16:1 fatty acids (Skrede et al., 1998). In the present experiment, the crude fat level in the BPM used in Exp. 1 was lower than the declared values. At, higher crude fat levels, the effects of
The effect of BPM on growth performance of the pigs in Exp. 2 is shown in Table 8. During the piglet period, the inclusion of up to 150 g kg⁻¹ BPM reduced ADG (linear P < 0.05), but had no effect on feed/gain or ADFI of pigs. There was no effect of BPM on ADG, feed/gain or ADFI during the growing-finishing period. Overall, BPM reduced ADG (linear P < 0.05) and tended to increase feed/gain (linear P < 0.10) of pigs.

Table 2. Composition (g kg⁻¹) and chemical content of diets used in Experiment 1.

| Level of bacterial protein meal (g kg⁻¹) | 0  | 60 | 120 |
|----------------------------------------|----|----|-----|
| Barley                                 | 743| 797| 823 |
| Soybean meal (45% crude protein)       | 200| 85 | 0   |
| Bacterial protein meal (BPM)           | 0  | 60 | 120 |
| Rendered fat                           | 15 | 15 | 15  |
| Fish meal (NorSeaMink, 70.4% crude protein) | 15 | 15 | 15  |
| Limestone                              | 11 | 11 | 11  |
| Monocalcium phosphate                  | 12 | 12 | 12  |
| Salt                                   | 3.1| 3.1| 3.1 |
| L-lysine · HCl (98%)                   | 0  | 0.5| 0.4 |
| DL-methionine                          | 0.1| 0.1| 0.1 |
| Premix¹                                | 0.9| 0.9| 0.9 |
| Calculated contents:                   |    |    |     |
| Metabolizable energy MJ kg⁻¹           | 13.0| 13.0| 12.9 |
| Digestible lysine g kg⁻¹               | 7.9 | 7.8 | 7.9  |
| Digestible methionine+cysteine "       | 5.4 | 5.3 | 5.5  |
| Digestible threonine "                 | 5.8 | 5.6 | 5.8  |
| Calcium "                              | 7.8 | 7.6 | 7.6  |
| Total phosphorus "                     | 6.6 | 6.4 | 6.3  |
| Analyzed content (g kg⁻¹):             |    |    |     |
| Dry matter                             | 891 | 892 | 889 |
| Crude protein                          | 184 | 171 | 173 |
| Total amino acids                      | 185 | 168 | 164 |
| Crude fiber                            | 42  | 40  | 35   |
| Crude fat                              | 34  | 36  | 40   |
| Ash                                    | 53  | 51  | 50   |
| Calcium                                | 7.0 | 6.9 | 7.0  |
| Total phosphorus                       | 7.2 | 7.6 | 8.4  |
| Lysine                                 | 10.0| 9.0 | 8.8  |
| Threonine                              | 7.1 | 7.0 | 6.9  |
| Methionine                             | 3.4 | 3.9 | 4.1  |
| Cysteine                               | 3.3 | 2.9 | 2.6  |

¹ Vitamins and trace elements included to provide the following amounts per kg of feed: 105 mg Zn; 75 mg Fe; 60 mg Mn, 15 mg Cu; 7.44 mg I; 0.3 mg Se; 8 400 U vitamin A; 700 U cholecalciferol; 115.9 mg d-α-tocopheryl acetate; 5 mg riboflavin; 15 mg d-pantothenic acid; 20 μg cyanocobalamin.
Table 3. Composition (g kg⁻¹) and chemical content of piglet diets used in Experiment 2.

| Level of bacterial protein meal (g kg⁻¹) | 0    | 50   | 100  | 150  |
|----------------------------------------|------|------|------|------|
| Barley                                 | 226  | 246  | 250  | 270  |
| Wheat                                  | 480  | 480  | 500  | 497  |
| Soybean meal (45% crude protein)       | 210  | 140  | 68   | 0    |
| Bacterial protein meal (BPM)           | 0    | 52   | 101  | 153  |
| Soy oil                                | 40   | 40   | 40   | 40   |
| Limestone                              | 15.8 | 16.2 | 16.6 | 16.9 |
| Monocalcium phosphate                   | 15.4 | 14.8 | 14.4 | 13.9 |
| Salt                                   | 4.7  | 4.6  | 4.5  | 4.4  |
| Iron fumarate                          | 0.33 | 0.33 | 0.33 | 0.33 |
| Zinc oxide                             | 0.10 | 0.10 | 0.10 | 0.10 |
| Choline chloride                       | 0.84 | 0.84 | 0.84 | 0.84 |
| Ascorbic acid                          | 0.6  | 0.6  | 0.6  | 0.6  |
| Vitamine E                             | 0.04 | 0.04 | 0.04 | 0.04 |
| Premix¹                                | 1.55 | 1.55 | 1.55 | 1.55 |
| L-lysine · HCl (98%)                   | 3.40 | 2.50 | 1.80 | 0.70 |
| DL-methionine                          | 0.30 | 0    | 0    | 0    |
| L-threonine                            | 1.00 | 0.63 | 0.40 | 0    |

Calculated content:

|                                | 0     | 50    | 100   | 150   |
|--------------------------------|-------|-------|-------|-------|
| Metabolizable energy (MJ kg⁻¹) | 14.0  | 14.0  | 14.1  | 14.2  |
| Digestible lysine (g kg⁻¹)     | 9.80  | 9.90  | 9.99  | 9.99  |
| Digestible methionine + cysteine| 5.21  | 5.47  | 5.97  | 6.54  |
| Digestible threonine           | 6.12  | 6.14  | 6.22  | 6.23  |
| Calcium                        | 8.61  | 8.67  | 8.74  | 8.78  |
| Total phosphorus               | 7.05  | 7.07  | 7.12  | 7.17  |

Analyzed content:

|                                | 0     | 50    | 100   | 150   |
|--------------------------------|-------|-------|-------|-------|
| Dry matter (g kg⁻¹)            | 876   | 877   | 886   | 878   |
| Crude protein (g kg⁻¹ DM)      | 210   | 218   | 219   | 230   |
| Crude fat                     | 70.8  | 76.4  | 88.0  | 94.5  |
| Ash                           | 41.1  | 37.6  | 31.6  | 28.5  |
| Calcium                       | 59.4  | 58.2  | 57.6  | 60.4  |
| Total phosphorus              | 10.2  | 9.9   | 9.7   | 8.5   |
| Lysine                        | 8.0   | 8.6   | 8.9   | 8.8   |
| Methionine                    | 12.2  | 11.6  | 11.1  | 9.8   |
| Cysteine                      | 3.2   | 3.3   | 3.8   | 4.3   |
| Threonine                     | 3.5   | 3.4   | 3.2   | 2.8   |
| Tryptophan                    | 8.0   | 7.9   | 8.0   | 7.7   |

¹ Vitamins and trace elements included to provide the following amounts per kg⁻¹ of feed: 140 mg of Zn; 201 mg of Fe; 80 mg of Mn; 20 mg of Cu; 10 mg of I; 0.4 mg of Se; 11 000 U of vitamin A; 1375 U of cholecalciferol; 137.5 mg of dl-α-tocopheryl acetate; 6.9 mg of riboflavin; 22.9 mg of d-pantothenic acid; 27.5 μg of cyanocobalamin.
BACTERIAL PROTEIN MEAL IN PIG DIETS

Table 4. Composition (g kg⁻¹) and chemical content of growing-finishing pig diets used in Experiment 2.

| Level of bacterial protein meal (g kg⁻¹) | 0    | 50   | 100  | 150  |
|----------------------------------------|------|------|------|------|
| Barley                                 | 487  | 518  | 541  | 563  |
| Wheat                                  | 250  | 250  | 250  | 250  |
| Soybean meal (45% crude protein)       | 224  | 146  | 72.0 | 0    |
| Bacterial protein meal (BPM)           | 0    | 50   | 100  | 150  |
| Soy oil                                | 6    | 3.6  | 5.0  | 5.0  |
| Limestone                              | 14.2 | 14.2 | 14.2 | 14.2 |
| Monocalcium phosphate                   | 11.7 | 11.7 | 11.8 | 11.8 |
| Salt, g/kg                             | 3.8  | 3.7  | 3.6  | 3.5  |
| Choline chloride                       | 0.6  | 0.6  | 0.6  | 0.6  |
| Premix¹                                | 1.2  | 1.2  | 1.2  | 1.2  |
| L-lysine HCl ‘98                       | 0.65 | 0.64 | 0.51 | 0.34 |
| DL-methionine                          | 0.54 | 0.32 | 0.06 | 0    |
| L-threonine                            | 0.60 | 0.37 | 0.09 | 0    |
| Calculated content                     |      |      |      |      |
| Metabolizable energy (MJ kg⁻¹)         | 13.0 | 13.0 | 13.0 | 13.0 |
| Digestible lysine (g kg⁻¹)              | 7.97 | 7.97 | 7.95 | 7.95 |
| Digestible methionine + cysteine       | 5.42 | 5.42 | 5.42 | 5.63 |
| Digestible threonine                   | 5.84 | 5.84 | 5.84 | 6.05 |
| Calcium                                | 7.44 | 7.42 | 7.43 | 7.43 |
| Total phosphorus                       | 6.37 | 6.52 | 6.70 | 6.87 |
| Analyzed content:                      |      |      |      |      |
| Dry matter (g kg⁻¹)                    | 886  | 876  | 883  | 876  |
| Crude protein (g kg⁻¹ DM)               | 211  | 215  | 206  | 204  |
| Crude fat (g kg⁻¹)                     | 38   | 41   | 49   | 53   |
| Crude fiber                            | 44   | 47   | 43   | 37   |
| Ash                                     | 54   | 55   | 53   | 54   |
| Calcium                                | 7.9  | 7.8  | 7.6  | 7.4  |
| Total phosphorus                       | 7.0  | 7.5  | 7.6  | 7.8  |
| Lysine                                 | 11.2 | 11.4 | 10.3 | 9.4  |
| Methionine                             | 3.4  | 4.1  | 4.0  | 4.2  |
| Cysteine                               | 3.6  | 3.3  | 2.9  | 2.7  |
| Threonine                              | 8.0  | 8.4  | 7.7  | 7.5  |
| Tryptophan                             | 2.9  | 3.3  | 3.4  | 3.7  |

¹ Vitamins and trace elements included to provide the following amounts per kg of feed: 105 mg Zn; 75 mg Fe; 60 mg Mn, 15 mg Cu; 7.44 mg I; 0.3 mg Se; 8 400 U vitamin A; 700 U cholecalciferol; 115.9 mg d-1-a-tocopheryl acetate; 5 mg riboflavin; 15 mg d-pantothenic acid; 20 mg cyanocobalamin.

tion in Exp. 2 is shown in Table 9. Increasing levels of BPM gave a reduction in daily intake of total amino acid and lysine (linear P < 0.01). All levels of BPM gave a better total amino acid and lysine utilization (linear P < 0.05) compared with the control diet. Also, BPM gave a quadratic effect (P < 0.05) on daily lysine intake and lysine utilization in that the highest level of 150 g kg⁻¹ BPM gave a lower lysine intake and a higher lysine utilization than the other levels of BPM.
Table 5. Effect of BPM on growth performance of growing-finishing pigs in Experiment 1.

| Level of bacterial protein meal (g kg⁻¹) | 0 | 60 | 120 | SEM¹ | P-value |
|----------------------------------------|---|----|-----|------|---------|
| N. of replicates                       | 6 | 6  | 6   | -    | -       |
| N. of gilts/barrows                   | 3/3| 3/3| 3/3 | -    | -       |
| Initial weight kg                      | 26.1| 25.7| 26.2 | 0.6  | 0.8     |
| Final weightc                          | 107.6⁺| 110.6⁺| 110.1⁺ | 0.7  | 0.03    |
| Days on testc                          | 93.2| 96.7| 96.7 | 1.1  | 0.10    |
| Growing period: ADG                    | g  | 796⁺| 744⁺| 738⁺ | 10      | 0.01    |
| Growing period: ADFI                   | kg | 1.59| 1.59| 1.59 | 0.02    | 1.0     |
| Growing period: Feed/gain              | kg | 1.99⁺| 2.15⁺| 2.16⁺ | 0.02 | 0.002   |
| Finishing period: ADG                  | g  | 1016| 1066| 1040 | 21     | 0.3     |
| Finishing period: ADFI                 | kg | 2.82| 2.85| 2.86 | 0.03   | 0.7     |
| Finishing period: Feed/gain            | kg | 2.79| 2.68| 2.75 | 0.06   | 0.4     |
| Overall period: ADG                    | g  | 913 | 910 | 897  | 14     | 0.7     |
| Overall period: ADFI                   | kg | 2.26| 2.25| 2.26 | 0.03   | 1.0     |
| Overall period: Feed/gain              | kg | 2.44| 2.45| 2.48 | 0.04   | 0.8     |

¹ Standard error of mean.
⁺ Means in a row with different superscript differ (P < 0.05).
² Control vs 60 and 120 g kg⁻¹ BPM (P < 0.05).
³ Control vs 60 and 120 g kg⁻¹ BPM (P < 0.01).

Table 6. Effect of BPM on protein utilization of growing-finishing pigs in Experiment 1.

| Level of bacterial protein meal (g kg⁻¹) | 0 | 60 | 120 | SEM¹ | P-value |
|----------------------------------------|---|----|-----|------|---------|
| Overall period: Average total AA² intakec g/day | 416⁺| 378⁺| 369⁺ | 5    | 0.001   |
| Overall period: Total AA² utilization g AA²/kg² gain | 457⁺| 416⁺| 412⁺ | 7    | 0.003   |
| Overall period: Average lysine intakec g/day | 22.6⁺| 20.2⁺| 19.9⁺ | 0.2  | 0.001   |
| Overall period: Lysine utilizationc g lys/kg gain | 24.7⁺| 22.3⁺| 22.2⁺ | 0.4  | 0.002   |

¹ Standard error of mean.
² Amino acids.
⁺⁺ Means in a row with different superscript differ (P < 0.05).
² Control vs 60 and 120 g kg⁻¹ BPM (P < 0.001).
³ Control vs 60 and 120 g kg⁻¹ BPM (P < 0.01).
The effect of BPM on carcass traits of pigs in Exp. 2 is shown in Table 10. Inclusion of BPM in the diets increased P2 backfat thickness and fat area in cutlet and reduced carcass lean percentage and carcass meatiness (linear P < 0.05) of pigs. The reduction in ADG and increase in feed/gain observed during the growing period in Exp. 1 and in the piglet period in Exp. 2, and the increase in carcass fat content of pigs in Exp. 2 with the addition of BPM to diets suggest that BPM may impair growth performance and carcass traits of pigs. This could be a result of the lower lysine level in these diets rather than an effect of the BPM. This was especially pronounced during the piglet period in Exp. 2 where the difference in lysine content ranged from 12.2 g kg\(^{-1}\) DM in the control to 9.8 g kg\(^{-1}\) DM in the diet containing 150 g kg\(^{-1}\) BPM. The latter value may be sub-optimal during the piglet period (NRC, 1998). Øverland et al. (2001) also reported a reduction in growth performance during the growing period, but no adverse effect on overall performance of pigs by BPM under marginal lysine levels. The authors concluded that this was a result of a reduced lysine level rather than an effect of BPM per se. Furthermore, when lysine levels were kept constant among diets, BPM improved growth performance of young pigs (Øverland et al., 2001). The improvement in amino acid and lysine utilization with increasing levels of BPM observed in both Exp. 1 and 2 suggests that BPM has a better protein quality than the SBM. This might be associated with the higher content of tryptophan in BPM compared with SBM as shown in Exp. 2, Table 1, and the increasing dietary content of tryptophan with increasing levels of BPM as shown in Exp. 2, Table 3 and 4. Tryptophan tends to become one of four first limiting amino acids in most practical diets for pigs (Warnants et al., 2003).

All levels of BPM in Exp. 2 increased backfat firmness score (linear P < 0.01), but had no effect on fat color score. The positive response of BPM on fat firmness score is in agreement with the observations in Exp. 1 and with the findings of Øverland et al. (2001) where fat firmness of pigs was improved by inclusion of BPM. In the same study, an improvement of sensory traits of backfat of pigs fed diets containing BPM was reported. The addition of 1% soy oil to the pelleted BPM used in Exp. 2, could to a certain degree mask the effect of BPM on the quality of the back fat.

### Table 7. Effect of BPM on carcass traits of growing-finishing pigs in Experiment 1.

| Level of bacterial protein meal (g kg\(^{-1}\)) | 0     | 60    | 120   | SEM\(^{1}\) | P-value |
|---------------------------------------------|-------|-------|-------|-------------|---------|
| Carcass weight\(^{c}\)                      | 81.8\(^{a}\) | 83.9\(^{b}\) | 84.0\(^{b}\) | 0.9         | 0.02    |
| Dressing percentage\(^{c}\)                 | 75.3  | 76.3  | 76.5  | 0.4         | 0.19    |
| Percentage carcass lean, GP2Q method         | 55.7  | 56.7  | 55.2  | 0.9         | 0.5     |
| P2 backfat thickness                         | 15.0  | 15.0  | 16.0  | 1.0         | 0.7     |
| Meat area in cutlet                          | 49.5  | 49.2  | 52.3  | 2.3         | 0.6     |
| Fat area in cutlet                           | 21.2  | 20.2  | 22.9  | 4.0         | 0.9     |
| Carcass meatiness (1-15)\(^{2}\)            | 12.1  | 12.6  | 12.8  | 0.2         | 0.2     |
| Fat firmness (1-15)\(^{2}\)                 | 12.0  | 12.0  | 12.8  | 0.2         | 0.1     |
| Fat color (1-15)\(^{2}\)                    | 12.3  | 11.8  | 12.6  | 0.2         | 0.12    |

\(^{1}\) Standard error of mean.

\(^{2}\) Judged visually using a scale from 1 to 15 in which 15 is the highest quality.

\(^{a,b}\) Means in a row with different superscript differ (P < 0.05).

\(^{c}\) Control vs 60 and 120 g kg\(^{-1}\) BPM (P < 0.01).

\(^{d}\) Control vs 60 and 120 g kg\(^{-1}\) BPM (P < 0.1).

\(^{e}\) 60 vs 120 g kg\(^{-1}\) BPM (P < 0.1)
Table 8. Effect of BPM on growth performance of pigs in Experiment 2.

| Level of bacterial protein meal (g kg⁻¹) | Contrasts¹ |
|-----------------------------------------|------------|
|                                         | 0  | 50 | 100 | 150 | SEM² | P-value | Linear | Quadratic |
| N. of replicates                        | 3  | 3  | 3   | 3   | -   | -       | -      | -         |
| N. of gilts/barrows                     | 5/7| 5/7| 5/7 | 5/7 | -   | -       | -      | -         |
| Initial weight                          | kg | 11.6| 11.5| 11.6| 11.3| 1.0   | 0.99   | 0.86      | 0.90      |
| Final weight                            | kg | 106.6| 107.3| 108.8| 106.0| 1.6  | 0.66   | 0.95      | 0.31      |
| Days on test                            |    | 116 | 118 | 120 | 124 | 2     | 0.48   | 0.57      | 0.41      |
| Piglet period:                          |    |     |     |     |     |       |        |           |           |
| ADFI                                    | kg | 1.057| 0.944| 1.016| 0.990| 0.049| 0.48   | 0.57      | 0.41      |
| ADG                                     | g  | 479 | 471 | 426 | 384 | 28    | 0.14   | 0.03      | 0.56      |
| Feed/gain                               |    | 2.23| 2.02| 2.41| 2.58| 0.184| 0.25   | 0.12      | 0.34      |
| Growing-finishing period:               |    |     |     |     |     |       |        |           |           |
| ADFI                                    | kg | 2.308| 2.316| 2.364| 2.210| 0.047| 0.21   | 0.28      | 0.12      |
| ADG                                     | g  | 910 | 893 | 930 | 883 | 14    | 0.15   | 0.46      | 0.30      |
| Feed/gain                               |    | 2.54| 2.59| 2.54| 2.51| 0.05  | 0.60   | 0.49      | 0.32      |
| Overall (weaning–slaughter):            |    |     |     |     |     |       |        |           |           |
| ADFI                                    | kg | 1.854| 1.828| 1.891| 1.793| 0.039| 0.40   | 0.54      | 0.40      |
| ADG                                     | g  | 820a| 811a| 811a| 767b| 12    | 0.055  | 0.02      | 0.19      |
| Feed/gain                               |    | 2.26| 2.26| 2.33| 2.34| 0.04  | 0.31   | 0.10      | 0.86      |

¹ Probability of linear and quadratic contrasts of increased dietary levels of BPM.
² Standard error of mean.
³ Means in a row with different superscript differ (P < 0.05).

Table 9. Effect of BPM on protein utilization of pigs in Experiment 2.

| Level of bacterial protein meal (g kg⁻¹) | Contrasts¹ |
|-----------------------------------------|------------|
|                                         | 0  | 50 | 100 | 150 | SEM² | P-value | Linear | Quadratic |
| Overall (weaning–slaughter):            |    |     |     |     |     |       |        |           |           |
| Average total AA³ intake                | g/day | 346a| 341a| 335a| 303a| 7     | 0.009  | 0.002    | 0.078     |
| Total AA³ utilization                   | g AA³/kg gain | 421| 420 | 414 | 395 | 7     | 0.09   | 0.025    | 0.32      |
| Average lysine intake                   | g/day | 18.7a| 18.3a| 17.5a| 14.9a| 0.4  | 0.001  | 0.001    | 0.015     |
| Lysine utilization                      | g lys/kg gain | 22.8a| 22.6a| 21.5a| 19.4a| 0.4  | 0.001  | 0.001    | 0.028     |

¹ Probability of linear and quadratic contrasts of increased dietary levels of BPM.
² Standard error of mean.
³ Amino acids.
⁴ Means in a row with different superscript differ (P < 0.05).
Because the data in the present study was collected from only six pigs per treatment in Exp. 1 and 3 replicates (12 pigs) per treatment in Exp. 2, further investigations are desirable.

Conclusions

In conclusion, adding up to 120 g kg⁻¹ BPM in diets for growing-finishing pigs had no adverse effect on overall live weight gain, feed efficiency or feed intake, or carcass lean or fat content. Thus, BPM can be used as a major protein source in diets for growing-finishing pigs.

Replacing SBM with up to 150 g kg⁻¹ BPM in pig diets from weaning until slaughter reduced growth performance during the piglet period, had no adverse effect on overall growth performance, but increased carcass fat content. This seemed to be a result of a sub-optimal lysine level rather than an effect of the protein source per se.

Increasing levels of BPM improved amino acid and lysine utilization of diets. Adding up to 120 and 150 g kg⁻¹ BPM to diets improved quality of pig back fat determined as firmness and color.

The authors are grateful to Arnljot Mehl, Lisbeth Holm Altern and Maria Eriksen for the technical assistance.

Parts of the results were presented first at the 54th Annual Meeting of the European Association of Animal Production, 31 August - 3 September 2003, Roma, Italy.

This study was supported by grant n.143196/140 "Protein produced from natural gas - a new feed resource for fish and other domestic animals” from the Research Council of Norway and by Norferm AS.

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