Organic Pig Meat Production

Nutrient Supply, Behaviour and Health

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Abstract

The aim of this thesis was to investigate the influence of dietary amino acid levels in a low-energy diet provided *ad libitum* on performance, carcass quality, behaviour and health of organic growing/finishing pigs in outdoor and indoor production systems. 192 piglets born outdoors were transferred to either a pen indoors (I) or a pasture outdoors (O). The pigs were allocated to six treatments (IR, IR-7, IR-14 and OR, OR-7, OR-14) with diets containing different amino acid levels. R was in accordance with the Swedish norm, R-7 and R-14 contained 7 and 14% lower levels than the norm.

The aim was also to determine whether additional roughage and access to outdoor areas affect activity behaviour and reduce aggression level among organic growing/finishing pigs. A total of 515 pigs in indoor housing systems with access to concrete outdoor runs were studied. The pigs were allocated to either a control treatment or one of three treatments with access to additional roughages in the outdoor run: hay, grass silage or whole crop barley silage.

Furthermore, the objective was to provide data on nutritional properties of some alternative organic protein feed resources. A 4-period changeover digestibility trial included pigs fitted with a post valve t-caecum cannula. The dietary treatments were faba bean and cake from hempseed, linseed and rapeseed.

The results showed that production system, rather than dietary amino acid level, affected pig performance and carcass quality and that pigs seem able to tolerate lower amino acid levels than the Swedish norm if fed *ad libitum*. The prevalence of erysipelas infections was higher in outdoor pigs and *Ascaris suum* infections were present in both production systems. Access to roughage and outdoor areas allowed pigs to express highly motivated natural behaviours, such as foraging, rooting and exploring, which generally resulted in a higher activity level. Roughage played an important role in occupying the pigs and reduced aggressions between the pigs. The alternative protein feed resources had satisfactory digestibility values and might have the potential to be used to a greater extent in the formulation of organic pig diets.

Keywords: Amino acid, Active behaviour, Carcass quality, Digestibility, Erysipelas, Outdoor, Organic, Parasites, Performance, Pig, Roughage, Social interactions.

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Till Leon och Tove

Det är bra att just Du får svåra uppgifter – annars hade ju vilken idiot som helst kunnat göra dem.
(H.K.Andersson)

Contents

List of Publications

This thesis is based on the work contained in the following Papers, referred to by Roman numerals in the text:

I Høøk Presto, M., Andersson, H.K., Wallgren, P. & Lindberg, J.E. 2007. Influence of dietary amino acid level on performance, carcass quality and health of organic pigs reared indoors and outdoors. *Acta Agriculturae Scandinavica Section A. Animal Science* 57, 61-72.

II Høøk Presto, M., Andersson H.K., Folestam, S. & Lindberg, J.E. 2008. Activity behavior and social interactions of pigs raised outdoors and indoors. *Archives of animal breeding* 51 (4), 338-350.

III Høøk Presto, M., Algers, B., Persson, E. & Andersson, H.K. 2008. Different roughages to organic growing/finishing pigs - influence on activity behaviour and social interactions. *Livestock Science*, (Accepted).

IV Høøk Presto, M., Lyberg, K. & Lindberg, J.E. Digestibility of organically cultivated white-flowering faba bean (*Vicia faba*) and cake from cold-pressed rapeseed (*Brassica napus*), linseed (*Linum usitatissimum*) and hempseed (*Cannabis sativa*) in growing pigs.

Papers I-III are reproduced with the permission of the publishers.

Abbreviations

AD	Apparent digestibility
AID	Apparent ileal digestibility
BS	Whole crop barley silage
C	Control
CA	Casein diet
DM	Dry matter
F	Faba bean diet
GMO	Genetically modified organism
GS	Grass silage
H	Hay
HC	Hempseed cake diet
I	Indoors
LC	Linseed cake diet
ME	Metabolisable energy
MJ	Megajoule
NDF	Neutral Detergent Fibre
O	Outdoors
PVTC	Post valve t-caecum
R	Amino acid level in accordance with the recommendation
R-7	7% lower amino acid level than the recommendation
R-14	14% lower amino acid level than the recommendation
RC	Rapeseed cake diet
SID	Standardized ileal digestibility
TID	True ileal digestibility
TiO_2	Titanium dioxide
TTAD	Total tract apparent digestibility
TTD	Total tract digestibility

Introduction

Organic pig production

Livestock is often of great importance in realizing some of the principle objectives in organic farming. The overall basic objectives of organic production are defined by the basic standards formulated by the International Federation of Organic Agriculture Movements (IFOAM, 2002). Of the 17 standards, 3 refer to organic livestock farming and are described as: (1) maintenance of biodiversity, (2) provision of freedom and access to natural behaviour by livestock and (3) promotion of a balanced mix of crop and livestock production, leading to closed and sustainable nutrient cycles. However, conflicts such as how and to what degree the aims can be pursued may occur. For farm animals, issues about suitable rearing practice and feed utilization, concerning the basic objectives of natural behaviour and nutrient requirements of animals, may come in conflict with the risk of pollution from the production system as well as satisfactory production quantities (Hermansen *et al.*, 2004).

Organic animal production in Sweden is regulated by the EU regulations (EC, 1999) or by the subordinated local organisation KRAV, which also follows the EU regulations, but have adjusted their rules according to the basic standards of IFOAM (2002). The rules from KRAV are intended to cover some areas excluded by EU regulation and include some additional rules, with the most distinct being values in animal production. National legislation, for example animal protection and environment, is the basis for all organic production in Sweden. In order to ensure that the legislation is followed, organic production is certified by some control organs accredited by the Swedish Board of Agriculture and the National Food Administration.

Feed resources

According to the EU regulations and those of IFOAM, diets used in organic animal production should be based on home-grown crops. Diets for organic pigs are based on cereals as the major source of nutrients and energy. To provide the important protein and amino acids needed by pigs, protein-rich legume and oil seeds such as field peas, faba beans and rapeseed are included in the diet. The self-sufficiency level at the farm should be at least 50% based on yearly feed consumption and 90% of the yearly feed intake for pigs should consist of organically produced feedstuffs. The level is gradually increasing to meet the goal of 100% organically produced feedstuffs by the year 2012. The regulations exclude feedstuffs that originate from genetically modified organisms (GMO), or have been extracted with the use of chemical solvents. It is not allowed to use synthetically produced amino acids or meat meal as protein additions to balance the amino acid profile of the diet. Furthermore, pigs in organic production should have unrestricted access to good quality roughage, to satisfy their foraging behaviour.

Housing and management

Besides the standards in national animal protection legislation about housing and management, pigs in organic production should be housed in systems that allow them to stay outdoors. According to KRAV (2008), growing/finishing pigs should be outdoors on pasture during 4 months during the summer. During winter, the outdoor area can be in the form of an outdoor run on concrete. Both indoors and outdoors pigs should be held in groups. A separate laying area on a deep straw bed, separate defecation area and a well-defined eating place should be included. The housing should provide the pigs with shelter from rain, wind and sun and uphold a good hygienic climate. The housing systems should offer more space than those in conventional systems and should be designed to meet the pigs' need to perform natural behaviour. Animals have a need to perform certain behaviours sometimes irrespective of the external environment, which can be expressed as a high motivation to perform the behaviour. The definition of a natural behaviour is thus a behaviour which the animal is highly motivated to perform, and when it is performed leads to a functional feedback (Algers, 2008), and the possibility for animals to perform natural behaviour is of great importance in organic production (Lund, 2003).

The production system should promote good health and low pathogen load. In organic production, the use of routine prophylactic treatment with medicines, such as antibiotics or preparation for deworming, or chemical pesticides is banned and will result in a prolonged qualifying period before slaughter. However, the use of vaccinations and anaesthetics is allowed when there is an obvious need (IFOAM, 2002; KRAV, 2008).

Protein and amino acid supply

The most important single factor that affects how well protein can be utilized is the profile of essential amino acids. Lysine and threonine have been shown to be the first and second limiting amino acids in cereal-based diets for pigs (Fuller *et al.*, 1974) and are both essential. If the requirements of protein and amino acids are not fulfilled performance, health and animal welfare can be negatively affected (NRC, 1998; Danielsen *et al.*, 2000). The use of feedstuffs that are rich in protein and have a desirable amino acid profile is limited by the regulations for the formulation of organic pig diets. Furthermore, the use of for example synthetic amino acids or meat meal, as protein additions, is not allowed (EC, 1999; IFOAM, 2002). In order to assure an adequate supply of essential amino acids, a high inclusion level of protein in the organic diet is necessary, resulting in a surplus of dispensable and non-limiting essential amino acids. This affects the protein utilization negatively, with excretion of nitrogen in urine and faeces to the environment as a consequence (Strid Eriksson *et al.*, 2005).

One way to overcome part of the problem is to use a phase feeding strategy for growing/finishing pigs because this allows a supply of protein and amino acids that better reflects the requirement during the actual period of the growth. According to previous performance studies on growing/finishing pigs fed *ad libitum*, the voluntary feed intake of pigs could be increased, to maintain a high daily energy intake, when the energy density of the diet was reduced by straw meal inclusion (Håkansson *et al.*, 2000). Thus, a diet with low energy density and reduced amino acid content, fed *ad libitum*, would theoretically assure a sufficient total daily intake of protein and amino acids as well as energy without any negative effects on the carcass quality, due to an increased total feed intake.

Legumes are of major concern for the fixation of nitrogen to the soil and roughage positively affects the soil structure, and they are important to integrate in the crop rotation. Organically produced legumes such as field peas and faba beans, and oil seeds such as rapeseed, linseed and hempseed are rich in protein and have a satisfying amino acid profile. They have the potential to be used as alternative protein feed resources in organic pig diets. However, there is a need to evaluate the nutritional value of these feedstuffs because the current information about them is scarce. In addition, roughages could be significant sources of protein (Reverter, 1999). They constitute a base in organic production systems and will improve the sustainability in the cropping system when included in the crop rotation.

Digestibility assessment

The digestibility i.e. the quantity of certain nutrients that is absorbed in the digestive tract of animals is important when evaluating the nutritive value of feed ingredients. It can be determined by qualitative collection grab samples (point samples several times) of ileal digesta and faeces. In grab sampling, an indigestible marker such as titanium dioxide (TiO_2) is used and the coefficient of apparent digestibility of the diets is then calculated using the indicator technique (Sauer *et al.*, 2000). Ileal digestibility of nitrogen and amino acids can be expressed by coefficients of apparent ileal digestibility (AID), which do not take into account the origin (dietary or endogenous) of nitrogen and amino acids present in the ileal digesta. Endogenous nitrogen and amino acids from microbial protein, sloughed intestinal cells, mucosal proteins and digestive enzymes are present in the digesta (Moughan & Schuttert, 1991). This causes an underestimation of digestibility. In contrast, an adjustment for the endogenous fractions allows for a more accurate assessment (Fan & Sauer, 1995) resulting in a true (TID) or standardized (SID) ileal digestibility.

Behaviour and social interactions

All aspects of animal production relate to the animals' behaviour (Broom *et al.*, 2007) and pigs in organic production should be able to express their natural behaviour such as rooting and grazing. These behaviours can be observed in pigs in their natural habitats. However, the environment influence the behaviour and animals that are offered more stimuli in their environment spend more time investigating these stimuli to get information about the environment. Farm animals can thus not be expected to act in the same way as they do in a natural habitat and the term natural behaviour is not equal to behaviour in the nature (Algers, 2008). Pigs are curious and have a well-developed exploratory behaviour (Wood-Gush & Vestergaard, 1991). Exploring, foraging and rooting behaviours are expressed largely in the pigs' general activity and are performed to search for possible locations of food and to gather general information in the surroundings (Studnitz *et al.*, 2007). Inglis & Ferguson (1986) suggested that the animal is motivated to work for information as well as to find food. Frustration due to prevention of highly motivated behaviours, or behaviours that give no functional feedback can be avoided. Enriched environments with larger areas and outdoor runs can give the pigs more opportunities to actively explore their environment. It will occupy the pigs and give them more possibilities to express behaviours for which they are motivated, and can lead to a reduction of stress and aggressive behaviours. Stolba & Wood-Gush (1989) found that pigs born and kept in a semi-natural environment (including grass and woodland) spent up to 75% of the daylight period examining rooting and grazing compared with correspondingly approximately 5% for pigs in conventional production systems. To understand how the environment should be designed to meet the biological demands for modern growing/finishing pigs, it is of great importance to study their motivation for foraging behaviour, given that their nutrient requirements are fulfilled.

In organic production, roughage such as grass (fresh or dried) or silage should be offered in unlimited amounts (EC, 1999). According to Swedish standards (KRAV, 2008), the roughage should have a high nutritionally and hygienic quality. Pigs have a capacity to digest forage fibres in the hindgut (Andersson & Lindberg, 1997) and roughages might, due to high fibre content, improve the well-being of pigs because they positively affect the development of the microflora and epithelium in the gut (Fernandez & Danielsen, 2002). Roughages also positively affect pigs by increasing their motivation to explore and forage (Roberts *et al.*, 1993; Vestergaard, 1996) and may influence the pigs' activity pattern and social interactions. It has been shown both that roughage can be included in the total diet up to 18-19% of dry matter (DM) without refusals (Carlson *et al.*, 1999) and that pigs with a live weight of 60 kg or more, are able to consume 10% of the energy from roughage (Jensen & Andersen, 2002). By increasing the time spent eating, roughage can occupy the pigs and most likely reduce stress and aggression between individuals. Several studies have shown a reduction in aggressive and harmful behaviours when enrichments such as barley-pea or whole crop silage roughage, and straw were supplied (Petersen *et al.*, 1995; Beattie *et al.*, 2000; Olsen, 2001; Persson *et al.*, 2004).

Health

The design of housing systems in organic pig production implies a variation in climate, which might affect the pathogen load of the pigs, and may differ from that documented among conventional indoor pigs (Kugelberg *et al.*, 2001). Respiratory infections (pleuritis) are less common in outdoor pigs than in pigs raised indoors in conventional systems, according to pathological and additional findings from post-mortem inspections at Swedish slaughterhouses (Hansson *et al.*, 2000). However, leg problems might be a problem and the authors reported that the number of incidences of arthritis and arthrosis at slaughter was higher for pigs raised outdoors. According to Kugelberg *et al.* (2001) this phenomenon can be linked to erysipelas, which is caused by the bacteria *Erysipelothrix rhusiopathiae*, found in the soil. An outdoor housing facility may also cause an increased infection risk from endo- and ectoparasites e.g. large round worm (*Ascaris suum*) and scabies (*Sarcoptes scabiei*), because preventive medication, for example routine deworming, is not practised. According to Kugelberg *et al.* (2001), who presented results registered at slaughter, the proportion of liver injuries, caused by large round worm, was at the same level in both outdoor and indoor pigs. However, the time of infection differed in pigs in organic and conventional herds (Nansen & Roepstorff, 1999). Organic pigs became heavily infected in the first weeks of life, whereas conventional pigs were infected late in the fattening period. Because the lesions caused by *Ascaris suum* heal with time, this influences registrations made at slaughter and affects the profitability.

Aims of the thesis

The overall objective was to get more knowledge about important issues in organic pig production. The main focus was on pigs' nutrient supply, performance, behaviour repertoire and health status, as well as utilization of alternative protein feed resources. The specific aims of the studies were to:

- investigate the influence of dietary amino acid levels in a low-energy diet provided *ad libitum*, on performance and carcass quality of organic growing/finishing pigs reared in indoor and outdoor production systems
- evaluate the pathogen load in growing/finishing pigs reared in indoor and outdoor production systems
- investigate whether dietary level of amino acids and outdoor production systems with pasture and larger areas, influence pigs at different ages to perform more natural behaviours
- determine whether additional roughage and access to outdoor areas affect activity behaviour and reduce aggression level in organic growing/finishing pigs
- provide data on the nutritional properties of some organic protein feed resources that are potentially available and could be utilized in organic pig meat production.

The hypotheses were *i*) that dietary amino acid content can be lower than current nutrient standards by applying *ad libitum* feeding with a low-energy diet without affecting pig performance *ii*) that access to pasture and roughage would change the pigs' behaviour repertoire and reduce aggressions and *iii*) that the digestibility of the alternative protein feed resources would be satisfactory, which could increase the use of these feedstuffs in organic pig diet formulation.

Summary of the investigations (Paper I-IV)

Material and methods

This project is a part of 'Ekogris' – a multidisciplinary research programme within organic pig production, which was founded by Formas (Swedish Research Council for Environment Agricultural Sciences and Spatial Planning). The research is based on three studies, presented in four papers. The performance, carcass quality and health study in Paper **I**, and the behaviour study in Paper **II** were performed together in the same study at Funbo-Lövsta research station, Swedish University of Agricultural Sciences, Uppsala, Sweden. The behaviour study in Paper **III** was carried out as a field study and was performed at three organic pig herds in the south-west part of Sweden. The digestibility study in Paper **IV** was performed at the experimental unit at the Department of Clinical Sciences, Swedish University of Agricultural Sciences, Uppsala, Sweden.

Performance, carcass quality and health study (Paper I)

Animals, housing, diets and experimental design

This two-year study included a total of 192 growing/finishing organic (Landrace x Yorkshire) x Hampshire piglets born outdoors (Wallenbeck *et al.*, 2008). At weaning (18.8 kg live weight) the pigs were transferred to a growing/finishing unit, either a pen indoors (I) or a pasture outdoors (O). The indoor pens on concrete were supplied with straw once a day. One feeder was placed in the front of the pen and four water nipples were in the dunging area. The outdoor pastures contained only natural weeds and grasses, had a shelter with straw bedding and were supplied with a water sprinkler to create a mud wallow. A feeder was placed in the front of every pasture with one water nipple close by.

In total there were 12 pens indoors and 12 pastures outdoors, i.e. two replicates per treatment and year. The studies were carried out during the summer (May-October). Each pen or pasture included four females and four castrates. The piglets were randomly allocated within litter to six treatments (IR, IR-7, IR-14 and OR, OR-7, OR-14), balanced according to sex and live weight. The pigs received diets containing different amino acid levels (lysine, methionine + cystine and threonine). The amino acid level in R was in accordance with the recommendation for growing/finishing pigs in Sweden (Simonsson, 1994), R-7 and R-14 contained 7 and 14% lower amino acid levels than the recommendation, respectively. The amino acid supply, based on values for total tract digestibility (TTD, g/MJ ME), was given as a 2-phase feed with a high level before 60 kg live weight (phase 1) and a lower level from 61 kg to slaughter (phase 2). Correspondingly, the amino acid supply, based on SID values (g/MJ ME), was calculated (Simonsson, 2006). The indoor and outdoor dietary energy content was 11 and 12 MJ ME, respectively and all diets were provided *ad libitum*.

Assessment of performance and health

Feed samples from the different diets were collected once a week during the experiment. Samples of blood and faeces were collected from each pig at a group average live weight of 25 kg and 60 kg, and one week prior to slaughter. The pigs were weighed at the start of the experiment and thereafter every third week and had a final average live weight of 113.1 kg. The weight of the cold carcass was recorded and the right half was portioned into cuts, the ham was defatted and weighed as meat and bone, and the fat was weighed separately. Carcass lean meat was determined according to Hansson (1997), internal reflectance (on samples of *M. biceps femoris*) and ultimate pH was measured.

The blood samples were analysed to detect serum antibodies to *Mycoplasma hyopneumoniae*, *Actinobacillus pleuropneumoniae*, serotype 2 and 3, *Erysipelothrix rhusiopathiae* and *Sarcoptes scabiei*, with a previously described indirect ELISA system (Wallgren *et al*., 1992). The occurrence of *Ascaris suum* and *Eimeria sp*. in faeces was determined by counting eggs and oocysts by the McMaster method.

Behaviour studies (Paper II and III)

Animals, housing, diets and experimental design

Animals, housing, diets and experimental design in the behaviour study in Paper **II** were the same as in the performance, carcass quality and health study in Paper **I**.

The two-year field behaviour study (Paper **III)**, comprised two experiments and included in total 515 organic growing/finishing pigs (Landrace x Yorkshire) x Hampshire. Experiment 1 included 377 pigs in three different herds (I, II, III) and experiment 2 included 138 pigs in herd III. The experiments started at an average live weight of 33.2 and 30.2 kg in experiment 1 and 2, respectively. The pigs in experiment 1 were weighed every second week until slaughter, which occurred at an average live weight of 111.3 kg. The pigs in experiment 2 were only weighed initially at arrival and had an average carcass weight of 88.7 kg. Both experiments were carried out during the winter period when the pigs were housed indoors with access to a concrete outdoor run. Housing systems were either an un-insulated barn with 29-49 pigs per pen (herd I), an insulated rebuilt stable with 22-32 pigs per pen (herd II) or an un-insulated barn with 31-36 pigs per pen (herd III). All pens contained a lying area with straw, and an eating area with feeding troughs which allowed all pigs to eat simultaneously.

All pigs were fed liquid diets based on organic produced feedstuffs complemented with either cream and whey, starch by-products or distiller's grain. All pigs were fed three times daily according to the standard feeding regime for growing/finishing pigs in Sweden (Andersson *et al.*, 1997). Pigs in experiment 1 were according to sex and live weight randomly allocated to either a control treatment (C) or one of three treatments with access to additional roughages: hay (H), grass silage (GS) or whole crop barley silage (BS). Pigs in C treatment received straw only in the lying area whereas additional roughages in H, GS and BS were given *ad libitum* in feeding hedges in the outdoor area. Based on the results from experiment 1, experiment 2 was set to include the control treatment (C) and the treatment with additional grass silage (GS).

Behaviour

Behaviour studies were directed at activity behaviour and social interactions of the pigs. In Paper **II**, three observation occasions per pen/pasture were performed at a mean age of 60, 110 and 140 days. Between 08.00 and

12.00, every pen/pasture was studied for six rounds with an eleven minute session per round, resulting in 66 minutes of observation per pen and occasion in total. In Paper **III**, four occasions were performed continuously; at arrival and later every four weeks throughout the growing/finishing period. In experiment 1, each occasion lasted two days with observations two times per day at 9.00 and 13.00. Every pen was studied for 12 rounds with a two minute session per round leading to in total 96 minutes of observation per pen and occasion. In experiment 2, all pigs changed alternately between the treatments; one week in treatment C and one in GS, and each occasion lasted two days per week with observations three times per day at 8.30, 12.00 and 15.00. Every pen was studied for 9 rounds with a two minute session per round leading to in total 108 minutes of observation per pen and occasion.

The observations in Paper **II** and **III** consisted of direct observations (by scanning the whole pen/pasture to identify the pigs' general activity behaviour) and continuous sampling (by counting frequencies of social interactions). Each eleven minute session (Paper **II)** consisted of direct observations during the first minute, between minute five and six and finally between minute ten and eleven. Between the direct observations, frequencies of social interactions were registered for a total of 8 minutes (2x4 minutes). This procedure was performed in each pen/pasture followed by repetition (rounds). Each two minute session (Paper **III)** started with direct observations and then one minute of continuous recording in each pen, followed by repetition (rounds). A time schedule of the observations during a session is presented in Figure 1. The behaviours recorded are shown in an ethogram separately in each paper.

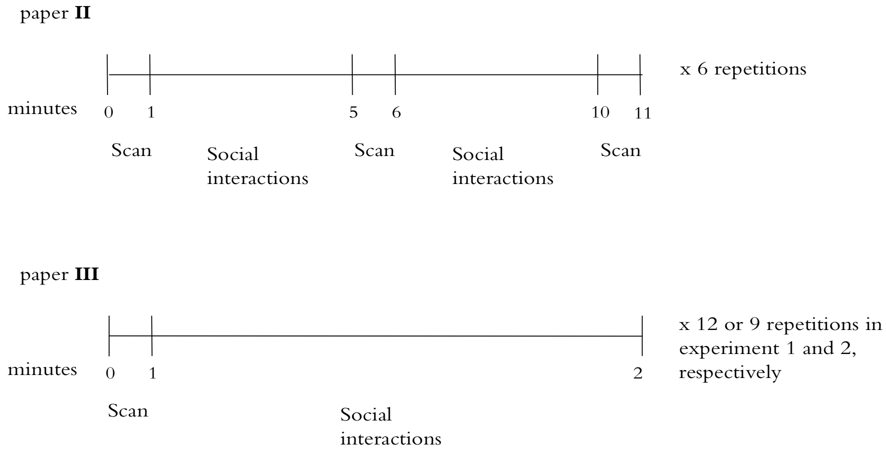

Figure 1. Time schedule of the behaviour observations during a session in Paper II and III.

Digestibility study (Paper IV)

Animals, housing and feeding

The study in Paper **IV** included six castrated male Yorkshire pigs fitted with a post valve t-caecum (PVTC) cannula (van Leeuwen *et al.*, 1991) at an average weight of 22.1 kg. The pigs were housed in individual pens on concrete. No bedding was allowed but the pens contained rubber carpets in more than half of the pen area and were provided with a heating lamp. The pigs were fed twice daily at 07.30 and 15.30. The total basal feed allowance was 4% of the individual live weight until 60 kg and adjusted every week. After 60 kg live weight the feed allowance was restricted to 2.4 kg per pig and day. Water was added to the feed with a 2:1 ratio.

Experimental design and dietary treatments

The experiment was designed as a 4-period changeover trial with four diets and six pigs. Four of the pigs were randomly subjected to four dietary treatments and two of the pigs were regarded as replicates. Thus, two pigs were allocated to two of the four treatments during each period. The four treatment diets were: hempseed cake (HC), linseed cake (LC), rapeseed cake (RC) and faba bean (F). A casein diet (CA) was used to determine endogenous amino acid secretions and was given to all six pigs in periods before and after the trial. All diets were based on cornstarch, sugar and casein, added with protein sources from hempseed cake, linseed cake, rapeseed cake, faba bean or casein, respectively and were formulated to obtain a crude protein content of 170 g/kg DM.

Sampling and calculations

Each experimental period lasted 14 days and consisted of 7 days of adaptation, 4 days of faecal collection and 2 days of ileal digesta collection. Faeces were collected from the pen twice daily in the morning and in the afternoon and collection of ileal digesta through the PVTC-cannula was carried out during 1-hour periods every other hour. Feed samples from feed ingredients were collected when mixing the treatment diets, and samples from the diets were collected during the last week of each period. All samples were immediately frozen and stored in -20°C.

TiO_2 in feed, digesta and faecal samples was used as an indigestible marker for calculations of AID and TTD. Apparent digestibility (AD) of the treatment diets was then calculated using the indicator technique according the equation:

$$AD_T = 100 - (I_T \text{ x } DC_{Dig}) / (DC_T \text{ x } I_{Dig})$$

where AD_T is the apparent digestibility value of the dietary component in the treatment diet (%), I_T is the indicator concentration in the treatment diet (g kg^{-1}), DC_{Dig} is the dietary component concentration in digesta or faeces (g kg^{-1}), DC_T is the dietary component concentration in the treatment diet (g kg^{-1}) and I_{Dig} is the indicator concentration in digesta or faeces (g kg^{-1}).

The contribution of crude protein and amino acids originating from casein in the basal feed in the diets were corrected and accounted for, to calculate AID of crude protein and amino acids for each protein feed ingredient (hempseed cake, linseed cake, rapeseed cake and faba bean) according to the equation:

$$AID_F = AID_T + [(AID_T - AID_C) \text{ x } (DCL_{CT} \text{ x } DC_B / DCL_{FT} \text{ x } DC_F)]$$

Where AID_F is the apparent ileal digestibility value of the dietary component in the feed ingredient (%), AID_T is the apparent ileal digestibility value of the dietary component in the treatment diet (%), AID_C is the digestibility value of the dietary component in the casein diet (%), DCL_{CT} is the dietary component level from casein in the treatment diet,

DC_B is the dietary component in the basal feed (%), DCL_{FT} is the dietary component level from the feed ingredient in the treatment diet and DC_F is the dietary component in the feed ingredient (%).

The endogenous losses of nitrogen and amino acids in ileal digesta were estimated using the equation:

$$ILE_{AA} = DC_{Dig} \text{ x } (I_F \text{ / } I_{Dig})$$

Where ILE_{AA} are the ileal losses of endogenous nitrogen or amino acids (g kg^{-1} DM intake), DC_{Dig} is the dietary component (nitrogen and amino acids) concentration in digesta (g kg^{-1} DM), I_F is the indicator concentration in the feed ingredient (g kg^{-1} DM) and I_{Dig} is the indicator concentration in digesta (g kg^{-1} DM).

Values for SID were calculated according to the following equation:

$$SID = AID_F + (ILE_{AA} \text{ / } DC_F) \text{ x } 100$$

Where SID is the standardized ileal digestibility value of the dietary component (%), AID_F is the apparent ileal digestibility value of the dietary component in the feed ingredient (%), ILE_{AA} is the ileal losses of endogenous nitrogen or amino acids (g kg^{-1} DM intake) and DC_F is the dietary component concentration in the feed ingredient (g kg^{-1} DM).

Chemical analysis

The feed samples in Paper **I** and **IV** and digesta and faecal samples in Paper **IV** were freeze-dried and ground through a 1-mm sieve and then analysed for contents of DM by drying at 103° C for 16 h and for ash after ignition at 550° C for 3 h. Nitrogen was determined by the Kjeldahl method (Nordic Committee on Food Analysis, 1976). Neutral Detergent Fibre (NDF) was determined with an ND solution (100%) and amylase, but no sulphite (Chai & Udén, 1998). Crude fat (EG fat) was determined according to the method described by Official Journal of the European Communities (1984). Dietary content of amino acids was analysed according to Llames & Fontaine (1994). In Paper **I**, the content of minerals (Ca, P, Mg, N and K) was determined by atomic absorption spectrophotometry after dry ashing the samples (Nordic Committee on Food analysis, 1991). In Paper **IV**, starch including maltodextriner was analysed with the enzymatic method described by Larsson & Bengtsson (1983), TiO_2 in feed, digesta and faecal samples was analysed according to

Short *et al.* (1996) and energy was measured with a Gallenkamp automatic adiabatic bomb calorimeter (CB-100).

Statistical methods

For Paper **I-IV** the statistical analysis were performed with the SAS program, version 9 (SAS Institute, Inc, Cary, NC, USA). All two-way interactions between the fixed effects were tested and excluded from the model if found to be not significant (p>0.05).

In Paper **I**, analysis of performance and carcass quality traits was performed with procedure Mixed. Feed conversion data were analysed on a group basis with the model including treatment as fixed effect and year and pen/pasture within year as random effects. Remaining performance as well as carcass quality traits was performed on an individual basis with treatment and sex as fixed effects. Year, dam within year, and pen/pasture within year were treated as random. Initial weight was included in the model as a covariate. Data were presented as least square means with pooled standard errors. Analysis of health parameters was performed with χ^2-test, Fisher's exact test, in procedure Freq to compare number of pigs seropositive to erysipelas, and to compare number of parasite eggs in faeces between indoor and outdoor pigs at different ages.

The model in Paper **II** included housing system, treatment and age as fixed effects and group within housing system as random. The majority of the variables in Paper **III** were either arc sin-transformed (activity behaviour) or square root-transformed (social interactions) to improve the normality of the distribution before the statistical analysis. The models for experiment 1 and 2 in Paper **III** both included treatment, observation occasion and session time as fixed effects and the effect of herd was regarded as fixed in experiment 1. Pen (within herd in experiment 1) was treated as the statistical unit. For the analysis of social interactions, number of pigs per pen within observation occasion was added as a covariate.

The behaviour studies in Paper **II** and **III** were applied with repeated measures and the covariance structure were Unstructured and Spatial Power for activity behaviour and social interactions, respectively (Paper **II)**, and Compound Symmetric (Paper **III)**. Direct observations of activity behaviour was analysed as the average total number of pigs per pen/pasture performing a behaviour within an observation period, and were presented as least square means of percent of pigs (Paper **II**) and observations (Paper

III). Social interactions were analysed as the total frequency of each behaviour performed per pen/pasture within an observation period, and presented as least square means of the number of times per period (Paper **II)** and hour (Paper **III)**.

In Paper **IV**, the models for the AID and TTD values included treatment and period as fixed effects and pig as random effect. Residuals followed the normal distribution. Carry-over effects from the previous period were also tested for as fixed effects; however, no such effects were found and were therefore excluded from the model. At overall significant effect of treatment, differences between treatments were tested using least square means (t-tests) and the results were presented as least square means.

Main results

Performance and carcass quality (Paper I)

Total feed and energy consumption did not differ between treatments and was on average 286 kg and 3277 MJ ME per pig, respectively and there was no difference in feed conversion ratio, expressed as MJ ME/kg weight gain between the treatments. In general, the consumption of total tract and standardized ileal digestible amino acids (g/day) agreed and showed that it was similar in all treatments during phase 1. However, the consumption was generally higher for outdoor than indoor pigs independent of amino acid level during phase 2. In common, all pigs consumed slightly less or similar standardized ileal digestible amino acids (g/day) than the recommended levels during phase 1 and 2 (except for methionine and cystine in phase 2) (Figure 2).

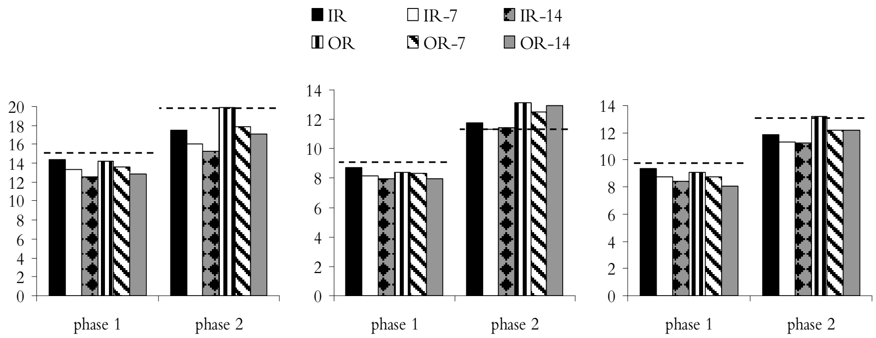

Figure 2. Daily consumption of standardized ileal digestible lysine (left), methionine+cystine (middle) and threonine (right) (g/day) for pigs in different treatments compared to the recommended values of daily intake ------ (Simonsson, 2006).

Pigs in OR, OR-7 and OR-14 treatments grew faster than IR, IR-7 and IR-14 pigs during phase 2, respectively and this difference was also found for the entire period. Consequently, the OR, OR-7 and OR-14 pigs required less time to reach final weight. Pigs in the outdoor system had higher carcass weight and dressing percentage than pigs in the indoor system. Lean meat content was similar in all treatments; however, the percentage of ham in carcass was lower and internal reflectance was higher in meat from OR, OR-7 and OR-14 compared with IR, IR-7 and IR-14 pigs, respectively. In the indoor systems, several pigs suffered from scurf.

Activity behaviour and social interactions (Paper II and III)

Activity behaviour

Amino acid level did not influence the activity of the pigs (Paper **II)**. Indoor pigs given diets R-7 and R-14 were drinking significantly more often than those indoor pigs receiving the R diet (1.8 and 1.7 vs. 0.5% pigs per pen/pasture and occasion), but had less contact with other pigs (1.9 and 1.6 vs. 5.2% pigs per pen/pasture and occasion). For outdoor pigs, however, no effect of amino acid level was found. Outdoor pigs were walking significantly more frequently and tended to root (foraging and rooting or trying to root) more often than indoor pigs (Paper **II)**.

Additional roughage in feeding hedges in the outdoor area resulted in more pigs staying outdoors than when no roughage was supplied (Paper **III**). Pigs in treatment H, GS and BS were observed outdoors, on average, 9.6, 12.5 and 11.0%, respectively compared with 3.8% for pigs in treatment C in experiment 1. The corresponding values for GS and C pigs in experiment 2 were 15.3 and 5.5%, respectively. Furthermore, roughage in the outdoor area made the pigs more active (standing and eating roughage) compared with the control pigs. Exploring (rooting in straw or other and eating roughage) did not differ between treatments in experiment 1; however, GS pigs explored more than C pigs in experiment 2. When analysing rooting in straw or other separately (Paper **III**), we found that C pigs were rooting in straw more frequently than GS pigs in both experiments. The prevalence of eating roughage was similar in H, GS and BS treatments.

Rooting decreased and sleeping increased with increasing age indoors, but did not show any consistent trend for outdoor pigs (Paper **II**). In the same way, rooting in straw or other was higher at younger age, whereas standing decreased with time in experiment 1 and 2 in the field behaviour study ($p<0.005$ for all, non published). In addition, a higher prevalence of staying outdoors and a tendency of eating roughage more frequently was found among older pigs in experiment 1. More pigs were staying outdoors, were active and were eating roughage in the afternoon session than in earlier sessions (Paper **III**). A herd effect was obtained for staying outdoors, exploring, rooting in straw or other, standing and lying indoors, being active, manipulating outdoor environment and eating feed from the feeding troughs (Paper **III)**.

Social interactions

Amino acid level did not affect social interactions between the pigs (Paper **II**). The frequency of sniffing, nibbling, pushing and tail manipulation were lower outdoors than indoors (Paper **II**). Aggressive behaviour in the indoor lying area occurred less among the pigs with access to roughage than among those in the control treatment in experiment 1 and lower, though not significantly, in experiment 2 (Paper **III**).

Aggression in the pen/pasture, riding and ear manipulation (Paper **II**), decreased with increasing age among indoor pigs, but were unaffected and in general performed less frequently among outdoor pigs. Similarly, aggression and riding indoors in experiment 1 (Paper **III**) was performed more often at earlier ages whereas it was unaffected by time in experiment

2. The frequency of aggressive behaviour was found to be higher in the noon session than in the morning and afternoon sessions. Riding and outdoor aggression were influenced by herd.

Health (Paper I)

Infections of *Mycoplasma hyopneumoniae* and *Actinobacillus pleuropneumoniae*, serotypes 2 and 3 occurred only in occasional pigs and were therefore not statistically tested. A higher prevalence of erysipelas was found in outdoor compared with indoor pigs; 22% of the outdoor pigs and 4.6% of the indoor pigs were seropositive for *Erysipelothrix rhusiopathiae* and there were generally more infected outdoor pigs at all ages. The prevalence of pigs infected with *Ascaris suum* (1-5000 eggs/g faeces) was 55.8 and 57.8% for outdoor and indoor pigs, respectively. For pigs infected with more than 5000 eggs/g faeces, corresponding values were 15.1 and 27.6%. The prevalence of *Ascaris suum* infections was higher among pigs at 60 kg live weight both outdoors and indoors. *Eimeria sp.* was only found outdoors with 14.5% infected pigs and the infection level was highest one week prior to slaughter.

Digestibility (Paper IV)

The chemical composition of the feed ingredients (hempseed, linseed and rapeseed cake and faba bean) varied to some extent (Paper **IV**). However, the analysed dietary content of crude protein, lysine and gross energy in the treatment diets was similar and on average 172, 11.0 g/kg DM and 18.7 MJ ME, respectively.

AID and total tract apparent digestibility (TTAD) of crude protein was not affected by treatment. AID of DM, organic matter and gross energy was higher in pigs fed treatment diets with F than with HC, LC and RC, whereas AID of starch showed the opposite trend. TTAD of DM, organic matter and gross energy was generally lower in HC compared with LC, RC and F treatment diets. An effect of dietary treatment was found on the AID for essential and non essential amino acids (except for phenylalanine, alanine and glycine), in general with lower digestibility for RC compared with F.

The adjustment for the contribution of casein in the basal feed to obtain the AID for the single protein feed ingredients (hempseed, linseed and rapeseed cake and faba bean), slightly reduced the AID values of crude protein, essential and non essential amino acids. After the correction of the basal endogenous fractions, the SID of crude protein was 84.6, 85.8, 81.3 and

85.8% for hempseed cake, linseed cake, rapeseed cake and faba bean, respectively. Corresponding SID values for lysine were 85.2, 82.6, 86.1 and 91.7%.

General discussion

The aim of this thesis was to get more knowledge about relevant issues in organic pig production and investigate how growing/finishing pigs are influenced by supply of nutrients, production system and housing conditions. These factors are important to get satisfactory results in terms of pig performance and carcass quality, possibility for pigs to perform natural behaviour and maintain a good health. The studies included in the thesis (Paper **I-III**) have given good information about this. Furthermore, the thesis aimed to evaluate the nutritional value of some alternative protein feed resources that could facilitate the practises of some of the regulations and principles for organic farming. This has been accomplished in the study in Paper **IV**.

Production system and pig performance

The results mainly showed that performance and carcass quality were affected by production systems rather than dietary amino acid levels (Paper **I**). Our hypothesis that growing/finishing pigs fed *ad libitum* theoretically are able to tolerate lower dietary amino acid levels with unaffected production results was verified. It appears that a sufficient total daily intake of protein and amino acids could be assured due to an increased voluntary feed intake to maintain a high daily energy intake, which has been suggested previously (Baker, 1993).

The formulation of the diets was aimed to contain generally lower levels of amino acids (lysine, threonine and methionine+cystine), crude protein and energy than recommended values (Paper **I**). These criteria were difficult to fulfil simultaneously and therefore focus was put on the content of amino acids and energy. The obtained variation between calculated and analysed content of amino acids might have affected the results and have to be considered when discussing the results. The design was, except for the general lower energy content, also to meet an expected higher energy requirement for outdoor pigs (Close & Poornan, 1993). The calculated energy content in the outdoor diets was therefore 12 MJ ME compared with 11 MJ ME in the indoor diets (Paper **I**). The difference in dietary energy content makes it difficult to interpret the obtained results. Equal energy content would probably have given a more accurate understanding of how factors such as energy, protein and amino acid requirements affect the performance and carcass quality of growing/finishing pigs with different housing conditions.

Daily consumption of energy (MJ ME) in the first part of the rearing period (phase 1) was in spite of different energy content similar for outdoor and indoor pigs, indicating that the pigs ate according to their energy requirements. However, higher energy consumption (on average 13%) was found for outdoor pigs in the later period (phase 2). In this phase the outdoor pigs had about 15% higher growth rate than the indoor pigs, which was unexpected and contrary to the results found by others, because outdoor pigs have a higher energy requirement due to outdoor housing and more activity (Andersson *et al.*, 1990; Lundeheim *et al.*, 1995; Enfält *et al.*, 1997; Strudsholm & Hermansen, 2005). Outdoor pigs in our study were however more active and rooted more frequently in the later rearing period than indoor pigs (Paper **II**), which might explain their higher energy consumption. Daily weight gain in our study was based on carcass weight because roughage and feed intake influence the dressing percentage. Estimated lean meat content was equal between outdoor and indoor pigs and confirms that outdoor pigs did not exceed the maximum protein deposition (Van Milgen *et al.*, 2000) and that the extra energy was not used for fat deposition. All pigs in our study were born and raised outdoors until weaning and thereafter moved to new environments, either outdoors or indoors. Environmental changes at the start of the growing/finishing period were found to be negative for the pigs' growth rate (Stern *et al.*, 2003), indicating that a change from outdoor areas to indoor pens at weaning might be a larger change for pigs than moving from one outdoor system to another. This might also have negatively influenced the growth of the indoor pigs in our study. Overall, our findings strengthen the speculation that the observed difference in daily weight gain between outdoor and indoor pigs largely depended on the occurrence of scurf among the indoor pigs, which negatively influenced their growth. Scurf is related to problems in assimilating zinc, which might have been influenced by the water supply (Hellberg, 1961). Indoor pigs in our study did not have a water nipple next to the feeder and could not drink in connection with eating. However, they were drinking significantly more frequently than outdoor pigs (p=0.020, not presented), The higher feed intake (kg) of the indoor pigs, due to a more diluted feed with lower energy content (MJ ME) led to lower dressing percentage. This was probably due to greater gut fill in accordance with Stern *et al.* (2003), Fischer (2001) and Heyer *et al.* (2006). This verifies that outdoor pigs did not consume any considerable amount of pasture late in the rearing period.

The paler meat (higher FOP_{BF} values) of the outdoor pigs is in agreement with results from previous studies (Enfält *et al.*, 1997; Stern *et al.*, 2003). On the contrary, other findings have shown opposite results (Gentry *et al.*, 2002; Heyer *et al.*, 2006) or no difference in lightness between outdoor and indoor reared pigs (Gentry *et al.*, 2004). In these studies, different cross breeds were used and genotype has been shown to affect the colour of the meat.

Lower levels of amino acids did not affect pig performance and carcass quality in our study. This disagrees with previous findings by Sundrum *et al.* (2000), who found lower daily weight gain in pigs fed lower levels of amino acids, although feed efficiency and carcass characteristics were less affected. The daily consumption of amino acids (lysine, methionine + cystine, threonine) was generally below the current Swedish amino acid recommendations (Simonsson, 2006). Our results indicate that the recommendations could be too high for organic pigs fed *ad libitum*. Recent studies support this by showing that the lysine requirements of growing pigs were only 94% of the current NRC requirements (Bertolo *et al.*, 2005). Furthermore, intestinal gut microbes produce essential amino acids, which can be absorbed from the small intestine and contribute to about 10% of the lysine requirement (Torrallardona *et al.*, 2003a; 2003b). This is not included when requirements are estimated and might also partly explain our results. Additionally, the diets in Paper **I**, had higher fibre content with a more variable composition containing a range of non-starch polysaccharides, which could be fermented by the gut microbes (Bach Knudsen, 1997). This could possibly have resulted in higher gut microbial activity (Bach Knudsen *et al.*, 1991) and even higher contribution of essential amino acids from the small intestine than reported by Torrallardona *et al.* (2003a; 2003b).

The feeding strategy in Paper **I** could be favourable with regard to lower content of dietary amino acids, and formulation of diets on the basis of amino acids rather than crude protein is a more precise approach (Lewis, 1991). The dietary crude protein is influenced by the content of amino acids in the protein and a higher level results in a greater excretion of nitrogen in the urin (Canh *et al.*, 1998; Strid Eriksson *et al.*, 2005) and has to be considered. However, the crude protein level in the diets (Paper **I**), was in the same range (or even lower) as the low levels presented by Canh *et al.* (1998). Moreover, the diets in our study consisted of protein complements such as potato protein and casein, both of which are expensive and uncommon to use in practice in Sweden. There might be some practical difficulties to obtain an optimal balance of amino acids and a low crude protein content in diets, which are based on home grown feedstuffs as the only resource of protein. Additionally, the results from Strid Eriksson *et al.* (2005) showed that it was more favourable for the environment (with regard to nitrogen excretion) to use synthetically produced amino acids to obtain a low crude protein content. This is however in conflict with the principles of organic production and the goal of 100% organically produced feedstuffs in the diets. The definition of what environmentally friendly and long term sustainability means, needs to be taken into consideration when discussing these issues.

Alternative protein feed resources

Digestibility

The alternative protein feed resources investigated (Paper **IV**) had satisfactory digestibility values and they might have the potential to be used to a greater extent in organic pig diet formulation. The obtained AID values were in general comparable with, or even higher than those of peas (Mariscal-Landín *et al.*, 2002), soya bean and soybean meal products (Furuya & Kaji, 1991; Van Leeuwen *et al.*, 1996; Woodworth *et al.*, 2001), canola meal (Fan & Sauer, 1995) and warm pressed rapeseed cake (Partanen *et al.*, 2001). However, the use of these types of feedstuffs might be affected by cultivation conditions, processing techniques, and seasonal and regional prerequisites. A large variation have been found in the literature on AID values, which depends on type of feedstuff, differences in processing conditions, level of nutritional properties e.g. level of fibre and anti-nutritional factors, as well as the methodology (Sauer *et al.*, 2000). Further, crude protein and amino acid content of the experimental diet influences the variation of AID for the dietary components (Sauer & Ozimek, 1986). The technique of PVTC cannulation has been stated to only slightly affect the digestibility (Lindberg, 1997) and to give the most biologically satisfactory results (Hodgkinson & Moughan, 2000). However, lower AID has been found for PVTC compared with other techniques (Köhler *et al.*, 1990; Pedersen & Boisen, 2002).

Depending on which proportion of the ileal nitrogen or amino acid outflow that is included in the calculation, AID, SID and TID differ (Stein *et al.*, 2007). Calculating AID causes an underestimation of the digestibility, due to not considering the origin of nitrogen and amino acids present in the digesta (if they originate from feed proteins or endogenous sources such as microbial protein, sloughed intestinal cells, mucosal proteins and digestive enzymes). Therefore SID is a more accurate assessment of the digestibility because of the adjustment of this factor. The ileal losses of nitrogen and amino acids are divided into a non-specific basal fraction and a specific fraction. The basal fraction is independent of the tested feed, whereas the specific fraction is influenced by factors such as dietary fibre or anti-nutritional compounds, which increase the endogenous flow (Jansman *et al.*, 2002; Stein *et al.*, 2007). When measuring TID, the total (basal + specific) endogenous nitrogen or amino acids are subtracted from the obtained AID value for the diet, whereas when measuring SID, only the basal fraction is subtracted.

The AID values of faba bean for nitrogen and several amino acids were in accordance with previously reported results (Jansman *et al.*, 1993; van der Poel *et al.*, 1992), but were generally higher than those reported by Mosenthin *et al.* (1993), Partanen *et al.* (2001), Mariscal-Landín *et al.* (2002) and Pedersen & Boisen (2002). Higher AID values for cold pressed rapeseed cake was also obtained compared with results found previously (Schöne *et al.*, 1996; Partanen *et al.*, 2001). The lack of information about the nutritive value and digestibility of linseed and hempseed cake makes it difficult to generalize our results. However, the chemical composition and the processing methods of these feed ingredients are similar to those of rapeseed cake and might be considered comparable with similar by-products from oil seeds. The SID values for nitrogen and amino acids were in most cases in agreement with the results found by others (Mariscal-Landín *et al.*, 2002; Pedersen & Boisen, 2002) and were, as expected, slightly lower than TID values (Mosenthin *et al.*, 1991; 1993).

Endogenous losses of nitrogen and amino acids

The casein diet in our study was used to calculate the basal ileal losses of endogenous crude protein and amino acids to obtain SID values of crude protein and amino acids. Casein is a highly digestible purified protein and the specific endogenous amino acid losses can be minimal when used as feed ingredient (Stein *et al.*, 2007). There are no specific components in casein that influence the endogenous ileal amino acid losses, indicating that the losses are of basal origin (Libao-Mercado *et al.*, 2006) and high TID values in casein indicate that protein from casein easily are hydrolysed and absorbed (Yin *et al.*, 2004; Libao-Mercado *et al.*, 2006). High estimates of the basal endogenous losses from casein might, on the contrary, indicate that it is not 100% digestible or that it leads to specific endogenous losses, resulting in some overestimation of the basal endogenous losses.

Our estimates of ileal basal losses of endogenous crude protein were lower or similar to estimates found previously in studies with different dietary methods or cannulation techniques (Jondreville *et al.*, 1995; Jansman *et al.*, 2002; Pedersen & Boisen, 2002; Fastinger & Mahan, 2006; Mariscal-Landín & Reis de Souza, 2006). Further, higher estimates of the basal losses of endogenous crude protein and amino acids were found in pigs with lower body weight, in agreement with previous studies (Leterme & Théwis, 2004; Mariscal-Landín & Reis de Souza, 2006). As expected, our estimates of the basal fraction of ileal endogenous losses were lower than reported values of total losses (Furuya & Kaji, 1991; Jansman *et al.*, 1995; Libao-Mercado *et al.*, 2006). The feed ingredients used in our diets are all known to contain fibre and anti-nutritional factors to some extent. This together with the physiological state of the animal might have influenced the losses of endogenous nitrogen and amino acids.

Natural behaviour

The results found in the behaviour studies (Paper **II** and **III**) support the hypothesis that access to pasture and roughage leads to a change in the pigs' behaviour repertoire and reduce aggressions. The design of the behaviour studies was however not completely the same and must therefore be considered when interpreting the results. In both studies activity and social interactions were investigated and direct observations of the pigs' general behaviour and their location, and continuous sampling of the pigs' social interactions were applied. However, different observers carried out the recordings and the performed behaviour observations varied between the studies. These factors have to be considered because they may have contributed to some variation of the results. The relatively small amount of data, due to practical reasons and few herds, has probably affected the results and more replicates would have resulted in a better validity of the results. The statistical analysis of the observations in the studies differed. In Paper **III**, data were transformed to improve the normality of the distribution, which was not done in Paper **II**. However, the same transformations as in Paper **III**, have now been tested in Paper **II**, but without any change of the results.

Activity behaviour

In general, more walking, standing and rooting were found for outdoor pigs and for pigs with additional roughage in the outdoor area, which can be regarded as a higher level of activity. The higher number of outdoor pigs walking (Paper **II**) might be because they had to move between the pasture and the shelter, feeding and drinking space. However, more walking, as well as the higher frequency of rooting, could be part of an explorative behaviour. The frequency of explorative behaviour in our studies is not entirely comparable with previous findings (Stolba & Wood-Gush, 1989), who reported that pigs examined the environment, manipulated and collected feed up to 75% of time. That study was carried out under semi-natural conditions with large areas, whereas our results may have been affected by pigs being housed in smaller pastures or indoor enriched systems only with access to an outdoor run on concrete. Several studies have concluded that various rooting materials increase exploratory behaviour directed towards the rooting materials (Beattie *et al.*, 1996; Olsen *et al.*, 2000; Guy *et al.*, 2002a, b; Long, 2002; Olsen *et al.*, 2002). The relatively small difference in exploring (rooting in straw or other and eating roughage) between treatments (Paper **III**), might be because C pigs were rooting straw in the lying area in absence of additional roughage and still this was recorded as exploring behaviour. All pigs had access to straw in the lying area and were fed three times a day. The fact that C pigs were rooting in straw more often than pigs with grass silage and tended to root more often than pigs with whole crop barley silage, suggests that pigs are motivated to use the additional roughage to explore and forage, and that it leads to a functional feedback. This can be an expression of the phenomenon contrafreeloading, which means that animals choose to perform some type of work, often explorative behaviour, to find feed (Inglis *et al.*, 1997). The function of contrafreeloading is that the animal receives some information investments about further feed resources, which in turn has a great value for survival. Indoor pigs were rooting less and sleeping more often with increasing age, in contrast to outdoor pigs, which were found to sleep less at older age (Paper **II**). This may also indicate that the pasture motivated the pigs to explore. Furthermore, additional roughage in the outdoor area (Paper **III**) encouraged pigs to stay outdoors to a greater extent than when straw was supplied only in the lying area. This is in accordance with previous findings that pigs with access to roughage in the outdoor area stayed outdoors more frequently than pigs without roughage (Olsen *et al.*, 2002).

We found no significant difference in time spent on eating the different types of roughages, contrary to previous investigations which found a higher prevalence of whole crop silage of oats, vetch and lupine compared with six other types of roughages including straw (Olsen *et al.*, 2000). Morover, maize silage was preferred to seed grass hay and straw (Jensen & Pedersen, 2007). It has previously been stated that the enrichment substrates should be complex, changeable and destructible to stimulate foraging behaviour (Studnitz *et al.*, 2007). Bracke *et al.* (2006; 2007) concluded that straw and whole straw with chopped beet roots, maize silage, a bale of straw or long straw with fir branches are valued highest as enrichment substrates for pigs, and that roughage might be sufficient. It has also been concluded that pigs require space as well as environmental enrichment for proper exploratory behaviour (Beattie *et al.*, 1996). Outdoor rearing often offers a more complex environment as well as more space than indoor rearing, and pigs in outdoor systems have been found to explore more than pigs in barren indoor systems without any enrichment materials (Cox & Cooper, 2001; Hötzel *et al.*, 2004). More time was spent outdoors later in the rearing period in experiment 1 (Paper **III**). Consequently, pigs also tended to perform the behaviour eating roughage more frequently at that time. This may be because the pigs were stimulated to continue exploring and eating the substrate. Correspondingly, pigs were rooting in straw or other significantly less during the later observation occasions compared with the first. This may indicate that roughage has a higher value as feeding and rooting substrate than straw as mentioned earlier in this thesis.

In general, pigs were standing less (Paper **III**) and sleeping more (Paper **II**) over time, which is in accordance with previous findings on more time spent on manipulating and investigating the environment in younger pigs than in older pigs (Stolba & Wood-Gush, 1989). A higher activity level, more pigs staying outdoors and eating roughage, during the afternoon session than in earlier sessions (Paper **III**) were confirmed and in accordance with Olsen *et al.* (2000).

Social interactions

Lower frequency of sniffing, nibbling, pushing and tail manipulation in the outdoor compared with the indoor system (Paper **II**) could partly be due to the larger available and more enriched outdoor area. Consequently, outdoor pigs had greater possibilities to perform natural behaviours such as rooting and foraging properly. This agrees with results presented previously, showing that behaviours directed at indoor pen mates were performed more often among pigs in barren environments (Lyons *et al.*, 1995; Petersen *et al.*, 1995; Haskell *et al.*, 1996; Beattie *et al.*, 2000) and that enriched environments considerably affect to diminish these behaviours (Simonsen, 1995). Additionally, riding, aggression-pen/pasture, ear manipulation and other social parameters were in general performed less frequently outdoors than indoors (Paper **II**). These types of social interactions can occur in response to a conflict (Petherick & Blackshaw, 1987) and might therefore be regarded as behaviours that are involved or lead to aggressive behaviours. For pigs with additional roughage (Paper **III**), the lower frequency of aggressive behaviours in the indoor lying area compared with pigs in the control treatment is in accordance with previous findings (Beattie *et al.*, 2000; Kelly *et al.*, 2000; Beattie *et al.*, 2001; Olsen, 2001; Guy *et al.*, 2002b; Long, 2002; Olsen *et al.*, 2002; Bolhuis *et al.*, 2005). In contrast, Morrison *et al.* (2003) found an increase in social tactile interactions and agonistic behaviours in pigs in deep-litter systems, probably as a consequence of increased locomotory and activity behaviours. Higher number of aggressions indoors in the lying area in the control treatment (Paper **III**) might have been influenced because those pigs wanted to lie and root in the same area. Straw and roughages are of importance to induce satiety and to maintain a normal behaviour repertoire. Pigs in our studies had either access to pasture, silage, hay or straw, and our findings indicate that access to more desirable roughages together with larger areas can diminish aggressive social interactions even more than when only straw is supplied.

The decrease in aggressive behaviours for indoor pigs (Paper **II**) and for pigs in the lying area (Paper **III**) as they grew older, and the higher occurrence of riding behaviour indoors and in the lying area at earlier age, agrees with previous findings (Newberry & Wood-Gush, 1988; Wood-Gush *et al.*, 1990; Lyons *et al.*, 1995). Aggression in the outdoor areas was, in common, not influenced by age and was generally higher in Paper **II** than in Paper

III. This might be explained by the observation that it seemed as if the outdoor pigs (Paper **II**) became aggressive when they were rooting next to each other and came too close. The higher aggression level indoors in the noon session than in the morning session (Paper **III**) could have been due to the lower activity during this session. The fact that aggressive behaviour decreased in the afternoon session supports our findings of more pigs staying outdoors and being more active during the afternoon session, which has been reported previously (Olsen *et al.*, 2000).

Tail biting may develop as a consequence of stress or restlessness, and we found a higher frequency of tail manipulation among the indoor pigs (Paper **II**), which is in accordance with Petersen *et al.* (1995). Stressful environments have been found to reduce welfare both in tail-biting pigs and their victims (Schrøder-Petersen & Simonsen, 2001). Outdoors areas in our studies (Paper **II** and **III**) offered more space and the pigs could increase their distance and escape if necessary, instead of being forced to deal with another pig's attentions. The lower growth rate (Paper **I**) might also have been influenced by the occurrence of tail manipulation, as suggested by Wallgren & Lindahl (1996). Less oral behaviour towards pen mates were influenced by access of roughages (Olsen, 2001); however, we found that tail biting occurred less than one time per hour with both additional roughage and straw (Paper **III**).

No effect of amino acid level on activity behaviour and social interactions of the pigs were obtained (Paper **II**), which seems reasonable because *ad libitum* feeding provided the pigs' nutrient requirement even in diets with low amino acid level (Paper **I**). Andresen & Redbo (1999) found no effect on rooting activity when studying the influence of crude protein level in the diet, whereas others have found that inadequate crude protein content in the diet induced rooting behaviour (Jensen *et al.*, 1993; Stern & Andresen, 2003).

Effects of environment

Due to different production systems and design of the housing conditions the variation in activity behaviours and social interactions could be explained. In a recent study by Munsterhielm *et al.* (2006), it was found that the social activity and the exploratory behaviour of growing pigs was affected by their early experience with enrichment as piglets. The environmental changes at the start of the growing/finishing period may have affected the pigs' behaviour suggested by Webster & Dawkins (2000) and Cox & Cooper (2001). Moreover, a deviance in outdoor temperature could also have affected the pigs' behaviour and has to be considered.

Health

The pathogen load monitored (Paper **I**) explains some potential differences between outdoor and indoor production systems, but the study includes only one outdoor and one indoor system, which does not make it possible to generalize the results.

Respiratory infections occurred rarely both outdoors and indoors in our study contrary to findings of registrations made at slaughter of organic and conventionally raised pigs (Hansson *et al.*, 2000). This might be due to a satisfactory air quality both outdoors and indoors. The heavier exposure to *Erysipelothrix rhusiopathiae* of outdoor pigs in our study has been established previously (Hansson *et al.*, 2000; Wallgren *et al.*, 2000; Kugelberg *et al.*, 2001; Beskow *et al.*, 2003). We observed that several pigs in the outdoor systems had difficulties to get up from lying position, due to leg problems. Erysipelas was earlier confirmed to be the cause of increased problems with lameness and arthritis in outdoor pigs (Kugelberg *et al.*, 2001). The incidence of lame pigs should constantly be checked in outdoor production. Vaccination against erysipelas should therefore be performed to prevent arthritis caused by chronic erysipelas.

Due to the prevalence of *Ascaris suum* and *Eimeria sp.* among outdoor pigs, an awareness of the potential risk of increased problems with parasites should be considered. The proportion of liver injuries caused by *Ascaris suum* has been found at the same level in organic as in conventional herds (Kugelberg *et al.*, 2001; Machold *et al.*, 2005), and the prevalence of pigs infected with 1-5000 eggs per g faeces was in accordance with our findings. However, fewer pigs with more than 5000 eggs per g faeces were found among outdoor than indoor pigs in our study. Similarly, Beskow *et al.* (2003) found only occasional samples of faeces that contained more than 5000 *Ascaris suum* eggs per g faeces, in a comparison between different organic herds. This can be compared with the results of Hansson *et al.* (2000), who found significantly fewer white spots in the liver of organic pigs. There is a variation of the distribution of *Ascaris suum* infections within a given population due to type of management system used (Nansen & Roepstorff, 1999). The recorded occurrence of *Eimeria sp.* among the outdoor pigs in our study is comparable with an earlier study where coccidia, considered to be *Eimeria sp.*, was found on all investigated organic farms (Carstensen *et al.*, 2002). Antihelmintics should be used when there is an obvious need, but routine deworming is not allowed in organic production (EC, 1999). Outdoor housing conditions on pasture require well planned systems with principles of worm control such as the use of uncontaminated land and rotation and cultivation of pastures (Nansen & Roepstorff, 1999), which emphasize the integration of pigs in the crop rotation.

Conclusions

- A reduction of the amino acid level in diets for organic growing/finishing pigs fed *ad libitum*, below current Swedish standards for conventionally raised growing/finishing pigs, can be used without any negative effects on performance and carcass quality.
- Reduced amino acid levels will make it easier to optimize nutritionally sufficient diets for organically raised pigs with available feed resources. In addition, this could also benefit the environment by minimizing the excretion of nitrogen.
- White flowering faba bean and cake from hempseed, linseed and rapeseed had satisfactory digestibility and might have the potential to be used more in organic pig diet formulation.
- Access to roughage and outdoor areas allows pigs to express highly motivated natural behaviours, such as foraging, rooting and exploring, to a greater extent. This can result in a general higher activity level.
- Roughage is a good resource that plays an important role in occupying the pigs, which can reduce aggressive behaviours and affect the well-being of pigs.
- The incidence of pigs seropositive to erysipelas in the organic outdoor system, indicating a potential need for vaccinations to avoid problems with lameness and deteriorated animal welfare. The prevalence of *Ascaris suum* and *Eimeria sp*. among outdoor pigs, calls for an awareness of the potential risk of increased problems with parasites.

Future research

To improve the organic pig meat production, further research needs to be carried out about how the production system should be managed to fulfil the goals for long term sustainability. Except for meeting the nutrient requirements, the design of the production system regarding outdoor areas, housing facilities and feeding systems should make allowance for the animals' needs for e.g. natural behaviour, and how it will affect the pathogen load and health of the pigs. It should also consider the risk for losses of nutrients to the environment by excretion of urine and faeces, which can increase when pigs are rooting in the soil. Environmental circumstances such as large variation in weather conditions and climate, and regional outbreaks of infectious diseases play a decisive role for the stability in the production system. Moreover, the system needs to be practical for the farmer to run and should meet the customer expectations for organic farming. In order to get a profitable production, these issues have to be regarded and are important to evaluate.

The effects of agriculture on the environment are influenced by the use of fossil fuels and chemicals. A high self sufficiency level and relying on local resources are important in the farming system, when thinking in terms of recycling. Therefore, it needs to be further investigated how to produce and improve the use of alternative feed resources. Feedstuffs that can be included in the crop rotation such as roughage and organically cultivated legumes and oilseeds, roots and tubers have to be evaluated further with regard to nutritional properties, content of anti-nutritional factors, inclusion level and the use of their by-products e.g. cakes from oilseeds. Additionally, feed resources from the food industry such as mussel meal, dairy by-products or distillers' grain all have the potential to be used to a greater extent in pig diet formulation. Also, it could be of interest to investigate whether food wastes could be utilized.

Populärvetenskaplig sammanfattning

Bakgrund

Djur är viktiga för att uppnå några av de grundläggande målen för ekologisk produktion. Djurhållningen måste vara anpassad och praktiskt fungerande. De resurser som finns bör utnyttjas på ett bra sätt och djurens behov av naturligt beteende och näring ska tillgodoses. Detta kan ibland medföra negativ inverkan på miljön och det kan vara svårt att uppnå en tillräckligt hög och lönsam produktionsnivå.

Foder som används i ekologisk produktion ska helst vara ekologiskt, och odlat på den enskilda gården eller inom landet. Olika regler gör att man i den ekologiska produktionen inte kan använda alla fodermedel och fodertillsatser som används traditionellt. Bland annat är syntetiska aminosyror och köttmjöl förbjudna att använda. Detta gör att det är svårt att täcka framför allt de yngre slaktgrisarnas behov av livsnödvändiga aminosyror. Lysin och treonin är de viktigaste aminosyrorna för grisar och om behovet inte tillfredsställs växer djuren sämre och det blir mindre kött i slaktkroppen. För att garantera tillräcklig mängd av dessa aminosyror måste därför proteinhalten i fodret höjas. Detta får negativa följder för såväl grisen som miljön och är inte en långsiktigt hållbar strategi. Om man kan sänka fodrets innehåll av aminosyror blir det lättare att tillverka ett ekologiskt foder grundat på hemmaodlade fodermedel. Grisar kan delvis styra mängden foder de äter efter sitt behov av energi. Genom att ge fri tilldelning av ett foder med lägre energi, kan de äta mer och teoretiskt kan de då få i sig tillräckligt med aminosyror.

Baljväxter är viktiga för att binda kväve i jorden och grovfoder ger en bra markstruktur och därför är dessa grödor bra i växtföljden. Ärtor som odlas till djurfoder, vitblommiga åkerbönor, rester från raps- och lin och hampa har högt proteininnehåll och bra balans av aminosyror. Dessa fodermedel skulle kunna användas mer i ekologiska foderblandningar, men smältbarheten dvs. hur mycket av näringen som grisen kan ta upp i tarmen, är inte känd.

Ekologiska grisar ska ha obegränsade mängder av näringsrikt grovfoder, de ska kunna gå ut på bete eller betongplatta och de ska ha större boxar än grisar i traditionella system. Berikade miljöer med större ytor och vistelse utomhus gör att grisarna får större möjlighet att utföra naturliga dvs. instinktiva, nedärvda beteenden som att utforska omgivningen, leta föda och böka. Grisar har en hög motivation för dessa beteenden och om de får utföra dem blir de mindre frustrerade, stressade och aggressiva. Förekomsten av tex. luftvägsinfektioner, benproblem och parasiter kan se olika ut hos grisar som vistas inne eller ute. Ekologisk produktion ska främja en god hälsa och lågt smittotryck. Rutinmässig användning av antibiotika eller avmaskningsmedel i förebyggande syfte är förbjudet. Däremot får man vaccinera djuren om det finns behov. Sjuka djur ska alltid behandlas, men det gör att man måste vänta längre innan djuret kan skickas till slakt.

Syfte och utförande

I mina studier (artikel **I** och **II)** undersökte jag hur ett lägre innehåll av aminosyrorna lysin, metionin och treonin i foder, som gavs i obegränsad mängd till ekologiskt växande grisar ute och inne påverkar djurens produktion. Jag studerade även grisarnas beteende och förekomsten av luftvägsinfektioner, rödsjuka och inälvsparasiter. 192 grisar födda ute, fördelades mellan boxar inne (I) och hagar ute (U) och fick foder med olika aminosyranivåer (IR, IR-7, IR-14 och UR, UR-7, UR-14). Foder R var enligt den svenska rekommendationen, R-7 och R-14 innehöll 7 respektive 14% lägre nivåer. Grisarnas vikt och den mängd foder de åt registrerades under uppfödningen, och vid tre tillfällen togs prover av blod och träck.

Jag studerade också om vistelse utomhus med extra grovfoder, som gavs i obegränsad mängd, påverkade grisars beteenden och om förekomsten av aggressioner minskade (artikel **III)**. I denna studie ingick 515 grisar med möjlighet att gå ut på en hårdgjord yta. Grisarna delades in i en kontrollgrupp eller en av tre behandlingar med tillgång till extra grovfoder (hö, ensilage av gräs eller ensilage av hela kornstrån). Alla grisar hade halm i liggutrymmet och de som hade extra grovfodret fick det i foderhäckar ute. Vid fyra tillfällen under uppfödningen studerades hur aktiva och sociala grisarna var.

Dessutom värderade jag smältbarheten för kallpressad rapskaka, linfrökaka och hampfrökaka samt vitblommig åkerböna (artikel **IV**). I den studien ingick sex grisar som hade en fistel inopererad i slutet av tunntarmen. Grisarna utfodrades omväxlande med de fyra fodermedlen i särskilda perioder och i en viss följd. I varje period samlades träck- och tarmprover för att analysera och bestämma smältbarheten.

Resultat

Foder med lägre nivå av aminosyror än vad som rekommenderas, hade ingen negativ inverkan på grisarnas produktion. Mängden aminosyror som grisarna åt per dag var generellt lägre än den rekommenderade nivån. I den senare delen av uppfödningen hade utegrisarna ett högre energiintag än de inomhus. Då växte de också snabbare, vilket var oväntat eftersom grisar utomhus har ett högre energibehov pga. att de rör sig mer och behöver hålla värmen. Det var ingen skillnad i andelen kött i slaktkroppen, vilket betyder att den extra energi som utegrisarna förbrukade inte användes till att ansätta fett. Slaktutbytet var lägre för innegrisarna, vilket kan ha berott på att deras foder innehöll mer fiber. Grisarna åt då mer och fick ett större mag- och tarminnehåll. Dessutom hade innegrisarna hudproblem (skorv), något som gjorde att de växte sämre.

Luftvägsinfektioner var sällsynta både inne och ute, medan förekomsten av rödsjuka var högre ute. Detta visar att det finns risk för infektion av rödsjuka när grisar föds upp ute och därför är det viktigt att uppmärksamma grisar med benproblem. För att undvika ledinflammationer som beror på rödsjuka bör grisar som föds upp ute vaccineras. Den stora rundmasken förekom både hos utomhus- och inomhusgrisar, men grisarna inne var mer infekerade. Dessutom hittades coccidier, en annan typ av parasit, bara i träcken från utomhusgrisar.

De alternativa fodermedlen som testades hade smältbarhetsvärden jämförbara med konventionella proteinfodermedel som tex. soja och ärtor. Därför kan de utnyttjas mer i ekologiska foderblandningar.

Vistelsen i hagar med bete, eller tillgången till grovfoder på uteplatsen gjorde att grisarna blev mer aktiva och bökade oftare. Grisarnas beteenden påverkades inte av olika nivåer av aminosyror i fodret. En berikad miljö motiverade grisarna till att utforska omgivningen mer, och gjorde att de valde att utföra någon typ av arbete för att hitta föda. Dessutom stimulerade det grisarna till att böka och vara aktiva när de blev äldre. Detta betyder att bete och grovfoder är bra som berikningsmedel, och tillsammans med större ytor minskar förekomsten av aggressiva beteenden mellan grisar.

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