Institut für Tierernährung
des Bundesforschungsinstitutes für Tiergesundheit
des Friedrich-Loeffler-Institutes
&
Institut für Agrar- und Ernährungswissenschaften
der Naturwissenschaftlichen Fakultät III
der Martin-Luther-Universität Halle-Wittenberg

Effects of varying supply of essential amino acids and energy on voluntary feed intake, performance, nitrogen retention and chemical body composition of growing-finishing boars

Dissertation

zur Erlangung des
Doktorgrades der Agrarwissenschaften (Dr. agr.)

vorgelegt von

Diplom-Agraringenieurin Caroline Otten
geb. am 29.11.1984 in Lingen (Ems)

Gutachter: Prof. Dr. Dr. Sven Dänicke
Prof. Dr. Annette Zeyner
Prof. Dr. Klaus Eder

Verteidigung am: 14.04.2014

Halle (Saale) 2014

Abbreviations

(used in Introduction, Background, General discussion and Conclusion)

AA	amino acid
ARC	Agricultural Research Council
DLG	Deutsche Landwirtschafts-Gesellschaft
DWG	daily weight gain
EAA	essential amino acid
EBW	empty body weight
EBWG	empty body weight gain
EFSA	European Food Safety Authority
e.g.	for example
FGR	feed-to-gain ratio
GfE	Gesellschaft für Ernährungsphysiologie
k_f	efficiency of utilisation of metabolizable energy for accretion of fat
k_p	efficiency of utilisation of metabolizable energy for accretion of protein
k_{pf}	efficiency of utilisation of metabolizable energy for accretion of protein and fat
$kg^{0.75}$	metabolic body mass
$kg^{0.67}$	metabolic body mass in case of N balance studies
LP	product of performance
LPA	Leistungsprüfungsanstalt
LSM	least square means
LW	live weight
Lys	lysine
ME	metabolizable energy
MEI	metabolizable energy intake
ME_m	metabolizable energy requirement for maintenance
MJ	megajoule
N	nitogen
n. a.	not available
NE	net energy
NRC	National Research Council
p	probability
pcd	precaecal digestible
Pi	Piétrain
PSEM	pooled standard error of means
r^2	coefficient of determination
RSD	rest standard deviation
SEM	standard error of means
VFI	voluntary feed intake

Tables

Background

Paper I

Paper II

Paper III

Figures

Background

Paper I

General discussion

Contents

1. Introduction

The pork production sector is the most important in the German meat industry, with a share of 61% of the average annual per capita meat consumption in Germany (Anonymous 2012). Nevertheless, at the moment the pork sector is in a state of upheaval caused by socially and politically intended changes which results in a shift from fattening of castrated male pigs (barrows) towards the fattening of entire males (boars). Castration of piglets without anaesthesia is traditionally practiced in most European countries to avoid “boar taint”, an unpleasant odour, which can occur in meat from entire male pigs and may result in consumers’ disaffirmation (Lunde *et al.* 2009). Fredriksen *et al.* (2009) stated that more than 94 million piglets were surgically castrated in Europe each year. Recently, the surgical castration of male piglets without anaesthesia has been criticized for animal welfare reasons by animal rights activists and consumer protection organisations. Research has proven that surgical castration without anaesthesia inflicts pain and even growth depression on piglets (Prunier *et al.* 2006). Therefore, the organisations of the pig sector planned to voluntarily end surgical castration in Europe by 2018 (Anonymous 2010).

Apart from other opportunities, fatting of boars is one possible solution to avoid the surgical castration. Boars are known to have several biological and economical benefits compared to barrows, e.g. boars consume less feed than barrows (Quiniou *et al.* 1999) and have a more efficient feed-to-gain ratio (FGR) compared to barrows (Van Lunen and Cole 1996a, Dunshea *et al.* 2001). In addition, the body composition of boars is described as different from the composition of barrows (Dobrowolski *et al.* 1995), but recent data of boars slaughtered at common German slaughter weights is hardly existent. Several authors described higher amino acid (AA) requirements for boars in order to exploit their maximum growth potential (Campbell *et al.* 1988, Fuller *et al.* 1995, Quiniou *et al.* 1995). Here also knowledge of nutrition requirements of modern genotype hybrid boars is only limited. Currently it is not clear whether boars need increased dietary AA levels and if so up to which level incensement may prove beneficial. For economic reasons, pig research focused on the possibilities of maximizing daily weight gain and feed efficiency and to lower production cost. It is well known, that inappropriate AA and/or energy concentrations in the diets could result in depressive growth performance of pigs (Campbell and Taverner 1988). Therefore, there is a need for further examination in order to generate nutrition recommendations for growing-finishing boars for the forthcoming extensive implementation of boar fattening.

2. Background

2.1 Performance and body composition of boars in comparison to barrows and gilts

The aim of pig nutrition is an efficient utilization of the feed potential in order to maximize daily weight gain and feed efficiency resulting in lower production costs. Under *ad libitum* feeding conditions, voluntary feed intake (VFI) determines the overall performance and is regulated by a number of physiological and dietary factors. Apart from the derived requirements of the pig the amount of feed intake is an important aspect in estimating nutrition recommendations for growing-finishing pigs. The VFI is influenced by several aspects, including the physiological status (age, body weight) of the pig (Kanis and Koops 1990, Quiniou *et al.* 2000). The type of pig (breed, sex) (Fuller *et al.* 1995) affects the VFI as well, as does the outside temperature (Quiniou *et al.* 2000). Claus and Weiler (1994) concluded that gonad hormones within the pigs decreased the VFI of boars compared to barrows. Likewise, boars are known to consume less feed than barrows or gilts.

Table 1: Differences between boars and barrows in production traits (modified and complemented after Lundström *et al.* (2009))

Reference	**Growth rate of boars (% of barrows)**	**Feed consumption of boars (% of barrows)**
Allen *et al.* (1981)[a]	106.4	100
Campbell and Taverner (1988)	101.6	84
Campell *et al.* (1989)[a]	>100	<100
Dunshea *et al.* (1989)[a]	>100	n. a.[b]
Fuller *et al.* (1995)	104.5	95.7
Kemm *et al.* (1995)	113 (gilts)	n. a.
Van Lunen and Cole (1996a)	105.4	100
Andersson *et al.* (1997)	102.8	98.7
Dunshea *et al.* (2001)	Group 1: 100 Group 2: 101.3	Group 1: 80.7 Group 2: 87.0
Turkstra *et al.* (2002)	105.4	n. a.
Zeng *et al.* (2002)	100	83.0
Lawlor *et al.* (2003)[a]	Experiment 1: 100 Experiment 2: 104.8	Experiment 1: 91.8 Experiment 2: 93.4
Pauly *et al.* (2008)	100	83.9

[a] Adopted from EFSA (2004) [b] n. a.= not available

Several authors mentioned less feed consumption combined with higher growth rates for boars compared to barrows (Table 1). Dunshea *et al.* (2001) measured between 19% and 13% higher feed intakes by barrows than by boars, depending on their age. Apart from sex specific influences, the VFI is also influenced by the composition of the diet. The question of whether and to what extent pigs respond to energy or AA dilution was also investigated. Expected consequences were an enhanced feed intake and/or a decline in performance. Henry (1985) concluded that the VFI was affected by dietary factors and primarily depended on the energy concentration of the diet. In addition, the AA level was suggested to influence the VFI. Zhang *et al.* (2011) observed an improved average daily weight gain as the dietary lysine-to-energy ratio was increased, whereas no effect on feed intake was measured. However, Friesen *et al.* (1994) showed a tendency of decreased average daily feed intake as dietary digestible lysine was increased. At the same time, a significantly improved average daily gain was measured. Therefore, a variation in the VFI may implicate changes in the growth rate (Henry 1985) which demonstrates the importance of the VFI in animal production.

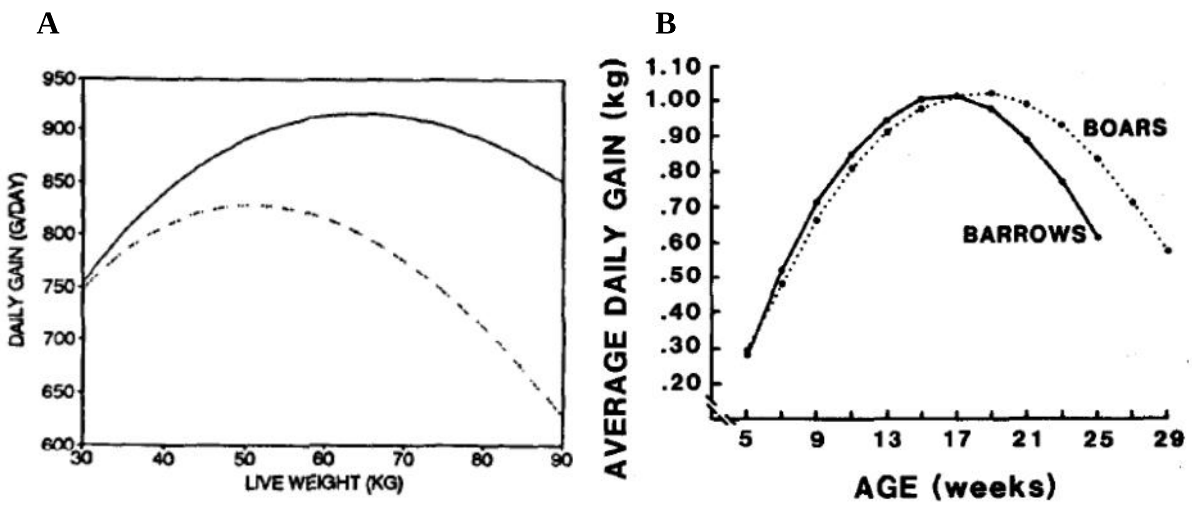


Figure 1: Mean daily live weight gain of boars (—) and gilts (---) depending on live weight modified after Kemm *et al.* (1995) (A); average daily gain of boars and barrows depending on age adopted from Knudson *et al.* (1985) (B)

Kemm *et al.* (1995) observed a significantly higher daily weight gain (DWG) for boars compared to female pigs (gilts) during the whole fattening period (Figure 1 A). Moreover, Knudson *et al.* (1985) also determined higher daily weight gains in comparison with barrows (Figure 1 B) and in this case boars reached their maximum rate of gain approximately 21 days later than barrows. Knudson *et al.* (1985) concluded that the differences in age and/or weight at the point of maximum gain could be a possible reason for the different growth performance of boars and barrows.

In addition, another benefit of the usage of entire males for fattening is the generally known higher anabolic potential of boars compared to gilts or barrows, which results in improved protein deposition. Claus and Weiler (1994) explained this hierarchy with the endogenous secretion of anabolic hormones, which differ between the sexes and Claus and Hoffmann (1980) stated that the simultaneous testicular synthesis of androgens and oestrogens in boars supported the anabolic potential. Based on literary data, the protein requirements of growing-finishing boars were expected to be increased because of the higher anabolic potential of boars for the accretion of lean meat. Nevertheless, knowledge on the exact protein requirement of boars is still limited. Generally, pigs need a diet with an appropriate AA-to-energy ratio for optimum protein conversion. Indeed, boars are considered to be superior to barrows with regard to performance. Although the feed intake of boars is lower, the growth performance of boars is higher (Dunshea *et al.* 1993, Andersson *et al.* 1997). Consequently, boars have a superior feed efficiency (Bonneau *et al.* 1994, Van Lunen and Cole 1996a) with a higher weight gain (Campbell and Taverner 1988, Van Lunen and Cole 1996a) and, at the same time, lower feed consumption (Dunshea *et al.* 1993, Dunshea *et al.* 2001). Despite these facts, Suster *et al.* (2006) contended that the daily weight gain of pigs depends on the housing conditions among other things. Improved daily weight gains were measured for individually penned boars compared to barrows, whereas under group penned conditions the advantages of boars were substantially reduced.

Several factors are known to influence the chemical body composition of pigs. Wagner *et al.* (1999) mentioned sex and Campbell *et al.* (1988) the genotype of pigs as an influencing factor. In addition, de Greef *et al.* (1992) and Berk and Schulz (2001) stated the significant influence of nutrition on the chemical body composition of pigs. The chemical body composition of pigs depends also on their age. During the fattening period, the body composition of pigs changes continuously with an increased fat content and decreased water content, whereas the protein content remains nearly constant, as described by Shields *et al.* (1983). Kirchgeßner (2004) called this process “physiological drying”. Table 2 gives a literary overview of the chemical body composition of male, female and castrated male pigs. Several authors mentioned that the carcasses of boars were leaner than those of barrows (Dunshea *et al.* 2001, Gispert *et al.* 2010, Boler *et al.* 2011). Fuller *et al.* (1995) examined male, female and castrated male pigs and observed intermediate figures for females. The bodies of female pigs were leaner than those of castrated ones (Wagner *et al.* 1999, Berk and Schulz 2001), but not leaner than male ones (Fuller *et al.* 1995).

Table 2: Literature overview of the chemical composition of carcass, emptied body or live weight (%) of male, female and castrated male pigs

Reference	**n**	**Sex**[2]	**Weight (kg)**	**Protein**	**Fat**	**Ash**	**Water**
Fortin *et al.* (1983)	12	m	75.9[a]	13.86	30.34	2.07	n. a.[3]
	12	c	76.4[a]	12.99	35.08	2.98	47.43
Campbell and	25	m	80.2[b]	14.6	36.6	2.1	45.9
Taverner (1988)	25	c	80.9[b]	12.5	46.5	1.8	39.6
Susenbeth and Keitel (1988)	4	c	112.6[b]	15.6	28.4	n. a.	n. a.
de Greef *et al.* (1992)	5	m	105[c]	16.5	20.4	n. a.	n. a.
Friesen *et al.* (1994)	6	f	51.9[a]	18.37	11.53	3.36	n. a.
Fuller *et al.* (1995)	5	m	59.8[a]	18.7	14.1	n. a.	n. a.
	5	f	61.3[a]	18.1	16.6	n. a.	n. a.
	5	c	59.5[a]	17.9	18.4	n. a.	n. a.
Wagner *et al.* (1999)[1]	20	c	103.6[b]	12.92	32.18	2.94	n. a.
	20	f	103.6[b]	13.78	27.82	3.18	n. a.
Berk and Schulz (2001)[1]	15	c	114.0[b]	15.97	26.37	2.90	n. a.
	15	f	115.0[b]	16.83	22.90	2.90	n. a.
Gómez *et al.* (2002)	3	c	75.7[b]	16.0	24.7	2.3	55.9
Weis *et al.* (2004)	4	m	114[b]	17.1	18.4	3.64	60.0
Martínez-Ramírez *et al.* (2008)	9	m	106[b]	16.8	18.1	2.81	62.0
Raj *et al.* (2010)	16	f	89.3[a]	16.7	23.8	2.91	56.5

[1] from GfE (2008)
[2] m = male; c = castrated male; f = female
[3] n. a. = not available
[a] Carcass weight; [b] empty body weight (EBW); [c] live weight (LW)

In the course of breeding progress, the chemical body composition of pigs changes, in particular carcass leanness increases substantially. Fortin *et al.* (1983) determined body fat contents in entire male pigs up to 30%, whereas Martínez-Ramírez *et al.* (2008) stated fat contents of only 18% in entire male pigs. The continuous reduction of body fat results from the rising customer demand for lean meat. Furthermore, the changes in body composition result in changes in the daily body mass gain, which is estimated by using the comparative slaughter technique (Oslage *et al.* 1986). Due to this technique the daily gain of crude protein and fat can be derived and serve as indicators for the net requirement for the so-called factorial approach for the derivation of the crude protein- and energy requirement. Therefore, the nutrition recommendations should be constantly reviewed especially with regard to the switch from the fattening of barrows towards the fattening of boars. For the derivation of nutrition requirements, knowledge the body composition of pigs may be an important aspect (Shields *et al.* 1983).

It was already mentioned, that Claus and Hoffmann (1980) explained the high anabolic potential of boars with the combined action of androgens and oestrogens that differ in their metabolic pathways. The protein synthesis is stimulated and the protein degradation is reduced by androgens. Furthermore, oestrogens increase the protein synthesis (Claus and Weiler 1994). In general, the capacity for protein deposition increases, plateaues and then decreases with age relatively to total gain. One of the strongest influencing factors on protein deposition is the sex of the animal. Towards the intended change in pork production from the fattening of barrows to boars this point obtains greater importance. Boars have a greater potential for lean deposition than gilts and gilts have a greater capacity than barrows (Batterham 1994, Van Lunen and Cole 1996b). This is also confirmed by the findings of Campbell *et al.* (1989) who found a about 32% increased protein accretion rate of boars compared to gilts and an even about 41% incensement compared to barrows. Metz *et al.* (2002) determined a significant higher N retention, on average 18% higher for boars compared to barrows.

Therefore, several authors conclude that boars need higher lysine/energy ratios for exploitation of their maximum potential (Williams *et al.* 1984, Campbell *et al.* 1988). The sex difference usually appears first in the growth period and becomes more evident during the finisher period. The capacity of barrows and gilts for a protein deposition plateau at an earlier stage than for boars, intends the presumption that boars have a longer period of efficient growth (Batterham 1994, Kemm *et al.* 1995).

2.2 Protein and amino acid requirements

Sufficient high quality feed is the basic precondition for farm animals to attain their potential growth rate. In the course of the breeding progress, the modern genotype fatting pig has achieved a high potential for protein deposition in accordance with a high daily weight gain. Protein usually refers to crude protein, which is defined as the nitrogen content of the diet multiplied by 6.25 and based on the assumption, that 100 g of protein contains 16 g of nitrogen (NRC 1998). In order to deposit a large amount of protein in muscle tissue, pigs need a specified amount of essential amino acids (EAA) in their diet (Sauer *et al.* 1999).

The formulation of pig diets requires special consideration of protein quality and availability of EAA. AA are components for body protein synthesis and are known to have a multitude of other functions in the organism. Proteins are assembled of proteinogenous AA, which can be divided up into those which are essential for the growing pig (threonine, methionine, isoleucine,valine, tryptophan, phenylalanie, histidine and lysine), those which are semi-essential (cysteine, tyrosine and arginine) and non-essential ones (serine, glycine, alanine, asparagine, aspartate, glutamate, glutamine and proline) (Boisen *et al.* 2000). Simple stomached animals, like pigs are unable to synthesize several AA which need to be supplied exogenously and are therefore called EAA (Pathak 2012). The other AA can be synthesized by the pig, but in consequence of unfavourable AA patterns of the diet they may also be in deficiency and may restrict the protein accretion (NRC 1998). The protein metabolism is characterized by a permanent and simultaneous degradation and synthesis of protein called protein turnover (Pfeiffer *et al.* 1984). The required AA originate from the degradation of feed or body protein, dietary protein is enzymatically cleaved to AA during the digestive process and resorbed into the blood. Excess protein intake is deaminated and the nitrogen faction is excreted in the urine (Jeroch *et al.* 1999). Therefore, EAA have to be supplemented with the feed either in the form of combinations of different AA sources or in the form of crystalline AA to meet the pig's requirements.

The GfE booklet of recommendations for the supply of energy and nutrients to pigs (2008) represents the main source of data for nutrition requirements of pigs in Germany. The AA requirements were listed in form of precaecal digestible (pcd) AA instead of brutto values in order to take into account the appropriate part of the feed-specific influence on the overall utilization of AA (GfE 2008). The ratios for the AA supply are calculated in relation to the lysine which is normally known to be the first-limiting AA in pig diets and represents a large share on lean growth (ARC 1981). There are indeed hardly any serious scientific studies concerning the nutrition requirements of growing-finishing boars. Despite that fact, there are large numbers of market- and application-orientated researches which can be used as feeding instructions only. Recommendations for the requirements of growing-fattening boars do currently not exist and are not mentioned in the current GfE booklet. Only recommendations for growing-fattening barrows and gilts are given and may be used for boar nutrition due to the absence of alternatives. Several authors expressed the suspicion that the requirements of boars, especially those for AA, are higher than those outlined in the present recommendations for barrows and gilts. Generally, the requirements for lysine are defined as the sum of the requirements for maintenance and for protein accretion (NRC 1998, GfE 2008).

One method for the derivation of protein and AA requirements is the factorial approach. This implies knowledge of maintenance requirements and a detailed description of all partial performance data. The necessary supply with precaecal digestible lysine (pcd Lys) in case of growth performance is derived from using the following equation adopted from GfE (2008):

$$pcd\ Lys = maintenance\ requirement\ (g/d) + \frac{Lys_{LP} \times tissue\ accretionn\ (g/d)}{intermediary\ utilisation\ oof\ pcd\ Lys}$$

Where: Lys_{LP} = lysine content (g/100g protein) in tissue accretion

Product of performance (LP) = Intake of pcd Lys only for tissue accretion (g/d)

Furthermore, the N retention could be determined by means of N balance studies. The N retention is known as one element of the N turnover and specified as the net difference between synthesis and catabolism (Simon 1989). Moreover, Gebhardt (1966) generated an N utilization model for estimation of the N retention potential by means of N dosing tests. This model was subsequently further developed by several authors for example (Thong and Liebert 2004a, b). In addition, the comparative slaughter technique is also used for deriving the accretion of protein and AA in pigs. Generally, a certain potential of errors is extant in the different methodological designs for deriving accretion of protein and AA using the comparative total body analysis or the N balance studies. Both methods have advantages and disadvantages for example the possible loss of some body tissue during total body analysis or the gaseous loss of N from faeces and urine and the indirect determination of N retention during N balance studies. None of these methods is used exclusively, they rather complement each other. Total body analysis could be used to derive recommendations from identical original data, whereas results from N balance studies are used to check the plausibility of recommendations derived by the factorial method (GfE 2008).

Undoubtedly, the development of the concept of “ideal” protein was one of the major points in the understanding of the AA requirements of pigs. The ideal protein contains all EAA in the correct balance and the correct ratio within all AA. Lysine is known as the first limiting AA and the other AA were added in a specified relation to lysine (NRC 1998). This concept is based on the assumption, that the ratio of AA in lean tissue represents the requirement of the pig for AA. (ARC 1981, Batterham 1994). For the deviation of the optimum AA relations, also results of nitrogen balance studies were taken into consideration. Fuller *et al.* (1989) and

Wang and Fuller (1989) outlined that the ideal protein was not only determined by the pattern for protein retention, but also by requirements for maintenance and different utilisation of various AA.

The lysine concentration of 7.2 g lysine per 100 g protein deposition was established for the use of further derivations for rearing piglets as well as for growing-fattening pigs (GfE 2008). Nevertheless Mahan and Shields (1998) supposed that the body lysine concentration was influenced by different factors like sex, genotype and diet. However, literary data is hardly available. Moreover, the application of the factorial method concerning other AA than lysine was not possible, because information concerning the intermediate utilization of other AA than lysine is not existent or insufficient. Therefore, the factorial approach is based on the respective relations of the other AA to lysine (GfE 2008).

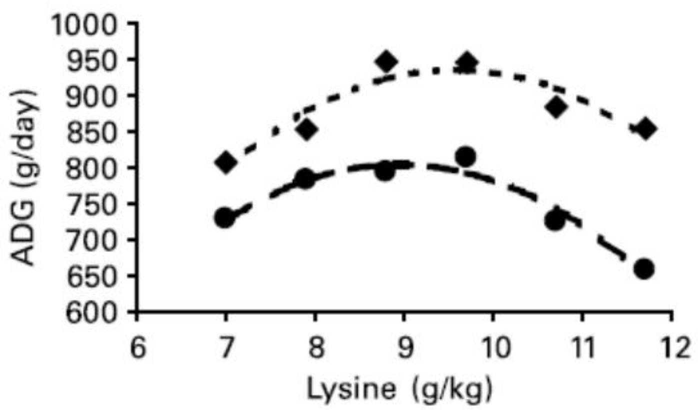


Figure 2: Average daily gain (ADG) of group penned boars (♦) and gilts (●) depending on lysine supply modified after O'Connell *et al.* (2006)

Another way to derive the protein and AA requirements are dose-response studies. Dose-response studies express the requirements of an AA as a point on the dose-response curve relating to the level of intake and the measurement of productivity (Moughan and Fuller 2003). For growing-finishing pigs for instance different dietary lysine levels were put into relation with the average daily weight gain. O'Connell *et al.* (2006) measured the maximum daily gain at a dietary lysine levels of 9.6 g/kg for boars and 8.9 g/kg for gilts (Figure 2). These findings illustrate the suggested differences in the AA requirements of boars compared to barrows and gilts and the need for further investigation with growing-fattening boars.

2.3 Energy requirement

Apart from protein and AA, energy is needed for the maintenance and for the growth of pigs. The evaluation level for energy is not internationally standardized. The GfE uses the metabolizable energy (ME) system as a basis for the derivation of requirements, instead of the net energy (NE) system. The ME system's advantage to the NE system is that it describes the potential of a feed independent of the efficiency of utilisation which is determined by the composition of the diet and the physiological status of the animal. In addition, the NE system may lead to an underestimation of the energy values of high protein feeds (GfE 2008). An over-supply of energy will be stored as fat. Therefore, the aim of formulating diets is to supply feed with balanced protein and energy contents in order to maximize the protein and to minimize the fat deposition in the body (Batterham 1994). However, the optimum AA-to-energy ratio is not fixed and decreases linear as live weight increases (NRC 1998). Moreover, inappropriate lysine-to-energy ratios might result in depressive growth performance of pigs (Campbell and Taverner 1988).

This underlines the importance of a suitable energy supply for efficient growth. The requirements for ME in growing pigs can be divided up into requirements for maintenance, thermoregulation and energy deposition in body tissue which requires the quantification of the rates of energy deposition as protein and as fat and the efficiencies of utilization of ME for protein (k_p) and fat (k_f) depositions (Noblet *et al.* 1999). The utilization of ME for the retention of energy is subdivided into protein and fat. The partial efficiencies of utilization adopted from ARC (1981) were the factor 0.56 for protein and the factor 0.74 for fat deposition in growing-fattening pigs. Gädeken *et al.* (1985) examined k_p values for rearing piglets between 0.7 and 0.8 and k_f values of 0.73 and it was therefore decided to use a partial efficiency of utilization of 0.7 for rearing piglets with no differentiation between protein and fat (k_{pf}).

Furthermore, the factorial approach is also used for the determination of the energy requirements.The energy requirements of growing pigs are characterized by the interaction of the requirements for maintenance and accretion and the composition of the diet; due to the usage of constant factors it is not possible to take all possible cases into account.

The energy requirements of maintenance for growing-finishing pigs between 30 and 100 kg LW are estimated by the following formula (GfE 2008):

$$ME_m = 0.44 \times \left(1.25 - 0.00357 \times (LW - 30)\right) \times LW^{0.75}$$

Where ME_m = ME required for maintenance (MJ/d)

LW = live weight (kg)

For live weight above 100 kg the extra charges for considering the increased physical activity of growing pigs are reduced continuously so that the ME_m requirements of growing-finishing pigs above 100 kg LW are estimated with the following equation (GfE 2008):

$$ME_m = 0.44 \times LW^{0.75}$$

Where ME_m = ME required for maintenance (MJ/d)

LW = live weight (kg)

Apart from these influencing factors, the energy requirement for maintenance of the growing-finishing pig is generally also affected by the ambient temperature and by physical activity. In this respect, several authors reported an increased physical activity and social behavior of boars compared to gilts and barrows, which might be an explanation for the discussed sex differences in energy requirements (Cronin *et al.* 2003, Vanheukelom *et al.* 2012).

As mentioned above for protein and AA, there were also no scientific reliable recommendations for the energy requirements of growing-finishing boars (DLG 2010). Therefore, the established recommendations for growing-finishing barrows and gilts with a high growth potential are transiently used until reliable recommendations for boars are available. This underlines again the necessity of performing further studies in order to identify the energy requirement of growing-finishing boars.

3. Scope of the thesis

Taking the background information into consideration, it is expressly stated that actual nutrition recommendations for growing-finishing boars are needed. It is anticipated that the requirements for boars differ from those of barrows and gilts. AA and energy requirements of modern genotype hybrid boars for the exploitation of their genetically determined growth potential are not exactly known. Furthermore, there has been little research on chemical body composition of hybrid boars. Within the joint research project "Feeding of boars" fundamentals of the recommendations for boar nutrition should be established in cooperation with several research institutes and partners from the economy. Recommendations for the supply of growing-finishing boars with protein (AA) and energy (ME) should be derived from the results of several experiments. Therefore, a range of experiments was conducted which focused on the effect of increased dietary lysine levels on performance of boars.

- The first aim of this thesis was to study the effect of selected lysine-to-energy levels as supposed causes for the specific differences in voluntary feed intake and growth performance of boars and barrows by means of a fattening trial (**Paper I**).
- Another aim was to determine the nitrogen retention of boars under the influence of different AA levels in nitrogen balance studies and to verify this data in subsequent fattening experiments (**Paper II**).
- An additional aim was to examine the effects of different dietary lysine levels on the chemical body composition of growing-finishing boars of different sire lines by usage of the chemical body analysis (**Paper III**).

The combination of the voluntary feed intake experiment, the N balance studies, the fattening experiment and the chemical body analysis are supposed to represent a "mixed approach" method for the investigation of the nutrient requirements of growing-fattening boars. In the following the results of these investigations are presented and in the General discussion the findings are elaborated and discussed further in the context of the available scientific literature.

4. Paper I

Voluntary feed intake and growth performance of boars and barrows in dependence on lysine-to-energy ratio

Caroline Otten, Andreas Berk and Sven Dänicke

Institute of Animal Nutrition, Friedrich-Loeffler-Institute (FLI),
Federal Research Institute for Animal Health, Braunschweig, Germany

Archives Animal Breeding
Arch Tierz 56 (2013) 39

Abstract

Boars (entire male pigs) consume less feed than barrows (castrated male pigs) under practical *ad libitum* feeding conditions, but knowledge on possible reasons is only limited. Since the lysine and energy contents of the diet are known to be important determinants of voluntary feed intake (VFI), it was of interest if sex specific responses to selected dietary lysine-to-energy ratios could explain the differences in feed intake between boars and barrows.

A total of ninety-five pigs (48 boars and 47 barrows) were used for this investigation. Four diets were fed with two different precaecally digestible lysine (Lys)-to-metabolise energy (ME) ratios, 0.93 and 0.86 (g/MJ) for grower diets and 0.71 and 0.66 (g/MJ) for finisher diets. The pigs were kept individually and divided into four feeding groups for each sex. A 2 x 2 x 2 factorial design with the factors sex (boars vs. barrows), lysine level and energy level was employed. The sex effect was dominant and influenced all variables ($P<0.001$). Superior growth potential with a concomitant lower feed intake was confirmed for boars compared to barrows. Energy and lysine levels of the diets exerted only minor effects on the measured variables, such as the intake ($P<0.05$) and conversion rate ($P<0.01$) of lysine and energy.

It was concluded that boars grew faster than barrows even though they consumed less feed. Boars and barrows responded to different lysine and ME levels of the diets in a similar manner suggesting the marked and dominating effect of sex.

Keywords: pig, growth performance, voluntary feed intake, lysine, energy

Introduction

Animal-rights activists demand meat production with more emphasis on animal welfare. The surgical castration of male piglets is one of the points under criticism. The castration of male piglets without anaesthesia is traditionally practiced in many European countries to avoid a boar taint. Nevertheless, in recent years it has become a significant concern in animal welfare. Research has proven that this surgical procedure inflicts pain on piglets (Prunier *et al.* 2006). For animal welfare reasons, the pig sector planned to voluntarily end the practice of surgical castration of pigs in the EU in 2018 (Anonymous 2010). Currently, boar (entire male pig) fattening seems to be one of the most likely alternatives to the surgical castration of pigs.

Under *ad libitum* feeding conditions, voluntary feed intake (VFI) determines overall performance and is regulated by a number of animal and dietary factors. The growth rate is influenced if VFI is compromised for any reason (Henry 1985). The aim of conventional pork production is to maximize daily weight gain and feed efficiency resulting in lower production costs. This makes the importance of VFI in animal production evident. Indeed, boars are considered to be superior to barrows (castrated male pigs) with regard to performance. For example, there are differences in the VFI of boars and barrows. Dunshea *et al.* (2001) measured between 19% and 12% higher feed intakes by barrows than boars, depending on their age. VFI is influenced by several factors, including physiological status (age, body weight) (Kanis and Koops 1990, Quiniou *et al.* 2000). The type of pig (breed, sex) (Fuller *et al.* 1995) affects the VFI as well, as does the composition of the feed (Henry 1985) and the outside temperature (Quiniou *et al.* 2000).

Although the feed intake of boars is lower, the growth performance of boars is higher (Dunshea *et al.* 1993, Andersson *et al.* 1997). Consequently, boars have a superior feed efficiency (Bonneau *et al.* 1994, Van Lunen and Cole 1996a) with a higher weight gain (Campbell and Taverner 1988, Van Lunen and Cole 1996a) and, at the same time, lower feed consumption (Dunshea *et al.* 1993, Dunshea *et al.* 2001).In addition, the carcasses of boars are leaner than those of barrows (Dunshea *et al.* 2001, Gispert *et al.* 2010, Boler *et al.* 2011). The growth performance of pigs depends on the first limiting amino acid lysine and the energy content of the diet. Inappropriate lysine (Lys)-to-metabolised energy (ME) ratios might result in depressive growth performance of pigs (Campbell and Taverner 1988).

Therefore, the aim of the present study was to examine selected lysine-to-energy levels as supposed causes for the specific differences in VFI and growth performance of boars and barrows.

Material and Methods

<u>Experimental design and diets</u>

A total of 95 crossbred pigs (Piétrain x (Large White x Landrace)), 48 boars and 47 barrows obtained from a commercial breeder, were included in this feeding trial. To simplify matters, the difference between these two groups is described as sex. Before the experiment started, the piglets were reared from the average live weight of 8 kg to 25 kg in pens with 5 pigs of the same sex per pen. Afterwards they were transferred to the experimental unit and switched to their respective treatment diets. The experimental period spanned the live weight range from an average of 27 kg up to the time of slaughter at 120 kg.

The pigs were randomly allotted to four diets in a 2 x 2 x 2 factorial arranged design with the fixed factors sex, energy level and lysine level and their interactions.

The feeding regimen was a two phase feeding, with an individual change from grower to finisher diet at approximately 75 kg live weight. There were four feeding groups for each sex; each feeding group included 24 animals (12 boars and 12 barrows); except the high Lys, high ME feeding group with only 11 barrows. Four dietary mixtures with two different Lys-to-ME ratios were used. The Lys-to-ME ratio was lowered from 0.93 to 0.86 (g/MJ) for the grower diets and from 0.71 to 0.66 (g/MJ) for the finishing diets. The feed composition and analysis of the diets are given in Table 1.

Table 1: Feed composition and analysis

Lys, ME level period	high/low Grower	high/low Finisher	high/high Grower	high/high Finisher	low/low Grower	low/low Finisher	low/high Grower	low/high Finisher
Components (%)								
Wheat	30.00	32.00	30.00	32.00	30.00	32.00	30.00	32.00
Barley	38.19	41.70	39.87	43.75	38.45	41.90	40.17	44.00
Soy bean meal	22.00	17.50	22.00	17.50	22.00	17.50	22.00	17.50
Soy bean oil	2.00	2.00	3.40	3.30	2.00	2.00	3.40	3.30
Mineral-vitamin premix*	3.00	2.50	3.00	2.50	3.00	2.50	3.00	2.50
Cellulose	3.30	3.50	-	-	3.30	3.50	-	-
Lysine-HCl	0.66	0.40	0.75	0.48	0.55	0.32	0.64	0.39
DL-Methionine	0.50	0.25	0.55	0.27	0.40	0.18	0.47	0.20
L-Threonine	0.30	0.15	0.35	0.17	0.25	0.10	0.27	0.11
L-Tryptophane	0.05	-	0.08	0.03	0.05	-	0.05	-
Feed calculated lysine and energy content								
ME (MJ/kg)**	12.79	12.81	13.60	13.61	12.78	12.79	13.60	13.59
Gross Lys (g/kg)	12.80	10.00	13.60	10.60	12.00	9.30	12.70	10.00
pcd Lys (g/kg)***	11.85	9.04	12.57	9.69	11.04	8.45	11.76	9.03
pcd Lys : ME	0.93	0.71	0.93	0.71	0.86	0.66	0.86	0.66
Analysed composition (%)								
ME (MJ/kg)**	13.00	12.89	13.77	13.80	13.45	12.85	13.76	13.77
Dry matter (%)	89.35	88.92	89.43	89.00	92.12	88.74	89.53	88.78
Crude protein	17.71	15.91	17.85	16.61	17.95	16.20	17.99	16.21
Lysine g/kg	13.10	10.20	13.60	11.30	12.30	9.90	13.20	10.20
Crude fat	4.09	3.73	5.19	5.40	4.58	3.57	5.02	5.45
Crude fiber	6.64	6.01	4.52	3.67	6.68	6.15	4.46	4.35
Crude ash	5.37	4.74	5.47	4.79	5.80	4.79	5.48	4.73

*Per kg diet (for grower with 3% premix): vitamin A, 8 000 IU; vitamin D_3, 800 IU; vitamin E, 24 mg; vitamin K_3, 1.05 mg; vitamin B_1, 0.75 mg; vitamin B_2, 2.0 mg; vitamin B_{12}, 0.015 mg; vitamin B_6, 2.0 mg; calcium pantothenate, 6.75 mg; nicotinic acid, 10 mg; choline chloride, 100 mg; Ca, 5 g; Na, 1.1 g; Mg, 0.2 g; Fe, 80 mg; Cu, 10 mg; Co, 0.55 mg; Zn, 67 mg; Mn, 55 mg; I, 1.35 mg; Se, 0.25 mg

** Calculated on base of digestible (table values of the used compounds) crude nutrients (as analysed) according to GfE (2008)

*** pcd Lys means precaecally digestible lysine; calculated on base of (GfE 2005b)

Housing and management

The pigs were housed individually in boxes on concrete floor during the experimental period. The box dimension was 3.1 m^2. Water was provided *ad libitum* via nipple drinkers. All pigs were able to consume the experimental diets as mash feed on *ad libitum* basis. Boars and barrows were housed alternately in the experimental barn to avoid housing effects. Minimum temperatures in the pig house were kept at above 18°C. Every pig had an own feed bucket which contained 10 kg of the respective experimental diet and was refilled after the pig emptied it. Feeding and refilling was done manually and recorded daily. All pigs were weighed before the beginning and at the end of the trial. The pigs were weighed weekly over the experimental period. The study was conducted at the experimental station of the Institute of Animal Nutrition, Friedrich-Loeffler-Institute (FLI), Braunschweig, Germany.

Analysis

Samples of each diet were collected and analysed for dry matter and proximate constituents according to the methods of the VDLUFA (2007). Crude protein in the diets was analysed using the method of Dumas (Method Number 4.1.2). Crude fat, crude fiber and crude ash were analysed according to Methods 5.1.1, 6.1.1 and 8.1, respectively. Furthermore, the diets were analysed for sugar (according to Luff-Schoorl) and starch (polarmetrically).

The amino acid content, with the exception of tryptophan, was analysed by ion exchange chromatography using an Amino Acid Analyser (Biochrom Ltd., Cambridge, UK). Tryptophan was determined by HPLC with fluorescence detection (Anonymous 2000).

Calculation and statistics

Daily weight gain (DWG) was calculated as the difference between end weight minus start weight divided by days of the feeding period. Daily feed intake was calculated weekly,as the difference between the amount of offered feed and the amount of feed remaining at the end of a test period, divided by the number of days of that test period. Energy and lysine intake were calculated by multiplying the feed intake by the corresponding energy and lysine concentrations. The feed conversion rate was obtained as feed intake divided by gain. Energy and lysine conversion ratio were assessed by dividing the energy and lysine intakes by the corresponding weight gains. The experimental data were analysed using the ANOVA procedure of Statistica 10 (StatSoft Inc., 1994).

The effects of sex, energy level and lysine level and their interactions were included in the model:

$$y_{ijkl} = \mu + a_i + b_j + c_k + a * b_{(ij)} + a * c_{(ik)} + b * c_{(jk)} + a * b * c_{(ijk)} + e_{ijkl}$$

where y_{ijkl} = 1st observation related to the sex i, lysine level j and energy level k;
μ = overall mean; a_i = effect of sex; b_j = effect of lysine level; c_k = effect of energy level;
$a * b_{(ij)}$ = interactions between sex and lysine level; $a * c_{(ik)}$ = interactions between sex and energy level; $b * c_{(jk)}$ = interactions between lysine level and energy level;
$a * b * c_{(ijk)}$ = interactions between sex, lysine level and energy level; e_{ijkl} = error term.

Arithmetic means, their pooled standard errors, levels of significance for main effects and interaction were determined. *P*-values <0.05 were considered to be significant. Besides the ANOVA-based evaluation of the general performance data, the live weight progression of individual pigs and the differences between the sexes were evaluated by fitting to a growth function according to Gompertz (1825):

$$y = a \cdot e^{-b \cdot e^{-c \cdot t}}$$

The time point of the maximum daily weight gain, which coincides with the inflection point of the cumulative sigmoid growth curve, can be deduced from the second derivative of the growth function:

$$t_{max} = \frac{\ln b}{c}$$

y	=	Live weight (kg)
a	=	Parameter of the function = asymptotic live weight (kg) at infinity
b, c	=	Parameters of the function
t	=	Time (d)
t_{max}	=	Time at maximum daily weight gain (d)

Individual data were fitted to the growth curve using the iterative Quasi-Newton-procedure implemented in the software package "Statistica for the Windows^{TM} Operating System" (StatSoft Inc., 1994).

Results

Initial and final weights were defined by the design of the trial; accordingly they were similar, 27.6± 0.98 kg (± standard deviation) for initial weight and 124.1± 4.29 kg for final weight.
Boars and barrows had different (P<0.001, Table 2) growth performance and feed intake. The average DWG of boars was 1188 g/d compared to 1107 g/d for barrows, respectively. On average, boars consumed 10% less feed than barrows over the whole experimental period. Accordingly, boars had an improved feed conversion ratio, which was approximately 16% lower compared to barrows.
No effects were observed of level of energy or lysine on DWG, VFI or feed conversion ratio (Table 2). The values for precaecally digestible lysine were calculated in this study (Table 1), but not determined analytically. The analysis that follows accordingly relates to gross lysine values. The values for gross lysine were analysed in the present study, thus these values were used in the results and discussion section. However, the lysine level affected the lysine intake (P<0.05) and as a consequence the corresponding lysine conversion ratios (P<0.01). The lysine intake and lysine conversion ratio for boars and barrows increased, depending on the lysine level of the diet. Animals receiving a high lysine diet had an increased lysine intake and lysine conversion ratio.
The energy level also influenced the energy intake (P<0.05) and the energy conversion ratio (P<0.01) and also the lysine intake (P<0.05) and the lysine conversion ratio (P<0.01). The ME level also had an increasing effect on ME intake, ME conversion ratio as well as on the lysine intake and lysine conversion ratio of boars and barrows. Just like the lysine level, pigs fed diets with a high ME level had increased ME variables.
Pigs of both sexes responded to dietary treatments in a similar manner as indicated by the absence of any significant interactions between sex and lysine or ME levels. Nevertheless there were several significant interactions observed between Lys*ME level and growth parameters. These interactions were presented as pooled values for both sexes in the whole experimental period.

Table 2: Growth performance and feed intake data (arithmetic means and PSEM (pooled standard error of means))

n	Sex	Lysine Level (Lys)*	Metabolise-able energy level (ME)*	Daily weight gain (g)	Feed intake (g/d)	Gross Lys intake (g/d)	ME intake (MJME/d)	Feed conversion ratio (kg/kg)	Gross Lys conversion ratio (g/kg)	ME conversion ratio (MJ/kg)
12	boar	high	low	1153	2.60	30.12	33.67	2.26	26.14	29.22
12	barrow	high	low	1130	2.92	33.78	37.79	2.59	29.95	33.50
12	boar	high	high	1193	2.67	32.93	36.75	2.24	27.64	30.84
11	barrow	high	high	1107	2.94	35.44	40.35	2.66	31.97	36.44
12	boar	low	low	1221	2.79	30.62	36.62	2.29	25.08	30.00
12	barrow	low	low	1093	3.02	33.01	39.53	2.77	30.31	36.31
12	boar	low	high	1185	2.59	30.02	35.57	2.18	25.33	30.02
12	barrow	low	high	1097	2.94	33.60	40.29	2.68	30.67	36.78
48	boar			1188	2.66	30.92	35.65	2.24	26.05	30.02
47	barrow			1107	2.95	33.93	39.47	2.67	30.70	35.74
ANOVA (*P*-value)										
Sex				<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lys				0.804	0.226	0.013	0.130	0.193	0.006	0.096
ME				0.783	0.242	0.028	0.021	0.309	0.009	0.008
Sex*Lys				0.060	0.898	0.922	0.969	0.105	0.118	0.088
Sex*ME				0.698	0.627	0.984	0.569	0.472	0.684	0.346
Lys*ME				0.395	0.031	0.028	0.011	0.093	0.063	0.031
Sex*ME* Lys				0.074	0.320	0.243	0.305	0.596	0.790	0.644
PSEM				0.29	0.02	0.06	0.06	0.02	0.06	0.06

* Values for "level" see table 1

Feed intake, energy intake, lysine intake and energy conversation ratio interacted (P<0.05) with the Lys*ME level. The highest VFI was observed for the pigs who received the low Lys and low ME diet (2.90 kg/d; arithmetic mean of both sexes). The animals in the other three feeding groups had a similar VFI between 2.76 kg/d and 2.80 kg/d. Additionally, the pigs fed with the two diets with decreased Lys-to-ME ratio (0.86 or respectively 0.66 g/MJ) presented higher deviation in VFI than that pigs consumed the two diets with increased Lys-to-ME ratio (0.93 or respectively 0.71 g/MJ).

These relationships were responsible for the significant interaction between Lys*ME level for VFI. Another interaction was determined between Lys*ME level and ME intake. The pigs which were fed the diet with high lysine and high ME level had the highest ME intake (38.47 MJ ME/d), those which were fed the low lysine and high ME feed showed the lowest ME intake (35.73 MJ ME/d). Furthermore the Lys*ME level interacted (P<0.05) with the ME conversion ratio. Animals receiving the low lysine and high ME diet showed the most advantageous energy conversion ratio (31.36 MJ/kg). The pigs supplied with the other three diets had similar energy conversion ratios of between 33.15 MJ/kg and 33.40 MJ/kg. The interaction of Lys*ME level with lysine and ME intake also depends on the amount of VFI. In consequence, these relationships influenced the significant interaction between Lys*ME level and the ME conversion ratio.

As daily weight gain was exclusively influenced by sex, the individual live weight data were subjected to growth curve evaluation independent of dietary lysine and ME level. Thus, pooled boar and pooled barrow data were fitted to the Gompertz function (Figure 1 and 2). Due to live weight-matched individual termination in the experiment, the growth curve evaluation was performed only until Day 78 of the experiment, while all pigs were still in the experiment.

Figure 1 showed differences between the sexes in the growth curves. The barrows needed a longer period of time to reach the same weights as boars, although there was no difference in mean live weight at the start of the study. At the beginning of the trial, boars and barrows showed similar weight development. During the middle of the trial boars started to grow faster than barrows. After 78 days in trial, the boars weighed an average of 117.8 kg, whereas barrows weighed only 112.5 kg on average.

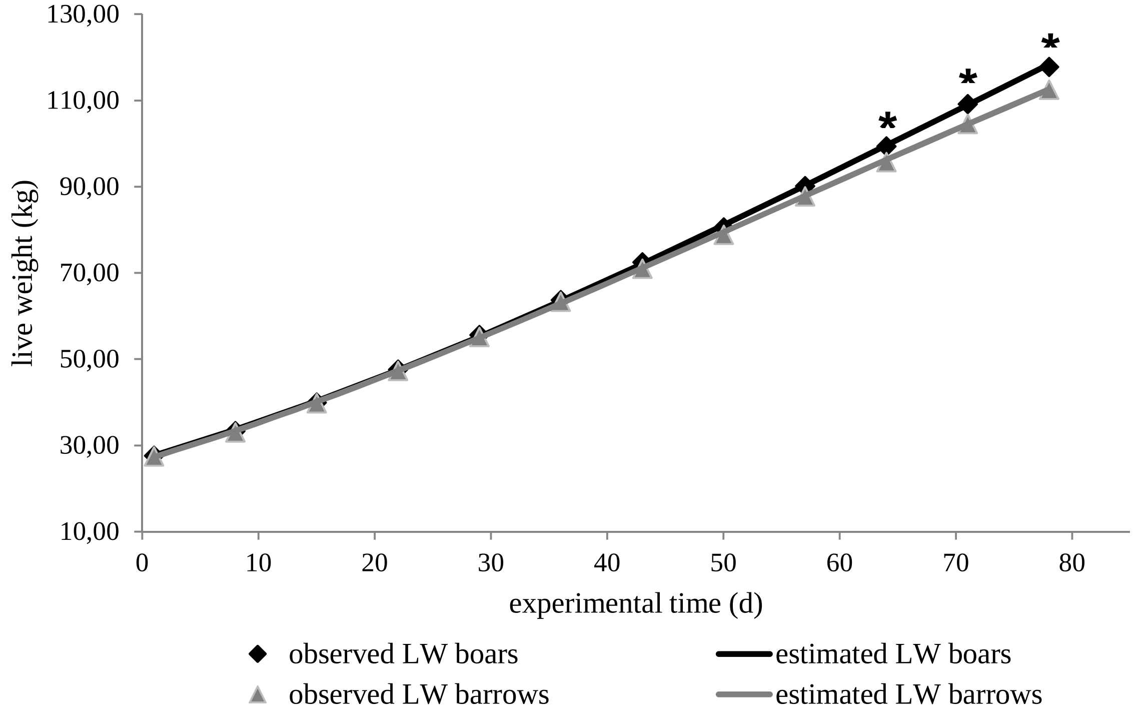


Figure 1: Live weight (LW) development in dependence on time and sex
* Values differ significantly (*P* <0.05)

The boars showed a clearly faster gaining rate than barrows, with, for example, significantly higher weight gain at the end of trial. The DWG of boars was approximately 7% higher than the DWG of barrows (Figure 2). There was an obvious short term reduction in DWG for boars on the 43rd day of trial when the average live weight was 75 kg. On Day 36 the boars gained 1224 g/d, which decreased to 1157 g/d on Day 43, and afterwards increased to 1351 g/d on Day 50. Additionally the feed intake of boars was temporarily reduced during this period. Barrows had a less clearly reduced DWG between the 36th and 43rd experimental day. The DWG of barrows decreased from the 29th day (1166 g/d) to Day 36 (1085 g) and then slowly increased from Day 43 (1104 g) until Day 50 (1282 g).

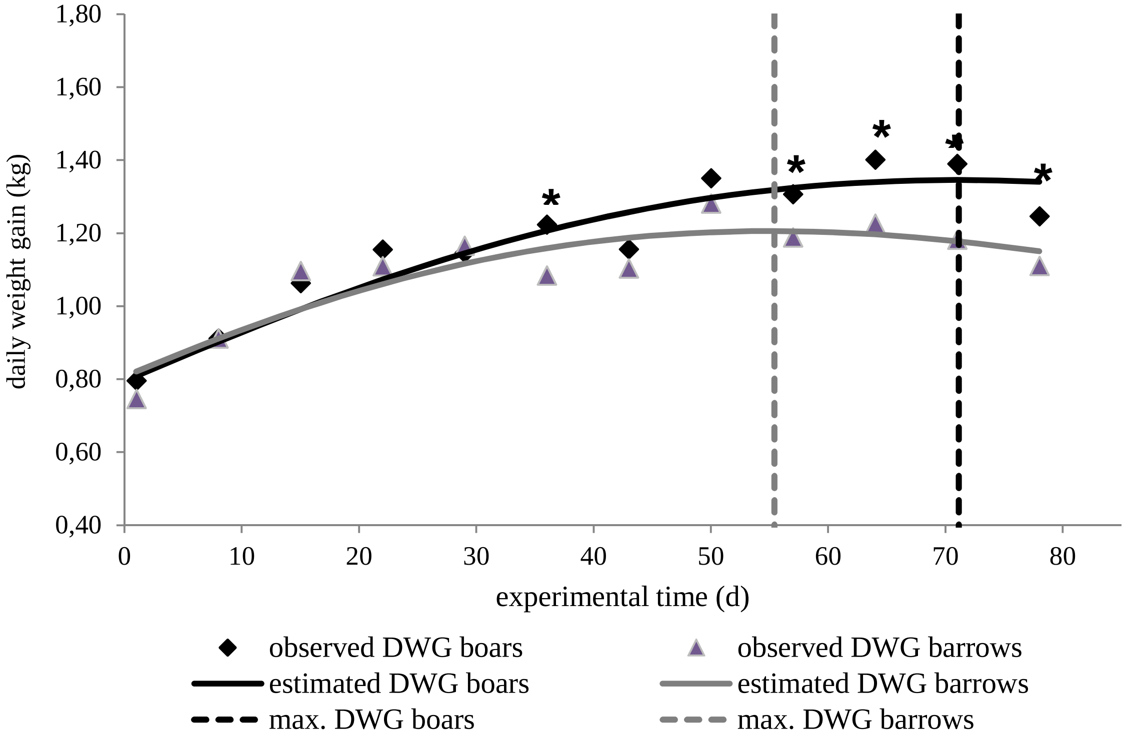


Figure 2: Daily weight gain development in dependence on time and sex
* Values differ significantly (*P* <0.05)

While matching the observed and estimated daily weight gain and calculating the point of maximum gain, it becomes obvious that boars have a 16-day longer increasing gain curve to meet this point than barrows (experimental Day 55 for barrow compared to Day 71 for boars, Table 3).

Table 3: Summary of regressive evaluation of live weight development according to the Gompertz function

Gender	a	b	c	t_{max} (d)*	LWG_{max} (kg)**	r^2	RSD*** (kg)
Boars	296.7	2.404	0.012	71	1.345	0.999	0.160
Barrows	233.6	2.176	0.014	55	1.206	0.999	0.162

* $y = a \cdot e^{-b \cdot e^{-c \cdot t}}$;

** $t_{max} = \frac{\ln b}{c}$, y = live weight (kg), a = parameter of the function (asymptotic live weight (kg) at infinity); b, c = parameter of the function; t = time (d); t_{max} = time at maximum daily weight gain (d); LWG_{max} = live weight gain at t_{max} (kg)

*** RSD= Residual Standard Derivation

After splitting the whole experimental period into several live weight stages, statistical analysis only showed sex effects (P<0.05) on DWG from 90 kg LW until the end of the trial. No significant sex effects were observed for DWG before 90 kg LW (data not shown).

Discussion

The present experiment is aimed at examining two lysine-to-ME ratios as supposed causes for the specific differences in feed intake and growth performance between boars and barrows. In accordance with current literature, the superior performance of boars was also confirmed in the present experiment.

During the whole experimental period the growth performance of boars was higher than that of barrows. In the present study boars had an improved feed conversion ratio, approximately 16% lower than barrows. Several authors mentioned the more efficient feed conversion ratio of boars compared to barrows (Campbell *et al.* 1989, Karg 1994, Van Lunen and Cole 1996a, Dunshea *et al.* 2001). In agreement with the results of Zeng *et al.* (2002) and Quiniou *et al.* (1999), barrows on average consumed more feed than boars on average for the whole experimental period. Forbes (1995) referred to the relationship between VFI and composition of the feed, hormone concentration and other influencing factors. One explanation for the sex difference in performance was the anabolic effects of gonad steroid hormones. Testosterone and oestradiol were found to reduce VFI in pigs, the combined action of steroids determined the reduced feed intake in boars compared to barrows (Claus and Weiler 1994).

Pigs who had been fed with low density lysine and energy feed (decreased Lys-to-ME ratio) consumed more feed than pigs who had been fed other lysine and ME levels as suggested by the significant interactions between lysine level and ME concentration. The significant difference between VFI of pigs fed the low density lysine and energy diet and pigs fed the other diets suggests that pigs are able to balance a deficit of lysine and /or ME in the diet by increasing their VFI. This observed animal adaption was confirmed by the findings described by Henry (1985). In addition and relating to these results, the pigs that consumed the diet with the high lysine and high ME level should have the lowest VFI.

Contrary to these expectations, in the present study the animals received the high lysine and high ME level had the second highest VFI and not the lowest VFI. Hence, no evidence could be found, that lysine or energy were one of the major factors affecting VFI.

Comparing the live weight development of boars and barrows, it becomes obvious, that boars reached the point of maximum daily gain 16 days later than barrows. As a consequence, the time of increasing DWG lasted longer for boars than for barrows. After reaching the point of maximum daily gain, boars and barrows had relatively higher maintenance requirements than performance requirements proportional to the total demand of ME. This fact suggests a more efficient growth of boars compared to barrows, because of their long term increasing gain curve.

A similar study, Andersson *et al.* (1997) also described a decreased weight gain of barrows compared to boars. Contrary to these results, Zamaratskaia *et al.* (2008) obtained lower daily weight gain for boars. Other authors observed similarly high growth rates for boars with 1015 g/d (Schulze *et al.* 2002), 1025 g/d (Von Felde *et al.* 1996) and 1110 g/d (Fuller *et al.* 1995) emphasizing the findings in the present study.

Zhang *et al.* (2011) demonstrated that average daily weight gain increased for growing finishing pigs as the lysine-to-energy ratio increased. Other authors also observed improved performance if the lysine-to-energy ratio was increased (Friesen *et al.* 1994, De la Llata *et al.* 2007). In contrast, in the current study an increased level of lysine and ME had no effect on DWG or feed conversion ratio (related to the average feeding group data). The lack of significant effects of the Lys-to-ME ratio concerning growth parameters might be an indication that possibly the chosen Lys-to-ME ratios do not differ clearly enough.

Apart from this, the energy level effected the amount of energy intake and lysine intake ($P<0.05$) and as a consequence of this also the energy and lysine conversion ratio ($P<0.01$). The lysine level also influenced the amount of lysine intake and the lysine conversation ratio ($P<0.001$). These results are caused by the amount of feed intake and the concentration of lysine and/ or ME in the diet.

Phase feeding is common practice in pig production in order to best meet the nutrient requirement of the growing animal. However, pigs react and are sensitive to unfamiliar diets and often decrease their VFI. As a result, the DWG may be depressed during the adaption period (Dong and Pluske 2007, Clouard *et al.* 2012). According to these findings, the decrease in DWG during the middle of the current experiment might be explained by the change from starter to finisher feed at this time. Boars showed this reduction more clearly than barrows. Indeed, boars seemed only to consume the amount of feed they required for optimum growth. Therefore, the reduced feed intake had a direct effect on the DWG on the 43rd experimental day. However, barrows had a higher feed intake and animal-individual deviations obliterate the small decrease in VFI.

The data from the present study clearly pointed out the superior growth performance of boars compared to barrows. However, it must be noted that this data was received under experimental conditions and does not represent practical growth performance. Nevertheless, the differences between boars and barrows were also reported in group-housed pigs although on a lower performance level (Andersson *et al.* 1997). In general, the housing conditions can influence the feed intake. Bornett *et al.* (2000) reported that individually penned pigs showed different feed intake behaviour than group-housed pigs, caused for example by aggression or social stress. The present study investigated the feed consumption of individually penned pigs, only. Therefore, more research is required to compare the feed intake of single and group-housed pigs.

In conclusion, the superior growth performance potential of boars compared to barrows was confirmed in the present experiment. Barrows and boars responded to different lysine and ME levels of the diets in a similar manner, suggesting the marked and dominating effect of sex.

Acknowledgements

The authors would like to thank the co-workers of the Institute of Animal Nutrition of the Friedrich-Loeffler-Institute (FLI) in Braunschweig Germany, for assistance in performing the experiment and the analyses.

References

Andersson K, Schaub A, Andersson K, Lundstrijm K, Thomke S, Hansson I (1997) The effects of feeding system, lysine level and gilt contact on performance, skatole levels and economy of entire male pigs. Livest Prod Sci 51**,** 131-140

Anonymous (2000) Establishing community methods for the determination of vitamin A, vitamin E and tryptophan, annex part C. Determination of Tryptophan. Official Journal of the European Communities. L174 45-50

Anonymous (2010) European Declaration on alternatives to surgical castration of pigs. [Online].Available:http://ec.europa.eu/food/animal/welfare/farm/docs/castration_pigs_declaration_en.pdf.

Boler DD, Kutzler LW, Meeuwse DM, King VL, Campion DR, Mc Keith FK, Killefer J (2011) Effects of increasing lysine levels on carcass composition and cutting yields of immunologically castrated male pigs. J Anim Sci 89**,** 2189-2199

Bonneau M, Dufour R, Chouvet C, Roulet C, Meadus W, Squires E (1994) The effects of immunization against luteinizing hormone-releasing hormone on performance, sexual development, and levels of boar taint-related compounds in intact male pigs. J Anim Sci 72**,** 14-20

Bornett HLI, Morgan CA, Lawrence AB, Mann J (2000) The effect of group housing on feeding patterns and social behaviour of previously individually housed growing pigs. Appl Anim Behav Sci 70**,** 127-141

Campbell RG, Steele NC, Caperna TJ, McMurtry JP, Solomon MB, Mitchell AD (1989) Interrelationships Between Sex and Exogenous Growth Hormone Administration on Performance, Body Composition and Protein and Fat Accretion of Growing Pigs. J Anim Sci 67**,** 177-186

Campbell RG, Taverner MR (1988) Genotype and sex effects on the relationship between energy intake and protein deposition in growing pigs. J Anim Sci 66**,** 676-686

Claus R, Weiler U (1994) Endocrine regulation of growth and metabolism in the pig: a review. Livest Prod Sci 37**,** 245-260

Clouard C, Meunier-Salaün M-C, Val-Laillet D (2012) The effects of sensory functional ingredients on food preferences, intake and weight gain in juvenile pigs. Appl Anim Behav Sci 138**,** 36-46

De la Llata M, Dritz SS, Tokach MD, Goodband RD, Nelssen JL (2007) Effects of increasing lysine to calorie ratio and added fat for growing-finishing pigs reared in a commercial environment: I. Growth performance and carcass characteristics. Prof Anim Sci 23**,** 417-428

Dong GZ, Pluske JR (2007) The low feed intake in newly-weaned pigs: Problems and possible solutions. Asian Austral J Anim 20**,** 440-452

Dunshea F, Colantoni C, Howard K, McCauley I, Jackson P, Long K, Lopaticki S, Nugent EA, Simons J, Walker J, Hennessy D (2001) Vaccination of boars with a GnRH vaccine (Improvac) eliminates boar taint and increases growth performance. J Anim Sci 79**,** 2524-2535

Dunshea F, King R, Campbell R, Sainz R, Kim Y (1993) Interrelationships between sex and ractopamine on protein and lipid deposition in rapidly growing pigs. J Anim Sci 71**,** 2919-2930

Forbes JM (1995) Voluntary feed intake and diet selection in farm animals. CAB International, Wallingford, UK, 152-185

Friesen KG, Nelssen JL, Goodband RD, Tokach MD, Unruh JA, Kropf DH, Kerr BJ (1994) Influence of dietary lysine on growth and carcass composition of high-lean-growth gilts fed from 34 to 72 kilograms. J Anim Sci 72**,** 1761-1770

Fuller MF, Franklin MF, McWilliam R, Pennie K (1995) The responses of growing pigs, of different sex and genotype, to dietary energy and protein. J Anim Sci 60**,** 291-298

GfE (2005) Standardised precaecal digestibility of amino acids in feedstuffs for pigs – methods and cocepts. Pro. Soc. Nutr. Physiol. 14**,** 185-205

GfE (2008) Recommendations for the supply of energy and nutrients to pigs. DLG Verlag, Frankfurt am Main, Germany

Gispert M, Angels Oliver M, Velarde A, Suarez P, Perez J, Font i Furnols M (2010) Carcass and meat quality characteristics of immunocastrated male, surgically castrated male, entire male and female pigs. Meat Sci 85**,** 664-670

Gompertz B (1825) On the nature of the function expressive of the law of humanmortality, and on a new mode of determining the value of lifecontingencies. Phil. Trans. Roy. Soc. London 5/2 ,513-585

Henry Y (1985) Dietary factors involved in feed intake regulation in growing pigs: A review. Livest Prod Sci 12, 339-354

Kanis E, Koops W (1990) Daily gain, food intake and food efficiency in pigs during the growing period. Anim Prod 50, 353-364

Karg H (1994) Hormonale Regulation des Wachstums. In: Döcke F (eds.) Veterinärmedizinische Endokrinologie. Gustav Fischer Verlag, Stuttgart, Germany ,176-203

Prunier A, Bonneau M, von Borell EH, Cinotti S, Gunn M, Fredriksen B, Giersing M, Morton DB, Tuyttens FAM, Velarde A (2006) A review of the welfare consequences of surgical castration in piglets and the evaluation of non-surgical methods. Anim Welfare 15, 277-289

Quiniou N, Dubois S, Le Cozler Y, Bernier JF, Noblet J (1999) Effect of growth potential (body weight and breed/castration combination) on the feeding behaviour of individually kept growing pigs. Livest Prod Sci 61, 13-22

Quiniou N, Dubois S, Noblet J (2000) Voluntary feed intake and feeding behaviour of group-housed growing pigs are affected by ambient temperature and body weight. Livest Prod Sci 63, 245-253

Schulze V, Roehe R, Bermejo JL, Looft H, Kalm E (2002) Genetic associations between observed feed intake measurements during growth, feed intake curve parameters and growing–finishing performances of central tested boars. Livest Prod Sci 73, 199-211

Van Lunen TA, Cole DJA (1996) The effect of lysine/digestible energy ratio on growth performance and nitrogen deposition of hybrid boars, gilts and castrated male pigs. Anim Sci 63, 465-475

VDLUFA (2007) (Verband Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten) Handbuch der Landwirtschaftlichen Versuchs- und Untersuchungsmethodik (VDLUFA-Methodenbuch), Band III. Die chemische Untersuchung von Futtermitteln. VDLUFA-Verlag, Darmstadt, Germany

Von Felde A, Roehe R, Looft H, Kalm E (1996) Genetic association between feed intake and feed intake behaviour at different stages of growth of group-housed boars. Livest Prod Sci 47, 11-22

Zamaratskaia G, Andersson HK, Chen G, Andersson K, Madej A, Lundström K (2008) Effect of a Gonadotropin-releasing Hormone Vaccine (ImprovacTM) on Steroid Hormones, Boar Taint Compounds and Performance in Entire Male Pigs. Reprod Domest Anim 43, 351-359

Zeng X, Turkstra J, Jongbloed A, van Diepen J, Meloen R, Oonkb H, Guoa D, van de Wiel D (2002) Performance and hormone levels of immunocastrated, surgically castrated and intact male pigs fed ad libitum high- and lowenergy diets. Livest Prod Sci 83, 1-11

Zhang G, Yi X, Chu L, Lu N, Htoo J, Qiao S (2011) Effects of dietary net energy density and standardized ileal digestible lysine: Net energy ratio on the performance and carcass characteristic of growing-finishing pigs fed low crude protein supplemented with crystalline amino acids diets. Agric Sci China 10, 602-610

5. Paper II

Effect of varying supply of amino acids on nitrogen retention and growth performance of boars of different sire lines

Caroline Otten[1], Andreas Berk[1], Luise Hagemann[2], Simone Müller[3], Manfred Weber[4] and Sven Dänicke[1]

[1] Institute of Animal Nutrition, Friedrich-Loeffler-Institute (FLI),
Federal Research Institute for Animal Health, Braunschweig
[2] State Office for Rural Development, Agriculture and Land Reallocation Brandenburg, Teltow/Ruhlsdorf
[3] Thuringian State Institute for Agriculture, Regional Office Bad Salzungen, Bad Salzungen
[4] State Institute for Agriculture, Forestry and Horticulture Saxony-Anhalt,
Centre for Livestock Husbandry and Equipment, Iden

Archives Animal Breeding
Arch Tierz 56 (2013) 75

Abstract

Three diets with varying amino acid (AA) levels were fed in two nitrogen (N) balance studies and two fattening experiments in order to determine the nitrogen retention and growth performance of boars of different sire lines. A total of twelve boars, six crossbreed boars sired by Piétrain boars (Study 1) and six crossbreed boars sired by Duroc boars (Study 2) were used in the N balance studies. The feeding trials with 214 boars (109 crossbreeds of Piétrain sire line 1 x hybrid sow (Pi 1) and 105 crossbreeds Piétrain sire line 2 x hybrid sow (Pi 2)) in Experiment 1 and 212 boars (106 Piétrain sire line 3 x hybrid sow (Pi 3) and 106 Duroc x hybrid sow (Du)) in Experiment 2 were carried out in three performance test centres in parallel to the N balance studies.

Three diets with increasing content of AA were used; it was intended to use the same diets in N balance studies and the fattening experiments in order to compare the N retention and performance of boars during the growth period. The diets used in all experiments contained 13.4 MJ ME and 11.5 g lysine/kg (Diet 1), 13.2 g lysine/kg (Diet 2), and 14.9 g lysine/kg (Diet 3). The increase of the AA content of the diets seemed to have only a very minor impact on N retention and on the growth performance of growing boars, whereas the location effect was found to be significant.

Keywords: amino acids, boars, nitrogen balance studies, lysine, fattening experiments

Introduction

Castration of male piglets without anaesthesia is traditionally practiced in many European countries to avoid boar taint. Meanwhile, castration without anaesthesia is known to produce pain and discomfort and will no longer be accepted by consumers and animal welfare organisations. Research has proven that this surgical procedure inflicts pain to piglets (Prunier *et al.* 2006). Apart from other possibilities, the fattening of non-castrated male pigs seems to be one of the most likely alternative solutions to surgical castration. Until today, it was common in Germany to use only gilts and barrows for fattening. Therefore, there are only incomplete recommendations for the feeding regimen of boars (DLG 2010). In general, boars have a superior growth performance and a higher lean meat percentage compared with barrows and/or gilts (Andersson *et al.* 1997). The higher anabolic potential of boars in comparison with castrated male pigs (barrows) was reported (Campbell and Taverner 1988, Van Lunen and Cole 1996a). Several authors stated that boars had a superior feed efficiency (Bonneau *et al.* 1994, Van Lunen and Cole 1996a) due to a simultaneous higher weight gain (Campbell and Taverner 1988) and lower feed consumption (Dunshea *et al.* 1993, Dunshea *et al.* 2001). Moreover, the carcasses of boars were leaner than those of barrows (Dunshea *et al.* 2001, Gispert *et al.* 2010, Boler *et al.* 2011).

In addition, it was determined that boars have a higher potential for protein deposition than gilts or barrows (Yen *et al.* 1986a, b), and therefore need more protein and amino acids (AA) in their diet in order to perform maximum growth (Campbell *et al.* 1988). These findings results in different nutrition requirements of boars. Due to the shift from the fattening of barrows towards the fattening of boars, a scientific evidence basis on nutrition requirements of growing-finishing boars under typical German conditions is needed.

Within the joint research project "Feeding of boars," fundamentals of recommendations for boar nutrition should be established in cooperation with several research institutes and economic partners. Recommendations for the supply of growing-finishing boars with protein (amino acids) and energy (ME) should be derived from the results of several experiments. The aim of the present study was to determine the nitrogen (N) retention of boars under the influence of different AA levels and to verify this data in subsequent fattening experiments. The data serves to differentiate the demand for nutrients and energy supply of growing boars in general.

Material and Methods

Nitrogen balance studies

A total of 12 boars were used in two N balance experiments. The studies were carried out at the Institute of Animal Nutrition, Friedrich-Loeffler-Institute (FLI), Federal Research Institute for Animal Health, Braunschweig, Germany. Treatments and experiments were in compliance with the European Union Guidelines concerning the protection of experimental animals and were approved by the Lower Saxony State Office for Consumer Protection and Food Safety (LAVES), Oldenburg, Germany (File Number 33.14-42502-04-078/09).

N Balance Study 1

Animals

In N Balance Study 1 six boars (Piétrain x commercial hybrid sow) with a mean start body weight (BW) of 43.6± 2.2 kg (± standard deviation) were used.

Experimental diets

The three isoenergetic diets (13.40 MJ ME; Table 1) differed in their concentration of essential amino acids (EAA) and generally based on the recommendation of the German Society of Nutrition Physiology for female pigs with a very high protein accretion based on the requirement of precaecal digestible AA per day (GfE 2008).

For calculation of the AA concentration of the diets the reference values of DLG (2010) for fattening of boars were taken into consideration. The dietary AA level of Diet 1 was slightly below these reference values and the AA level of Diet 2 and 3 were above these values. The AA were indicated as gross values instead of precaecal digestible AA because only the gross values were determined analytically in this study.

Other AA were added in relation to the first limiting AA lysine (lysine: methionine/cystine: threonine: tryptopane: valine = 1 : 0.60 : 0.65 : 0.18 : 0.75). The experimental diets were fed as pellet feed.

Design and Procedure

The experiment was conducted as a double 3 x 3 Latin square with 6 replicates per diet and consisted of three trial periods; each trial period was divided into an at least 7-day adaption period and an exactly 7-day collection period. During the adaption period the animals were kept in concrete floor boxes, each pig was fed twice daily. Before the collection period started, the boars were adapted to the balance cages for two days as described by Farries and Oslage (1961). The animals were housed in air-conditioned rooms. During the collection period the pigs were kept in single metal metabolism cages to enable the separate quantitative collection of urine and faeces. Urine was collected once and faeces twice daily. All the faeces produced in one collection period by one pig were stored at -18°C. The daily feed amount was restricted to an amount consumed by all animals voluntarily. Pigs were fed at the level of 2.1 times the ME requirement for maintenance. The daily feed amount was given in two equal portions at 6:30 a.m. and 1:30 p.m. During the feeding times, the pigs had plenty of opportunity to take water according to their individual needs.

Table 1: Feed composition and analysis of N Balance Studies 1 and 2

Diet	1	2	3
Components (%) Study 1 and 2			
Wheat	45.30	44.70	44.10
Barley	30.00	30.00	30.00
Soy bean meal	15.00	15.00	15.00
Rapeseed meal	4.50	4.50	4.50
Soy bean oil	2.00	2.00	2.00
Mineral-Vitamin premix*	1.43	1.52	1.60
Minerals	1.20	1.30	1.40
Lysine-HCl	0.34	0.51	0.68
DL-Methionine	0.09	0.19	0.30
L-Threonine	0.14	0.26	0.37
L-Tryptophane	-	0.02	0.05
Calculated composition Study 1 and 2			
ME (MJ/kg)**	13.40	13.40	13.40
Lysine (g/kg)	11.50	13.20	14.90
pcd Lysine (g/kg)***	10.10	11.80	13.40
Analysed composition (%) Study 1			
ME (MJ/kg)**	13.20	13.58	13.61
Dry matter	88.62	88.89	88.96
Crude protein	17.11	18.17	18.31
Lysine (g/kg)	11.10	12.90	14.30
Crude fat	3.69	3.25	3.01
Crude fiber	4.16	3.15	3.50
Crude ash	4.81	5.07	4.71
Analysed composition (%) Study 2			
ME MJ/kg**	12.73	13.26	13.21
Dry matter	88.44	88.30	88.58
Crude protein	18.42	17.80	18.87
Lysine (g/kg)	10.70	12.40	13.70
Crude fat	3.77	3.25	3.29
Crude fiber	5.01	3.58	3.66
Crude ash	5.43	4.33	4.62

* Per kg grower diet (for diet 1 with 1.43 % premix): vitamin A ,10 000 IE; vitamin D_3, 1 250 IE; vitamin E 80 mg; vitamin B_1, 1.3 mg; vitamin B_2, 5.0 mg; vitamin B_6, 2.5 mg; vitamin B_{12}, 25 µg; vitamin K_3, 1.1 mg; nicotinic acid, 12.5 mg; calcium pantothenate, 5.0 mg; choline chloride, 125 mg; ferrous sulphate, 125 mg; copper sulphate, 15 mg; manganese (oxide), 80 mg; zinc (oxide), 100 mg; calcium iodate, 2 mg; sodium selenite, 0.40 mg; cobalt carbonate, 0.25 mg; phytase, 500 FTU

**Calculated on base of digestible (table values of the used compounds) crude nutrients (as analysed) according to (GfE 2008)

*** pcd Lysine means precaecally digestible lysine; calculated on base of table values (GfE 2005b)

Sample preparation

At the end of the collection period the faeces were homogenized and representative samples were taken. The samples were freeze-dried and milled with a rotation lab mill through a 1 mm screen before being analysed. The urine was collected in bottles containing 20 ml of 5% sulphuric acid to minimize atmospheric loss of N. Aliquot samples of acidified urine were pooled for each individual pig and were kept frozen. Before analysis, the urine was mixed, strained through super fine glass wool (Hecht Assistent, Sondheim, Germany) in order to remove possibly still present impurities. Representative samples of each diet were taken for feed analysis and milled through a 1 mm screen.

N Balance Study 2

Six boars (Duroc x commercial hybrid sow) with a mean start body weight of 45.6± 3.1 kg were used in N Balance Study 2. Boars were fed at the level of 1.7 to 1.8 times the ME requirement for maintenance. The further experimental design and procedure was in accordance with the procedure of Study 1.

Chemical Analysis (Study 1 and 2)

Collected samples of feed and faeces were analysed according the methods of VDLUFA (2007). Crude fat, crude fiber and crude ash were analysed according to Methods 5.1.1, 6.1.1 and 8.1, respectively. Crude protein in the diets and in the faeces was measured using the method of Dumas (Method number 4.1.2). Furthermore, the diets were analysed for sugar (according to Luff-Schoorl, Method 7.1.1) and starch (polarmetrically, Method 7.2.1). The amino acid content of the diets, with the exception of tryptophan, was analysed by ion exchange chromatography using an Amino Acid Analyser (Method number 4.11.1; Biochrom Ltd., Cambridge, UK). Tryptophan was determined by HPLC with fluorescence detection (Anonymous 2000). Urine was analysed for nitrogen content following the Kjeldhal method (Method number 4.1.1).

Calculations and statistics (Study 1 and 2)

The nitrogen retention was calculated as the diet N minus N in faeces and urine (in grams per day). For nitrogen utilisation (expressed as a percentage) the N retention was divided by the N intake.

The digestibility was calculated with the (GfE 2005a) formula:

$$Digestability\ (\%) = \frac{Intake - Excretion}{Intake} * 100$$

*Intake (g/d) = DM (dry matter) Intake (g/d) * Content of the nutrient (g/kg DM)*
Excretion (g/d) = DM Amount excreted with the faeces (kg/d) Nutrient content in the faeces (g/kg DM)*

ME concentration of the diets was estimated using the prediction equation based on apparent digestible nutrients as proposed by the GfE (2008). For analysis of the nitrogen balances, the body weights of the animals were raised to the power of 0.67 in order to minimize the influence of individual body weight on the results (Hoffmann and Gebhardt 1973). The experimental data was analysed by a repeated measures analysis using the PROC MIXED procedure of SAS (9.2). The effects of period and diet and their interactions were included in the model. The least square means, their standard errors, levels of significance for main effects and the associated interaction were determined. *P*-values <0.05 were considered to be significant.

Fattening experiments

Animals

Two successive fattening experiments were conducted with a total of 228, respectively 229, boars at the beginning of the experiments. The pigs were produced specifically for the project and were progeny of four genetic different sire lines (Piétrain 1-3 and one Duroc). On experimental grounds, 14 pigs (Experiment 1), respectively 17 pigs (Experiment 2), had to be removed from the experiment, with the result that the experiment was finished by 214, respectively 212, boars.

Experimental diets

The feed composition of the diets fed in Experiment 1 and 2 was consistent with the composition of the diets used in N Balance Study 1 and 2. The analyses of the diets of the fattening experiments showed only minimal deviations within the latitude compared to the analysis results of the N balance diets. Therefore the analysis result of N Balance Study 1 was equated with the analysis results of Fattening Experiment 1 and for N Balance Study 2 with Experiment 2 (Table 1).

Design and Procedure

In Experiment 1 and 2 the total number of animals was randomly divided within the full- and half-sibling groups over three pig performance test centres in Germany: Location 1, 2 and 3. N balance Study 1 and Fattening Experiment 1 used full- and half-sibling boars of the same sire lines and N Balance Study 2 and Fattening Experiment 2 also. The pigs were randomly allotted to three diets in consideration of their genetic relationships

Pigs were housed in climate controlled buildings (on average 13 pigs per pen (Location 1 and 2), respectively 12 pigs per pen (Location 3) and 1.0 m^2 per pig) with partly slatted floor (Location 1 and 2) or fully slatted concrete floor (Location 3). Pelleted feed and water were offered for consumption on *ad libitum* basis. Every performance test centre had demand feeding stations with a single animal detection via transponder (FIRE-stations (Osborne) in Location 1 and INSENTEC-stations in Location 2 and 3).

The overall experimental period lasted from an average BW of 30 kg until the time of slaughter up to a BW of aspired 120 kg. The feeding regimen was a two phase feeding, with a per pen change from grower to finisher feed at approximately 70 kg BW. To enhance comparability with the N balance studies, only the performance data from the grower phase (30-70 kg BW) were considered in this study.

Sample preparation and Analysis

Samples of each diet were collected and analysed for dry matter, crude nutrients and amino acids according to the methods described in detail above.

Calculations and statistics

The experimental data was analysed using the PROC MIXED procedure of SAS (9.2). The effects of performance test centre (location), diet and sire line and their interactions were included in the model as fixed factors and the biological father was used as a random factor. Based on data from pig individual performance the statistics were built. The least square means, their standard errors, levels of significance for main effects and the associated interaction were determined. *P*-values <0.05 were considered to be significant.

Daily weight gain (DWG) was calculated as the difference between body weight at the end of the growth period minus start weight divided by days of the experimental period. Feed intake was measured daily by the respective feeding station. ME intake was calculated using the feed intake data and the ME level of the respective diet. The feed conversion (FCR) rate was obtained as feed intake divided by gain. Moreover pooled least square means of the three fixed factors were calculated for each experimental run.

Results

N balance studies

The effects of period and diet on N retention, N utilisation and digestibility of crude nutrients of the boars used in N Balance Study 1 and 2 are presented in Table 2. In Period 1 of Study 2, one boar of Feeding Group 3 had to be excluded from the trial for health reason.

Table 2: N retention and nutrient digestibility in N Balance Studies 1 and 2 (least square means and pooled standard error of means)

N Balance Study 1	Period			Diet			PSEM	ANOVA (*P*-value)*	
	1	2	3	1	2	3		Period	Diet
N-Ret (g/kg BW $^{0.67}$)	1.87	1.89	1.81	1.78	1.93	1.85	0.02	0.305	0.067
N-Ret (g/d)	24.32^{c}	27.96^{b}	30.78^{a}	26.71	28.70	27.65	0.38	<0.001	0.163
N-Utilisation (%)	60.75	61.08	58.76	60.35	61.32	58.91	1.46	0.326	0.347
dXP (%)	83.74^{b}	86.11^{a}	88.04^{a}	84.14^{b}	87.14^{a}	86.61^{ab}	0.31	<0.01	0.025
dOM (%)	86.90	87.54	88.05	85.65^{b}	88.36^{a}	88.48^{a}	0.30	0.238	<0.01
dXL (%)	71.06	71.36	69.82	70.98	71.20	70.06	1.36	0.752	0.854
dXF (%)	33.77	36.09	38.27	32.61	34.29	41.23	2.42	0.388	0.062
dXX (%)	91.99	92.00	92.11	90.76^{b}	92.55^{a}	92.78^{a}	0.19	0.936	0.003

N Balance Study 2	Period			Diet			PSEM	ANOVA (*P*-value)*	
	1	2	3	1	2	3		Period	Diet
N-Ret (g/kg BW $^{0.67}$)	1.61	1.62	1.67	1.52^{b}	1.66^{a}	1.72^{a}	0.14	0.360	<0.01
N-Ret (g/d)	21.05^{b}	23.93^{b}	28.24^{a}	22.38^{b}	24.72^{ab}	26.11^{a}	1.27	<0.01	0.028
N-Utilisation (%)	59.62	58.25	60.09	54.21^{b}	61.79^{a}	61.96^{a}	4.56	0.638	0.016
dXP (%)	82.66^{b}	84.78^{ab}	87.34^{a}	82.39^{b}	86.38^{a}	86.01^{a}	1.34	0.016	0.015
dOM (%)	84.44	85.48	86.92	83.69	86.79	86.36	0.87	0.136	0.055
dXL (%)	66.42^{b}	69.55^{ab}	71.84^{a}	71.03^{a}	69.51^{ab}	67.28^{b}	1.81	<0.01	0.037
dXF (%)	25.58	30.99	36.52	33.67	30.74	28.69	3.93	0.057	0.340
dXX (%)	90.01	90.42	91.22	89.43	91.24	90.98	0.72	0.216	0.060

*period*diet were non-significant (P<0.05)

Values with different superscripts differ significantly (P<0.05), N-Ret (g/kg BW$^{0.67}$)= N retention (g/kg body weight$^{0.67}$), dXP= digestibility of crude protein, dOM= digestibility of organic matter, dXL= digestibility of crude lipid, dXF= digestibility of crude fiber, dXX=digestibility of nitrogen free extractives

In Study 1 there was no significant effect on N retention of the boars, neither for period nor for diet. In Study 2, there was a significant increased N retention for the pigs received Diet 2 or 3 compared to those consumed Diet 1 (P<0.01). Likewise, the N utilisation increased (P<0.05). The crude protein digestibility of the pigs also increased (P<0.05) parallel to the increasing body weight and age (period) and AA content of the diet in Studies 1 and 2. This result also applies to the digestibility of crude fat in Study 2. Organic matter and N-free extract digestibility was higher (P< 0.01) in pigs that received Diet 2 or 3 than in pigs received Diet 1 in Study 1. However, the digestibility of N-free extracts was higher (P<0.05) for pigs that received Diet 1 than pigs fed with Diet 3. In none of the studies could significant interactions be observed between period*diet.

Fattening experiments

The data from the growth period (30 kg until approximately 70 kg BW) of Fattening Experiment 1 and 2 were presented in Tables 3 and 4. As the N balance experiments are performed during the growth period, only the corresponding growth performance results of the fattening experiments are presented here. Therefore, data from the subsequent finishing period will not be considered in detail. In general, the boars of all used sire lines were characterized by a high performance level over the complete fattening period (30 kg until approximately 120 kg) in both experiments with average daily weight gains between 921 g/d and 1149 g/d (Data not shown).

Experiment 1

Dietary treatment or sire line did not affect growth performance or feed intake of the boars in Experiment 1 (Table 3). The location, which implies the housing conditions, was identified to be the major factor influencing performance. Average DWG was similar for boars kept at Locations 1 and 2 (937 g/d respectively 929 g/d) but for pigs kept at Location 3 this parameter was significantly reduced to 867 g/d (P<0.001). Pigs reared in Location 1 showed a significantly higher daily feed intake (1.82 kg/d (Location 1) vs. 1.74 kg/d (Location 3)) and therefore also a higher energy intake (24.52 MJ/d (Location 1) vs. 23.44 MJ/d (Location 3)) on average than the pigs housed in Location 3. Moreover, the pigs housed in Location 3 had an about 4% improved mean FCR compared to pigs of Location 1 and 2. There was a location*diet interaction (P<0.05), a location*sire line interaction (P<0.05) and a diet*sire line interaction (P<0.05) observed for FCR.

Table 3: Performance and feed intake (least square means (LSM) and pooled standard error of means (PSEM)) in Fattening Experiment 1 (growth period)

Location	Diet	Sire line	n	DWG (g)	Feed intake (kg/d)	ME intake (MJ ME/d)	FCR (kg/kg)
1	1	Pi 1	13	913	1.84	24.30	2.01
1	1	Pi 2	11	941	1.86	24.59	1.97
1	2	Pi 1	11	919	1.81	24.54	1.97
1	2	Pi 2	12	950	1.84	24.99	1.94
1	3	Pi 1	13	945	1.80	24.45	1.90
1	3	Pi 2	12	952	1.78	24.27	1.88
2	1	Pi 1	12	917	1.86	24.49	2.02
2	1	Pi 2	13	913	1.81	23.86	1.98
2	2	Pi 1	13	960	1.79	24.24	1.86
2	2	Pi 2	11	903	1.72	23.42	1.91
2	3	Pi 1	13	957	1.81	24.58	1.89
2	3	Pi 2	11	923	1.81	24.70	1.96
3	1	Pi 1	12	873	1.73	22.84	1.98
3	1	Pi 2	12	874	1.72	22.65	1.97
3	2	Pi 1	12	905	1.75	23.74	1.94
3	2	Pi 2	12	845	1.75	23.73	2.01
3	3	Pi 1	10	899	1.74	23.70	1.94
3	3	Pi 2	11	804	1.76	23.96	2.23
Pooled LSM							
Location							
1			72	937	1.82	24.52	1.94
2			73	929	1.80	24.21	1.94
3			69	867	1.74	23.44	2.01
	Diet						
	1		73	905	1.80	23.79	1.99
	2		71	914	1.78	24.11	1.94
	3		70	913	1.78	24.27	1.97
		Sire line					
		Pi 1	109	921	1.79	24.10	1.94
		Pi 2	105	900	1.78	24.02	1.98
PSEM				28.1	0.05	0.73	0.05
ANOVA (*P-value*)							
location				<0.001	0.033	0.034	0.015
diet				0.825	0.645	0.443	0.166
sire line				0.304	0.876	0.878	0.107
location*diet				0.711	0.477	0.487	0.008
location*sire line				0.069	0.705	0.708	0.031
diet*sire line				0.252	0.949	0.949	0.024
location*diet*sire line				0.784	0.940	0.938	0.275

Values with $P<0.05$ were considered to be significant; Sire line Pi 1 = Piétrain sire line 1, Sire line Pi 2 = Piétrain sire line 2

DWG= Daily weight gain; FCR= Feed conversion ratio

Experiment 2

The location was the main influence factor on performance and feed intake of the boars used in Experiment 2 (Table 4).

Table 4: Performance and feed intake (least square means (LSM) and pooled standard error of means (PSEM)) in Fattening Experiment 2 (growth period)

Location	Diet	Sire line	n	DWG (g)	Feed intake (kg/d)	ME intake (MJ ME/d)	FCR (kg/kg)
1	1	Pi 3	12	899	1.85	23.52	2.06
1	1	Du	16	1048	1.92	24.37	1.83
1	2	Pi 3	11	967	1.80	23.89	1.86
1	2	Du	13	986	1.87	24.80	1.89
1	3	Pi 3	12	904	1.77	23.33	1.96
1	3	Du	11	1076	1.85	24.45	1.71
2	1	Pi 3	12	961	1.81	23.03	1.88
2	1	Du	12	996	1.76	22.43	1.77
2	2	Pi 3	13	774	1.67	22.13	2.17
2	2	Du	11	860	1.62	21.51	1.89
2	3	Pi 3	12	760	1.69	22.31	2.23
2	3	Du	10	677	1.54	20.41	2.36
3	1	Pi 3	11	887	1.79	22.77	2.03
3	1	Du	10	1054	1.87	23.76	1.78
3	2	Pi 3	11	936	1.85	24.56	1.99
3	2	Du	12	1077	1.82	24.19	1.70
3	3	Pi 3	12	994	1.96	25.86	1.97
3	3	Du	11	1067	1.83	24.23	1.73
Pooled LSM							
Location							
1			75	980	1.84	24.06	1.89
2			70	838	1.68	21.97	2.05
3			67	1003	1.85	24.23	1.87
	Diet						
	1		73	974	1.83	23.32	1.89
	2		71	934	1.77	23.51	1.92
	3		68	913	1.77	23.43	1.99
		Sire line					
		Pi 3	106	898	1.80	23.49	2.02
		Du	106	983	1.79	23.35	1.85
PSEM				30.3	0.06	0.81	0.05
ANOVA (*P-value*)							
location				<0.001	<0.001	<0.001	<0.001
diet				0.001	0.123	0.898	0.002
sire line				<0.001	0.832	0.823	<0.001
location*diet				<0.001	0.074	0.064	<0.001
location*sire line				0.001	0.072	0.072	0.012
diet*sire line				0.168	0.362	0.368	0.368
location*diet*sire line				0.003	0.735	0.733	<0.001

Values with $P<0.05$ were considered to be significant; Sire line Pi 3 = Piétrain sire line 3, Sire line Du = Duroc sire line

DWG= Daily weight gain; FCR= Feed conversion ratio

It is conspicuous that pigs reared in Location 2 showed significant lower average DWG (P<0.001) of 838 g/d compared to pigs of Location 1 (980 g/d) or Location 3 (1003 g/d). This observation continues with all other measured parameters, where the pigs housed in Location 2 showed less average performance values (P<0.001) than pigs raised in Location 1 or 3. However, boars received the experimental Diet 1 exhibited significantly increased DWG (974 g/d compared to 934 g/d (Diet 2) or 913 g/d (Diet 3)) on average for the whole experimental run. In addition the type of sire line influenced the amount of DWG (P<0.001). Crossbreeds of Du sired pigs showed an approximately 9% higher DWG than Pi 3 crossbreeds. The FCR of Pi 3 crossbreeds were reduced by 9% on average as well. There were significant interactions detected between location*diet, location*sire line and location*diet*sire line for DWG. The same interactions were observed for FCR.

Discussion

The present experiments aimed at examining the nitrogen retention of boars under the influence of different amino acid levels and detecting the optimum AA level for maximum growth rate and feed efficiency by mean of feeding trials. In Table 2 the N retention was mentioned in (g/d) and in (g/kg BW $^{0.67}$). The N retention in grams per day was significantly affected by the period (depending on BW and feed intake) in both studies. For reason mentioned above, the period effect was eliminated by using the N retention in the unit of (g/kg BW $^{0.67}$). Therefore, the results were discussed in the unit of N retention (g/kg BW $^{0.67}$) in the following.

In contrast to recent suggestions, the diet composition (the dietary AA content, in this case) seemed to have only a very minor impact on N retention and performance in the current investigations. Moreover, the experimental diet exhibited no significant effect on the N retention of the Piétrain sired boars used in Study 1. Whereas the Duroc sired boars used in Study 2 showed a significantly increased N retention for pigs received Diet 2 or 3 compared to those that consumed Diet 1. Several authors mentioned higher N retention for pigs fed diets with increased AA concentrations (5.0 g lysine/kg and 11.0 g lysine/kg) in the diets, respectively several diets, with increasing AA levels (8.1 till 13.1 g lysine/kg) during the growth period (Fabian *et al.* 2004, O'Connell *et al.* 2006b). Reynolds and O'Doherty (2006) also described that the pigs fed a high lysine level (12.5 g/kg) had a higher (P<0.05) N retention than pigs fed diets with lower lysine concentrations (10.5 till 8.5 g lysine/kg). These findings support the presumption that the chosen range of lysine levels in the current study did not induce significant differences in N retention of boars from all tested sire lines.

Acciaioli *et al.* (2011) described significant differences in N retention and utilisation between pigs of different breeds. It would seem that one reason for the lack of comparability of the results of the current two N balance studies might be use of boars with different genetic backgrounds.

In the present study it is not clearly defined whether a high or low lysine level is relevant for an improved N utilisation, the N utilisation fluctuated around 60%. Other authors observed also increasing and decreasing N utilisations (O'Connell *et al.* 2006b, Reynolds and O’Doherty 2006). In general, the reported N utilisations of the present studies (approximately 60%) were in good accordance with the findings of Lenis *et al.* (1999) and Markert *et al.* (1993).

Many factors are known to influence apparent digestibility of nutrients, for instance characteristics of the feed or animal factors like body weight or genotype (Le Goff and Noblet 2001). In the present study, the apparent digestibility of crude nutrients was influenced by the period as well as by the diet. The period influenced the digestibility of crude protein (Studies 1 and 2) and crude fat (Study 2). Consistent to the present study, Le Goff and Noblet (2001) also observed improved digestibility of organic matter, energy and crude protein for adult sows compared to growing pigs. The data from the present experiment showed in most instances a positive effect of increasing body weight on apparent digestibility, comparable with the results of Fernández *et al.* (1986) and Le Goff and Noblet (2001), where adult sows showed superior digestibility of nutrients to growing pigs. In contrast, Kass *et al.* (1980) found a negative effect of increasing body weight on digestive capacity. Freire *et al.* (2000) and Acciaioli *et al.* (2011) concluded that pigs are able to improve their digestive ability with increasing age. Longland *et al.* (1994) stated that the immature gut micoflora in young pigs is responsible for the decreased apparent digestibility of some nutrients. These findings were in good accordance with the present study and may be used as explanation for the current results.

Acciaioli *et al.* (2011) reported a significant increase ($P<0.01$) in crude protein digestibility of pigs of the same age, but different breeds, parallel to the increase of the lysine level in the diet. These findings were in accordance with the results of the present N balance studies. The apparent digestibility of crude protein was with 4% (Study 1), respectively 5 % (Study 2), significantly higher ($P<0.05$) in pigs receiving Diet 2 than in pigs consuming Diet 1. In addition, in the present study the digestibility of the organic matter was significantly higher for Diet 2 and 3 than for Diet 1, but only for Study 1. In contrast to the apparent digestibility of crude protein and organic matter, the digestibility of crude fat decreased with increasing dietary AA content. Morales *et al.* (2002) discussed that digestibility was markedly influenced by the animal breed and to a lesser extent by the diet. In general, the present studies delivered partly inconsistent results; there was no firm evidence for an improvement of N retention and/or apparent digestibility of boars consuming diets with increased AA levels.

In the present investigation, growth performance of boars was mainly affected by the environmental impact (location) of the three pig performance test centres in both experiments. In Experiment 2 the type of sire line was another important factor. These effects were superimposed by several interactions between location*diet, location*sire line, diet*sire line and location*diet*sire line. Morrison *et al.* (2003) stated that housing effects, like reduced feeding space, affected growth performance of entire male pigs. The authors also assumed that other factors such as reduced pen space and, as a consequence, increased social stress could influence the performance. According to Bolhuis *et al.* (2006) pigs might respond to a negative change in environmental conditions by a reduction in weight gain depending on their coping behaviour. In Experiment 1 there were striking interactions between location*diet, location*sire line and diet*sire line for FCR. As in the N balance studies, the diet had no single effect on any of the observed parameters in Fattening Experiment 1. These results indicated the already mentioned presumption that the tested range in dietary AA content was obviously too small to induce effects on growth performance. The sire line had also no significant influence on the growth performances and feed intake exceptional of the boars in Location 3 fed Diet 3. The mentioned group of boars had a 15% worse FCR for Pi 2 compared Pi 1. The FCR in Location 3 was in total less favourable than in Location 1 or 2. The reason was a defined lower DWG caused by a lower feed intake; the poorer FCR affects in particular boars fed Diet 3.

In Experiment 2, DWG and FCR were influenced by location*diet, location*sire line and location*diet*sire line. As opposed to Experiment 1, the type of sire line and diet influenced the DWG and FCR (P<0.01), which is determined arithmetically. Du crossbreed pigs exhibited an improved growth performance compared to Pi 3 crossbreeds, independent of the used diet or location. Several authors mentioned the superior growth performance of Duroc terminal sired pigs compared to other crossbreed pigs, McGloughlin *et al.* (1988) outlined that Duroc crosses grew faster and had an advantageous FCR compared to Landrace or Large White sired pigs. Moreover, Latorre *et al.* (2003) found improved growth rates and FCR for

Duroc progeny which fit together with the performance results of Du crosses in the present study. Furthermore, there are no clear indications of a positive or negative effect of an increased AA level of the diet on growth performance. To some extent, it would seem that an increased AA concentration even had a negative effect on the DWG of some boars in the current experiments. As justified by AA analysis the target AA concentrations of the diets were entirely met. Therefore, an unintended variation in dietary AA levels can be excluded as a possible reason for the lack of performance response to the graded AA levels.

Gatel and Grosjean (1992) and Van Lunen and Cole (1996a) stated that increasing the AA content of the diet led to a significant improvement of performance, but only up to a certain AA value. If the AA level was increased further on, the growth rate of the pigs plateaued at first and afterwards decreased. These findings were in good accordance with the decreased DWG for Du crossbreed boars consuming Diet 3 compared to those fed Diet 1 in Experiment 2. Therefore, the authors suggest that an oversupply with lysine might cause a growth depression in some types of crossbreed pigs.

In Fattening Experiment 2 measurable significant interactions were found between the location, the diet and the sire line for DGW and as a result for FCR of the boars. These significant results are caused by the amount of feed intake. For health grounds, the average daily feed intake of boars housed in Location 2 was significantly lower than for those in Location 1 or 3. For that reason, it was impossible for the pigs raised in Location 2 to realise higher DGW with this low amount of feed intake. The mean DWG of boars reared in Location 2 is significantly lower than the DWG for boars for both sire lines housed in Location 1 or 3. The low feed intake level also caused the interaction between location and sire line. Induced by the low feed intake, the Du crossbreeds with normally superior growth potential were not able to realise their full performance potential and therefore showed only growth rates like the Pi 3 crosses.

In conclusion, the tested range of increasing dietary AA concentrations was on an overall basis insufficient to influence the N retention and the performance of pigs during the growth period. Only the N retention of Duroc sired boars was positively influenced by an increased AA level. Therefore, it seemed to be unnecessary to increase the dietary AA concentration in diets for growing boars generally above the AA levels used in Diet 1 to achieve maximum performance. Furthermore the decisive impact of the type of sire line, in particular on the growth performance, was authenticated. In addition, the significant influence of the environmental impact (location) on animal performance was confirmed and the nature of these effects needs to be studied further.

Acknowledgements

This study was part of the joint research project “Feeding of boars” and was financially supported by the innovation program of the Bundesministeriums für Ernährung, Landwirtschaft und Verbraucherschutz (Support code 2813802610). The authors gratefully acknowledge the partners of the joint research project “Feeding of boars”: A. Berk and C. Otten, Braunschweig; K. Büsing, Rostock; H. Claus; Kiel, L. Hagemann, Ruhlsdorf; A. Hardinghaus, Neuenkirchen-Vörden; W. Matthes, Dummerstorf; S. Müller, Bad Salzungen; M. Rademacher and K. Krüger, Hanau-Wolfgang; G. Riewenherm, Düsseldorf; M. Weber, Iden; A. Zeyner, Halle. In addition, the authors would like to thank the co-workers of the Institute of Animal Nutrition of the Friedrich-Loeffler-Institute (FLI) in Braunschweig and the co-workers of the performance test centres in Dornburg, Iden und Ruhlsdorf for assistance in performing the experiments.

References

Acciaioli A, Sirtori F, Pianaccioli L, Campodoni G, Pugliese C, Bozzi R, Franci O (2011) Comparison of total tract digestibility and nitrogen balance between Cinta Senese and Large White pigs fed on different levels of dietary crude protein. Anim Feed Sci Tech 169**,** 134-139

Andersson K, Schaub A, Andersson K, Lundstrijm K, Thomke S, Hansson I (1997) The effects of feeding system, lysine level and gilt contact on performance, skatole levels and economy of entire male pigs. Livest Prod Sci 51**,** 131-140

Anonymous (2000) Establishing community methods for the determination of vitamin A, vitamin E and tryptophan, annex part C. Determination of Tryptophan. Official Journal of the European Communities. L174 45-50

Boler DD, Kutzler LW, Meeuwse DM, King VL, Campion DR, Mc Keith FK, Killefer J (2011) Effects of increasing lysine levels on carcass composition and cutting yields of immunologically castrated male pigs. J Anim Sci 89**,** 2189-2199

Bolhuis JE, Schouten WGP, Schrama JW, Wiegant VM (2006) Effects of rearing and housing environment on behaviour and performance of pigs with different coping characteristics. Appl Anim Behav Sci 101**,** 68-85

Bonneau M, Dufour R, Chouvet C, Roulet C, Meadus W, Squires E (1994) The effects of immunization against luteinizing hormone-releasing hormone on performance, sexual development, and levels of boar taint-related compounds in intact male pigs. J Anim Sci 72**,** 14-20

Campbell R, Taverner M, Curic D (1988) The effect of sex and live weight on growing pig`s response to dietary protein. Anim Prod 46**,** 123-130

Campbell RG, Taverner MR (1988) Genotype and sex effects on the relationship between energy intake and protein deposition in growing pigs. J Anim Sci 66**,** 676-686

DLG (2010) Erfolgreiche Mastschweinefütterung. DLG Verlag, Frankfurt am Main, 34-36

Dunshea F, Colantoni C, Howard K, McCauley I, Jackson P, Long K, Lopaticki S, Nugent EA, Simons J, Walker J, Hennessy D (2001) Vaccination of boars with a GnRH vaccine (Improvac) eliminates boar taint and increases growth performance. J Anim Sci 79**,** 2524-2535

Dunshea F, King R, Campbell R, Sainz R, Kim Y (1993) Interrelationships between sex and ractopamine on protein and lipid deposition in rapidly growing pigs. J Anim Sci 71**,** 2919-2930

Fabian J, Chiba LI, Frobish LT, McElhenney WH, Kuhlers DL, Nadarajah K (2004) Compensatory growth and nitrogen balance in grower-finisher pigs. J Anim Sci 82**,** 2579-2587

Farries FE, Oslage HJ (1961) Zur Technik langfristiger Stoffwechselversuche an wachsenden Schweinen. Zeitschrift für Tierphysiologie Tierernährung und Futtermittelkunde 16**,** 11-19

Fernández JA, Jørgensen H, Just A (1986) Comparative digestibility experiments with growing pigs and adult sows. Anim Sci 43**,** 127-132

Freire JPB, Guerreiro AJG, Cunha LF, Aumaitre A (2000) Effect of dietary fibre source on total tract digestibility, caecum volatile fatty acids and digestive transit time in the weaned piglet. Animal Feed Science and Technology 87**,** 71-83

Gatel F, Grosjean F (1992) Performance of pigs from two genotypes inrelation to the amino acid content of the diet. Livest Prod Sci 30**,** 129-140

GfE (2005a) Determination of digestibility as the basis for energy evaluation of feedstuffs for pigs. Pro. Soc. Nutr. Physiol. 14**,** 207-213

GfE (2005b) Standardised precaecal digestibility of amino acids in feedstuffs for pigs – methods and cocepts. Pro. Soc. Nutr. Physiol. 14**,** 185-205

GfE (2008) Recommendations for the supply of energy and nutrients to pigs. DLG Verlag, Frankfurt am Main, Germany

Gispert M, Angels Oliver M, Velarde A, Suarez P, Perez J, Font i Furnols M (2010) Carcass and meat quality characteristics of immunocastrated male, surgically castrated male, entire male and female pigs. Meat Sci 85**,** 664-670

Hoffmann M, Gebhardt G (1973) Stickstoffausscheidung von wachsendem Geflügel bei stickstofffreier Ernährung. Arch Anim Nutr 23**,** 273-289

Kass ML, Van Soest PJ, Pond WG, Lewis B, McDowell RE (1980) Utilization of Dietary Fiber from Alfalfa by Growing Swine. I. Apparent Digestibility of Diet Components in Specific Segments of the Gastrointestinal Tract. J Anim Sci 50**,** 175-191

Latorre MA, Lázaro R, Gracia MI, Nieto M, Mateos GG (2003) Effect of sex and terminal sire genotype on performance, carcass characteristics, and meat quality of pigs slaughtered at 117 kg body weight. Meat Sci 65**,** 1369-1377

Le Goff G, Noblet J (2001) Comparative total tract digestibility of dietary energy and nutrients in growing pigs and adult sows. J Anim Sci 79**,** 2418-2427

Lenis NP, van Diepen HT, Bikker P, Jongbloed AW, van der Meulen J (1999) Effect of the ratio between essential and nonessential amino acids in the diet on utilization of nitrogen and amino acids by growing pigs. J Anim Sci 77**,** 1777-1787

Longland AC, Carruthers J, Low AG (1994) The ability of piglets 4 to 8 weeks old to digest and perform on diets containing two contrasting sources of non-starch polysaccharide. Anim Sci 58**,** 405-410

Markert W, Kirchgessner M, Roth FX (1993) Bilanzstudien zur Reduzierung der N-Ausscheidung von Mastschweinen. J Anim Physiol an N 70**,** 159-171

McGloughlin P, Allen P, Tarrant PV, Joseph RL, Lynch PB, Hanrahan TJ (1988) Growth and carcass quality of crossbred pigs sired by Duroc, Landrace and Large White boars. Livest Prod Sci 18**,** 275-288

Morales J, Pérez JF, Baucells MD, Mourot J, Gasa J (2002) Comparative digestibility and lipogenic activity in Landrace and Iberian finishing pigs fed ad libitum corn- and corn–sorghum–acorn-based diets. Livest Prod Sci 77**,** 195-205

Morrison RS, Hemsworth PH, Cronin GM, Campbell RG (2003) The effect of restricting pen space and feeder availability on the behaviour and growth performance of entire male growing pigs in a deep-litter, large group housing system. Appl Anim Behav Sci 83**,** 163-176

O'Connell MK, Lynch PB, O'Doherty JV (2006) The effect of dietary lysine restriction during the grower phase and subsequent dietary lysine concentration during the realimentation phase on the performance, carcass characteristics and nitrogen balance of growing–finishing pigs. Livest Prod Sci 101**,** 169-179

Prunier A, Bonneau M, von Borell EH, Cinotti S, Gunn M, Fredriksen B, Giersing M, Morton DB, Tuyttens FAM, Velarde A (2006) A review of the welfare consequences of surgical castration in piglets and the evaluation of non-surgical methods. Anim Welfare 15**,** 277-289

Reynolds A, O'Doherty J (2006) The effect of amino acid restriction during the grower phase on compensatory growth, carcass composition and nitrogen utilisation in grower–finisher pigs. Livest Prod Sci 112-120

Van Lunen TA, Cole DJA (1996) The effect of lysine/digestible energy ratio on growth performance and nitrogen deposition of hybrid boars, gilts and castrated male pigs. Anim Sci 63**,** 465-475

VDLUFA (2007) (Verband Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten) Handbuch der Landwirtschaftlichen Versuchs- und Untersuchungsmethodik (VDLUFA-Methodenbuch), Band III. Die chemische Untersuchung von Futtermitteln. VDLUFA-Verlag, Darmstadt, Germany

Yen HT, Cole DJA, Lewis D (1986a) Amino acid requirements of growing pigs 8. The response of pigs from 50 to 90 kg live weight to dietary ideal protein. Anim Sci 43**,** 155-165

Yen HT, Cole DJA, Lewis D (1986b) Amino acid requirements of growing pigs. 7. The response of pigs from 25 to 55 kg live weight to dietary ideal protein. Anim Sci 43**,** 141-154

6. Paper III

Influence of dietary amino acids on chemical body composition and performance of growing-finishing boars of two sire lines

Caroline Otten [a], Andreas Berk [a*], Simone Müller [b], Manfred Weber [c], Sven Dänicke [a]

[a] Institute of Animal Nutrition, Friedrich-Loeffler-Institute (FLI),
Federal Research Institute for Animal Health, Braunschweig, Germany
[b] Thuringian State Institute for Agriculture, Regional Office Bad Salzungen,
Bad Salzungen, Germany
[c] State Institute for Agriculture, Forestry and Horticulture Saxony-Anhalt,
Centre for Livestock Husbandry and Equipment, Iden, Germany

Archives of Animal Nutrition
accepted

Abstract

There is only little information available concerning the chemical body composition of growing-finishing boars. For that reason, a total of 26 entire male pigs (boars) of two different Piétrain sire lines were fed with different levels of dietary essential amino acids (EAA) and the influence of this treatment on performance and chemical body composition was evaluated. In addition, an additional initial group of eight boars (n = 4 per sire line) was slaughtered at approximately 21 kg live weight (LW). The other 26 boars were fed three different diets containing 11.5, 13.2 and 14.9 g lysine/kg during the grower period and 9.0, 10.4, 11.7 g lysine/kg during the finisher period, respectively. Other EAA were added in relation to lysine (Lys : Met + Cys : Thr : Trp : Val = 1 : 0.60 : 0.65 : 0.18 : 0.75). At a LW of approximately 122 kg these 26 boars **(**six groups with three to seven animals each) were also slaughtered. The effects of EAA level and sire line on fattening and slaughter performance was recorded, and body and weight gain composition were analysed. There were no significant effects of EAA level on performance or on chemical body composition. Boars sired with Piétrain line 1 demonstrated increased lean meat content and protein body content ($p < 0.05$) as compared to Piétrain line 2 sired boars.

Keywords: amino acids; boar; sire line; chemical body composition

1. Introduction

Surgical castration of piglets is the most common practice to avoid boar taint in many countries. About 94 million male piglets are surgically castrated without anaesthesia in Europe each year (Fredriksen *et al.* 2009). Nonetheless, castration is known to hinder animal welfare and to produce pain and discomfort in piglets (Prunier *et al.* 2006). Hence, the fattening of boars might provide an economical and animal-welfare friendly alternative to avoid surgical castration. Entire male pigs (boars) had improved daily weight gain (Fuller *et al.* 1995, Otten *et al.* 2013a), a superior feed efficiency (Bonneau *et al.* 1994, Van Lunen and Cole 1996a, Otten *et al.* 2013a) and a higher lean meat content in the carcass than gilts or castrated males (Barton-Gade 1987, Andersson *et al.* 1997). It was found that boars require an increased level of protein and essential amino acids (EAA) in their diet compared to castrated male pigs in order to achieve maximum growth (Campbell *et al.* 1988).

Boars are generally considered to be leaner than gilts or castrated males (Yen *et al.* 1986b, Van Lunen and Cole 1996a, Bañón *et al.* 2004), although data on chemical body analysis of boars is scarce. There are indications that pigs of modern genotypes are much leaner than those of previous generations (Person *et al.* 2005).

Several authors have determined particular carcass and/or meat traits (Ellis *et al.* 1996, García-Macías *et al.* 1996, Latorre *et al.* 2004), or the body composition (Rinaldo and Le Dividich 1991, Wagner *et al.* 1999, Raj *et al.* 2010) of females or castrated male pigs of different ages, breeds or life weights. For example, Weis *et al.* (2004) observed increasing body lipid content of boars when energy intake level increased. However, only little information exists about the whole chemical body composition of modern genotype hybrid boars at the common German slaughter weights. Until recently, the fattening of boars was unusual in most European countries (EFSA 2004), and therefore boars were not a focus of general interest. Hence, it would be interesting to study the impact of dietary factors on the body composition of boars. Assuming that boars require a generally higher level of EAA, a special focus of the present experiment was on increasing levels of the most relevant EAA.

2. Material and Methods

The present study was part of a joint research project “Feeding of boars”, in which fundamentals of recommendations for boar nutrition are to be established in cooperation with several research institutes and economic partners (see acknowledgements). In the current study, one sub-project of the joint research project, namely the examination of the chemical body composition of boars, is presented.

2.1 Experimental design and diets

A total of 34 boars (8 piglets and 26 growing-finishing boars) from two different sire lines (Piétrain line 1 (Pi 1) and Piétrain line 2 (Pi 2)) crossed with commercial hybrid sows (Landrace x Large White/Yorkshire) were used in the current experiment. The Piétrain sires were pure-bred animals out of two German breeding associations which planned their breeding work independently of each other. They differ in their breeding focus (emphasis on lean meat content or muscle structure of the value-determining parts, stress stability and meat quality) and their genetic relationship.

The experimental animals were part of the first fattening experiment described by Otten *et al.* (2013b). Their growth performance data were included in the calculation of the results of the previous study, while the outcomes of the chemical body analysis are presented in the current experiment. The boars were housed in climate controlled buildings (on average 12 pigs per pen and 1.0 m^2 per pig) on fully slatted concrete floor. Demand feeding stations with a single animal detection via transponder (INSENTEC-station) were used for feed supply and registering the individual feed consumption, the pelleted feed and water was offered for consumption on an *ad libitum* basis. All pigs were the product of selective matings produced specifically for this project and were siblings or half siblings within their sire lines. A commercial breeder was commissioned with the production of all pigs used in the current and the above mentioned experiment according to the project specifications. The eight piglets of the initial group were slaughtered at 20.8 ± 1.4 kg (± standard deviation) live weight (LW) immediately after they were delivered from the breeder and used as an “initial value” in order to calculate the body gain composition of the “final” 26 boars. The other 26 pigs were fattened to a LW of 121.8 ± 3.1 kg together with the boars of the above mentioned fattening experiment at the pig performance test centre in Iden, Germany. They were randomly allotted within their sire lines to three isoenergetic diets (13.40 MJ ME) that differed in their EAA concentrations (Table 1).

Generally, the composition of the diets was based on the recommendation of the German Society of Nutrition Physiology for female pigs, with a very high protein accretion measured on the requirement of the precaecal digestible EAA per day (GfE 2008). On this occasion, the dietary EAA level of Diet 1 is oriented to the GfE recommendations and the levels of Diet 2 and 3 represent additional allowance thereof. The EAA were given as total values and precaecally digestible (pcd) EAA values in Table 1 but only the total values were determined analytically in this study. Other EAA were added in total relation to the commonly known as the first limiting AA lysine (lysine: methionine+cystine: threonine: tryptophan: valine = 1 : 0.60 : 0.65 : 0.18 : 0.75). The experimental period lasted from an average LW of 21 kg at a LW of on average 122 kg. The feeding regimen was a two phase feeding, with a group change from grower to finisher feed at an intended LW of 70 kg.

Table 1. Ingredients and chemical composition of the experimental diets

Diet	1		2		3	
	Grower	Finisher	Grower	Finisher	Grower	Finisher
Components [g/kg]						
Wheat	453	499	447	499	441	501
Barley	300	309	300	300	300	290
Soy bean meal	150	83	150	91	150	99
Rapeseed meal	45	80	45	80	45	80
Soy bean oil	20	-	20	-	20	-
Vegetable fatty acids	-	5.5	-	4.0		2.0
Mineral-Vitamin premix*	14.3	5.0	15.2	5.0	16.0	5.0
Natrium chloride	4.5	3.6	4.5	3.6	4.5	3.6
Calcium carbonate	4.0	10.5	5.0	10.5	6.0	10.0
Calcium phosphate	3.5	1.0	3.5	1.0	3.5	1.0
Lysine-HCl	3.40.34	3.0	5.1	4.5	6.8	5.9
DL-Methionine	0.90.09	-	1.9	0.5	3.0	0.8
L-Threonine	1.40.14	0.3	2.6	1.1	3.7	1.8
L-Tryptophane	-	-	0.2	-	0.5	-
Calculated composition						
ME [MJ/kg]†	13.40	13.00	13.40	13.00	13.40	13.00
Lysine [g/kg]	11.5	9.0	13.2	10.4	14.9	11.7
pcd Lysine [g/kg]‡	10.1	7.8	11.8	9.1	13.4	10.4
Analysed composition [g/kg]						
ME [MJ/kg]†	13.20	13.15	13.60	13.16	13.40	13.14
Dry matter [%]	88.0	88.1	88.5	88.0	88.0	88.1
Crude protein	169	168	180	172	180	174
Lysine	11.10	9.10	12.90	10.50	14.30	11.70
Crude fat	37.0	21.6	33.0	20.2	32.0	18.5
Crude fiber	44.0	38.3	34.0	37.3	38.0	37.0
Crude ash	48.0	47.4	47.0	47.3	46.0	47.9

Notes:

* Provided per kg grower (finisher) diet: vitamin A, 10 000 (8 000) IU; vitamin D_3, 1 250 (1 000) IU; vitamin E, 80 (80) mg; vitamin B_1, 1.3 (-) mg; vitamin B_2, 5.0 (2.0) mg; vitamin B_6, 2.5 (-) mg; vitamin B_{12}, 25 (15) µg; vitamin K_3, 1.1 (-) mg; nicotinic acid, 12.5 (5.0) mg; calcium pantothenate, 5.0 mg; (pantothenate, 5.0 mg); choline chloride, 125 mg; (choline, 50 mg); ferrous sulphate, 125 mg; (ferrous carbonate, 50 mg); copper sulphate, 15 (8) mg; (copper chelate, 3 mg); manganese oxide, 80 (60) mg; zinc oxide, 100 mg; (zinc sulphate, 50 mg); calcium iodate, 2 (0.6) mg; sodium selenite, 0.4 (0.4) mg; cobalt carbonate, 0.25 (0.5) mg; phytase, 500 (500) FTU

† Calculated on base of digestible (table values of the used compounds) crude nutrients (as analysed) according to the formula of the GfE (2008): ME [MJ] = 0.0205 •DCP [g] + 0.0398 • DCL [g] + 0.0173 • St [g] + 0.0160 • Su [g] + 0.0147 • (DOM – DCP – DCL – St – Su) [g] ; where: OM = organic matter, CP = crude protein, CL = crude fat, St = starch, Su = sugar and D = digestible

‡ pcd Lysine means precaecally digestible lysine; calculated on base of table values (GfE 2005)

2.2 Slaughter procedure

The pigs of the final groups were slaughtered in the facilities at the performance test centre in Iden, next to the animals' housing. The pigs were weighed and transported to the abattoir on the evening before the slaughter day and the feed was withheld overnight. Pigs were stunned electrically, hoisted by one hind leg and exsanguinated. Blood was collected quantitatively for each pig. The carcasses were scaled and mechanically dehaired, but the collection of hair and hooves was not possible for pigs slaughtered at 122 kg LW. Visceral organs, the emptied gastrointestinal tract and urinary bladder, the testicles as well as parts of the spinal cord and brain and any other trimmings were collected and weighed together with the blood. Emptying of the gastrointestinal tract and urinary bladder was carried out carefully by hand in order to prevent tissue loss. The carcasses, including the head, were split lengthwise into halves. Hot carcass weight was recorded, the right half was chilled and marketed and the left half was transported for manual dissection after overnight chilling in the experimental abattoir of the Institute of Animal Nutrition, Friedrich-Loeffler-Institute (FLI), Federal Research Institute for Animal Health, Braunschweig.

In general, chemical composition of the two halves was assumed to be similar. For this reason only one half of the carcass was further processed for chemical analysis. The whole body was separated into three fractions: offal (visceral organs, blood and empty gastrointestinal tract), soft tissue of the left half (meat, fat, soft bones and rind), and bones for pigs killed at 122 kg LW. For pigs killed at 21 kg LW (initial group), the whole body was used and separated into two fractions: offal and soft tissue; here bones and hooves were included in the soft tissue because the pigs were not used for food purposes and therefore not scaled and dehaired.

Offal and soft tissue was ground to a fine paste with a commercial meat cutter, mixed and one representative sample per fraction was taken for chemical analysis. The samples were freeze dried, mixed and homogenised again with a meat cutter before being analysed. Bones were deep frozen and milled in a frozen state using a bone mill. Also one representative sample was taken, freeze dried, mixed and homogenised using a meat cutter for chemical analysis. A similar procedure was adopted for pigs killed with 21 kg LW, with the exception that soft tissue and bones were not separated and therefore mixed and analysed together.

2.3 Analysis

Samples of each diet were collected and analysed for dry matter and proximate constituents. The grower diets were analysed according to the methods of the VDLUFA (2007) and the finisher diets by NIRS (near-infrared spectrometry) in the feed manufacturers own feedstuff laboratory (calibrated by chemical analysis in several accredited laboratories). The analysis methods depended on the respective feed manufacture, the usage of the feed analysis data of the manufacturers was determined by the project partners in order to ensure that all partners refer in further publications to equivalent analysis data. To guarantee a comparability of the analysis results of both methods, parallel analysis of selected samples was performed regularly and any detected deviations were within the analytical tolerances. Collected samples of offal, soft tissue, bones were analysed for crude protein, crude fat and crude ash according to the methods of VDLUFA (2007). The water content of the empty body was determined as difference. The EAA content of the diets, with the exception of tryptophan, was analysed by ion exchange chromatography using an Amino Acid Analyser (Biochrom Ltd., Cambridge, UK) according to Method Number 4.11.1 of (VDLUFA 2007). Tryptophan was determined by HPLC with fluorescence detection (Anonymous 2000) according to Method Number 4.11.2 of (VDLUFA 2007).

2.4 Calculation and statistics

Live weight gain (LWG) was calculated as the difference between LW at the end of the growth period minus LW at the start of the growth period divided by days of the experimental period. Feed intake was weighted individually for each boar by transponder-mediated identification at the respective feeding station. Feed to gain ratio (FGR) rate was obtained as feed intake divided by gain. Dressing percentage was calculated by dividing the warm carcass weight of the boars by their LW. The lean meat percentage was calculated with a regression equation for lean meat content [%] estimation called the “Bonner Formula” (Anonymous 2004). The “Bonner Formula” presented a regression equation taking into account meat and fat area at the muscle *longissimus dors*i at the 13./14. rib and backfat at loin, middle and withers as well as thickness of side fat and fat above the back muscle area.

The whole body gains of protein, fat, ash and water were calculated by deducting the initial (21 kg LW) from the corresponding final (122 kg LW) body content of the boars. Four boars of each sire line were used for the determination of the initial chemical body composition. There was no significant difference between the initial chemical body compositions of the

boars of the two sire lines. Therefore, mean values of all the eight piglets were used as initial values. Empty body weight (EBW) was defined as LW minus gastrointestinal and urinary bladder content, empty body weight gain (EBWG) was calculated as difference between the final EBW of each individual boar and the initial EBW, calculated from the initial LW of every individual boar and the mean values of the initial group of protein, fat and ash per kg LW. The analysed values for crude protein, crude fat and crude ash were corrected to 100% of dry matter content. In addition, the final total content of crude protein, crude fat and crude ash of each animal slaughtered at 122 kg LW was added with 155 g crude protein, 33 g crude fat and 9 g crude ash (personal communication from Berk and Schulz, unreferenced) in order to take into account the undetermined composition of hair and hooves.
The experimental data was analysed by using the PROC MIXED procedure of SAS (9.2). The effects of diet and sire line and their interactions were included in the model as fixed factors. The least square means, their pooled standard errors, levels of significance for main effects and the associated interaction were determined. p-values < 0.05 were considered to be significant and p-values < 0.1 were regarded as tendency for a significant difference.

3. Results

Least square mean fattening and slaughter performance as well as EAA and ME intake of the boars is given in Table 2. Fattening and slaughter performance of boars was unaffected by dietary EAA level. The intake of EAA increased in parallel to their increasing content of the diet. Lysine, methionine + cystine and threonine showed a significant increase ($p < 0.01$) and tryptophan a tendency for a significant increase. The ME intake remains nearly constant within the diet groups. There were no significant differences between the sire lines in all measured fattening and slaughter performance parameters, except for lean meat content. Regarding slaughter performance, Pi 1 sired boars presented significantly ($p < 0.05$) leaner carcasses (61.0%) than Pi 2 crossbreed boars (59.3%). The sire line had no effect on the intake of EAA and ME. In addition, a significant interaction between diet x sire line ($p < 0.05$) could be measured for dressing percentage. The other examined parameters showed no significant interactions between diet x sire line.

Table 2. Fattening and slaughter performance and AA and energy intake of final hybrid boars; n = 3-7‡; approximately 21-122 kg LW; Least square means (LSM) and Pooled standard error of means (PSEM)

	Diet	Sire line Pi 1	Pi 2	Mean	PSEM	*p*-Value Diet	Sire line	Diet x Sire line
LWG [g/d]*								
	1	856	890	873	40	0.356	0.647	0.863
	2	907	927	917				
	3	935	927	931				
	Mean	899	915					
Feed intake [kg/d]								
	1	2.04	2.26	2.15	0.12	0.865	0.359	0.594
	2	2.13	2.22	2.18				
	3	2.24	2.20	2.22				
	Mean	2.14	2.23					
FGR [kg/kg]†								
	1	2.38	2.53	2.46	0.08	0.514	0.353	0.568
	2	2.36	2.40	2.38				
	3	2.39	2.38	2.38				
	Mean	2.38	2.44					
Dressing percentage [%]								
	1	78.1	79.6	78.8	0.6	0.152	0.201	0.026
	2	78.4	77.0	77.7				
	3	79.7	77.7	78.7				
	Mean	78.7	78.1					
Lean meat content “Bonner Formula” [%]								
	1	61.9	58.1	60.0	1.0	0.859	0.040	0.090
	2	61.2	58.9	60.0				
	3	60.1	60.9	60.5				
	Mean	61.0[a]	59.3[b]					
Lysine intake [g/d]								
	1	20.0	22.2	21.1[a]	1.4	<0.001	0.373	0.690
	2	24.2	25.3	24.7[b]				
	3	28.1	27.9	28.0[b]				
	Mean	24.1	25.1					
Methionine + Cystine intake [g/d]								
	1	12.5	13.8	13.1[a]	0.8	<0.01	0.375	0.651
	2	14.3	14.9	14.6[ab]				
	3	16.7	16.5	16.6[b]				
	Mean	14.5	15.1					
Threonine intake [g/d]								
	1	13.0	14.5	13.7[a]	0.9	<0.001	0.395	0.685
	2	15.9	16.6	16.2[b]				
	3	18.7	18.5	18.6[c]				
	Mean	15.9	16.5					
Tryptophan intake [g/d]								
	1	4.34	4.81	4.58	0.26	0.087	0.308	0.633
	2	4.68	4.91	4.79				
	3	5.20	5.17	5.19				
	Mean	4.74	4.96					
ME intake [MJ/d]								
	1	26.7	29.7	28.2	1.5	0.804	0.246	0.628
	2	28.1	29.5	28.8				
	3	29.2	29.2	29.2				
	Mean	28.0	29.5					

Notes: *LWG, Live weight gain; †FGR, Feed to gain ratio
‡ Sire line Pi 1, Diet 1,2,3: n = 5,7,3; Sire line Pi 2, Diet 1,2,3: n = 3,3,5

In general, the sum of chemical body constituents (protein, lipid, ash and water) amounted to 98.0 ± 0.5% of EBW for initial chemical body composition respectively 98.6 ± 0.5% of EBW for final body composition, before correction mentioned in *2.4 Calculation and statistics* was done. The mentioned recovery rate values confirmed the adequacy of sampling and analytical procedures. Initial and final chemical body compositions are shown in Table 3. Chemical body composition of the initial boars was unaffected by sire line. In addition, the influence of dietary EAA level and sire line on average chemical body composition at the time of slaughter was shown.

Table 3. Initial and final chemical body composition [g/kg EBW] of hybrid boars; average EBW initial: 20.2 ± 1.5 kg, n = 4; average EBW final: 113.7 ± 2.7 kg, n = 3-7*; Least square means (LSM) and Pooled standard error of means (PSEM)

[g/kg EBW]	Slaughter time	Diet	Sire line Pi 1	Pi 2	Mean	PSEM	*p*-Value Diet	Sire line	Diet x Sire line
Protein									
	Initial		165	163	164	2		0.527	
	Final	1	181	169	175	4	0.774	0.044	0.169
	Final	2	180	169	174				
	Final	3	176	178	177				
		Mean	179[a]	172[b]					
Fat									
	Initial		85.7	84.1	84.9	3.1		0.728	
	Final	1	151	192	171	14	0.817	0.052	0.121
	Final	2	149	187	168				
	Final	3	168	157	162				
		Mean	156	178					
Ash									
	Initial		31.5	33.3	32.4	0.6		0.085	
	Final	1	30.4	28.9	29.7	0.7	0.445	0.126	0.056
	Final	2	30.0	27.8	28.9				
	Final	3	29.1	30.2	29.6				
		Mean	29.8	29.0					
Water									
	Initial		718	719	718	3		0.728	
	Final	1	638	610	624	11	0.812	0.107	0.216
	Final	2	642	616	629				
	Final	3	627	635	631				
		Mean	635	620					

Notes: *Sire line Pi 1, Diet 1,2,3: n = 5,7,3; Sire line Pi 2, Diet 1,2,3: n = 3,3,5

Table 4. Chemical composition of empty body weight gain [g/kg EBWG] of final hybrid boars; n = 3-7*; average EBW: 113.7 ± 2.7 kg; Least square means (LSM) and Pooled standard error of means (PSEM)

[g/kg EBWG]	Diet	Sire line Pi 1	Pi 2	Mean	PSEM	*p*-Value Diet	Sire line	Diet x Sire line
Protein								
	1	185	170	177	5	0.774	0.044	0.172
	2	183	170	176				
	3	178	181	180				
	Mean	182[a]	174[b]					
Fat								
	1	165	212	189	16	0.885	0.058	0.158
	2	164	208	186				
	3	186	175	180				
	Mean	172	198					
Ash								
	1	29.9	28.1	29.0	0.8	0.445	0.141	0.070
	2	29.4	26.7	28.0				
	3	28.3	29.5	28.9				
	Mean	29.2	28.1					
Water								
	1	620	590	605	13	0.897	0.127	0.295
	2	624	596	610				
	3	607	615	611				
	Mean	617	600					

Notes: *Sire line Pi 1, Diet 1,2,3: n = 5,7,3; Sire line Pi 2, Diet 1,2,3: n = 3,3,5

The outcomes for mean chemical composition of empty body weight gain (EBWG) influenced by dietary EAA level and sire line is given in g per kg EBWG in (Table 4) and in g EBWG per d in (Table 5). Again, the composition of body weight gain is unaffected by dietary EAA level. Similar to body composition, the composition of EBWG in g per kg EBWG (Table 4) was affected by sire line. Pi 1 crosses demonstrated 4.4% higher protein gain than Pi 2 progenies ($p < 0.05$). The tendency towards a higher fat content of Pi 2 crossbreeds continued with regard to the composition of EBWG. Similar to the above mentioned results, the composition of EBWG in g per d is also unaffected by diet. Contrary to the composition of the empty body and the EBWG [g/kg] the sire line had no significant effect on the composition of EBWG [g/d]. However, there is a tendency that Pi 1 crossbreeds seem to contain less fat than Pi 2 crosses, which was in accordance with the results of the empty body and the EBWG [g/kg]. In general, no interactions between diet x sire line could be observed for either empty body composition or for the composition of EBWG in [g/kg] and [g/d].

Table 5. Chemical composition of empty body weight gain [g EBWG/d] of final hybrid boars; n = 3-7*; average EBW: 113.7 ± 2.7 kg; Least square means (LSM) and Pooled standard error of means (PSEM)

[g/d]	Diet	Sire line Pi 1	Pi 2	Mean	PSEM	*p*-Value Diet	Sire line	Diet x Sire line
Protein								
	1	146	144	145	6	0.236	0.361	0.836
	2	153	145	149				
	3	157	154	155				
	Mean	152	147					
Fat								
	1	130	181	155	17	0.989	0.080	0.149
	2	138	178	158				
	3	164	150	157				
	Mean	144	169					
Ash								
	1	23.5	23.8	23.7	1.4	0.520	0.781	0.669
	2	24.6	22.8	23.7				
	3	24.9	25.4	25.2				
	Mean	24.3	24.0					
Water								
	1	701	652	676	20	0.801	0.226	0.275
	2	684	655	670				
	3	654	671	663				
	Mean	680	659					

Notes: *Sire line Pi 1, Diet 1,2,3: n = 5,7,3; Sire line Pi 2, Diet 1,2,3: n = 3,3,5

4. Discussion

The aim of the current study was to determine the chemical whole body composition and performance of modern hybrid boars of two sire lines and to work out whether these are influenced by the EAA level of the diet. Contrary to the expectations, dietary EAA level showed no significant effect on fattening and slaughter performance in the present study.

In contrast to these examinations, other authors described increased LWG if the protein content (and therewith the EAA level) of the diet was increased (Fuller *et al.* 1995, Quiniou *et al.* 1995). De la Llata *et al.* (2007) and Zhang *et al.* (2011) also observed improved performance if the lysine-to-energy ratio was increased from 3.31 till 3.61 g lysine/Mcal ME depending on the body weight and sex respectively from 0.89 till 1.03 g standardised ileal digestible lysine per MJ NE. Van Lunen and Cole (1996a), on the other hand, mentioned that increasing the EAA content of the diet led to a significant improvement of daily gain at first, but only up to a lysine content of the diet between 11.8 and 15.0 g/kg. Any increase above 15.0 g lysine per kg diet implicated no further performance improvement, which was consistent with the current results. The furthermore noticeable interaction between diet and sire line for dressing percentage in the present study was assumed to be conditioned multifactorially by different aspects of the slaughter procedure and therefore will not be explained in more detail. The significant differences between the diet groups concerning the intake of EAA was caused by the deliberately different concentrations of the EAA levels in the diets according to the experimental design. Moreover, the ME intake was unaffected by the diet, caused likewise by the experimental design.

The chemical body composition of boars and, as a result, the composition of EBWG in [g/kg] and in [g/d] were also unaffected by dietary EAA level in the present study. Contrary to these results Rao and McCracken (1990) and Quiniou *et al.* (1995) found that the composition of body weight gain could be modified though the composition of the diet. Campbell and Dunkin (1983) and Martínez-Ramírez *et al.* (2008) examined the potential for compensatory growth of boars due to a temporary restriction of protein (from 1.8 till 15 kg LW) or AA (from 15 till 38 kg LW) in the diet. Both authors reported a definite undersupply of protein/AA induced changes in body composition, in particular the body fat content increased. The authors also stated that the restrictively fed pigs are able to achieve the same body composition at slaughter time when switching to a well balanced diet afterwards. Nevertheless, the mentioned studies employed an EAA concentration which caused a deficiency and in turn lead to significantly improved performance if the EAA level was increased again. In contrast, in the current study, no explicit EAA deficiency was induced; this could be one reason for the lack of significant differences in the present study. Friesen *et al.* (1994) and O'Connell *et al.* (2006) determined that increasing the EAA level above the optimum (0.94 % digestible lysine respectively 9.7 g lysine per kg diet) had a depressive effect on LWG. Both authors were able to modify the body composition by increasing the lysine concentration, but as with LWG it was not possible to increase the protein accretion or the lean meat content continuously. Beyond the maximum the protein accretion and the lean content plateaued or even decreased.

In relation to the requirement and utilisation of EAA, it was interesting to note that although the intake of the EAA was significantly different between the diet groups in accordance with the experimental design, the deposition of protein did not differ between the diet groups. On average the intake of pcd lysine was 18.08 g/d (Diet 1), 21.67 g/d (Diet 2) and 25.03 g/d (Diet 3) on average over all boars. In case of a mean lysine concentration of 7.2 g pcd lysine per 100 g protein deposition (GfE 2008) a utilisation of 57.7% (Diet 1), 49.5% (Diet 2), 44.6% (Diet 3) was calculated for the mean protein gain of the boars receiving Diet 1 to 3 (Table 5), respectively. These values were all smaller than the utilisation of 63% stated by the (GfE

2008). Hence, it may be concluded that the boars consuming Diet 1 were adequately supplied with EAA, or in other words that the boars consumed Diet 2 and 3 were fed above the requirements.

The performance results of the boars used in the present study for chemical body analysis were also exploited in a fattening experiment as part of the joint research project “Feeding of Boars” described by Otten *et al.* (2013b). Hence, it was anticipated that the animal performance data of both experiments is comparable. This holds true, although the sample number of the chemical body analysis experiment is much smaller than that of the fattening experiment. Therefore, it would seem that the chosen EAA levels were not diverse enough, and especially the EAA level of Diet 1 was not low enough, to show significant differences in fattening and slaughter performance between the pigs on the different diets. This presumption was in accordance with the suggestion of Otten *et al.* (2013b). Furthermore, the results of the present study were in accordance with McCracken *et al.* (1997) who also found no effect of lysine and concluded that if dietary EAA level did not affect body composition or gain, the given values are adequate for pigs at present.

Commonly, breeding progress had made decisive changes in the chemical body composition of pigs. The potential of fat deposition was decreased and protein deposition was increased after decades of selection (Roehe *et al.* 2003). The selection of modern genotype pigs for leaner carcasses has led to a decrease in total carcass fat (Cliplef and McKay 1993).
Several factors like sex (Fàbrega *et al.* 2010) or genotype (Campbell *et al.* 1988) are known to influence the chemical body composition of pigs. In general, boars are leaner than sows, which in turn are leaner than castrated males (Campbell *et al.* 1989, Fuller *et al.* 1995, Gispert *et al.* 2010). The boars of the current study contained on average 177 ± 8.2 g protein/kg EBW and 162 ± 28.8 g fat/kg EBW and were in good accordance with the findings of Weis *et al.* (2004) and Martínez-Ramírez *et al.* (2008). The relatively large variation in fat deposition compared to protein deposition was mentioned by several authors (Bikker *et al.* 1994, Friesen *et al.* 1994, Wagner *et al.* 1999, Gómez *et al.* 2002), which was in accordance with the results of the present study. The lean tissue content is generally estimated from physical measures of body fatness and was inversely related to fat content. Rook *et al.* (1987) and De Lange *et al.* (2003) stated that body fatness is more variable than lean content.
In fact, the chemical body composition of boars in the current study differs from the composition of females with 16.9% protein and 18.2% fat or castrated males with

16.1% protein and 21.8% fat of the carcass described by Fàbrega *et al.* (2010). The body composition changed in comparison with former boar body composition data, especially the lower fat level in the current data was striking. Campbell and Taverner (1988) reported a body fat content of 260 g/kg and 366 g/kg for boars of different strains, respectively. Moreover, Campbell *et al.* (1989) found 23.4% fat in the empty whole body of boars. In contrast Martínez-Ramírez *et al.* (2008) recovered about 18.6% fat in the empty body of boars, which agreed more consistently with the present results.

Apart from this it must be underlined that only a limited number of boars were analysed in the current study. Hence further research with larger numbers of boars is necessary in order to determine generally valid results concerning the effects of dietary EAA level on the chemical body composition of boars. In the present study, the type of sire line influenced parameters of performance, body composition and, consequently, the composition of body weight gain. Differences between sire lines in performance and body compositions were mentioned by García-Macías *et al.* (1996), Wagner *et al.* (1999) and Bertol *et al.* (2013). None of the measured performance parameters were affected by sire line in the present study, except lean meat content ($p < 0.05$). A higher lean meat content was observed for the progenies of Pi 1 boars than of Pi 2 boars. In contrast, Morales *et al.* (2011) observed no sire line genotype difference concerning carcass lean percentage of two different Large White sire lines. This statement leads to the presumption that the Piétrain sire lines used in the current study differ among each other to a larger extent than the mentioned Large White sire lines. Nevertheless, Fuller *et al.* (1995) concluded that pigs with different genetic backgrounds may differ in their lean growth potential, which was in good accordance with the findings of the present study.

Relating to the body composition and gain, Pi 2 sired progenies demonstrated lower average values for protein in the empty body ($p < 0.05$) and in the composition of the EBWG ($p < 0.05$) (172 g/kg EBW (Pi 2) respectively 174 g/kg EBWG (Pi 2) instead of 179 g/kg EBW (Pi 1) respectively 182 g/kg EBWG (Pi1)) than Pi 1 crossbreeds in the present study. Furthermore, there is a tendency for a lower fat content of Pi 1 boars than Pi 2 boars regarding the composition of the empty body and the EBWG in [g/kg] and in [g/d] confirm the assumption that Pi 1 progenies are leaner than Pi 2 progenies. Similarly to the current findings, Campbell and Taverner (1988) outlined that protein deposition is affected by genotype as well as by sex. Roehe *et al.* (2003) also reported that protein and lipid deposition rates are influenced by the genetic level.

5. Conclusion

The results of the present investigation clearly indicated that the chemical body composition and performance of boars was unaffected by the used dietary EAA levels. Hence, the EAA concentration used in Diet 1 appeared to be sufficient to exploit the full genetic potential of hybrid boars concerning body composition and performance. Furthermore, the type of sire line (within two different Piétrain sire lines) affected the chemical body composition and performance as well. Sire line significantly influenced the lean meat content, the protein deposition and showed a tendency for a significant effect on fat deposition. Nonetheless, it must be emphasized that these findings are based on a limited number of animals and further research is needed to manifest the results.

Acknowledgements

The authors gratefully acknowledge the partners of the joint research project “Feeding of boars” (Friedrich-Loeffler-Institute (FLI), Federal Research Institute for Animal Health, Braunschweig; State Office for Rural Development, Agriculture and Land Reallocation Brandenburg, Teltow/Ruhlsdorf; State Institute for Agriculture, Forestry and Horticulture Saxony-Anhalt, Centre for Livestock Husbandry and Equipment, Iden; Thuringian State Institute for Agriculture, Regional Office Bad Salzungen, Bad Salzungen; University of Rostock, Faculty of Agriculture and Environmental Science, Chair for Nutrition Physiology and Animal Nutrition, Rostock; Hauptgenossenschaft Nord AG, Kiel; Deutsche Vilomix Tierernährung GmbH, Neuenkirchen-Vörden; Institute of Agriculture and Fishery Mecklenburg-Vorpommern, Institute for Animal Production, Dummerstorf; Evonik Industries AG, Hanau-Wolfgang; Deutsche Tiernahrung Cremer GmbH & Co. KG, Düsseldorf; Martin-Luther-University Halle-Wittenberg, Faculty of Natural Science III, Institute of Agriculture and Nutritional Science, Chair for Animal Nutrition, Halle (Saale)). In addition, the authors would like to thank the co-workers of the Institute of Animal Nutrition of the Friedrich-Loeffler-Institute (FLI) in Braunschweig and the co-workers of the performance test centre in Iden for assistance in performing the experiment and the analysis.

Funding

This study was part of the joint research project “Feeding of boars” and was financially supported by the innovation program of the Federal Ministry of Food, Agriculture and Consumer Protection (Support Code 2813802610).

References

Andersson K, Schaub A, Andersson K, Lundstrijm K, Thomke S, Hansson I. 1997. The effects of feeding system, lysine level and gilt contact on performance, skatole levels and economy of entire male pigs. Livest Prod Sci. 51: 131-140.

Anonymous 2000. Establishing community methods for the determination of vitamin A, vitamin E and tryptophan, annex part C. Determination of Tryptophan. Official Journal of the European Communities. L174: 45-50.

Anonymous. 2004. Richtlinie für die Stationsprüfung auf Mastleistung, Schlachtkörperwert und Fleischbeschaffenheit beim Schwein [Online]. Available: www.zds-bonn.de/services/files/pdf/rlnkp04geaendert0704.pdf [retrieved May 28, 2013]

Bañón S, Andreu C, Laencina J, Garrido Ma-D. 2004. Fresh and eating pork quality from entire versus castrate heavy males. Food Qual Prefer 15: 293-300.

Barton-Gade PA. 1987. Meat and fat quality in boars, castrates and gilts. Livest Prod Sci. 16: 187-196.

Bertol TM, Campos RMLd, Ludke JV, Terra NN, Figueiredo EAPd, Coldebella A, Santos Filho JId, Kawski VL, Lehr NM. 2013. Effects of genotype and dietary oil supplementation on performance, carcass traits, pork quality and fatty acid composition of backfat and intramuscular fat. Meat Sci. 93: 507-516.

Bikker P, Verstegen MW, Campbell RG, Kemp B. 1994. Digestible lysine requirement of gilts with high genetic potential for lean gain, in relation to the level of energy intake. J Anim Sci. 72: 1744-1753.

Bonneau M, Dufour R, Chouvet C, Roulet C, Meadus W, Squires E. 1994. The effects of immunization against luteinizing hormone-releasing hormone on performance, sexual development, and levels of boar taint-related compounds in intact male pigs. J Anim Sci. 72: 14-20.

Campbell R, Taverner M, Curic D. 1988. The effect of sex and live weight on growing pig`s response to dietary protein. Anim Prod. 46: 123-130.

Campbell RG, Dunkin AC. 1983. The influence of protein nutrition in early life on growth and development of the pig. 1. Effects on growth performance and body composition. Brit J Nutr 50: 605-617.

Campbell RG, Steele NC, Caperna TJ, McMurtry JP, Solomon MB, Mitchell AD. 1989. Interrelationships Between Sex and Exogenous Growth Hormone Administration on Performance, Body Composition and Protein and Fat Accretion of Growing Pigs. J Anim Sci. 67: 177-186.

Campbell RG, Taverner MR. 1988. Genotype and sex effects on the relationship between energy intake and protein deposition in growing pigs. J Anim Sci. 66: 676-686.

Cliplef RL, McKay RM. 1993. Carcass quality characteristics of swine selected for reduced backfat thickness and increased growth rate. Can J Anim Sci. 73: 483-494.

De la Llata M, Dritz SS, Tokach MD, Goodband RD, Nelssen JL. 2007. Effects of increasing lysine to calorie ratio and added fat for growing-finishing pigs reared in a commercial environment: I. Growth performance and carcass characteristics. Prof Anim Sci. 23: 417-428.

De Lange CFM, Morel PCH, Birkett SH. 2003. Modeling chemical and physical body composition of the growing pig. J Anim Sci. 81: E159-E165.

EFSA. 2004. Welfare aspects of the castration of piglets. The EFSA Journal. 1-18.

Ellis M, Webb AJ, Avery PJ, Brown I. 1996. The influence of terminal sire genotype, sex, slaughter weight, feeding regime and slaughter-house on growth performance and carcass and meat quality in pigs and on the organoleptic properties of fresh pork. Anim Sci. 62: 521-530.

Fàbrega E, Velarde A, J. Cros MG, P. Suárez, J. Tibau, J. Soler. 2010. Effect of vaccination against gonadotrophin-releasing hormone, using Improvac®, on growth performance, body composition, behaviour and acute phase proteins. Livest Prod Sci. 132: 53-59.

Fredriksen B, Font i Furnols M, Lundström K, Migdal W, Prunier A, Tuyttens FAM, Bonneau M. 2009. Practice on castration of piglets in Europe. Animal. 3: 1480-1487.

Friesen KG, Nelssen JL, Goodband RD, Tokach MD, Unruh JA, Kropf DH, Kerr BJ. 1994. Influence of dietary lysine on growth and carcass composition of high-lean-growth gilts fed from 34 to 72 kilograms. J Anim Sci. 72: 1761-1770.

Fuller MF, Franklin MF, McWilliam R, Pennie K. 1995. The responses of growing pigs, of different sex and genotype, to dietary energy and protein. J Anim Sci. 60: 291-298.

García-Macías JA, Gispert M, Oliver MA, Diestre A, Alonso P, Muñoz-Luna A, Siggens K, Cuthbert-Heavens D. 1996. The effects of cross, slaughter weight and halothane genotype on leanness and meat and fat quality in pig carcasses. Anim Sci. 63: 487-496.

GfE. 2005. Standardised precaecal digestibility of amino acids in feedstuffs for pigs – methods and cocepts. Pro. Soc. Nutr. Physiol. 14: 185-205.

GfE. 2008. Recommendations for the supply of energy and nutrients to pigs. DLG Verlag, Frankfurt am Main, Germany

Gispert M, Angels Oliver M, Velarde A, Suarez P, Perez J, Font i Furnols M. 2010. Carcass and meat quality characteristics of immunocastrated male, surgically castrated male, entire male and female pigs. Meat Sci. 85: 664-670.

Gómez RS, Lewis AJ, Miller PS, Chen HY, Diedrichsen RM. 2002. Body composition and tissue accretion rates of barrows fed corn-soybean meal diets or low-protein, amino acid-supplemented diets at different feeding levels. J Anim Sci. 80: 654-662.

Latorre MA, Lázaro R, Valencia DG, Medel P, Mateos GG. 2004. The effects of gender and slaughter weight on the growth performance, carcass traits, and meat quality characteristics of heavy pigs. J Anim Sci. 82: 526-533.

Martínez-Ramírez HR, Jeaurond EA, de Lange CFM. 2008. Dynamics of body protein deposition and changes in body composition after sudden changes in amino acid intake: II. Entire male pigs. J Anim Sci. 86: 2168-2179.

McCracken K, Beattie VE, Weatherup RN, McIlroy SG, Henry RW. Effects of diet energy density and protein (amino acid) content on intake, body composition and energy metabolism of boars and gilts fed *ad libitum* from 22 to 46 kg. *In:* McCracken KJ, Unsworth E. F., Wylie A. R. G., eds. Symposium of Energy Metabolism, 1997 Newcastle, Northern Ireland. CAB International, 237-240.

Morales JI, Cámara L, Berrocoso JD, López JP, Mateos GG, Serrano MP. 2011. Influence of sex and castration on growth performance and carcass quality of crossbred pigs from 2 Large White sire lines. J Anim Sci. 89: 3481-3489.

O'Connell MK, Lynch PB, O'Doherty JV. 2006. Determination of the optimum dietary lysine concentration for boars and gilts penned in pairs and in groups in the weight range 60 to 100 kg. Anim Sci. 82: 65-73.

Otten C, Berk A, Dänicke S. 2013a. Voluntary feed intake and growth performance of boars and barrows in dependence on lysine-to-energy ratio. Arch Tierz. 56: 39.

Otten C, Berk A, Hagemann L, Müller S, Weber M, Dänicke S. 2013b. Effect of varying supply of amino acids on nitrogen retention and growth performance of boars of different sire lines. Arch Tierz. 56: 75.

Person RC, McKenna DR, Griffin DB, McKeith FK, Scanga JA, Belk KE, Smith GC, Savell JW. 2005. Benchmarking value in the pork supply chain: Processing characteristics and consumer evaluations of pork bellies of different thicknesses when manufactured into bacon. Meat Sci. 70: 121-131.

Prunier A, Bonneau M, von Borell EH, Cinotti S, Gunn M, Fredriksen B, Giersing M, Morton DB, Tuyttens FAM, Velarde A. 2006. A review of the welfare consequences of surgical castration in piglets and the evaluation of non-surgical methods. Anim Welfare. 15: 277-289.

Quiniou N, Dubois S, Noblet J. 1995. Effect of dietary crude protein level on protein and energy balances in growing pigs: comparison of two measurement methods. Livest Prod Sci. 41: 51-61.

Raj S, Skiba G, Weremko D, Fandrejewski H, Migdał W, Borowiec F, Poławska E. 2010. The relationship between the chemical composition of the carcass and the fatty acid composition of intramuscular fat and backfat of several pig breeds slaughtered at different weights. Meat Sci. 86: 324-330.

Rao D, McCracken K. 1990. Protein requirement of boars of high genetic potential for lean growth. Anim Prod. 51: 179-187.

Rinaldo D, Le Dividich J. 1991. Assessment of optimal temperature for performance and chemical body composition of growing pigs. Livest Prod Sci. 29: 61-75.

Roehe R, Plastow GS, Knap PW. 2003. Quantitative and molecular genetic determination of protein and fat deposition. HOMO - Journal of Comparative Human Biology. 54: 119-131.

Rook AJ, Ellis M, Whittemore CT, Phillips P. 1987. Relationships between whole-body chemical composition, physically dissected carcass parts and backfat measurements in pigs. Anim Sci. 44: 263-273.

Van Lunen TA, Cole DJA. 1996. The effect of lysine/digestible energy ratio on growth performance and nitrogen deposition of hybrid boars, gilts and castrated male pigs. Anim Sci. 63: 465-475.

VDLUFA. 2007. (Verband Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten) Handbuch der Landwirtschaftlichen Versuchs- und Untersuchungsmethodik (VDLUFA-Methodenbuch), Band III. Die chemische Untersuchung von Futtermitteln. VDLUFA-Verlag, Darmstadt, Germany

Wagner JR, Schinckel AP, Chen W, Forrest JC, Coe BL. 1999. Analysis of body composition changes of swine during growth and development. J Anim Sci. 77: 1442-1466.

Weis RN, Birkett SH, Morel PCH, de Lange CFM. 2004. Effects of energy intake and body weight on physical and chemical body composition in growing entire male pigs. J Anim Sci. 82: 109-121.

Yen HT, Cole DJA, Lewis D. 1986. Amino acid requirements of growing pigs. 8. The response of pigs from 50 to 90 kg live weight to dietary ideal protein. Anim Sci. 43: 155-165.

Zhang G, Yi X, Chu L, Lu N, Htoo J, Qiao S. 2011. Effects of dietary net energy density and standardized ileal digestible lysine: Net energy ratio on the performance and carcass characteristic of growing-finishing pigs fed low crude protein supplemented with crystalline amino acids diets. Agric Sci China. 10: 602-610.

7. General discussion

The present study aimed at examining the effects of dietary AA and energy levels on the voluntary feed intake, the growth performance, and the nitrogen retention as well as on the chemical body composition of growing-finishing boars of different sire lines. Moreover, concerning the aspect of voluntary feed intake and growth performance a comparison between boars and barrows under the influence of different lysine-to-energy ratios was carried out (**Paper I**).

The influence of the AA supply on the nitrogen retention and performance of boars was further examined (**Paper II**) and the relationship between dietary AA levels and the chemical body composition of boars were considered in more detail (**Paper III**). Finally, the consequences of the current study on derivation of nutrition recommendations of growing-finishing boars are discussed.

7.1 Amino acid- and energy levels in diets for boars

7.1.1 Effects on performance: Voluntary feed intake and growth performance

The voluntary feed intake of pigs is known to be influenced by numerous factors. The most frequently named aspects are sex, age and diet composition (Henry 1985, Fuller *et al.* 1995, Quiniou *et al.* 2000). The feed intake determines the quantity of AA consumed by the pig and is influenced by the energy content of the diet (NRC 1998). The lower feed intake of entire male pigs compared to castrated males is well investigated (Dunshea *et al.* 2001, Zeng *et al.* 2002, Pauly *et al.* 2008). The results of these investigations are in accordance to the findings of the current study. On average within all experimental groups and separated by gender boars showed a 10% lower feed intake than barrows with 2.66 kg/d compared to 2.95 kg/d (**Paper I**). These findings correspond almost exact with the results of Lanferdini *et al.* (2013) who found an 11% lower daily feed intake in boars than in barrows. Claus and Weiler (1994) explained the sex specific difference in voluntary feed intake with the impact of hormones. Whereas Pauly *et al.* (2008) supposed other aspects as reasons for the lower feed intake, such as a more active and aggressive behavior or a generally lower ingestion capacity of boars. Cronin *et al.* (2003) also specified an increased physical activity as a possible reasons.

Several authors mentioned that the feed intake of pigs was affected by the composition of the diet (Henry 1985, Friesen *et al.* 1994). Conversely, Nam *et al.* (1995) stated that pigs did not have the ability to control their protein and lysine intake to meet their nutrient requirements. Admittedly, the lysine-to-energy ratio is known to influence the growth performance of growing-fattening pigs. Smith *et al.* (1999) observed improved growth performance when feeding diets with increased lysine-to-energy ratios to pigs. Therefore, in the current study (**Paper I**) it was decided to use lysine (known as the first limiting AA) and energy (ME) as key factors in order to examine whether the feed intake of boars is influenced by the AA and energy concentration of the diet. It was determined if boars would change their feed intake according to the AA and/or energy content of the diet or to neither of them. De la Llata *et al.* (2007) and Zhang *et al.* (2011) likewise demonstrated that the growth performance was improved as the lysine-to-energy ratio was increased. Conversely, in the present study, the pigs consuming the diet with an increased content of lysine and ME showed no significantly improved average daily weight gain or a reduced voluntary feed intake. Thus, the lack of significant effects of the lysine-to-ME ratio concerning growth parameters might be an indication that the chosen lysine-to-ME ratio in the present study was not set low enough to induce measureable significant differences.

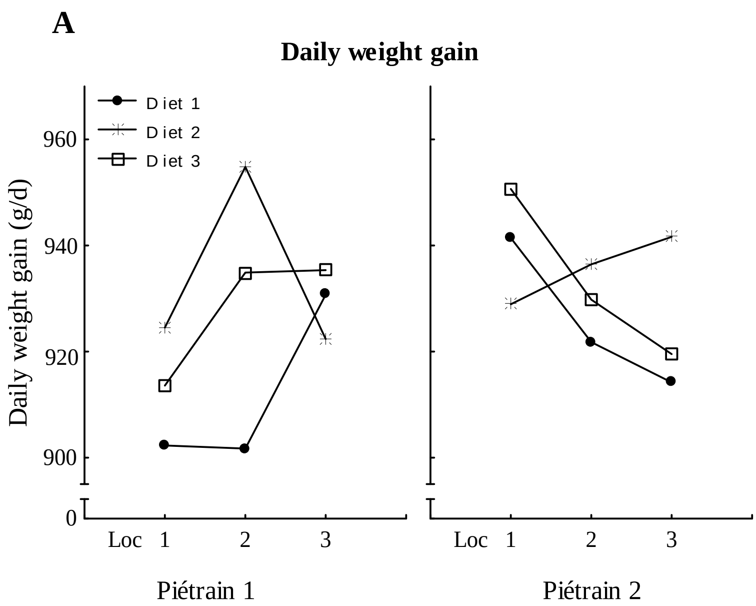
Moreover, De la Llata *et al.* (2007) employed a lysine concentration of the starter diet of 0.98% - 1.38% for gilts and 0.80% - 1.18% for barrows. These lysine concentrations were explicitly lower than the 1.20% – 1.36% used in the current study. The ME level was slightly above the level of the present experiment. Consequently it is not surprising that De la Llata *et al.* (2007) observed reduced feed intake in certain weight sections when the lysine-to-energy ratio was increased. In addition, the daily weight gain significantly increased as the lysine-to-energy ratio was increased. Friesen *et al.* (1994) also showed a tendency towards decreased average daily feed intake as the digestible lysine increased with significantly improved average daily weight gain at the same time.

As opposed to this, but just like in the present study, Lanferdini *et al.* (2013) supplemented the feed of boars with 3% and 5% of AA and energy and observed no improved growth performance. The lysine-to-energy ratio used in the present study represented no undersupply and therefore no measureable change was detectable. Summarizing the above it can be concluded that the AA level and the energy content of the diet are considered to be one of the most important influencing factors on voluntary feed intake and growth performance of pigs, but the concentration of AA and ME used in the current study was too high to induce significant effects on feed intake and growth performance.

In fact, the superior performance potential of boars compared to barrows has been described in literature before (Van Lunen and Cole 1996a, Andersson *et al.* 1997, Turkstra *et al.* 2002). This corresponds with the findings of the current trial. On average, the daily weight gain was 6.8% higher for boars than for barrows (**Paper I**). In contrast to this, Zamaratskaia *et al.* (2008) and Pauly *et al.* (2008) determined increased growth rates for barrows compared to boars. Whereas Knudson *et al.* (1985) stated a higher daily weight gain of boars in comparison to barrows, boars reached their maximum rate of gain approximately 21 days later than barrows. These findings are in accordance with the results of the current study (**Paper I**), where the point of maximum daily gain was reached by boars 16 days later than barrows and for this reason the growth of boars seems to be more efficient than the one of barrows due to their increasing long term gain curve.
In addition, the improved feed-to-gain ratio of 16% of boars compared to barrows was measured in the current study (2.24 kg feed/kg gain instead of 2.67 kg feed/kg gain; **Paper I**) was in good accordance with Lanferdini *et al.* (2013) who found an improved feed efficiency of about 15% of boars compared to barrows. The discrepancies between the results for growth performance of boars and barrows might be explained by factors such as genotype or nutrition. Bowen *et al.* (2006) explained the improved FGR of boars with the anabolic action of estrogens and testicular androgens. Nevertheless, according to literature and the results of the current study, a general superior performance potential of boars was noticed.

Commonly the growth performance of pigs is influenced, among other things, by the diet composition and not least by the AA concentration of the diet. Chiba (1994) contended that pigs which were fed a high AA diet tend to gain faster and more efficiently than those offered a low AA diet. Warnants *et al.* (2003) and Reynolds and O'Doherty (2006) observed an increased growth performance in accordance with an increased dietary AA level. However, information published on optimal levels of lysine supply for growth performance of growing-finishing boars is limited. Based on **Paper II** (showed only the results of the growth period), the results from the entire fattening period were analysed. The impact of the three factors location, diet and sire line and their interactions with DWG and FGR divided into Experiment 1 (Figure 1) and Experiment 2 (Figure 2) were shown. In contrast to other authors, but according to the results of **Paper II**, the findings of the current study do not show increased growth performance as the dietary AA level increased. Despite the positive impact of AA on performance reported in literature, an increased AA level does not lead to a significant improvement of performance in Experiment 1 (Figure 1). These results were in good accordance with the findings of Lanferdini *et al.* (2013), who suggested that boars fed with different nutritional levels did not differ in weight gain. Chiba (1995) and Deng *et al.* (2007) reported that advantages obtained by feeding a high AA diet during the growth phase were lost in the finisher phase due compensatory growth. Advantages in the growth period could not be confirmed in the current study, the growth period (**Paper II**) as well as the entire period showed no improved DWG or FGR when the AA level was increased. Moreover the sire line also had no impact on the DWG and FGR in Experiment 1, whereas the location influenced the FGR ($p<0.001$). Boars housed in Location 1 (2.29 kg/kg) or 2 (2.31 kg/kg) showed a more efficient FGR than boars housed in Location 3 (2.46 kg/kg). Furthermore, there was an interaction with the FGR between location*diet ($p<0.05$) and location*sire line ($p<0.01$).

In general, the location seems to have a great influence on the growth performance results of the current study. Morrison *et al.* (2003) also suggested that environmental conditions like a reduced pen space may affect the performance results of pigs. This underlines the necessity of testing the impact of dietary AA under different environmental conditions in order to receive general valid results about the requirements of boars and of pigs in general. Citing the example of the DWG of Pi 1 boars (Figure 1A), it was demonstrated that the boars housed in Locations 1, 2 and 3 react in a completely different way.



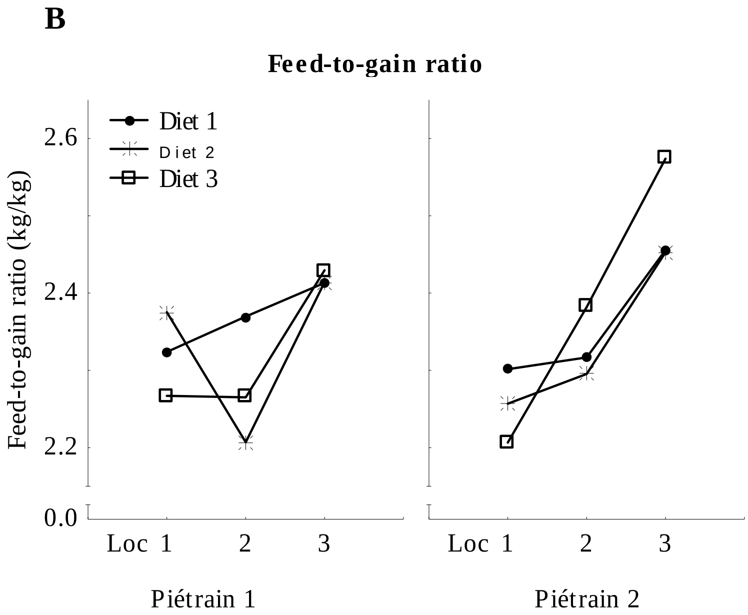


Figure 1: Daily weight gain (A) and feed-to-gain ratio (B) of the entire fattening period of the boars of Experiment 1 (Pi 1 and Pi 2) of **Paper II** separated into location (Loc), diet (Diet 1: 11.5 g lysine/kg (Grower), 9.00 g lysine/kg (Finisher); Diet 2: 13.2 g lysine/kg (Grower), 10.40 g lysine/kg (Finisher); Diet 3: 14.9 g lysine/kg (Grower), 11.70 g lysine/kg (Finisher)) and sire line; values represent means

As opposed to Experiment 1, in Experiment 2 the dietary AA level affected the DWG of the boars significantly ($p<0.01$). The average DWG was decreased from Diet 1 (1118 g/d) to Diet 2 (1082 g/d) and Diet 3 (1070 g/d) (Figure 2A). In addition, the location ($p<0.01$) and the sire line ($p<0.001$) could also be identified as significant influencing factors as well as the interaction between location*diet and location*sire line. In general, the Duroc sired boars showed a superior DWG (1149 g/d) compared to the Piétrain progenies (1030 g/d). As mentioned in **Paper II**, the unexpectedly decreasing DWG of the Duroc boars in parallel to the increasing AA content of the diet accounted for the largest share on these findings. The DWG of the Piétrain pigs used in Experiment 2 was also decreasing, although not as much as the Durocs' did. Quite in line with this, Gatel and Grosjean (1992) and Almeida *et al.* (2010) reported stagnating or plateaued growth curves when the dietary AA concentration exceeded a certain level. However, excessive AA can reduce the beneficial effects on growth performance reported above.

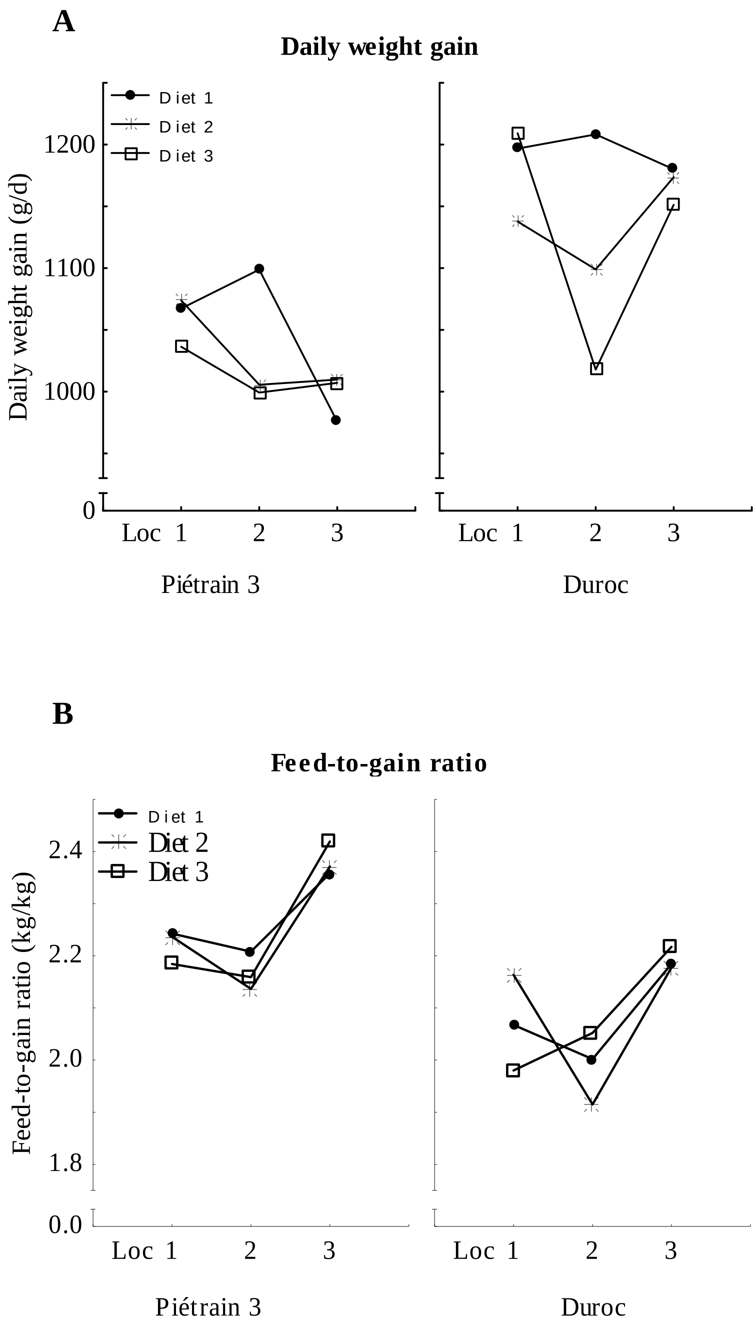


Figure 2: Daily weight gain (A) and feed-to-gain ratio (B) of the entire fattening period of the boars of Experiment 2 (Pi 3 and Du) of **Paper II** separated into location (Loc), diet (Diet 1: 11.5/9.00 g lysine/kg; Diet 2: 13.20/10.40 g lysine/kg; Diet 3: 14.90/11.70 g lysine/kg) and sire line); values represent means

Despite the fact that the dietary AA level influenced the DWG of the pigs used in Experiment 2 (Figure 2A), the diet had no effect on the FGR of these pigs (Figure 2B). However the location (p<0.001) and the sire line (p<0.001) significantly influenced the FGR in Experiment 2 as well as the interaction between location*diet (p<0.01) (Figure 2B). Again, the environmental impact (location) played an important role and it is conspicuous that the boars sired by Piétrain sire line 3 showed a similar FGR depending on the respective location and diet. Nonetheless, it is not possible to conclude general statements from this point, due to the fact that the location effect of other performance parameters and sire lines is hard to explain. Likewise, Duroc sired boars had a more efficient FGR than the Piétrain boars (2.08 kg/kg compared to 2.26 kg/kg). This underscores even further that the Duroc progenies were on a higher performance level than the Piétrain progenies, which is in well accordance with the findings of Latorre *et al.* (2003) and **Paper II**.

Overall, the environmental impact and the type of sire line seemed to be the major factor affecting the DWG and FGR of crossbred boars in the entire growth period and were consistent with the findings in **Paper II.** As suggested in **Paper II**, the used levels of dietary AA might be insufficient to influence growth performance of boars of different sire lines.

7.1.2 Influence on nitrogen retention

Lysine is usually known as the first limiting AA in diets for pigs based on cereals and soy, which leads to the general practice of expressing the requirements for all other EAA relative to lysine (Boisen *et al.* 2000). This procedure has also been adopted in the current study. The AA requirements of pigs are determined by various factors such as live weight, weight gain, sex, genotype and environment (Fuller 1994). Wecke and Liebert (2009) outlined that the efficiency of lysine use for protein gain was related to the concept of the “ideal protein”. Hence, the reaction of animals was influenced by the ideal balance of AA and energy (Kim *et al.* 2009).

An ideal protein for growth was described by Yen *et al.* (1986a) as one which supplies the optimum balance of EAA together with sufficient alpha-amino-nitrogen for the synthesis of non-EAA. Additionally, it was assumed that the optimum balance of AA was mainly influenced by growth rather than maintenance requirements. The application of the concept of the “ideal protein” may reduce the level of excess AA and as a consequence the level of crude protein in the diet which means that the level of excreted nitrogen is reduced, too. Moughan and Fuller (2003) mentioned that most of the daily AA requirements (>90%) accounted for the growth process. This underlines the importance of adequate protein nutrition for the subsequent level of protein accretion for the growth performance of pigs.

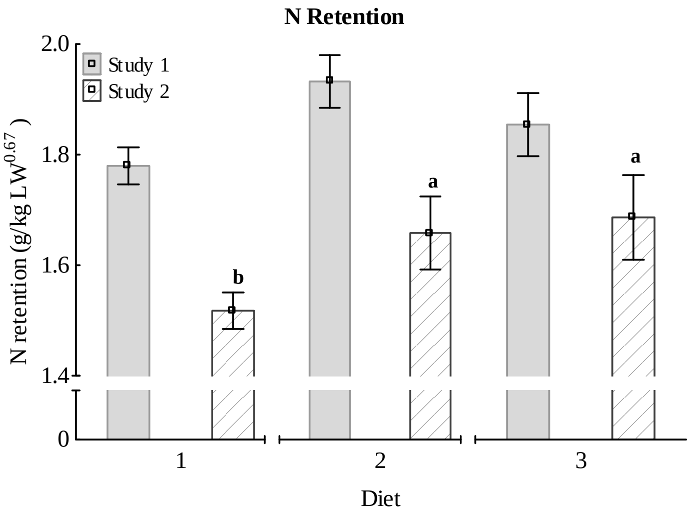


Figure 3: Comparison of the N retention (g/kg LW$^{0.67}$) of boars of Study 1 (Piétrain) and Study 2 (Duroc) of **Paper II**; values represent means ± SEM; values with different superscript differ significantly (p<0.05) between the diets (Diet 1: 11.5 g lysine/kg; Diet 2: 13.2 g lysine/kg; Diet 3: 14.9 g lysine/kg)

Studies dealing with the effect of an increased AA level in the diet of pigs are available. In these studies the nitrogen (N) retention was increased parallel to the increased AA content of the diet (Quiniou *et al.* 1995, Fabian *et al.* 2004, Reynolds and O'Doherty 2006). However, in the first N balance study of the current study (**Paper II**) an increased AA concentration of the diet (presented using lysine as first limiting AA) of 11.5, 13.2 and 14.9 g lysine/kg had no effect on the N retention of growing boars (Figure 3). In contrast, the results of the second N balance study (**Paper II**) agreed to some extent with the findings of the authors mentioned above. The N retention of boars consumed Diet 1 was significantly lower than the N retention of boars received Diet 2 or 3 (Figure 3). However, an increased AA concentration above the level used in Diet 2 results did not result in any further increased N retention. Moreover, it has to be considered that the boars used in the present study were sired by two different breeds (Piétrain in N balance Study 1 and Duroc in N balance Study 2). This underlines the influences of the pig breed on N retention and performance and has to be considered when interpreting the AA effects in the current study. Acciaioli *et al.* (2011) mentioned significant breed effects comparing the N retention of pigs of different genetic backgrounds. The results confirmed that an increased AA level has a fractional impact on the N retention of growing boars depending on their particular breed.

7.1.3 Effects on the chemical body composition

In recent years, in addition to animal welfare benefits pig producers wanted to take advantage of the ability of boars to deposit more muscle and less fat than surgical castrated males (Dunshea *et al.* 2001). The composition of the diet is known as an important factor influencing the chemical body composition of pigs. The protein content in particular and especially the AA level of the diet are mentioned as influential factors in the literature. Wood *et al.* (2013) measured a significantly increased intramuscular fat content of boars as the protein and AA level of the diet had been decreased. Likewise, Kerr *et al.* (2003) outlined that a supplementation with AA to boars improved the production of lean meat. The chemical body composition is related to the supply of AA (lysine) and the sex of the pig (Berk and Schulz 2001). Apple *et al.* (2004) reported an increased protein content and a decreased fat content in the *longissimus* muscle with increased AA levels. In opposition to the literature, the present study (**Paper III**) showed no significant impact of the dietary AA level on the chemical body composition of boars. In addition to the body composition of 26 boars of two Piétrain sire lines examined in **Paper III**, the chemical body composition of 15 Duroc sired boars (five animals per diet group; Figure 4) were analysed in accordance to the procedure described in **Paper III**. Due to the default of an initial group of Duroc piglets, the initial figures of Piétrain piglets were used to calculate the empty body weight gain (EBWG) of Duroc boars. Considering data of the Piétrain boars (**Paper III**) together with the data of the Duroc boars (Figure 4A), the dietary AA level does not have any impact on the composition of the empty body of Piétrain crossbreds or Duroc crosses.

As opposed to the findings of **Paper III** (no significant dietary effect on the composition of body gain of Piétrain boars), the composition of body gain of the Duroc boars was significantly (p<0.05) influenced by the diet (Figure 4B). In accordance with Bikker *et al.* (1994), the protein deposition rate increased with increasing dietary lysine level, but not continuously. The boars consuming Diet 3 showed a significantly higher amount of protein per kg gain (180 g/kg EBWG) than the boars receiving Diet 2 (166 g/kg EBWG) and the boars fed with Diet 1 showed the lowest measurement (174 g/kg EBWG). The absence of a continuous incensement of protein deposition parallel to the increasing dietary AA level is hard to explain. However, the measured values of fat showed similar inconsistent results. Moreover, while interpreting this data the missing initial group of Duroc piglets has to be mentioned and conclusions from the composition of empty body weight gain should be drawn carefully.

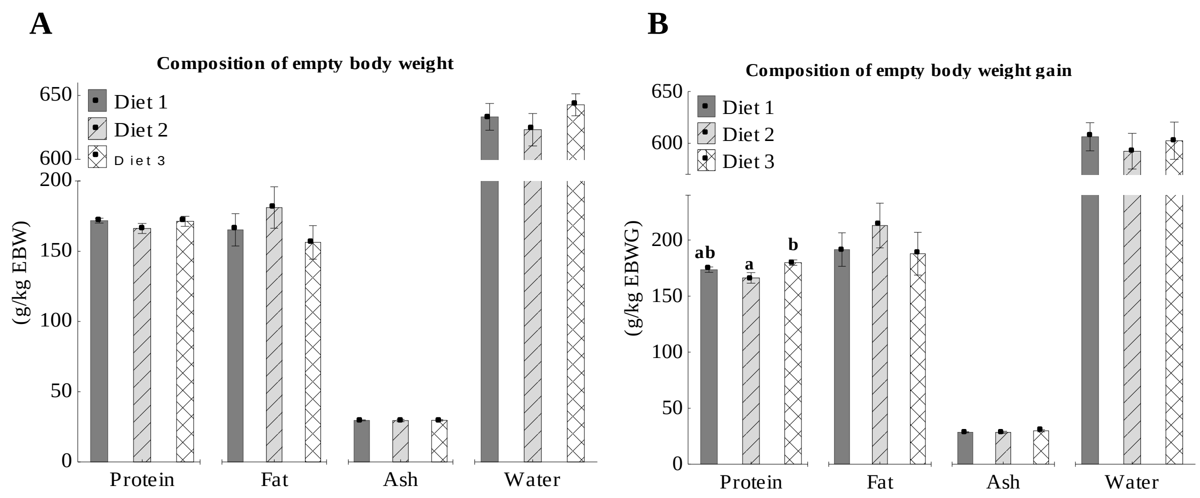


Figure 4: Chemical composition of empty body weight (A) and empty body weight gain (B) of Duroc boars (n = 5; 124.5 ± (SE) 4.4 kg live weight), divided into diet (Diet 1: 11.5/9.00 g lysine/kg; Diet 2: 13.20/10.40 g lysine/kg; Diet 3: 14.90/11.70 g lysine/kg); values represent means ± SEM; values with different superscript differ significantly (p<0.05) within the different body components

The minor influence of the dietary AA level on the protein content of the empty body and the empty body gain of boars of different sire lines indicates that the AA requirements of boars are not as high as previously expected. In addition, the clearly lower body fat content of the present boars compared to those from former studies suggests that the energy requirements of boars appear to be even lower than discussed before. Moreover, in the current study, the usage of boars of two different Piétrain (Pi) sire lines resulted in significantly different lean meat content and protein content in the empty body and in the gain. The carcasses of boars of Pi sire line 1 contained 2.8% more lean meat and approximately 4% more protein in the empty body and gain compared to Pi sire line 2.

Fuller *et al.* (1995) suggested that pigs from different genetic backgrounds might differ in their lean growth potential. This agreed with the findings of the current study. Appropriately, the type of sire line tended to influence the fat content, Pi 2 sired boars showed a tendency for a higher fat content than Pi 1 sired boars (**Paper III**). Due to the fact that only one Duroc sire line was used in the analysis presented in Figure 4 obviously no sire line effects were available. But generally the improved growth performance of Duroc pigs or Duroc crossbreds compared to other breeds confirmed literary findings (McGloughlin *et al.* 1988, Latorre *et al.* 2003). Furthermore, the superior growth and lean meat production potential of boars compared to barrows or gilts are commonly known. Boars are known to be leaner than sows which in turn are leaner than barrows (Andersson *et al.* 1997). The Piétrain boars used in the current study contained 175 g protein/kg and 167 g fat/kg and the Duroc boars 170 g protein/kg and 168g fat/kg on average in the empty body. For this reason, the boars of the current study are slightly leaner but overall in accordance to the body composition Weis *et al.* (2004) and Martínez-Ramírez *et al.* (2008) reported for boars. Thus it was assumed that the boars used in the present study had a high potential for lean tissue growth and therefore were better than boars used in other studies reported in the literature.

In principle, the bodies of modern genotype hybrid pigs seem to be much leaner than the ones of previous generations. This is made evident by Campbell and Taverner (1988) who measured 14.6% protein and 36.6% fat in the empty body of boars whereas Weis *et al.* (2004) reported 17.1% protein and only 18.4% fat in boars. Rao and McCracken (1990) estimated increasing protein deposition in pigs over the course of time and concluded that this is attributable to the breeding focus on lean deposition. This applies not only for boars, but also for barrows. The barrows analysed by Berk and Schulz (2001) were much leaner than the barrows used by Campbell and Taverner (1988). In fact, the general improvement of lean meat content by genetic selection has to some extent induced that these sex depending differences on performance were reduced (Claus 1993).

7.2 Impact on the recommendations for boars

Until quite recently, the fattening of entire male pigs was not practiced in most European countries (EFSA 2004). But for some time, the fattening of boars has been implemented in Germany and will presumably take on even greater importance. The higher anabolic potential of boars compared to other sexes was contended in the literature and in particular increased requirements of AA for boars were assumed (Yen *et al.* 1986a, b, Campbell *et al.* 1988, Van Lunen and Cole 1996a). Nevertheless, an oversupply of AA even caused growth depression in some types of boars of the current study (**Paper II**). These findings were in line with the depressive effect of an excess supply of AA observed by O'Connell *et al.* (2006).

Undoubtedly there is a lack of scientific examinations regarding the nutrition requirements of modern genotype hybrid boars. The German Agricultural Society (DLG) stated that reliable results from experiments with growing-finishing boars that gave the opportunity to formulate nutrient recommendations for boars were not available (DLG 2010). However, the anticipated change in the German pig production system to fattening of entire male pigs may require a dietary adaption.

Therefore, one of the main focuses of the present study was the investigation of the nutrient requirements of growing-finishing boars. The maintenance requirements are one important aspect for the derivation of the energy requirements of boars. Generally the metabolizable energy required for maintenance (ME_m) for pigs (gilts and castrated males) above 100 kg LW is stated to be 0.44 MJ per kg metabolic body mass ($kg^{0.75}$) per day and extra charges are included for the calculation of ME_m of pigs between 30kg and 120kg LW (GfE 2008).
The ME intake and the net energy accretion from the boars presented in **Paper III** and in Figure 5 (n= 41) was calculated. By using these data the calculation of ME_m was possible with the linear regression method. The ME_m was estimated by linear regression of ME intake on net energy accretion (NE). The NE was calculated by summing up the deposition of fat and protein. Taking into consideration the data of all chemical analysed boars, independent of diet group and sire line, the ME_m was 0.35 MJ/$kg^{0.75}$/d for boars with a mean live weight of 75 kg (Figure 5). Remarkably, this ME_m falls below the value of approximately 0.48 MJ/$kg^{0.75}$/d for pigs of 75 kg LW, which is postulated and usually used by the GfE (2008), by 27%. Moreover the diet groups seem to be more or less equally distributed on the line, whereas the Duroc sired boars seems to have a higher ME_m due to their position on the regression line. Due to the overall relatively small number of animals no separated interpretation between the sire lines was performed.

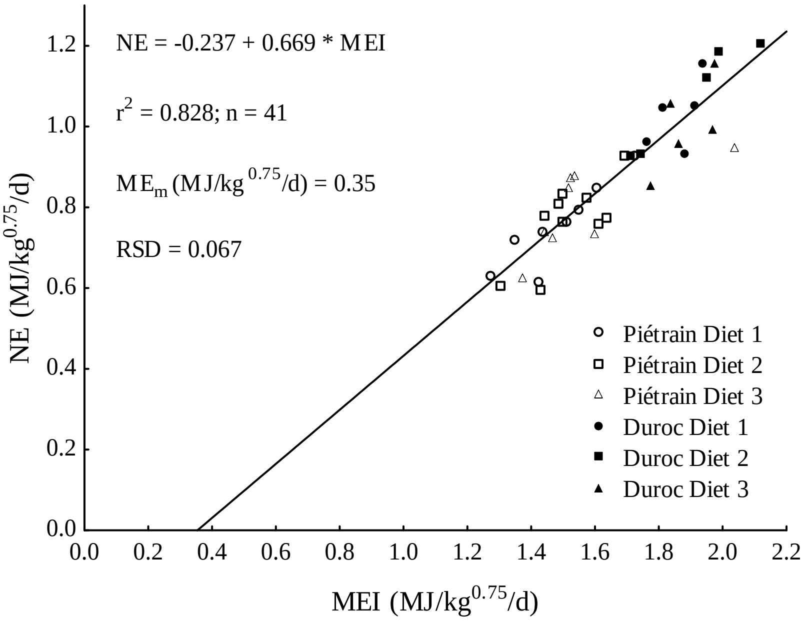


Figure 5: Metabolizable energy requirement for maintenance (ME_m) calculated by using the linear regression technique of metabolizable energy intake (MEI) on net energy (NE) of Piétrain (n = 26) and Duroc (n = 15) sired boars divided into diet (Diet 1: 11.5/9.00 g lysine/kg; Diet 2: 13.20/10.40 g lysine/kg; Diet 3: 14.90/11.70 g lysine/kg); r^2 = coefficient of determination; RSD = residual standard deviation

The current results generally indicated a lower ME_m of boars compared to those found in the literature, which are nearly always based on data obtained from gilts and castrated males, but due to the extrapolative manner of estimating the ME_m the corresponding results remain uncertain. Besides, the boars in the present study were sufficiently supplied with energy throughout their entire growth period. Maybe a staggered energy supply can also contribute to make the ME_m estimation for boars more accurate. Interpreting this data, the wide LW range (20 – 120 kg) in the current study and the expandable number of boars in contrast to the large quantity of data the GfE (2008) results are based on should also be mentioned. Therefore only cautious conclusions can be drawn from these regressions. Moreover, the efficiency of ME utilization for growth (k_{pf}), with no differentiation between protein and fat, was estimated to be 0.669 for boars (Figure 5). Gädeken *et al.* (1985) calculated a k_{pf} of 0.7, which lies above the k_{pf} for boars in the present study. This result was predetermined since due to the relatively low fat content of the boars, the calculated k_{pf} tended more likely towards the value for accretion of protein (k_p = 0.56) (ARC 1981) than to the value for accretion of fat (k_f = 0.74) (ARC 1981).

However, this result invalidates the assumption that the superior performance potential of boars is caused by increased utilization ability. The reservation must be made, however, that a relatively small sample was used.

Nevertheless, several authors mentioned changes in body composition associated with the breeding progress towards a generally leaner carcass for boars as well as for barrows and gilts (Cliplef and McKay 1993, Roehe *et al.* 2003). Therefore, the continuous improvement in the genetics of pigs makes it necessary to monitor nutritional requirements at regular intervals.

Taking everything into consideration, neither the voluntary feed intake and the N retention, nor the performance and whole body composition were decisively influenced by the different experimental diets. Altogether, the studies presented in **Paper I-III** produce consistent results. Consequently, the results of all trials of the current study lead to the general assumption that the chosen AA level was inappropriate to induce significant differences between the diet groups, which in other words means that the lowest AA level was obviously sufficient to meet the requirements of boars. Thus, the evidence available indicates that the AA requirements of boars were not as high as previously expected. These findings imply that the considerably enhanced AA levels in the diets of boars, which were discussed earlier, were unnecessary to archive optimum performance. Anyway, it should not be neglected that boars indeed need AA levels at the upper end of the nutrition recommendations for growing pigs with high potential for lean growth. Otherwise, it is impossible for boars to exploit their genetically determined growth potential.

8. Conclusion

The results of the present study confirm the superior growth performance of boars compared with barrows. Boars consumed 10% less feed than barrows and a 16% lower feed-to-gain ratio of boars compared to barrows was determined. A literature review also attested that boars have an advantage in growth performance over barrows and gilts. However, the dietary AA and energy levels used in this study failed to show expected differences in voluntary feed intake of boars and barrows depending on the AA and energy content of the diet.

There were inconsistent results concerning the proposed assumption that boars need explicitly increased dietary AA levels to achieve their full growth potential. The feeding of diets with varying AA content only has little influence on the N retention of boars of different sire lines. However, the type of sire line affected the growth performance in a significant manner.

The chemical body composition of Piétrain sired boars was unaffected by the AA content of the diet, whereas Duroc sired boars showed significant, but inconsistent differences in the composition of empty body weight gain. Furthermore, within the Piétrain sire lines, different values for protein content and gain were observed. From this study it was concluded that the boars’ higher content of lean meat, which is also described in literature, is substantiated in a considerably lower fat content (on average 167.5 g/kg EBW) and a marginally higher protein content (on average 172.5 g/kg EBW).
Additionally, the estimated ME requirements of boars for maintenance (0.35 MJ/kg$^{0.75}$/d) were noticeably lower than the value taken as a basis from the GfE (2008) for maintenance requirements of pigs. The progress in pig breeding generally leads to leaner pigs, which results in the necessity of a constant re-evaluation of the nutrient recommendations for boars as well as for barrows and gilts.

From an economic point of view, fattening of boars could be very profitable since the boars’ demands on the feed seem to be not substantially higher than the ones of barrows, with simultaneously higher performance of boars. Although the current results confirmed a higher efficiency of boars compared to barrows, the possibly occurring “boars taint” represent a major challenge to implement entire males production extensively.

Overall, the used “mixed approach” method (a combination of N balance study, fattening experiment and chemical body analysis) could be an auspicious start to achieve progress towards the goal to establish reliable nutrient recommendations for growing-finishing boars. The results of the current study lead to the conclusion that nutrient requirements for modern genotype hybrid boars were not as high as previously discussed. They should orientate on the recommendations for pigs with very high protein deposition rates in order to deposit the maximum genetic growth potential of boars. Nonetheless, further research is needed to optimize the nutrition recommendations of boars.

9. Summary

As a contribution to an on-going public and politically intended animal welfare debate the surgical castration of male piglets without anaesthesia was specially targeted and critics have expressed their concern about the lack of animal welfare. One possible solution seems to be the fattening of entire male pigs (boars) instead of castrated males (barrows). The superior growth performance of boars compared to barrows and gilts and the reduced feed consumption of boars under practical *ad libitum* feeding conditions have been reported by several authors. A greater potential for lean meat deposition of boars and as a result a higher essential amino acid (EAA) requirement of growing-finishing boars was assumed in literature. Among other factors, the chemical body composition of pigs is affected by diet composition and sex. However, the knowledge of nutrition requirements of boars according to their performance is limited und these aspects have not yet been investigated in detail.

Therefore, the aim of the present study was to examine the effects of dietary EAA and energy levels on voluntary feed intake, growth performance and nitrogen (N) retention as well as on chemical body composition of growing-finishing boars of different sire lines. Additionally, first recommendations on the nutrient requirements of boars should be derived by use of a "mixed approach" method combining fattening experiments with N balance studies and the analysis of chemical body composition.

For this purpose, experiments with boars and to some extent barrows were carried out and published in three papers. In paper one, a fattening experiment was conducted assigning 48 crossbred boars and 47 crossbred barrows to four diets with two different precaecal digestible lysine-to-metabolize energy (ME) ratios of 0.93 and 0.86 (g/MJ) for grower diets and 0.71 and 0.66 (g/MJ) for finisher diets. Other essential amino acids (EAA) were added in relation to the first limiting EAA lysine as recommended by the Society of Nutrition Physiology (GfE) in 2008. The pigs were kept individually and divided into four feeding groups for each sex. The effect of the sex was dominant and influenced all variables ($p<0.001$). Energy and lysine levels of the diets exerted only minor effects on the measured variables, such as the intake ($p<0.05$) and conversion ratio ($p<0.01$) of lysine and energy. Whereas boars consumed 10% less feed than barrows and had an improved feed-to-gain ratio which was approximately 16% lower than the one of barrows. Overall, a superior growth potential together with a lower feed intake was confirmed for boars compared to barrows. Generally, dietary AA level and energy content are determined as important factors affecting the performance of pigs, but the lysine and ME concentration chosen in the current experiment was obviously too high to affect the feed intake and the growth performance significantly.

The second paper consists of two N balance studies in parallel with two fattening experiments, whereby in the N balance experiment twelve crossbred boars were used (six Piétrain crossbreds in Study 1 and six Duroc crossbreds in Study 2). In the fattening experiments (30 kg - 70 kg live weight (LW)) 214 boars were used in Experiment 1 and 212 boars in Experiment 2, in each experiment the number was almost equally split into progenies of two sire lines. All used boars were siblings or half siblings within their sire line. In Experiment 1 crossbred boars of two different Piétrain sire lines and in Experiment 2 crosses of one Piétrain and one Duroc sire line were used. The fattening Experiments 1 and 2 were conducted in each case at three different performance test centres, so that the same sire lines were examined simultaneously at three locations. Three diets with increased EAA content were used. The diets were also used in the N balance studies in order to compare the N retention and performance of boars during the growth period. The diets which were fed in all experiments were isoenergetic (13.4 MJ ME) and contained either 11.5 g lysine/kg (Diet 1) or 13.2 g lysine/kg (Diet 2) or 14.9 g lysine/kg (Diet 3) during the examined growth period. Other EAA were added in relation to lysine recommended by the GfE (2008). Overall, the increase of the AA content of the diets seemed to have only a very minor impact on N retention and on the growth performance of growing boars, whereas for the fattening experiments the location effect and to some extent the sire line effect was found to be significant.

Additionally, the performance of the entire fattening period (30 - 120 kg LW) was examined in this thesis. The diets which were fed in the finishing period (70 - 120 kg LW) contained either 13.00 MJ ME and 9.00 g lysine/kg (Diet 1) or 10.40 g lysine/kg (Diet 2) or 11.70 g lysine/kg (Diet 3). According to the results of the growth period the dietary AA level had only a minor impact on the growth performance of boars. However, observing the entire fattening period of Experiment 2 the boars showed a significantly higher daily weight gain consuming Diet 1 than those consuming Diet 2 or 3. In addition, location and sire line had partly an effect, too on the growth performance during the entire fattening period. The results from the growth period and the entire fattening period indicate that the used dietary AA level of Diet 1 seems to be high enough to exploit the maximum genetic N retention and growth potential of boars of different sire lines.

For the third paper, a total of 24 crossbred boars of two different Piétrain sire lines were used. These were out of the pigs of one location used in the first fattening experiment of the second

paper. A chemical body analysis was conducted to figure out whether the dietary AA level influences the performance and chemical body composition of growing-finishing boars. To generate start data, an additional initial group of eight boars was slaughtered at approximately 21 kg LW. The final group of 26 boars was continuously fed and slaughtered at approximately 122 kg LW. The initial and final body composition was chemically analysed for protein, fat and ash and interpreted together with the composition of gain and the performance data of the 26 final boars. As a result, no significant effects of EAA level on performance or chemical body composition and gain could be measured. On this basis it can be concluded that the EAS level of Diet 1 is sufficient to exploit the full genetically determined performance potential. However, the investigation revealed further that boars sired with Piétrain line 1 demonstrated significantly increased protein content (approximately 4%) in the empty body and gain and lean meat content (2.8%) compared to Piétrain line 2 sired boars.

Apart from the results of the third paper, the chemical body composition of 15 Duroc sired crossbred boars (equally divided into boars of the diet groups of the second fattening experiment of the second paper) was examined and discussed in this thesis in comparison to the results of the Piétrain boars of the second paper. Hence, the used AA levels do not have any effect on the body composition of the Duroc sired boars, but in contrast to the Piétrain boars, the composition of gain of the Duroc boars was significantly ($p<0.05$) influenced by the diet. However, there were no definite results, the Duroc boars of Diet group 3 showed a significantly higher amount of protein per kg gain (180 g/kg) than boars receiving Diet 2 (166 g/kg) and boars fed with Diet 1 reached mean values (174 g/kg). Obviously, the absence of a continuous incensement of protein deposition parallel to the increasing dietary AA level remains unclear and emphasises the necessity to perform further studies with an increased number of growing-finishing boars. Based on an additional regression analysis, the results of the present study suggested that the metabolizable energy requirement used for maintenance of the present boars was 27% lower than in currently used recommendations of the GfE (2008). These results indicate a requirement for further research.

In conclusion, the present thesis shows that the used “mixed approach” method represents a promising start in order to give reliable nutrient recommendations for growing-finishing boars. It was determined that under the conditions of the present studies the AA and energy requirements of growing-finishing boars were not as high as expected in some literature and therefore should be based on a transitional basis on the recommendations of the GfE of 2008 for pigs with very high protein deposition rates.

10. Zusammenfassung

Die betäubungslose Kastration von männlichen Ferkeln wird aus Tierschutzgründen kritisiert und ein möglicher Lösungsweg scheint die Mast von unkastrierten männlichen Schweinen (Ebern) anstelle von kastrierten männlichen Schweinen (Börgen) zu sein. Es ist bekannt, dass Eber im Vergleich zu Börgen ein höheres Wachstumspotential haben und aus nicht vollständig geklärten Gründen unter gewöhnlichen *ad libitum* Fütterungsbedingungen weniger Futter aufnehmen. In der Literatur wird außerdem berichtet, dass Masteber ein höheres Potential zur Magerfleischbildung haben, aus welchem ein erhöhter Bedarf an essentiellen Aminosäuren (EAS) im Futter abgeleitet wird.
Die chemische Körperzusammensetzung von Schweinen wird unter anderem von der Nährstoffzusammensetzung des Futtermittels und dem Geschlecht des Tieres bestimmt. Die optimale Futterzusammensetzung zur Ausschöpfung des Leistungspotentials von Mastebern wurde noch nicht im Detail untersucht. Daher war das Ziel der vorliegenden Studie, den Effekt von EAS- und Energiekonzentrationen im Futter auf die freiwillige Futteraufnahme, die Wachstumsleistung und die Stickstoff(N)-Retention ebenso wie auf die chemische Körperzusammensetzung von Mastebern verschiedener genetischer Herkünfte zu untersuchen. Zusätzlich sollten erste Empfehlungen für den Nährstoffbedarf von Ebern mit Hilfe einer „gemischten Ableitungsmethode“ (Kombination aus Mastversuchen, N-Bilanzstudien und Analyse der chemischen Körperzusammensetzung) bestimmt werden.

Hierzu wurden Experimente mit Mastebern und zum Teil auch mit Börgen durchgeführt, die in drei Veröffentlichungen publiziert wurden. In der 1. Veröffentlichung wurde ein Mastversuch mit 48 Ebern und 47 Börgen beschrieben. Die Tiere wurden mit vier verschiedenen Futtermitteln mit zwei unterschiedlichen Lysin(Lys)-zu-umsetzbarer-Energie(ME)-Konzentrationen im Futter gefüttert und einzeln gehalten. Die Lys-zu-ME Gehalte betrugen in der Vormast 0,93 bzw. 0,86 (g/MJ) und in der Endmast 0,71 bzw. 0,66 (g/MJ). Die anderen EAS wurden in dem von der Gesellschaft für Ernährungsphysiologie (GfE) im Jahr 2008 empfohlenen Verhältnis zum Lysin ergänzt. Das Geschlecht hatte einen signifikanten Einfluss auf alle untersuchten Parameter (p<0,001), während das Lys-zu-ME-Niveau nur einen geringen Einfluss zeigte. Die freiwillige Futteraufnahme von Ebern lag 10 % unter der von Börgen, ebenso war die Futterverwertung der Eber 16 % besser als die der Börge. Insgesamt konnten der Gehalt an EAS und Energie im

Futter als wichtige Einflussgrößen auf die Leistung der Schweine ermittelt werden, allerdings waren die in der vorliegenden Studie gewählten Gehalte zu hoch angesetzt, um signifikante Leistungsunterschiede zwischen den Fütterungsgruppen feststellen zu können.

Grundlage der 2. Veröffentlichung waren zwei N-Bilanzversuche, die parallel zu zwei Mastversuchen (Vormastperiode: 30-70 kg Lebendmasse (LM)) durchgeführt wurden. Im ersten Bilanzversuch befanden sich sechs Kreuzungseber der Vaterrasse Piétrain und im zweiten Bilanzversuch sechs Kreuzungseber der Vaterrasse Duroc. Für die Mastversuche wurden 214 Ebern aus zwei Piétrainlinien (Durchgang 1) bzw. 212 Ebern aus einer Piétrainlinie und einer Duroclinie (Durchgang 2) verwendet. Die Eber wurden für beide Durchgänge jeweils auf drei Leistungsprüfungsanstalten (LPA) aufgeteilt, sodass die gleiche Eberherkunft zeitgleich an drei Standorten geprüft wurde. Alle eingesetzten Eber waren Geschwister oder Halbgeschwister innerhalb ihrer jeweiligen genetischen Herkunft. In den Bilanz- sowie in den Mastversuchen kamen drei isoenergetische Futtermittel (13,40 MJ ME) zum Einsatz, die sich in ihrem Gehalt an EAS unterschieden (Diät 1: 11,50 g Lys/kg; Diät 2: 13,20 g Lys/kg; Diät 3: 14,90 g Lys/kg). Die weiteren EAS wurden in dem von der GfE (2008) empfohlenen Verhältnis zum Lysin ergänzt. Insgesamt hatte der EAS-Gehalt des Futters nur einen sehr geringen Einfluss auf die N-Retention und die Wachstumsleistung der geprüften Eber, bei den Mastversuchen allerdings hatten die Haltungsumwelt und zum Teil auch die genetische Herkunft einen signifikanten Effekt auf die Wachstumsleistung.

Die Wachstumsleistung der Eber über die gesamte Mastperiode (30-120 kg LM) hinweg wurde zusätzlich betrachtet. In der Endmastperiode (70-120 kg LM) erhielt das Futter 13,00 MJ ME sowie einem dem Vormastfutter entsprechend reduzierten EAS-Gehalt. Vergleichbar mit den Ergebnissen der Vormastperiode war in der gesamten Mastperiode nur ein geringer Einfluss des Aminosäureniveaus des Futters auf die Leistung der Eber erkennbar. Entgegen der Erwartungen hatten die Eber aus dem 2. Durchgang, die Diät 1 erhalten hatten, über die gesamte Mastperiode gesehen signifikant höhere Tageszunahmen als die Eber, welche Diät 2 oder 3 erhielten. Darüber hinaus konnte teilweise ein signifikanter Effekt der Umgebung sowie der Herkunft auf die Leistung in der gesamten Mastperiode festgestellt werden. Insgesamt weisen die Ergebnisse darauf hin, dass der Aminosäuregehalt von Diät 1 ausreichend ist, um das maximale genetische Potential der eingesetzten Eber in Hinblick auf die N-Retention und das Wachstum auszuschöpfen.

Für die 3. Veröffentlichung wurde aus jeder der drei Fütterungsgruppen aus beiden Piétrainlinien des 1. Durchgangs (aus einer LPA der 2. Veröffentlichung) eine in etwa gleiche Anzahl an Ebern (insgesamt 26) mit einer LM von ca. 122 kg einer Ganzkörperanalyse unterzogen. Es wurde untersucht, inwiefern der EAS-Gehalt des Futters einen Einfluss auf die Leistung und chemische Körperzusammensetzung der Masteber hat. Dazu waren zu Beginn des Versuchs zusätzlich acht Ferkel (n= 4) mit einer LM von ca. 21 kg geschlachtet, entsprechend analysiert und als „Startwert“ zur Berechnung des Zuwachses während des Versuchszeitraumes genutzt worden. Neben den in der Leistungsprüfanstalt erfassten Leistungsparametern erfolgte eine chemische Analyse des gesamten Leerkörpers auf Protein, Fett und Asche. Als Ergebnis bleibt festzuhalten, dass der EAS-Gehalt des Futters keinen Einfluss auf die Leistung oder die chemische Zusammensetzung von Körper und Zuwachs hatte. Daraus ist zu schließen, dass das EAS-Niveau der Diät 1 für eine Ausschöpfung des genetischen Leistungspotentials ausreichend war. Allerdings ergab die Berücksichtigung der Herkunft der Eber, dass der Proteingehalt im Körper bzw. im Zuwachs sowie der Magerfleischanteil von Piétrain 1 Ebern signifikant über dem von Piétrain 2 Ebern lag.

Zusätzlich zu diesem Versuch wurden 15 Durockreuzungseber (ebenfalls aus einem Mastversuch der 2. Veröffentlichung; n= 5) einer Ganzkörperanalyse unterzogen und es erfolgte eine gemeinsame Ergebnisdiskussion mit den Ergebnissen der Piétraineber. Die eingesetzten EAS-Konzentrationen im Futter hatten hier ebenfalls keinen Einfluss auf die chemische Körperzusammensetzung, es konnten allerdings signifikante Unterschiede in der Zusammensetzung des Zuwachses in Abhängigkeit von der EAS-Konzentration des Futters ermittelt werden. Entgegen der Erwartungen stieg der Proteingehalt jedoch nicht parallel zum Anstieg des EAS-Gehaltes des Futters. Duroceber, welche Diät 3 erhielten, zeigten einen signifikant höheren Gehalt an Protein je kg Zuwachs (180 g/kg) als solche, die Diät 2 (166 g/kg) erhielten. Mit Diät 1 versorgte Eber zeigten mittlere Werte mit einem Proteingehalt im Zuwachs von 174 g/kg. Die Inkonsistenz dieser Ergebnisse ist möglicherweise auch auf die begrenzte Tierzahl (n=5) zurückzuführen. Eine mittels Regressionsanalyse durchgeführte energetische Betrachtung lässt darauf schließen, dass der Anteil der umsetzbaren Energie, der für Erhaltung genutzt wird, bei den untersuchten Ebern 27 % geringer ist, als derzeit von der GfE (2008) angegeben wird. Dieser Aspekt sollte weiter untersucht werden.

Abschließend kann aus dieser Studie geschlussfolgert werden, dass die angewandte Methode der „gemischten Ableitung“ erste Ergebnisse zur Ableitung von Versorgungsempfehlungen für Masteber liefert. Es wurde ermittelt, dass eine deutliche Erhöhung des EAS-Gehaltes des Futters keine Leistungssteigerung der Masteber zur Folge hatte. Daher sollten Eber bis zum Vorliegen belastbarer Empfehlungen in Anlehnung an die Empfehlungen für Mastschweine mit sehr hohem Proteinansatzvermögen (GfE, 2008) versorgt werden.

11. References (cited in Introduction, Background and General discussion)

Acciaioli A, Sirtori F, Pianaccioli L, Campodoni G, Pugliese C, Bozzi R, Franci O (2011) Comparison of total tract digestibility and nitrogen balance between Cinta Senese and Large White pigs fed on different levels of dietary crude protein. Anim Feed Sci Tech 169**,** 134-139

Almeida ECd, Fialho ET, Rodrigues PB, Zangeronimo MG, Lima JAdF, Fontes DdO (2010) Ractopamine and lysine levels on performance and carcass characteristics of finishing pigs. Revista Brasileira de Zootecnia 39**,** 1961-1968

Andersson K, Schaub A, Andersson K, Lundstrijm K, Thomke S, Hansson I (1997) The effects of feeding system, lysine level and gilt contact on performance, skatole levels and economy of entire male pigs. Livest Prod Sci 51**,** 131-140

Anonymous (2000) Establishing community methods for the determination of vitamin A, vitamin E and tryptophan, annex part C. Determination of Tryptophan. Official Journal of the European Communities. L174 45-50

Anonymous (2004) Richtlinie für die Stationsprüfung auf Mastleistung, Schlachtkörperwert und Fleischbeschaffenheit beim Schwein [Online]. Available: www.zds-bonn.de/services/files/pdf/rlnkp04geaendert0704.pdf [retrieved May 28, 2013]

Anonymous (2010) European Declaration on alternatives to surgical castration of pigs. [Online].Available:http://ec.europa.eu/food/animal/welfare/farm/docs/castration_pigs_declaration_en.pdf.

Anonymous (2012) Verbrauch an Nahrungsmitteln je Kopf und Jahr in Deutschland [Online]. Available: http://berichte.bmelv-statistik.de/WBB-2000002-2013.pdf

Apple JK, Maxwell CV, Brown DC, Friesen KG, Musser RE, Johnson ZB, Armstrong TA (2004) Effects of dietary lysine and energy density on performance and carcass characteristics of finishing pigs fed ractopamine. J Anim Sci 82**,** 3277-3287

ARC (1981) The Nutrient Requirements of Pigs. Commonwealth Agricultural Bureaux. Slough, London,

Bañón S, Andreu C, Laencina J, Garrido Ma-D (2004) Fresh and eating pork quality from entire versus castrate heavy males. Food Qual Prefer 15**,** 293-300

Barton-Gade PA (1987) Meat and fat quality in boars, castrates and gilts. Livest Prod Sci 16**,** 187-196

Batterham ES (1994) Protein and energy relationships for growing pigs. In: Cole D.J.A., Wiseman J., Varley M.A. (ed.) Principles of Pig Science. Nottingham University Press, Loughborough, 107-121

Berk A, Schulz E. Body composition of pigs depending on lysine supply. 2001 Göttingen. 73.

Bertol TM, Campos RMLd, Ludke JV, Terra NN, Figueiredo EAPd, Coldebella A, Santos Filho JId, Kawski VL, Lehr NM (2013) Effects of genotype and dietary oil supplementation on performance, carcass traits, pork quality and fatty acid composition of backfat and intramuscular fat. Meat Sci 93**,** 507-516

Bikker P, Verstegen MW, Campbell RG, Kemp B (1994) Digestible lysine requirement of gilts with high genetic potential for lean gain, in relation to the level of energy intake. J Anim Sci 72**,** 1744-1753

Boisen S, Hvelplund T, Weisbjerg MR (2000) Ideal amino acid profiles as a basis for feed protein evaluation. Livest Prod Sci 64, 239-251

Boler DD, Kutzler LW, Meeuwse DM, King VL, Campion DR, Mc Keith FK, Killefer J (2011) Effects of increasing lysine levels on carcass composition and cutting yields of immunologically castrated male pigs. J Anim Sci 89, 2189-2199

Bonneau M, Dufour R, Chouvet C, Roulet C, Meadus W, Squires E (1994) The effects of immunization against luteinizing hormone-releasing hormone on performance, sexual development, and levels of boar taint-related compounds in intact male pigs. J Anim Sci 72, 14-20

Bowen A, Khan S, Berghman L, Kirby JD, Wettemann RP, Vizcarra JA (2006) Immunization of pigs against chicken gonadotropin-releasing hormone-II and lamprey gonadotropin-releasing hormone-III: Effects on gonadotropin secretion and testicular function. J Anim Sci 84, 2990-2999

Campbell R, Taverner M, Curic D (1988) The effect of sex and live weight on growing pig`s response to dietary protein. Anim Prod 46, 123-130

Campbell RG, Dunkin AC (1983) The influence of protein nutrition in early life on growth and development of the pig. 1. Effects on growth performance and body composition. Brit J Nutr 50, 605-617

Campbell RG, Steele NC, Caperna TJ, McMurtry JP, Solomon MB, Mitchell AD (1989) Interrelationships Between Sex and Exogenous Growth Hormone Administration on Performance, Body Composition and Protein and Fat Accretion of Growing Pigs. J Anim Sci 67, 177-186

Campbell RG, Taverner MR (1988) Genotype and sex effects on the relationship between energy intake and protein deposition in growing pigs. J Anim Sci 66, 676-686

Chiba LI (1994) Effects of dietary amino acid content between 20 and 50 kg and 50 and 100 kg live weight on the subsequent and overall performance of pigs. Livest Prod Sci 39, 213-221

Chiba LI (1995) Effects of nutritional history on the subsequent and overall growth performance and carcass traits of pigs. Livest Prod Sci 41, 151-161

Claus R (1993) Resumée: Vergleichende Wertung der bisherigen Ergebnisse aus dem Gemeinschaftsversuch zur Ebermast. In: Mitteilungsblatt der Bundesanstalt für Fleischforschung Kulmbach, 32. Jahrgang. 120,. 150-152

Claus R, Hoffmann B (1980) Oestrogens, compared to other steroids of testicular origin, in bloodplasma of boars. Acta Endocrinologica 94, 404-411

Claus R, Weiler U (1994) Endocrine regulation of growth and metabolism in the pig: a review. Livest Prod Sci 37, 245-260

Cliplef RL, McKay RM (1993) Carcass quality characteristics of swine selected for reduced backfat thickness and increased growth rate. Can J Anim Sci 73, 483-494

Cronin GM, Dunshea FR, Butler KL, McCauley I, Barnett JL, Hemsworth PH (2003) The effects of immuno- and surgical-castration on the behaviour and consequently growth of group-housed, male finisher pigs. Appl Anim Behav Sci 81, 111-126

de Greef KH, Kemp B, Verstegen MWA (1992) Performance and body composition of fatteningpigs of two strains during protein deficiency and subsequent realimentation. Livest Prod Sci 30, 141-153

De la Llata M, Dritz SS, Tokach MD, Goodband RD, Nelssen JL (2007) Effects of increasing lysine to calorie ratio and added fat for growing-finishing pigs reared in a commercial environment: I. Growth performance and carcass characteristics. Prof Anim Sci 23**,** 417-428

De Lange CFM, Morel PCH, Birkett SH (2003) Modeling chemical and physical body composition of the growing pig. J Anim Sci 81**,** E159-E165

Deng D, Li A-K, Chu WY, Huang RL, Li TJ, Kong XF, Liu ZJ, Wu GY, Zhang YM, Yin YL (2007) Growth performance and metabolic responses in barrows fed low-protein diets supplemented with essential amino acids. Livestock Science 109**,** 224-227

DLG (2010) Erfolgreiche Mastschweinefütterung. DLG Verlag, Frankfurt am Main, 34-36

Dobrowolski A, Höreth R, Branscheid W (1995) Der Schlachtkörperwert von Ebern und Börgen und Probleme der Klassifizierung. Die Ebermast - Fragen und Konsequenzen bei der Produktion von Schweinefleisch. Schriftenreihe des Bundesministeriums für Ernährung, Landwirtschaft und Forsten / A, Angewandte Wissenschaft, 449. Landwirtschaftsverlag, Münster, 6-13

Dunshea F, Colantoni C, Howard K, McCauley I, Jackson P, Long K, Lopaticki S, Nugent EA, Simons J, Walker J, Hennessy D (2001) Vaccination of boars with a GnRH vaccine (Improvac) eliminates boar taint and increases growth performance. J Anim Sci 79**,** 2524-2535

Dunshea F, King R, Campbell R, Sainz R, Kim Y (1993) Interrelationships between sex and ractopamine on protein and lipid deposition in rapidly growing pigs. J Anim Sci 71**,** 2919-2930

EFSA (2004) Welfare aspects of the castration of piglets. The EFSA Journal 1-18

Ellis M, Webb AJ, Avery PJ, Brown I (1996) The influence of terminal sire genotype, sex, slaughter weight, feeding regime and slaughter-house on growth performance and carcass and meat quality in pigs and on the organoleptic properties of fresh pork. Anim Sci 62**,** 521-530

Fabian J, Chiba LI, Frobish LT, McElhenney WH, Kuhlers DL, Nadarajah K (2004) Compensatory growth and nitrogen balance in grower-finisher pigs. J Anim Sci 82**,** 2579-2587

Fàbrega E, Velarde A, J. Cros MG, P. Suárez, J. Tibau, J. Soler (2010) Effect of vaccination against gonadotrophin-releasing hormone, using Improvac®, on growth performance, body composition, behaviour and acute phase proteins. Livest Prod Sci 132**,** 53-59

Fortin A, Friend DW, Sarkar NK (1983) A NOTE ON THE CARCASS COMPOSITION OF YORKSHIRE BOARS AND BARROWS. Can J Anim Sci 63**,** 711-714

Fredriksen B, Font i Furnols M, Lundström K, Migdal W, Prunier A, Tuyttens FAM, Bonneau M (2009) Practice on castration of piglets in Europe. Animal 3**,** 1480-1487

Friesen KG, Nelssen JL, Goodband RD, Tokach MD, Unruh JA, Kropf DH, Kerr BJ (1994) Influence of dietary lysine on growth and carcass composition of high-lean-growth gilts fed from 34 to 72 kilograms. J Anim Sci 72**,** 1761-1770

Fuller M (1994) Amino acid requirements for maintenance, body protein accretion and reproduction in pigs. In: D'Mello JPF (ed.) Amino acids in farm animal nutrition. CAB International, Wallingford, 155-184

Fuller MF, Franklin MF, McWilliam R, Pennie K (1995) The responses of growing pigs, of different sex and genotype, to dietary energy and protein. J Anim Sci 60**,** 291-298

Fuller MF, McWilliam R, Wang TC, Giles LR (1989) The optimum dietary amino acid pattern for growing pigs. British Journal of nutrition 62**,** 255-267

Gädeken D, Oslage HJ, Böhme H (1985) Untersuchungen zum energetischen Erhaltungsbedarf und zur Verwertung der umsetzbaren Energie für den Protein- und Fettansatz bei Ferkeln. Archiv für Tierernaehrung 35**,** 481-494

García-Macías JA, Gispert M, Oliver MA, Diestre A, Alonso P, Muñoz-Luna A, Siggens K, Cuthbert-Heavens D (1996) The effects of cross, slaughter weight and halothane genotype on leanness and meat and fat quality in pig carcasses. Anim Sci 63**,** 487-496

Gatel F, Grosjean F (1992) Performance of pigs from two genotypes inrelation to the amino acid content of the diet. Livest Prod Sci 30**,** 129-140

Gebhardt G (1966) Die Bewertung der Eiweißqualität von Nahrungs- und Futtermitteln mit Hilfe des N-Bilanzversuches. In: Hock A. (ed.) Vergleichende Ernährungslehre des Menschen und seiner Haustiere. VEB Gustav Fischer Verlag, Jena, 323-348

GfE (2005) Standardised precaecal digestibility of amino acids in feedstuffs for pigs – methods and cocepts. Pro. Soc. Nutr. Physiol. 14**,** 185-205

GfE (2008) Recommendations for the supply of energy and nutrients to pigs. DLG Verlag, Frankfurt am Main, Germany

Gispert M, Angels Oliver M, Velarde A, Suarez P, Perez J, Font i Furnols M (2010) Carcass and meat quality characteristics of immunocastrated male, surgically castrated male, entire male and female pigs. Meat Sci 85**,** 664-670

Gómez RS, Lewis AJ, Miller PS, Chen HY, Diedrichsen RM (2002) Body composition and tissue accretion rates of barrows fed corn-soybean meal diets or low-protein, amino acid-supplemented diets at different feeding levels. J Anim Sci 80**,** 654-662

Henry Y (1985) Dietary factors involved in feed intake regulation in growing pigs: A review. Livest Prod Sci 12**,** 339-354

Jeroch H, Drochner W, Simon M (1999) Ernährung landwirtschaftlicher Nutztiere. Verlag Eugen Ulmer Stuttgart, 43-52

Kanis E, Koops W (1990) Daily gain, food intake and food efficiency in pigs during the growing period. Anim Prod 50**,** 353-364

Kemm EH, Siebrits FK, Ras MN, Coetzee SE (1995) Feed intake, growth and protein deposition of pigs fed three protein levels. Livest Prod Sci 1994**,** 163-170

Kerr BJ, Yen JT, Nienaber JA, Easter RA (2003) Influences of dietary protein level, amino acid supplementation and environmental temperature on performance, body composition, organ weights and total heat production of growing pigs. J Anim Sci 81**,** 1998-2007

Kim BG, Petersen GI, Hinson RB, Allee GL, Stein HH (2009) Amino acid digestibility and energy concentration in a novel source of high-protein distillers dried grains and their effects on growth performance of pigs. J Anim Sci 87**,** 4013-4021

Kirchgeßner M (2004) Tierernährung. DLG Verlag, Frankfurt am Main,

Knudson BK, Hogberg MG, Merkel RA, Allen RE, Magee WT (1985) Developmental Comparisons of Boars and Barrows: I. Growth Rate, Carcass and Muscle Characteristics. J Anim Sci 61**,** 789-796

Lanferdini E, Lovatto PA, Melchior R, Orlando UAD, Ceccantini M, Poleze E (2013) Feeding surgically castrated, entire male and immunocastrated pigs with different levels of amino acids and energy at constant protein to energy ratio with or without ractopamine. Livestock Science 151**,** 246-251

Latorre MA, Lázaro R, Gracia MI, Nieto M, Mateos GG (2003) Effect of sex and terminal sire genotype on performance, carcass characteristics, and meat quality of pigs slaughtered at 117 kg body weight. Meat Sci 65**,** 1369-1377

Latorre MA, Lázaro R, Valencia DG, Medel P, Mateos GG (2004) The effects of gender and slaughter weight on the growth performance, carcass traits, and meat quality characteristics of heavy pigs. J Anim Sci 82**,** 526-533

Lunde K, Skuterud E, Nilsen A, Egelandsdal B (2009) A new method for differentiating the androstenone sensitivity among consumers. Food Quality and Preference 20**,** 304-311

Lundström K, Matthews KR, Haugen J-E (2009) Pig meat quality from entire males. animal 3**,** 1497-1507

Mahan DC, Shields RG (1998) Essential and nonessential amino acid composition of pigs from birth to 145 kilograms of body weight, and comparison to other studies. J Anim Sci 76**,** 513-521

Martínez-Ramírez HR, Jeaurond EA, de Lange CFM (2008) Dynamics of body protein deposition and changes in body composition after sudden changes in amino acid intake: II. Entire male pigs. J Anim Sci 86**,** 2168-2179

McCracken K, Beattie VE, Weatherup RN, McIlroy SG, Henry RW. Effects of diet energy density and protein (amino acid) content on intake, body composition and energy metabolism of boars and gilts fed *ad libitum* from 22 to 46 kg. *In:* McCracken KJ, Unsworth E. F., Wylie A. R. G., eds. Symposium of Energy Metabolism, 1997 Newcastle, Northern Ireland. CAB International, 237-240.

McGloughlin P, Allen P, Tarrant PV, Joseph RL, Lynch PB, Hanrahan TJ (1988) Growth and carcass quality of crossbred pigs sired by Duroc, Landrace and Large White boars. Livest Prod Sci 18**,** 275-288

Metz C, Hohl K, Waidelich S, Drochner W, Claus R (2002) Active immunization of boars against GnRH at an early age: consequences for testicular function, boar taint accumulation and N-retention. Livest Prod Sci 74**,** 147-157

Morales JI, Cámara L, Berrocoso JD, López JP, Mateos GG, Serrano MP (2011) Influence of sex and castration on growth performance and carcass quality of crossbred pigs from 2 Large White sire lines. J Anim Sci 89**,** 3481-3489

Morrison RS, Hemsworth PH, Cronin GM, Campbell RG (2003) The effect of restricting pen space and feeder availability on the behaviour and growth performance of entire male growing pigs in a deep-litter, large group housing system. Appl Anim Behav Sci 83**,** 163-176

Moughan P, Fuller M D´Mello JPF (2003) Modelling Amino Acid Metabolism and the Estimation od Amino Acid Requirements. Amino Acids in Animal Nutrition. 187-202

Nam DS, Aherne FX, Darroch CS (1995) Growth performance of pigs given a choice of natural ingredient diets containing different levels of protein and amino acid(s). Animal Feed Science and Technology 56**,** 265-276

Noblet J, Karege C, Dubois S, van Milgen J (1999) Metabolic utilization of energy and maintenance requirements in growing pigs: effects of sex and genotype. J Anim Sci 77**,** 1208-1216

NRC (1998) Nutrient Requirement of Swine. National Academy Press, Washington, DC,

O'Connell MK, Lynch PB, O'Doherty JV (2006) Determination of the optimum dietary lysine concentration for boars and gilts penned in pairs and in groups in the weight range 60 to 100 kg. Anim Sci 82**,** 65-73

Oslage HJ, Petersen U, Böhme H, Gädeken D (1986) Untersuchungen zur optimalen Protein- und Energieversorgung wachsender Schweine. Landbauforschung Applied Agricultural and Forestry Research 36**,** 190-200

Otten C, Berk A, Dänicke S (2013a) Voluntary feed intake and growth performance of boars and barrows in dependence on lysine-to-energy ratio. Arch Tierz 56**,** 39

Otten C, Berk A, Hagemann L, Müller S, Weber M, Dänicke S (2013b) Effect of varying supply of amino acids on nitrogen retention and growth performance of boars of different sire lines. Arch Tierz 56**,** 75

Pathak NN (2012) Feeding and nutrition of swine. In: Mehra U.R., Singh P., Verma A.K. (ed.) Animal Nutrition. Satish Serial Publishinh House, Delhi, India, 135-161

Pauly C, Spring P, O'Doherty JV, Ampuero Kragten S, Bee G (2008) Performances, meat quality and boar taint of castrates and entire male pigs fed a standard and a raw potato starch-enriched diet. animal 2**,** 1707-1715

Person RC, McKenna DR, Griffin DB, McKeith FK, Scanga JA, Belk KE, Smith GC, Savell JW (2005) Benchmarking value in the pork supply chain: Processing characteristics and consumer evaluations of pork bellies of different thicknesses when manufactured into bacon. Meat Sci 70**,** 121-131

Pfeiffer H, von Lengerken G, Gebhardt G (1984) Wachstum und Schlachtkörperqualität bei landwirtschaftlichen Nutztieren - Schweine. VEB Deutscher Landwirtschaftsverlag, Berlin,

Prunier A, Bonneau M, von Borell EH, Cinotti S, Gunn M, Fredriksen B, Giersing M, Morton DB, Tuyttens FAM, Velarde A (2006) A review of the welfare consequences of surgical castration in piglets and the evaluation of non-surgical methods. Anim Welfare 15**,** 277-289

Quiniou N, Dubois S, Le Cozler Y, Bernier JF, Noblet J (1999) Effect of growth potential (body weight and breed/castration combination) on the feeding behaviour of individually kept growing pigs. Livest Prod Sci 61**,** 13-22

Quiniou N, Dubois S, Noblet J (1995) Effect of dietary crude protein level on protein and energy balances in growing pigs: comparison of two measurement methods. Livest Prod Sci 41**,** 51-61

Quiniou N, Dubois S, Noblet J (2000) Voluntary feed intake and feeding behaviour of group-housed growing pigs are affected by ambient temperature and body weight. Livest Prod Sci 63**,** 245-253

Raj S, Skiba G, Weremko D, Fandrejewski H, Migdał W, Borowiec F, Poławska E (2010) The relationship between the chemical composition of the carcass and the fatty acid composition of intramuscular fat and backfat of several pig breeds slaughtered at different weights. Meat Sci 86**,** 324-330

Rao D, McCracken K (1990) Protein requirement of boars of high genetic potential for lean growth. Anim Prod 51**,** 179-187

Reynolds A, O'Doherty J (2006) The effect of amino acid restriction during the grower phase on compensatory growth, carcass composition and nitrogen utilisation in grower–finisher pigs. Livest Prod Sci 112-120

Rinaldo D, Le Dividich J (1991) Assessment of optimal temperature for performance and chemical body composition of growing pigs. Livest Prod Sci 29**,** 61-75

Roehe R, Plastow GS, Knap PW (2003) Quantitative and molecular genetic determination of protein and fat deposition. HOMO - Journal of Comparative Human Biology 54**,** 119-131

Rook AJ, Ellis M, Whittemore CT, Phillips P (1987) Relationships between whole-body chemical composition, physically dissected carcass parts and backfat measurements in pigs. Anim Sci 44**,** 263-273

Sauer WC, Huang S, Blank R, Mosenthin R (1999) Ideal protein and digestible amino acids for pigs. Feed Magazine/Kraftfutter 1**,** 22-25

Shields RG, Jr., Mahan DC, Graham PL (1983) Changes in swine body composition from birth to 145 kg. J Anim Sci 57**,** 43-54

Simon O (1989) Metabolism of protein and amino acids. In: Bock H.-D., Eggum B. O., Low A. G., Simon O., Zebrowska T. (ed.) Protein Metabolism in Farm Animals. VEB Deutscher Landwirtschaftsverlag

Oxford University Press, Berlin and Oxford, 273-366

Smith JW, Tokach MD, O'Quinn PR, Nelssen JL, Goodband RD (1999) Effects of dietary energy density and lysine:calorie ratio on growth performance and carcass characteristics of growing-finishing pigs. J Anim Sci 77**,** 3007-3015

Susenbeth A, Keitel K (1988) Partition of whole body protein in different body fractions and some constants in body composition in pigs. Livest Prod Sci 20**,** 37-52

Suster D, Leury BJ, Kerton DJ, Borg MR, Butler KL, Dunshea FR (2006) Longitudinal DXA measurements demonstrate lifetime differences in lean and fat tissue deposition between boars and barrows under individual and group-penned systems. Australian Journal of Agricultural Research 57**,** 1009-1015

Thong HT, Liebert F (2004a) Amino acid requirement of growing pigs depending on amino acid efficiency and level of protein deposition 1st communication: lysine. Archives of Animal Nutrition 58**,** 69-87

Thong HT, Liebert F (2004b) Amino acid requirement of growing pigs depending on amino acid efficiency and level of protein deposition. 2nd communication: threonine. Archives of Animal Nutrition 58**,** 157-168

Turkstra JA, Zeng XY, van Diepen JTM, Jongbloed AW, Oonk HB, van de Wiel DFM, Meloen RH (2002) Performance of male pigs immunized against GnRH is related to the time of onset of biological response. J Anim Sci 80**,** 2953-2959

Van Lunen TA, Cole DJA (1996a) The effect of lysine/digestible energy ratio on growth performance and nitrogen deposition of hybrid boars, gilts and castrated male pigs. Anim Sci 63**,** 465-475

Van Lunen TA, Cole DJA (1996b) Energy-amino acid interactions in modern pig genotypes. Recent advances in animal nutrition 1996. Nottingham University Press, S. 233-261

Vanheukelom V, Van Beirendonck S, Van Thielen J, Driessen B (2012) Behavior, production results and meat quality of intact boars and gilts housed in unmixed groups: A comparative study. Appl Anim Behav Sci 142**,** 154-159

VDLUFA (2007) (Verband Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten) Handbuch der Landwirtschaftlichen Versuchs- und Untersuchungsmethodik (VDLUFA-Methodenbuch), Band III. Die chemische Untersuchung von Futtermitteln. VDLUFA-Verlag, Darmstadt, Germany

Wagner JR, Schinckel AP, Chen W, Forrest JC, Coe BL (1999) Analysis of body composition changes of swine during growth and development. J Anim Sci 77**,** 1442-1466

Wang TC, Fuller MF (1989) The optimum dietary amino acid pattern for growing pigs. British Journal of nutrition 62**,** 77-89

Warnants N, Van Oeckel MJ, De Paepe M (2003) Response of growing pigs to different levels of ileal standardised digestible lysine using diets balanced in threonine, methionine and tryptophan. Livest Prod Sci 82**,** 201-209

Wecke C, Liebert F (2009) Lysine requirement studies in modern genotype barrows dependent on age, protein deposition and dietary lysine efficiency. Journal of Animal Physiology and Animal Nutrition 93**,** 295-304

Weis RN, Birkett SH, Morel PCH, de Lange CFM (2004) Effects of energy intake and body weight on physical and chemical body composition in growing entire male pigs. J Anim Sci 82**,** 109-121

Williams WD, Cromwell GL, Stahly TS, Overfield JR (1984) The Lysine Requirement of the Growing Boar versus Barrow. J Anim Sci 58**,** 657-665

Wood JD, Lambe NR, Walling GA, Whitney H, Jagger S, Fullarton PJ, Bayntun J, Hallett K, Bünger L (2013) Effects of low protein diets on pigs with a lean genotype. 1. Carcass composition measured by dissection and muscle fatty acid composition. Meat Sci 95**,** 123-128

Yen HT, Cole DJA, Lewis D (1986a) Amino acid requirements of growing pigs. 7. The response of pigs from 25 to 55 kg live weight to dietary ideal protein. Anim Sci 43**,** 141-154

Yen HT, Cole DJA, Lewis D (1986b) Amino acid requirements of growing pigs. 8. The response of pigs from 50 to 90 kg live weight to dietary ideal protein. Anim Sci 43**,** 155-165

Zamaratskaia G, Andersson HK, Chen G, Andersson K, Madej A, Lundström K (2008) Effect of a Gonadotropin-releasing Hormone Vaccine (ImprovacTM) on Steroid Hormones, Boar Taint Compounds and Performance in Entire Male Pigs. Reprod Domest Anim 43**,** 351-359

Zeng X, Turkstra J, Jongbloed A, van Diepen J, Meloen R, Oonkb H, Guoa D, van de Wiel D (2002) Performance and hormone levels of immunocastrated, surgically castrated and intact male pigs fed ad libitum high- and lowenergy diets. Livest Prod Sci 83**,** 1-11

Zhang G, Yi X, Chu L, Lu N, Htoo J, Qiao S (2011) Effects of dietary net energy density and standardized ileal digestible lysine: Net energy ratio on the performance and carcass characteristic of growing-finishing pigs fed low crude protein supplemented with crystalline amino acids diets. Agric Sci China 10**,** 602-610

CURRICULUM VITAE

Caroline Otten
Born on 29 November 1984
In Lingen (Ems), Germany

1997 - 2004	Franziskusgymnasium Lingen (Ems) Degree: Abitur
2004 - 2009	Diploma studies of Agricultural Science at the Rheinische Friedrich-Wilhelms-Universität Bonn Degree: Diplom-Agraringenieurin
2009 - 2011	Quality management employee and animal welfare officer at the Westfleisch eG Meatplant, Coesfeld
Since March 2011	Guest scientist at the Institute of Animal Nutrition, Federal Research Institute for Animal Health, Friedrich-Loeffler-Institute, Braunschweig

EIDESSTATTLICHE ERKLÄRUNG

Ich erkläre an Eides statt, dass ich die Arbeit selbstständig und ohne fremde Hilfe verfasst, keine anderen als die von mir angegebenen Quellen und Hilfsmittel benutzt und die den benutzten Werken wörtlich oder inhaltlich entnommenen Stellen als solche kenntlich gemacht habe.

Braunschweig, 14.10.2013 Caroline Otten

DANKSAGUNG

An dieser Stelle bedanke ich mich herzlich bei allen Personen, die mich im Laufe meiner Promotionszeit begleitet und mir sowohl bei der Versuchsplanung und Durchführung, als auch bei der Erarbeitung meiner Dissertation hilfreich zur Seite standen.

Ein besonderer Dank gilt Herrn Prof. Dr. Dr. Sven Dänicke für die fortwährende Unterstützung bei der Erstellung der vorliegenden Arbeit sowie die kompetente und lösungsorientierte Diskussion der Versuchsergebnisse.

Herrn Dr. Andreas Berk danke ich für die wissenschaftliche Betreuung meiner Arbeit, die wertvollen Gespräche und das stets „offene Ohr" in allen Phasen meiner Dissertation.

Des Weiteren danke ich dem Bundesministerium für Ernährung und Landwirtschaft bzw. der Bundesanstalt für Landwirtschaft und Ernährung für die finanzielle Unterstützung des Projektes, welches mir die Anfertigung dieser Arbeit erlaubte. Stellvertretend für alle weiteren Mitglieder des Verbundforschungsprojektes „Eberfütterung" bedanke ich mich bei der Projektkoordinatorin Frau Dr. Simone Müller für die angenehme und konstruktive Zusammenarbeit.

Ein großes Dankeschön geht außerdem an alle Mitarbeiter des Institutes für Tierernährung in Braunschweig und der LPA in Iden für die vielfältige Mithilfe vom Stall über das Schlachthaus bis ins Labor. Nur so war es möglich die verschiedenen aufwendigen Versuche durchzuführen, die im Rahmen dieser Arbeit von Nöten waren.

Den Gastwissenschaftlern des Institutes für Tierernährung danke ich für ihre Hilfsbereitschaft bei der Versuchsdurchführung zu allen Tages- und Nachzeiten als auch für die schöne und intensive Zeit am Institut.

Zu guter Letzt einen lieben Dank an meine Eltern und an meinen Freund David, welche mich immer bestärkt und unterstützt haben. Außerdem danke ich meiner Familie und meinen Freunde, die für den nötigen Ausgleich und die Motivation sorgten.