

Can compensatory growth contribute to reduce the so-called protein gap in organic pig fattening?

Andreas Berk* and Friedrich Weißmann**

Abstract

The lack of organic feed with high quality amino acid pattern (protein gap) makes it more difficult to achieve Lysine-energy-ratios in 100 % organic grower diets required for high yielding growing-finishing pigs. The resultant marginal Lysine supply threatens to reduce body protein synthesis. Hence, the objective of our study was to investigate whether a moderate oversupply of Lysine in the finisher period after a marginal Lysine supply in the grower period will result in compensatory growth (CG). 48 gilts and 48 barrows were equally divided into four groups with different Lysine-energy-ratios (g Lysine per MJ Metabolisable Energy [ME]) in the grower diet (grodi) and in the finisher diet (findi): (i) Group_1 – experimental group: 0.69 (grodi)/0.69 (findi); (ii) Group_2 – negative control group: 0.69 (grodi)/0.59 (findi); (iii) Group_3 – positive control group: 0.89 (grodi)/0.69 (findi); (iv) Group_4 – regular control group: 0.89 (grodi)/0.59 (findi). N-retention (as criterion for body protein gain) was measured for a random sample of barrows, and growth performance, carcass quality, and meat quality were recorded for all pigs. N-retention indicated compensatory body protein gain for Group_1 barrows. All groups were similar in meat quality and growth performance for the whole fattening period but Group_1 pigs showed CG for daily weight gain and daily feed intake in the finishing period. Group_1 and Group_2 pigs showed only slightly, non-significant lower lean meat percentages than Group_3 and Group_4 pigs, this is taken to be at least partial CG. It is concluded that CG mechanisms help to reduce the protein gap in organic pig fattening, facilitating the implementation of 100 % organic feeding.

Keywords: organic pig fattening; compensatory growth; N-retention; growth performance; carcass quality; meat quality

Zusammenfassung

Kann kompensatorisches Wachstum einen Beitrag zur Entschärfung der sogenannten Proteinlücke in der ökologischen Schweinemast leisten?

Der Mangel an Öko-Futtermitteln mit einem hochwertigen Aminosäuremuster (Proteinlücke) erschwert die Einstellung des für Hochleistungstiere notwendigen Lysin-Energie-Verhältnisses im Vormastfutter ausschließlich ökologischer Herkunft und droht den körpereigenen Proteinansatz zu vermindern. Daher wurde geprüft, ob der negative Effekt einer marginalen Lysinversorgung in der Anfangsmast durch eine moderate Überversorgung in der Endmast kompensiert werden kann. 48 weibliche und 48 kastrierte männliche Mastschweine wurden gleichmäßig auf vier Gruppen mit unterschiedlichen Lysin-Energie-Verhältnissen (g Lysin pro MJ Umsetzbare Energie) in der Anfangsmastration (AM) und in der Endmastration (EM) aufgeteilt: (i) Gruppe_1 – Versuch: 0,69 (AM)/0,69 (EM); (ii) Gruppe_2 – Negativkontrolle: 0,69 (AM)/0,59 (EM); (iii) Gruppe_3 – Positivkontrolle: 0,89 (AM)/0,69 (EM); (iv) Gruppe_4 - reguläre Kontrolle: 0,89 (AM)/0,59 (EM). Erfasst wurden: N-Retention (Stichprobe der Kastraten), Mastleistung, Schlachtkörper- und Fleischqualität (sämtliche Schweine). Die N-Retention belegte einen kompensatorischen Proteinansatz bei den Gruppe_1-Kastraten. Die vier Gruppen unterschieden sich nicht in der Fleischqualität und Mastleistung in der Gesamtmastperiode. Aber Gruppe_1 zeigte bei der Tageszunahme und Futteraufnahme in der Endmast kompensatorische Wachstumseffekte. Der Muskelfleischanteil war in den Gruppen 1 und 2 auf gleichem Niveau nur geringfügig niedriger als bei den auch auf gleichem Niveau liegenden Gruppen 3 und 4, was ein zumindest teilweiser kompensatorischer Effekt ist. Es wird geschlussfolgert, dass kompensatorische Wachstumsmechanismen die Proteinlücke in der ökologischen Schweinemast entschärfen und damit die Implementierung der 100 % Biofütterung erleichtern können.

Schlüsselwörter: Ökologische Schweinemast; kompensatorisches Wachstum; N-Retention; Mastleistung; Schlachtkörperqualität; Fleischqualität

* Friedrich-Loeffler-Institut (FLI), Institute of Animal Nutrition, Bundesallee 50, D 38116 Braunschweig, Germany

** Johann Heinrich von Thünen-Institut, Federal Research Institute for Rural Areas, Forestry and Fisheries, Institute of Organic Farming, Trenthorst 32 23847 Westerau, Germany

Corresponding author: Dr. Friedrich Weißmann, E.mail: friedrich.weissmann@vti.bund.de

Introduction

Also in *organic* pig fattening carcass quality significantly influences farmers' economic success. Corresponding market-driven lean meat contents predominantly depend on the choice of a suitable genotype and an adequate diet (Weißmann, 2011). Nutrition-related body protein synthesis is primarily determined by the ratio of feed energy to essential amino acids (EAAs) in the diet – in particular Lysine, mostly the first limiting amino acid – which in turn depends on available protein feeds (Szabo et al., 2001). Organic monogastric feeding is characterised by the so-called protein gap, a lack of feedstuffs of organic origin with a high quality amino acid pattern (Zollitsch, 2007). Hence, it is particularly difficult to achieve the DLG-required (Deutsche Landwirtschafts-Gesellschaft) Lysine-energy-ratio for high yielding growing-finishing pigs in the grower period with possible negative impact on growth performance, carcass quality, and resulting profits. Usually two solution strategies are combined (Wlcek & Zollitsch, 2004): **(i)** high amount of protein feeds in the diet to achieve the required amino acid contents via high crude protein contents but with possible negative environmental impact and **(ii)** use of non-organic high quality protein feeds (in Germany usually potato protein) based on the legal exceptions within the EU-Eco-regulations 834/2007 (EU-Kommission, 2007) and 889/2008 (EU-Kommission, 2008) which will expire in 2014 (EU-Kommission, 2012). Both strategies with their inherent shortcomings have to be negatively valued with regard to the reliability and the future profile of organic agriculture (Niggli, 2005; Rahmann et al., 2009).

In this context the biological principle of compensatory growth could be of interest. Compensatory growth is a phenomenon observed in livestock and describes the animals' ability to recover from a previous period of nutritional restriction during the realimentation period (Molnar, 1995). Restriction and realimentation occur in terms of limited versus free access to feed (e.g. Therkildsen et al., 2004) or in terms of marginal versus improved diet quality (e.g. Yang et al., 2008). The compensatory effect is caused by an increased feed intake (e.g. Critser et al., 1995) and/or by an improved feed conversion reflecting better metabolic nutrient utilisation (e.g. Oksbjerg et al., 2002). The compensation rate can be complete (e.g. Fabian et al., 2004) or partial (e.g. Wahlstrom & Libal, 1983) and mostly depends on the severity of the restrictive period. The metabolic processes behind compensatory growth are not yet completely understood (Hornick et al., 2000).

Against that background, an organic feeding trial was set up to clarify whether reduced body protein gain in the grower period (due to a lower Lysine-energy-ratio in the grower diet because of the non-use of increased dietary

crude protein and the non-use of non-organic protein feeds) can be *compensated* by a slightly enhanced Lysine-energy-ratio in the finisher period compared to the DLG recommendations (DLG, 1991; GfE, 2008).

Methods

Test design

The feeding trial was divided into the actual fattening trial and a therein embedded nitrogen (N) balance trial with a limited number of barrows from the fattening trial.

Four different groups were set up with differing ratios of dietary Metabolisable Energy (ME) and dietary Lysine (g Lysine per MJ ME) in the grower diet (grodi) and in the finisher diet (findi) (Table 1): **(i)** Group_1: 0.69 (grodi)/0.69 (findi) – experimental group for the confirmation of compensatory growth, i.e. body protein synthesis, with a Lysine undersupply in the grower diet and a slight Lysine oversupply in the finisher diet in the form of a one-phase diet; **(ii)** Group_2: 0.69 (grodi)/0.59 (findi) – negative control group in the form of a Lysine undersupply in the grower and a regular supply in the finisher diet, so that the missing enhanced Lysine supply in the finisher diet would not initiate compensatory protein gain; **(iii)** Group_3: 0.89 (grodi)/0.69 (findi) – positive control group with the expectation that an oversupply of Lysine in the finisher diet would not result in an additional body protein synthesis; **(iv)** Group_4: 0.89 (grodi)/0.59 (findi) – regular control group with a regular Lysine-ME-ratio in the grower and in the finisher diet corresponding to the German feeding recommendations of the DLG (1991).

Table 1:
Experimental design

| | Group_1 | Group_2 | Group_3 | Group_4 |
|---|-----------------|------------------|------------------|-----------------|
| Number of intended animals (barrows + gilts) | 24 (12 + 12) | 24 (12 + 12) | 24 (12 + 12) | 24 (12 + 12) |
| Lysine-energy-ratio [g Lysine/MJ Metabolisable Energy] in the ... | | | | |
| grower diet | 0.69 | 0.69 | 0.89 | 0.89 |
| finisher diet | 0.69 | 0.59 | 0.69 | 0.59 |
| Labelling | Experiment | Negative control | Positive control | Regular control |
| Diet in the ... | | | | |
| grower period | Feed_2 | Feed_2 | Feed_1 | Feed_1 |
| finisher period | Feed_2 | Feed_3 | Feed_2 | Feed_3 |

Feed

Table 1 illustrates that the three differing Lysine-ME-ratios of 0.89, 0.69 and 0.59 in the grower and finisher periods were achieved by feeding three different feeds. Table 2 describes the corresponding feed ingredients and the analysed feed nutrients according to the German VDLUFA-standard (Naumann & Bassler, 1993). The diets consisted of feed ingredients of 100 % organic origin except for potato protein in Feed_1 which is necessary to achieve the high Lysine content and which is inherent to the subject of the study. Table 2 points out the good congruence of the intended and analysed Lysine-ME-ratios which is of extreme interest for the goals of the study. Inexplicably, the targeted contents of the sulphur-containing amino acids (g Methionine + g Cystine per g Lysine) of 0.59, 0.62 and 0.66 in Feed_1, Feed_2 and Feed_3, respectively, were not exactly achieved (Table 2) which cannot be explained.

Table 2:
Characteristics of the three feeds used in the experiment

| | Feed_1 | Feed_2 | Feed_3 |
|---|--------|--------|--------|
| Feed ingredients | | | |
| Winter barley [g/kg] | 362 | 382 | 416 |
| Triticale [g/kg] | 150 | 210 | 240 |
| Field peas + field beans [g/kg] | 200 | 200 | 185 |
| Soybean cake [g/kg] | 80 | 90 | 50 |
| Rapeseed cake [g/kg] | 75 | 50 | 40 |
| Wheat bran [g/kg] | 55 | 40 | 40 |
| Potato protein, conventional origin [g/kg] | 50 | -- | -- |
| Mineral feed* [g/kg] | 20 | 20 | 20 |
| CaCO ₃ [g/kg] | 8 | 8 | 9 |
| Feed composition (referring to dry matter = DM) | | | |
| Metabolisable energy, ME [MJ/kg DM] | 14.24 | 14.21 | 14.16 |
| Crude protein [g/kg DM] | 212 | 168 | 148 |
| Crude fat [g/kg DM] | 44 | 40 | 37 |
| Crude fibre [g/kg DM] | 54 | 52 | 51 |
| Nitrogen-free extract [g/kg DM] | 632 | 681 | 709 |
| Starch [g/kg DM] | 447 | 503 | 512 |
| Sugar [g/kg DM] | 41 | 43 | 41 |
| Lysine [g/kg DM] | 12.66 | 9.54 | 8.44 |
| Methionine + Cystine [g/kg DM] | 6.57 | 5.65 | 4.89 |
| Threonine [g/kg DM] | 7.23 | 6.56 | 5.25 |
| Lysine - energy - ratio [g Lysine/MJ ME] | 0.89 | 0.67 | 0.60 |
| Methionine + Cystine - Lysine - ratio [g Methionine + Cystine/g Lysine] | 0.52 | 0.58 | 0.58 |
| Threonine - Lysine - ratio [g Threonine/g Lysine] | 0.57 | 0.69 | 0.62 |
| * Commercial supplement containing minerals, trace elements and vitamins (contains per kg: 210 g Ca; 70 g P; 60 g Na; 10 g Mg; 500,000 I.E. Vit. A; 50,000 I.E. Vit. D3; 2,500 mg Vit. E; 60 mg Vit. B1; 185 mg Vit. B2; 150 mg Vit. B6; 1,200 mcg Vit. B12; 120 mg Vit. K3; 1,250 mg Vit. C; 750 mg Nicotinic acid; 450 mg Ca-Pantothenate; 30 mg Folic acid; 4,000 mcg Biotin; 10,000 mg Choline Chloride; 4,500 mg Fe; 400 mg Cu; 2,130 mg Mn; 2,670 mg Zn; 53 mg I; 10.5 mg Se; 6.6 mg) | | | |

However the congruence to the DLG-recommendations is good enough in all three feeds to exclude negative impacts on the subject of the paper. This is also the case for Threonine with a target level of 0.68, 0.68 and 0.69 g Threonine per g Lysine in Feed_1, Feed_2 and Feed_3 respectively (Table 2) (DLG, 1991). Dietary energy supply in the three feeds is in accordance with the German recommendations for growing-finishing pigs with intended 900 g average daily weight gain (DLG, 1991).

Animals

The trial consisted of 48 gilts and 48 barrows randomly assigned to four groups considering equal distribution of sex and of body weight except pedigree. All animals came from the research farm of the Institute of Organic Farming in Trenthorst with known dams and sires. The dams' genetic origin are Schaumann®-sows, i.e. DE*DL-crossbreds (DE = Deutsches Edelschwein, German Large Wight; DL = Deutsche Landrasse, German Landrace) and replacement sows by criss-crossing the Schaumann®-sow with

DE or DL respectively. Two individual Piétrain*Duroc-crossbred terminal sires were used via artificial insemination and natural service respectively. Four gilts were lost due to diseases of the respiratory and the musculoskeletal system without relation to the experimental approach. Hence, Group_1, Group_2, Group_3 and Group_4 ultimately consisted of 22, 23, 24 and 23 recorded and analysed pigs respectively.

Experimentation

The trial was performed at the pig fattening facility of the Institute of Animal Nutrition in Braunschweig. The fattening trial started in December 2008 and consisted of two runs of 54 and 42 animals respectively, at intervals of four weeks.

The animals were individually housed in a Danish housing system with individual trough feeding and without straw bedding. All animals were individually identified by ear tags on the occasion of initial weighing and grouping at the pig fattening facility for complete individual data recording concerning growth performance, carcass and meat quality.

The fattening period ranged from about 28 kg to about 116 kg live weight. The change between the grower period and the finisher period was projected at an animal's live weight between 75 kg and 80 kg. Slaughtering took place in the Institute's own abattoir usually on Mondays when the animals had reached > 109.5 kg live weight in the previous week. Subsequent to a resting period of 40 min at the abattoir the animals were slaughtered after electrical stunning. Table 3 shows the corresponding data. Feed was offered daily *ad libitum*.

The feed-, faeces-, and urine-based N-balances in in-

Table 3:

Number, mean live weight, mean carcass weight, and mean amino acid consumption of the recorded pigs (standard deviation)

| | Group_1 Experiment | Group_2 Negative control | Group_3 Positive control | Group_4 Regular control |
|---|-----------------------|--------------------------------|--------------------------------|-------------------------------|
| Barrows + gilts [n] | 12 + 10 | 12 + 11 | 12 + 12 | 12 + 11 |
| Live weight [kg] at the ... | | | | |
| start of the trial | 28.2 (1.8) | 28.7 (2.2) | 28.2 (1.5) | 29.5 (2.7) |
| end of the grower period | 76.8 (5.6) | 76.1 (5.0) | 77.5 (5.3) | 81.2 (6.7) |
| end of the trial | 115.9 (3.5) | 116.8 (3.9) | 117.0 (4.2) | 117.3 (4.4) |
| Carcass weight, warm [kg] | 91.0 (2.8) | 91.5 (2.6) | 91.6 (2.9) | 91.3 (2.9) |
| Consumption [g/animal] during the whole fattening period of ... | | | | |
| Lysine | 2458 (130) | 2305 (200) | 2853 (251) | 2691 (236) |
| Methionine+Cystine | 1416 (75) | 1331 (115) | 1546 (136) | 1451 (124) |
| Threonine | 1690 (89) | 1517 (134) | 1762 (155) | 1583 (136) |

dividual metabolism crates with individual feeding and separated collection of faeces and urine were in accordance with the guidelines of the German Gesellschaft für Ernährungsphysiologie – Society of Nutrition Physiology – (GfE, 2005). A total of 24 barrows were involved (4 groups x 2 runs x 3 barrows per group and run) always with the same individuals in the grower and in the finisher period. Two animals in Group_4 had to be withdrawn as they

failed to accept the metabolism crates at the end of the collection period in the finisher period in Run 1 and Run 2. Hence Group_4 consisted of only four recorded animals, whereas the other three groups consisted of the intended six barrows per group. The balance period was divided into a collection period of seven days and a previous period of 4 days to adapt the animals to the metabolism crates and to replace the *ad libitum* feeding with twice daily restricted feeding. This kind of feeding is necessary to (i) avoid feed losses and (ii) to achieve daily a nearly equal digestion process. The balance trials started with a mean live weight of 42.5 ± 2.7 kg (grower period) and 83.6 ± 5.5 kg (finisher period).

Data collection

The pigs were individually weighed at the outset and at the end of the trial on the day of slaughtering with intermediate weekly weighing. The daily weight gain of each animal was calculated for the grower, finisher and whole fattening period respectively. The daily feed intake was calculated from the weekly offered feed and the rest in the trough as weighed. Total consumption of the relevant amino acids Lysine, Methionine+Cystine and Threonine (Table 3) was derived from animals' mean feed intake and respective amino acid contents of the diets (Table 2). Feed conversion ratio is the relation between feed intake and live weight gain and presented for the grower, finisher and whole fattening period.

Warm carcass weight was recorded in order to calculate dressing percentage based on the final live weight. The day following slaughtering, the chilled right carcass half was used for measuring muscle and fat area and five different fat thicknesses (for its locations compare Results: Table 7) following the guideline for on-station testing of growth performance, carcass quality, and meat quality of the German Board for Performance Testing and Estimation of Breeding Value of the Pig (ZDS, 2007). Lean-to-fat ratio is the quotient of fat area and muscle area. Lean meat content is calculated with the "Bonner Formula" (ZDS, 2007), which uses the above mentioned fat area, muscle area, and five fat thickness measurements; lean meat percentage in the belly is calculated with the "Gruber Formula" taking muscle area, fat area, and two fat thickness measurements into account (ZDS, 2007).

The measuring of the physical meat quality traits *electrical conductivity* (EC) and *pH-value* (for its locations compare Results: Table 8) followed the above-mentioned pro-

cedure of data collection of the federal standard of the German testing stations (ZDS, 2007). In addition, the intramuscular fat content (IMF) of the *Musculus longissimus dorsi* (13th rib) was estimated by Near-Infrared-Reflectance (NIR) Spectroscopy (FOSS NIRS-System 6500) for a random sample of 50 % of the total number of animals equally divided between the four groups, the two runs and both sexes. NIR-calibration was additionally validated for half of the random sample by wet chemistry technique (modified §64-method without hydrochloric acid digestion, Lebensmittel- und Futtermittelgesetzbuch as amended on July 24, 2009).

Sampling and analysis of the N-balances were in accordance with the methodology of the German Society of Nutrition Physiology (GfE, 2005).

Statistical analysis

The data of growth performance, carcass quality and meat quality were statistically analysed with the analysis of variance procedure GLM of SAS Version 9.2 (SAS, 2008). The general linear model included the fixed effects of feeding group (FG: Group_1 (0.69-grodi/0.69-findi), Group_2 (0.69-grodi/0.59-findi), Group_3 (0.89-grodi/0.69-findi),

Group_4 (0.89-grodi/0.59-findi)), sex (SEX: barrows or gilts), interaction FG*SEX, and run (RUN: first or second trial run). Terminal sires and breed of dams were also tested as fixed effects and removed from the model due to non-significance. In addition the live weight at the start of the trial (LWS), the live weight at the change from the grower to the finisher period (LWC) and the live weight at the end of the trial (LWE) for growth performance traits, and carcass weight (CW) for carcass traits and IMF were included as covariates in the model. The LSQ-Means were statistically compared using the Tukey-Kramer-Test at 5 % significance level. N-balance data of the barrows are presented as means incl. standard deviation and the Tukey-Kramer-Test was used for multiple mean comparisons between groups and feeds respectively, at 5 % significance level.

Results

N-balance trial

The live weight (LW) data were raised to 0.67 to eliminate the influence of LW on N-retention as well as possible (Gebhardt, 1966). Further, all measured data were divided by $LW_{kg}^{0.67}$ of the respective animal. So it is possible to use

Table 4a:

Effect of the three feeds used in the trial on mean N-consumption and mean N-retention of the balanced barrows during the 7-day N-collection periods, joined for the grower and the finisher period (standard deviation)

| | Feed_1 0.89 | Feed_2 0.69 | Feed_3 0.59 |
|---|---------------------------|---------------------------|---------------------------|
| Barrows [n] | 11 | 24 | 10 |
| Live weight (LW), [kg ^{0.67}] | 12.35 ^c (0.68) | 15.93 ^b (3.82) | 19.17 ^a (0.77) |
| N*-consumption [g N/day and LW _{kg} ^{0.67}] | 3.08 ^a (0.27) | 2.65 ^b (0.28) | 2.28 ^c (0.09) |
| N*-retention [g N / day and LW _{kg} ^{0.67}] | 1.52 ^a (0.24) | 1.18 ^b (0.17) | 0.95 ^c (0.10) |
| N*-retention [g N/kg weight gain and LW _{kg} ^{0.67}] | 2.35 ^a (0.78) | 1.70 ^b (0.66) | 1.04 ^c (0.30) |

^{a, b, c} Means with different letters within a row differ significantly for P < 0.05 (Tukey-Kramer-Test)
* N = Nitrogen

Table 4b:

Mean N-consumption and mean N-retention of the balanced barrows during the 7-day N-collection periods, joined for the grower and the finisher period (standard deviation)

| | Group_1 Experiment | Group_2 Negative control | Group_3 Positive control | Group_4 Regular control |
|---|-----------------------|-----------------------------|-----------------------------|----------------------------|
| Number of barrows [n] | 12 | 12 | 12 | 9 |
| Live weight (LW), [kg ^{0.67}] | 16.30 (3.78) | 15.38 (3.79) | 15.67 (3.87) | 15.73 (3.62) |
| N*-consumption [g N/day and LW _{kg} ^{0.67}] | 2.68 (0.31) | 2.50 (0.31) | 2.84 (0.34) | 2.68 (0.48) |
| N*-retention [g N/day and LW _{kg} ^{0.67}] | 1.22 (0.18) | 1.13 (0.19) | 1.31 (0.33) | 1.20 (0.35) |
| N*-retention [g N/kg weight gain and LW _{kg} ^{0.67}] | 1.62 (0.54) | 1.66 (0.54) | 1.89 (0.98) | 1.66 (0.62) |

Means without letters within row differ NOT significantly (Tukey-Kramer-Test, P < 0.05)
* N = Nitrogen

all balance data, independently of the period (grower or finisher), to achieve the results shown in Tables 4a and 4b.

The N-balance results in Table 4a refer to the three different feeds. All differences between feeds are significant. Feed_1 with the highest quality (Lysine-ME-ratio 0.89) generated the best results and poor Feed_3 (Lysine-ME ratio 0.59) caused the lowest N-retention.

In Table 4b the results of the N-balances refer to the four feeding groups. The lack of significances of N-retention between groups indicates its independence from the different feeding strategies.

Feeding trial

The significances of the effects of the statistical model on growth, carcass and meat traits are summarised in Table 5. The interaction between group and sex was non-significant for all traits, so the following results concerning growth performance, carcass, and meat quality for groups are presented in each case as LSQ-Mean (LSQM) over both sexes (overall non-significance of group*sex-interaction is not presented due to better clarity of Table 5).

In Table 5 it can be seen that daily weight gain as well as feed intake are affected by the different feeding strategies only in the finisher period, the last mentioned also by Sex. Feed and energy conversion ratios are not influenced by feeding group and sex, in contrast to the conversion ratios of Lysine, Methionine+Cystine, and Threonine due to the intended experimental design, i.e. the huge variation of AA-contents in the three feeds. The striking, highly significant effect of the run (first run better than the second, results not presented) cannot be explained. Concerning carcass quality the different dietary Lysine-ME-quotients only affect muscle area which is directly associated with body protein gain, i.e. N-retention. The visible effect of sex on lean meat and fat associated carcass criteria is in accordance with biological principles (Latorre et al., 2003). No meat quality characteristics are significantly influenced by the different feeding strategies.

Table 6 illustrates growth performance traits. Whereas weight gain in the grower and in the whole fattening period is not influenced by the different feeding strategies, Group_1 animals in the finisher period show a significantly enhanced daily weight gain of nearly 10 % compared to Group_3 and Group_4 animals, whereas Group_2 pigs represent a medium position with 6 % higher weight gain than Group_3 and Group_4 pigs. These findings obviously correspond with feed intake. Group_1 animals have a significantly increased intake of 11 % in the finisher period compared to Group_3 and Group_4 animals and again, Group_2 pigs represent a medium position with 6 %. Feed

and feed energy conversion ratios remain unaffected by the feeding strategies. Amino acid conversion ratios correspond to amino acid consumption (compare Table 3).

Table 5:

Significance levels of the fixed effects on growth performance, carcass quality, and meat quality traits

| | FEEDING GROUP (FG 1 – 4) | SEX (barrows or gilts) | RUN (1 st or 2 nd) |
|-------------------------------------|-----------------------------|---------------------------|--|
| Daily weight gain in the ... | | | |
| grower period | ns | * | ns |
| finisher period | * | ns | * |
| whole period | ns | ns | ns |
| Daily feed intake in the ... | | | |
| grower period | ns | ns | ** |
| finisher period | ** | * | ns |
| whole period | ns | ns | * |
| Feed conversion ratio in the ... | | | |
| grower period | ns | ns | *** |
| finisher period | ns | ns | *** |
| whole period | ns | ns | *** |
| Energy conversion ratio in the ... | | | |
| grower period | ns | ns | *** |
| finisher period | ns | ns | *** |
| whole period | ns | ns | *** |
| Amino acid conversion ratio for ... | | | |
| Lysine | *** | ns | *** |
| Methionine+Cystine | *** | ns | *** |
| Threonine | *** | ns | *** |
| Dressing percentage | ns | ns | ns |
| Back fat thickness, hind | ns | ns | ns |
| Back fat thickness, mid | ns | ns | ns |
| Back fat thickness, fore | ns | ns | ns |
| Lateral fat size | ns | ** | ns |
| Fat size B | ns | * | ns |
| Muscle area | ** | ** | * |
| Fat area | ns | * | ns |
| Lean-fat ratio | ns | ** | ns |
| Lean meat content | ns | * | ns |
| Lean in belly | ns | ** | ns |
| pH_1 | ns | ns | ns |
| Electrical conductivity | ns | ns | ns |
| pH_24 | ns | ns | ns |
| Intramuscular fat content | ns | * | ns |

ns: not significant, * P < 0.05, ** P < 0.01, *** P < 0.001

FG*SEX-Interaction not presented due to complete non-significance

Table 6:

Growth performance traits of pigs fed with diets of different Lysine-energy-ratios in the grower and finisher period (LSQM \pm SE)

| | Group_1 Experiment 22 | | Group_2 Negative control 23 | | Group_3 Positive control 24 | | Group_4 Regular control 23 | |
|---|-----------------------------|------------|-----------------------------------|------------|-----------------------------------|------------|----------------------------------|------------|
| Number of animals [n] | | | | | | | | |
| Daily weight gain [g / animal] in the ... | | | | | | | | |
| grower period | 908 | \pm 7 | 917 | \pm 7 | 915 | \pm 6 | 903 | \pm 7 |
| finisher period | 999 ^a | \pm 22 | 971 ^{ab} | \pm 22 | 918 ^b | \pm 21 | 911 ^b | \pm 24 |
| whole period | 943 | \pm 13 | 927 | \pm 12 | 912 | \pm 12 | 927 | \pm 13 |
| Daily feed intake [g / animal] in the ... | | | | | | | | |
| grower period | 2.88 | \pm 0.05 | 2.86 | \pm 0.04 | 2.80 | \pm 0.04 | 2.81 | \pm 0.05 |
| finisher period | 3.38 ^a | \pm 0.07 | 3.24 ^{ab} | \pm 0.07 | 3.06 ^b | \pm 0.07 | 3.03 ^b | \pm 0.08 |
| whole period | 3.07 | \pm 0.05 | 2.98 | \pm 0.05 | 2.90 | \pm 0.05 | 2.97 | \pm 0.05 |
| Feed conversion ratio [kg feed/kg weight gain] in the ... | | | | | | | | |
| grower period | 3.17 | \pm 0.05 | 3.12 | \pm 0.05 | 3.06 | \pm 0.05 | 3.11 | \pm 0.05 |
| finisher period | 3.38 | \pm 0.04 | 3.35 | \pm 0.04 | 3.34 | \pm 0.04 | 3.34 | \pm 0.05 |
| whole period | 3.26 | \pm 0.04 | 3.23 | \pm 0.04 | 3.19 | \pm 0.04 | 3.21 | \pm 0.04 |
| Energy conversion ratio [MJ Metabolisable Energy/kg weight gain] in the ... | | | | | | | | |
| grower period | 40.50 | \pm 0.63 | 39.94 | \pm 0.62 | 39.30 | \pm 0.60 | 39.97 | \pm 0.66 |
| finisher period | 43.26 | \pm 0.55 | 42.56 | \pm 0.55 | 42.68 | \pm 0.53 | 42.41 | \pm 0.59 |
| whole period | 41.64 | \pm 0.53 | 41.15 | \pm 0.51 | 40.84 | \pm 0.50 | 41.03 | \pm 0.53 |
| Amino acid conversion ratio [g ... /kg weight gain] for ... | | | | | | | | |
| Lysine | 28.0 ^b | \pm 0.4 | 26.1 ^c | \pm 0.4 | 32.2 ^a | \pm 0.4 | 31.3 ^a | \pm 0.4 |
| Methionine+Cystine | 16.1 ^b | \pm 0.2 | 15.1 ^c | \pm 0.2 | 17.5 ^a | \pm 0.2 | 16.9 ^{ab} | \pm 0.2 |
| Threonine | 19.2 ^{ab} | \pm 0.2 | 17.2 ^c | \pm 0.2 | 19.9 ^a | \pm 0.2 | 18.5 ^b | \pm 0.3 |

^{a, b, c} LSQM with different letters within a row differ significantly for P < 0.05 (Tukey-Kramer-Test)

Table 7:

Carcass quality traits of pigs fed with diets of different Lysine-energy-ratios in the grower and finisher period (LSQM \pm SE)

| | Group_1 Experiment 22 | | Group_2 Negative control 23 | | Group_3 Positive control 24 | | Group_4 Regular control 23 | |
|---|-----------------------------|------------|-----------------------------------|------------|-----------------------------------|------------|----------------------------------|------------|
| Number of animals [n] | | | | | | | | |
| Dressing percentage [%] | 78.1 | \pm 0.3 | 78.3 | \pm 0.3 | 78.2 | \pm 0.3 | 78.3 | \pm 0.3 |
| Back fat thickness [cm] ... | | | | | | | | |
| hind (thinnest location above <i>M. gluteus medius</i>) | 1.7 | \pm 0.1 | 1.8 | \pm 0.1 | 1.6 | \pm 0.1 | 1.6 | \pm 0.1 |
| mid (thinnest location above <i>M. long. dorsi</i>) | 2.1 | \pm 0.1 | 2.1 | \pm 0.1 | 2.0 | \pm 0.1 | 1.9 | \pm 0.1 |
| fore (thickest location at withers) | 3.8 | \pm 0.1 | 3.9 | \pm 0.1 | 3.7 | \pm 0.1 | 3.8 | \pm 0.1 |
| Lateral fat thickness, ventral end of <i>M. latissimus dorsi</i> , 13 th rib [cm] | 3.1 | \pm 0.1 | 3.2 | \pm 0.1 | 3.1 | \pm 0.1 | 3.1 | \pm 0.1 |
| Fat thickness B, thinnest location lateral of <i>M. long. dorsi</i> , 13 th rib [cm] | 1.5 | \pm 0.1 | 1.4 | \pm 0.1 | 1.2 | \pm 0.1 | 1.3 | \pm 0.1 |
| Muscle area, <i>M. long. dorsi</i> , 13 th rib [cm ²] | 45.5 ^{ab} | \pm 0.8 | 45.2 ^b | \pm 0.7 | 48.0 ^a | \pm 0.7 | 47.9 ^{ab} | \pm 0.8 |
| Fat area, <i>M. long. dorsi</i> , 13 th rib [cm ²] | 18.1 | \pm 0.7 | 18.0 | \pm 0.6 | 17.3 | \pm 0.6 | 16.5 | \pm 0.7 |
| Lean-fat-ratio [fat area / muscle area] | 0.40 | \pm 0.02 | 0.40 | \pm 0.02 | 0.36 | \pm 0.02 | 0.35 | \pm 0.02 |
| Lean meat in the carcass [%] | 55.1 | \pm 0.6 | 55.0 | \pm 0.5 | 56.4 | \pm 0.5 | 56.4 | \pm 0.6 |
| Lean meat in the belly [%] | 54.9 | \pm 0.6 | 54.6 | \pm 0.6 | 55.9 | \pm 0.6 | 56.4 | \pm 0.6 |

^{a, b} LSQM with different letters within a row differ significantly for P < 0.05 (Tukey-Kramer-Test)

Table 8:

Meat quality traits of pigs fed with diets of different Lysine-energy-ratios in the grower and finisher period (LSQM \pm SE)

| | Group_1 Experiment 22 | Group_2 Negative control 23 | Group_3 Positive control 24 | Group_4 Regular control 23 |
|--|-----------------------------|-----------------------------------|-----------------------------------|----------------------------------|
| Number of animals [n] | | | | |
| pH_1, 40 min <i>post mortem</i> , 13 th /14 th rib, <i>M. long. dorsi</i> | 6.2 \pm 0.1 | 6.3 \pm 0.1 | 6.3 \pm 0.1 | 6.3 \pm 0.1 |
| Electrical conductivity, 24 h <i>post mortem</i> , 13 th /14 th rib, <i>M. long. dorsi</i> [mS/cm] | 5.1 \pm 0.5 | 4.5 \pm 0.4 | 4.7 \pm 0.4 | 4.2 \pm 0.5 |
| pH_24, 24 h <i>post mortem</i> , 13 th rib, <i>M. long. dorsi</i> | 5.7 \pm 0.03 | 5.7 \pm 0.03 | 5.7 \pm 0.03 | 5.7 \pm 0.03 |
| Intramuscular fat*, 13 th rib, <i>M. long. dorsi</i> [%] | 1.5 \pm 0.2 | 1.9 \pm 0.2 | 1.6 \pm 0.2 | 1.5 \pm 0.2 |

LSQM without letters within a row differ NOT significantly (Tukey-Kramer-Test, $P < 0.05$)
* Random sample of 12 animals (6 castrates + 6 females) in each group

Table 7 illustrates carcass quality traits. Dressing percentage with slightly above 78 % remains unaffected by the four different feeding strategies. Also all body fat associated traits are statistically independent from the differing feeding groups with a slight tendency to lower fat measurements for Group_3 and Group_4 carcasses of pigs fed with improved dietary Lysine-ME-ratio. Muscle area of Group_2 carcasses significantly amounts to only about 94 % of Group_3 pigs' muscle area; whereas the differences between the other groups are non-significant. Group_3 and Group_4 carcasses have insignificantly improved lean-to-fat-ratios compared to Group_1 and Group_2 carcasses; as a result, Group_3 and Group_4 carcasses have somewhat higher lean meat contents than Group_1 and Group_2 carcasses. However in both cases differences are not significant between the respective pairs of groups: about 11 % for lean-to-fat-ratio, and about 2 % for carcass lean. Also lean meat content in the belly has only an insignificant difference of about 3 % between the highest (Group_4) and the lowest (Group_2) roughly corresponding to carcass lean gradation.

Table 8 shows meat quality traits. Physical meat quality criteria, like pH and EC, as well as intramuscular fat content (IMF) as a chemical meat quality trait are not significantly affected by the differing Lysine-ME-ratios in the grower and finisher diets of the four feeding groups. However Group_2 pigs have a non-significantly higher IMF of at least 24 % compared to the mean IMF of the remaining three groups.

Discussion

Lowest N-retention of Feed_3 (Table 4a) is due to the undersupply with EAAs compared to the German recommendations (DLG, 1991; GfE, 2008). This result was to be expected. Data of N-retention concerning day and $LW_{kg}^{0.67}$ in Table 4b explicitly point out the influence of feed quality and the influence of the application of the different feeds during pigs' growth period, i.e. in the grower and

in the finisher period. Pigs of the negative control group (Group_2) – both fattening periods with poor feed quality – show non-significantly lowest N-retention (1.13 g per day and $LW_{kg}^{0.67}$). Group_3 pigs of the positive control group (with high feed quality in the starter and in the finisher period) exhibit non-significantly highest N-retention (1.31g per day and $LW_{kg}^{0.67}$). However there are no N-retention differences between Group_1 pigs (experimental group) with 1.22 g per day and $LW_{kg}^{0.67}$ and Group_4 pigs (regular control group) with 1.20 g per day and $LW_{kg}^{0.67}$ although only Group_4 pigs received a diet in the grower period according to the German recommendations (DLG, 1991; GfE, 2008). The slightly higher feed quality in the finisher period for Group_1 pigs (0.69 Lysine-ME-ratio vs. 0.59 Lysine-ME-ratio for Group_4 pigs) seems to compensate the lower N-retention of Feed_2 compared to Feed_1 (Table 4a) in the grower period. This fact is denoted as "compensatory growth" – according to other studies (De Greef et al., 1992; Therkildsen et al., 2004; Whang et al., 2003) which connect compensatory growth with enhanced muscle protein synthesis (= N-retention). The results of the N-balance studies are supported by the growth performance data of Table 6 summarized under "whole period" due to the lack of significances between the four feeding strategies.

Concerning carcass quality traits (Table 7) there is obviously a lack of clear confirmation of a significant carcass-related compensatory effect due to the insignificant decline of meat associated measurements and the simultaneous insignificant increase of fat associated measurements related to carcass graduation (Table 7). This overall tendency is in accordance with Critser et al. (1995) but in conflict with findings of Fabian et al., (2002), Therkildsen et al. (2004) and Skiba (2010).

The lack of variability of the adipose traits in terms of only small differences (Table 7) can be explained by the fact that body fat synthesis is largely independent of the amino acid supply, if simultaneous feed energy supply does not greatly exceed energy demand (Apple et al., 2004), as

it is the case in the present study (compare Table 2 and Methods: Feed). At the same time, the Lysine-ME-ratio is of eminent importance for body protein synthesis (Moehn et al., 2000), leading to a pronounced decline in muscle area of Group_1 and Group_2 pigs (Table 7). Lean meat content of the carcasses reflects the gradation of muscle area (Table 7). In this context it is conspicuous that the differences of lean meat contents between groups are not statistically confirmed in contrast to the above mentioned muscle areas. The lack of significance could be explained by carcass classification procedure. The Bonner Formula for carcass lean estimation uses a regression equation based on muscle area, fat area, three back fat thickness measurements and two lateral fat thickness measurements, as presented in Table 7. The clear predominance of six only slightly shifting adipose traits reduces the effect of declining muscle areas, obviously leading to an only minor numerical graduation in carcass leanness. Similarly, the lean-to-fat-ratio gradation shows the same trend (Table 7).

The question concerning muscle area and lean meat content is whether there is a compensatory effect for Group_1 (and Group_2) pigs or not. Comparing the declining Lysine consumption in Group_3, Group_4, Group_1 and Group_2 pigs following 1 : 0.94 : 0.84 : 0.81 (calculated after Table 3) with its respective muscle area decline of 1 : 0.99 : 0.95 : 0.94 (calculated after Table 7) and carcass lean decline of 1 : 1 : 0.98 : 0.98 (calculated after Table 7) a compensatory effect seems to be visible for Group_1 and Group_2 growing-finishing pigs. Concerning lean meat content, the lack of significance of the differences with simultaneously rigorous interpretation could suggest nearly complete compensation. This is also true when gilts and barrows are considered separately. Only Group_1 barrows with 53.8 % carcass lean differ significantly ($p < 0.05$) from Group_3 gilts with 57.2 % carcass lean, whereas all other differences between group and sex are within a non-significant range from 54.6 % to 56.9 % (data not presented). The same trends apply for muscle area (data not presented). This is in contrast to Martinez-Ramirez et al. (2008b) who report that the greater the intensive genetically determined protein synthesis capacity of the growing-finishing pig, the more pronounced the effect of compensatory protein growth, e.g., intact males are superior to castrated barrows. The same effect could be expected when gilts and barrows are compared according to their well known differing body protein synthesis capacity (Wood et al., 2004). On the other hand, the decline in muscle area and carcass lean is so obvious that compensation is at most partial, as reported by Millet et al. (2006). All things considered, complete negotiation of any compensatory effect concerning muscle area and lean meat content should be denied. And finally, considering muscle area, lean meat content, and N-retention, it can be

maintained that the Lysine oversupply of Group_3 animals does indeed not cause significantly enhanced body protein gain, as mentioned in the characterisation of the four groups (compare Methods: Test design).

The enhanced daily weight gain in the finisher period of Group_1 (and Group_2) pigs is attended by an increased feed intake (Table 6), which is a compensatory strategy (Critser et al. 1995) and which is also reported by Millet et al. (2006). The significantly sex-related influence on feed intake (Table 5) is mainly due to an increased feed intake of Group_1 barrows (3.6 ± 0.1 kg/d) compared to 2.9 - 3.2 (S.E. ± 0.1) kg/d for both, barrows and gilts in Group_3 and Group_4 (data not presented). Together with the slightly increased feed intake of Group_2 pigs, the theory reviewed by Whittemore et al. (2001) that pigs "eat by energy and protein" could be supported. So, under lower energy content and limiting amino acids (here Lysine) in the diet, pigs increased their voluntary feed intake (King et al. 2000). The unaffected feed conversion ratio (Table 6) does not support the compensatory growth effect by metabolically improved nutrient utilisation, as mentioned by Kristensen et al. (2004).

The overall weight gain level of the pigs (Table 6) is high and feed and energy conversion ratios represent an improved organic standard compared to conventional pig fattening (Millet et al., 2004). The respective conversion levels reflect ad libitum offered feed. Furthermore it can be seen that the different Lysine-ME-ratios between the groups do not influence daily weight gain in the grower and whole fattening period as well as feed and energy conversion ratios in all periods. The development of these traits is primarily influenced by the dietary energy supply (Moehn et al., 2000). Therefore the respective results are not surprising because dietary energy supply was according to need compared to DLG-recommendations (DLG, 1991; GfE, 2008), as mentioned in Table 2 (compare Methods: Feed). In contrast, the ratio of the essential amino acids (in particular relating to the first limiting amino acid Lysine) to the energy content in the diet is responsible for the body's own protein and fat synthesis (Moehn et al., 2000). The chosen Lysine-ME-ratios in the four feeding groups – together with the optimised ratios of the further limiting amino acids to each other (Table 2) – obviously did not result in augmented adiposis (Table 7), otherwise daily weight gain, feed and energy conversion ratios (Table 6) would have been negatively affected (Kapelanski et al., 2001).

As expected, physical meat quality criteria (pH and electrical conductivity) are unaffected by the four feeding strategies (Table 8), because its variability is based on the genetic origin or on the environmental pre-slaughter conditions but not on the diet fed (Fischer, 2001). The values above 6.0 for pH₁ (measured about 40 minutes post mortem) and beneath 6.0 mS/cm for electrical conductivity (mea-

sured 24 hours post mortem) indicate the absence of PSE (pale, soft, exudative) meat quality aberrance (Weißmann & Honikel, 1998). The pH₂₄ values (measured 24 hours post mortem) indicate lacking DFD (dark, firm, dry) meat quality defect. Also intramuscular fat content does not differ significantly between the four feeding strategies (Table 8). The range from 1.5 % to 2.0 % approximately corresponds to the expectations resulting from the level of lean meat in the carcass (Table 7). The highest ($P > 0.05$) intramuscular fat content of the pigs of the negative control group (Table 8) corresponds with its lowest ($P > 0.05$) N-retention (Table 4b) and with the poor characteristic of its lean meat and body fat associated carcass traits (Table 7).

Conclusions

The study demonstrated that diets of 100 % organic origin with moderate crude protein content result in decreased Lysine-ME-ratios in the grower diet. Independently from a slight over-supply or demand-covering Lysine-ME-ratio in the finisher period, economically important traits were insignificantly enhanced (daily weight gain), more or less unaffected (feed conversion ratios), and insignificantly reduced (lean meat content of the carcass) compared to finisher diets according to or exceeding German Lysine-ME-ratio recommendations. It is concluded that at least a certain degree of compensatory growth takes place. The results indicate that a 100 % organic-based feeding of growing-fattening pigs is slightly problematical for carcass quality, but not problematical for growth performance or meat quality. Hence, the current market situation with the predominance of lean meat which determines the price situation must be taken into account; in particular, farmers' marketing partners have to adjust their carcass quality-related standards and payment system to the potential of the desired organic fattening system. In conclusion, 100 % organic-based feeding in pig fattening is a challenge which can be met, not least due to the presence of compensatory growth mechanisms which help to reduce the protein gap in organic monogastric feeding.

Acknowledgments

This work was funded by BMELV/BLE under project 06oe060.

References

- 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
- Critser DJ, Miller PS, Lewis AJ (1995) The effects of dietary protein concentration on compensatory growth in barrows and gilts. *J Anim Sci* 73:3376-3383
- De Greef KH, Kemp B, Verstegen MWA (1992) Performance and body composition of fattening pigs of two strains during protein deficiency and subsequent realimentation. *Livestock Prod Sci* 30:141-153
- DLG (1991) DLG-Futterwerttabellen - Schweine - Frankfurt DLG-Verlag, 64 p.
- EU-Kommission (2007) Verordnung (EG) Nr. 834/2007 des Rates vom 28. Juni 2007 über die ökologische/biologische Produktion und die Kennzeichnung von ökologischen/biologischen Erzeugnissen und zur Aufhebung der Verordnung (EWG) Nr. 2092/91 [online]. To be found at <<http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:189:0001:0023:DE:PDF>> [quoted 25.07.2012]
- EU-Kommission (2008) Verordnung (EG) Nr. 889/2008 der Kommission vom 5. September 2008 mit Durchführungsvorschriften zur Verordnung (EG) Nr. 834/2007 des Rates über die ökologische/biologische Produktion und die Kennzeichnung von ökologischen/biologischen Erzeugnissen hinsichtlich der ökologischen/biologischen Produktion, Kennzeichnung und Kontrolle [online]. To be found at <<http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:250:0001:0084:DE:PDF>> [quoted 25.07.2012]
- EU-Kommission (2012) Durchführungsverordnung (EU) Nr. 505/2012 der Kommission vom 14. Juni 2012 zur Änderung und Berichtigung der Verordnung (EG) Nr. 889/2008 mit Durchführungsvorschriften zur Verordnung (EG) Nr. 834/2007 des Rates über die ökologische/biologische Produktion und die Kennzeichnung von ökologischen/biologischen Erzeugnissen hinsichtlich der ökologischen/biologischen Produktion, Kennzeichnung und Kontrolle [online]. To be found at <<http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:154:0012:0019:DE:PDF>> [quoted 25.07.2012]
- Fabian J, Chiba LI, Kuhlert DL, Frobish LT, Nadarajah K, Kerth CR, McElhenney WH, Lewis AJ (2002) Degree of amino acid restrictions during the grower phase and compensatory growth in pigs selected for lean growth efficiency. *J Anim Sci* 80:2610-2618
- Fabian J, Chiba LI, Frobish LT, McElhenney WH, Kuhlert DL, Nadarajah K (2004) Compensatory growth and nitrogen balance in grower-finisher pigs. *J Anim Sci* 82:2579-2587
- Fischer K (2001) Bedingungen für die Produktion von Schweinefleisch guter sensorischer und technologischer Qualität. *Mitteilungsbl BAFF* 40:7-22
- 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*. Stuttgart : Fischer, pp 323-348
- GfE-Gesellschaft für Ernährungsphysiologie (2005) Determination of digestibility as the basis for energy evaluation of feedstuffs for pigs. *Comm Committee Requirement Standards / Soc Nutr Physiol* 14:207-213
- GfE-Gesellschaft für Ernährungsphysiologie (2008) Recommendations for the supply of energy and nutrients to Pigs. Frankfurt a M : DLG-Verl, pp 17-23, Energy and Nutrients Requirements for Livestock 10
- Hornick JL, van Eenaeme C, Gérard O, Dufrasne I, Istasse L (2000) Mechanisms of reduced and compensatory growth. *Domest Anim Endocrinol* 19(2):121-132
- Kapelanski W, Falkowski J, Hammermeister A (2001) The effect of ad libitum and restricted feeding on fattening performance, carcass composition and meat quality of pigs. *Nature Sci* 9:269-276
- King RH, Campbell RG, Smits RJ, Morley WC, Ronnfeldt K, Butler K, Dunshea FR (2000) Interrelationships between dietary lysine, sex, and porcine somatotropin administration on growth performance and protein deposition in pigs between 80 and 120 kg live weight. *J Anim Sci* 78:2639-2651
- Kristensen L, Therkildsen M, Aaslyng MD, Oksbjerg N, Ertbjerg P (2004) Compensatory growth improves meat tenderness in gilts but not in barrows. *J Anim Sci* 82:3617-3624

- 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
- Martinez-Ramirez HR, Jeurond EA, de Lange CF (2008a) Dynamics of body protein deposition and changes in body composition following sudden changes in amino acid intake : I. Barrows. *J Anim Sci* 86:2156-2167
- Martinez-Ramirez HR, Jeurond EA, de Lange CF (2008b) Dynamics of body protein deposition and changes in body composition following sudden changes in amino acid intake : II. Entire male pigs. *J Anim Sci* 86:2168-2179
- Millet S, Hesta M, Seynaeve M, Ongena E, De Smet S, Debraekeleer J, Janssens GPJ (2004) Performance, meat and carcass traits of fattening pigs with organic versus conventional housing and nutrition. *Livestock Prod Sci* 87:109-119
- Millet S, Ongena E, Hesta M, Seynaeve M, De Smet S, Janssens GPJ (2006) The feeding of ad libitum dietary protein to organic growing-finishing pigs. *Vet J* 171:483-490
- Moehn S, Gillis AM, Mougham PJ, De Lange CFM (2000) Influence of dietary lysine and energy intakes on body protein deposition and lysine utilization in the growing pig. *J Anim Sci* 78:1510-1519
- Molnar S (1995) Wachstum. In: Abel HJ, Flachowsky G, Jeroch H., Molnar S (eds) *Nutztierernährung : Potentiale – Verantwortung - Perspektiven*. Jena : Fischer, pp 280-288
- Naumann C, Bassler R (1993) *Die chemische Untersuchung von Futtermitteln : Band III. Darmstadt : VDLUFA-Verl*
- Niggli U (2005) Folgen des Wachstums – verliert der Öko-Landbau seine Unschuld? *Ökologie Landbau* 133:14-16
- Oksbjerg N, Sorensen MT, Vestergaard M (2002) Compensatory growth and its effect on technological meat quality in growing pigs. *Acta Agric Scand A: Anim Sci* 52:85-90
- Rahmann G, Oppermann R, Paulsen HM, Weißmann F (2009) Good, but not good enough? Research and development needs in Organic Farming. *Landbauforsch* 59(1):29-40
- SAS (2008) *SAS/STAT Users guide : version 9.2*. Cary, NC, USA
- Skiba G (2010) Effects of energy or protein restriction followed by realimentation on the composition of gain and meat quality characteristics of *Musculus longissimus dorsi* in pigs. *Arch Anim Nutr* 64:36-46
- Szabo C, Jansman AJ, Babinszky L, Kanis E, Verstegen MW (2001) Effect of dietary protein source and lysine:DE ratio on growth performance, meat quality, and body composition of growing-finishing pigs. *J Anim Sci* 79:2857-2865
- Therkildsen M, Vestergaard M, Busk H, Jensen MT, Riis B, Karlsson AH, Kristensen L, Ertbjerg P, Oksbjerg N (2004) Compensatory growth in slaughter pigs : in vivo muscle protein turnover at slaughter, circulating IGF-I, performance and carcass quality. *Livestock Prod Sci* 88:63-75
- Wahlstrom RC, Libal GW (1983) Compensatory responses of swine following protein insufficiency in grower diets. *J Anim Sci* 56:118-124
- Weißmann F (2011) An exemplary view on the influence of genotype and feeding on growth performance, carcass quality, and meat quality in organic pig fattening. *Landbauforsch* 61(2):75-82
- Weißmann F, Honikel KO (1998) Zur Frage einer Referenzmethode zum Abschluss von PSE-Fleisch in der Wareneingangskontrolle. *Mitteilungsbl BAFF* 37:300-303
- Whang KY, Kim SW, Donovan SM, McKeith FK, Easter RA (2003) Effects of protein deprivation on subsequent growth performance, gain of body components, and protein requirements in growing pigs. *J Anim Sci* 81:705-716
- Whittemore CT, Green DM, Knap PW (2001) Technical review of the energy and protein requirements of growing pigs: food intake. *Anim Sci* 73:3-17
- Wlcek S, Zollitsch W (2004) Sustainable pig nutrition in organic farming: by-products from food processing as a feed resource? *Renew Agric Food Syst* 19:159-167
- Wood JD, Nute GR, Richardson RI, Whittington FM, Southwood O, Plastow G, Mansbridge R, Da Costa N, Chang KC (2004) Effects of breed, diet and muscle on fat deposition and eating quality in pigs. *Meat Sci* 67:651-667
- Yang YX, Guo J, Jin Z, Yoon SY, Choi JY, Wang MH, Piao XS, Kim BW, Chae BJ (2008) Lysine restriction and realimentation affected growth, blood profiles and expression of genes related to protein and fat metabolism in weaned pigs. *J Anim Physiol Anim Nutr* 93(6):732-743
- ZDS-Zentralverband der Deutschen Schweineproduktion (2007) *Richtlinie für die Stationsprüfung auf Mastleistung : Schlachtkörperwert und Fleischbeschaffenheit beim Schwein*. Bonn : ZDS, 30 p
- Zollitsch W (2007) Perspective challenges in the nutrition of organic pigs. *J Sci Food Agric* 87:2747-2750

