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Effects of feeding strategies, genotypes, sex, and birth weight on carcass and meat quality traits under organic pig production conditions[☆]

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ABSTRACT

Nutrient supply in organic pig production is characterized by limited amino acids (AA) availability due to the preferable use of home-grown feedstuffs and restrictions on purchased feedstuffs. This can cause large variations in the quality of diets, carcasses, and pork. The objective of two feeding trials was to assess the interactions between feeding regimes, genotype, and birth weight on carcass and pork quality. A control regime was compared with two feeding regimes that were partly (only in the finishing phase (FIN)) or both in the growing and finishing phase (GRO + FIN) restricted to home-grown feedstuffs, thus differing in AA supply. Using an isocaloric ration, individually housed pigs differing in genotype (Experiment 1) or birth weight (Experiment 2) were allocated to the three feeding regimes.The highest daily live weight gain, the best feed conversion, and the highest values for performance traits and meat composition were achieved by Du × DL pigs, while the highest carcass yield was achieved by Pi × (DL × DE) pigs. In Experiment 1, performance traits were significantly higher in the control feeding regime than in the GRO + FIN treatment, with the feeding regime FIN being intermediate. Lean meat percentage was significantly lower in the GRO + FIN feeding regime than in the control while the fat area was not influenced by feeding regime. Intramuscular fat content was higher under the GRO + FIN feeding regime without AA supplementation than in the control. In Experiment 2, birth weight showed no significant effect on carcass yield, carcass traits and meat composition, but affected growth rate. Performance traits were highest in the control, while meat composition was best in the GRO + FIN treatment, confirming results of Experiment 1. Exclusion of AA supplementation in the feeding regime reduced growth but increased intramuscular fat content (IMF). The feeding regime was the main source of variation for intramuscular fat content in the *longissimus muscle*. Organic pig production can yield high quality pork, but information on feed, feed intake, and pig characteristics is important to steer the production process.

1. Introduction

Due to various negative side effects together with the intensification process in conventional pig production, there is an increasing interest of consumers in pork from organic and low-input production systems [1]. Introduction of the wholesomeness concept in meat production, most often represented by organic production, is mainly due to a wish for re-establishing a positive meat sector image, including eating quality, food safety and animal welfare aspects [2,3]. Consumers draw a whole range of positive inferences from the label 'organic', and these do not only refer to concerns about the environment and health, but also about animal welfare and a better taste [4]. The organic concept refers to the whole farm as the base of a comprehensive system where the production process is intended to ensure quality production rather than maximum production. Labelling meat as being 'organic' identifies the products as deriving from a production method defined by guidelines that clearly go beyond other brand label programmes [5].

Organic pig production is based on organically grown feedstuffs. The ingredients of a diet should derive in the first place from home-grown feedstuffs. The restriction of organically produced feedstuffs, however, limits the availability of feedstuffs with high quality protein [6,7]. Due to a limited availability of high quality protein feed, it is clearly more difficult in organic pig production than in conventional pig production to formulate diets that accurately meet the requirements of high-yielding animals.

As a high level of meat quality does not necessarily emerge from specific regulations or a low-input production method, it is a real

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challenge in organic farming to adapt pig production to a limited availability of nutrients while simultaneously optimizing product quality.

While a pig's potential for growth is ultimately determined by its genotype [8], growth is accomplished by cellular hyperplasia early in life and cellular hypertrophy thereafter [9]. Quantitative and qualitative aspects of postnatal nutrition have a major effect on muscle development through their effect on growth rate and body composition. The dietary impact can vary depending on the stage of development and age of the pig. Additionally, myofibre characteristics play a critical role in the determination of final meat composition.

In the past, various studies have shown that diets low in amino acids have the potential to increase intramuscular fat (IMF) content, a prominent criterion for eating quality without causing an overly fat pig [10,11]. The IMF content is well known for enhancing softness, tenderness and overall liking of pork [12,13]. The authors consider IMF contents of 2–2.5% as a minimum level to influence sensory properties. The non-consideration of this trait and the unidirectional selection for lean meat in conventional production results in IMF contents averaging clearly below the desirable IMF values [14,15]. The relative growth rates of different fat depots vary with the stage of maturity of the animal, with the intramuscular depot being the slowest and the perirenal depot the fastest growing in pigs. Thus, the age of the animal will affect the distribution of fat [16]. A low postnatal growth rate via restricted dietary protein intake is associated with a lower muscle fibre diameter and more intramuscular lipid in the *porcine longissimus muscle* [17]. As an imbalanced supply of amino acids is characteristic of organic diets based on organic cereals and home-grown grain legumes, this feeding strategy may provide an appropriate tool for organic farmers to manipulate meat quality in order to meet specific market demands.

So far only few studies have been conducted on the quality of pork produced under organic conditions. The QualityLowInputFood project (QLIF, http://www.qlif.org) has addressed this issue in its fourth sub-project on organic livestock production, aimed to develop strategies that could lead to an improvement of the eating quality of pork. Two experiments were conducted to assess potentials and limitations in quality production of pork based on a restricted availability of limited amino acids (AA).

The objective of the first experiment (Experiment 1) was to test the hypothesis that pigs with different genetic potential for protein accretion react differently to an imbalanced amino acid diet in the grower and the subsequent finisher phase, thereby causing different effects on the quality traits of pork. The second experiment (Experiment 2) was conducted to validate the hypothesis that pigs with different birth weights react differently to an imbalanced amino acid diet in the growing and the subsequent finishing phase, thereby affecting pork quality.

2. Interactive effects of pig genotype and amino acid balance in the diet

2.1. Materials and methods

Experiment 1 was of the randomized complete block design. Pigs were individually housed and fed in pens on half solid concrete and half concrete slats (2.5 × 1.0 m), which were equipped with a cup drinker. Animals were transported to the abattoir in the evening and slaughtered the following morning.

The experiment included 198 weaned piglets (30 kg live weight), derived from four different genotypes: (1) Pietrain × (German Landrace × Large White) (Pi × (DL × DE)), (2) Duroc crossed with a strain of German Landrace (Du × DL), (3) Pietrain × German Swabian Hall (Pi × SH), and (4) purebred German Swabian Hall breed (SH). From the genotypes Pi × (DL × DE) and Du × DL, 22 crossbred pigs were used in each of the different treatments in a sex ratio of 50:50. Concerning the genotypes Pi × SH and SH, only castrated pigs were available so that 11 pigs were allotted to each dietary treatment. Due to different diseases three pigs from different treatments had to be excluded from the experiment.

A total number of 12 treatments (3 feeding regimes × 4 genotypes) were compared. The three feeding regimes were (1) a control diet (CON), with AA supply closely related to the requirements; (2) a diet balanced in the growing phase, and imbalanced in AA in the finishing phase (FIN); and (3) a diet imbalanced in AA in both the growing and the finishing phase (GRO + FIN). The fattening period ended when a live weight of 120 kg was reached. The time of slaughter was determined individually on the basis of individual live weights.

Analyses of proximate constituents of feeds were conducted following standard procedures. The energy content of the diets was calculated on the basis of the nutrient contents. All dietary treatments were calculated isocalorically at a level of 13.0 MJ metabolic energy (ME) per kg dry matter. Amino acid analysis of complete diets was carried out by ion-exchange chromatography, following hydrolysis of the samples in 6 N HCl. None of the diets contained growth promoting sub-therapeutic antibiotics or probiotics. The organic diets were formulated on the basis of the availability of amino acids in organically producing units. The dietary treatments were imposed at an average initial weight of 30 kg. From 30 to 70 kg live weight, the pigs had *ad libitum* access to isocaloric grower diets, whereas for castrates and females and during the finisher phase (70–120 kg live weight) feed intake was restricted to 32 and 36 MJ ME, respectively. Diets were changed from grower to finisher feed ration on an individual weight basis. Amino acid supply was obtained from different sources, based on grain legumes (faba beans and lupines), with or without external supplementation. The supplementation was offered either as a conventional protein concentrate (control treatment) or in line with the formal organic standards as potato protein. The supplementary diets were formulated to meet the AA requirements of growing and finishing pigs [18]. The diets without supplementation included faba beans and lupines. The ingredients were calculated to attain the highest level of limiting AA possibly available by using home-grown feedstuffs. Composition and ingredients of the diets used are presented in Table 1.

The analytical data of the feed mixture, except for energy content of the feeding regimes CON and FIN, differed only slightly from the calculated data that were based on the analyses of the single ingredients. The main differences between the diets were related to the protein sources. The use of different ingredients caused large differences in protein content and in the content of limiting AA between the diets. These contents clearly decreased from diet CON to GRO + FIN.

Feed intake and live weight were determined once a week. From these data the daily live weight gain (dlwg) and the feed conversion ratio (feed intake per kg live weight) were calculated. Immediately after slaughter the carcass was weighed (carcass weight warm).

For the assessment of carcass quality a cut was carried out between the 13th and 14th rib in the loin area to measure the following characteristics: back fat thickness, fat area, *M. longissimus dorsi* (Mld) area and the percentage of lean meat in an abdominal 8 cm long cut that was made vertically towards the rind, beginning at the abdominal border of the *M. iliocostalis*. Grading for the assessment of lean muscle was carried out with FOM-equipment, which measured lean cut yield, subcutaneous fat and the Mld (area, colour, firmness).

Meat quality was measured by pH_1 (45 min after slaughter) and pH_{24}-values (24 h after slaughter) in the loin muscle and by opto-results (reflectance measurement, opto-value 1). Additionally, the

Table 1
Ingredients and composition of the feeding regimes[a] used in the growing and the finishing phase of the pigs (Experiment 1).

Ingredient[b]	Growing phase			Finishing phase	
	CON	FIN	GRO + FIN	CON	FIN and GRO + FIN
Barley (%)	35.0	29.5	23.5	38.0	32.5
Wheat (%)	35.0	29.0	23.5	38.0	32.5
Soya bean meal – 43% CP (%)	24.5	–	–	21.0	–
Faba beans (%)	–	18.0	30.0	–	16.0
Lupine (%)	–	14.0	18.0	–	15.0
Potato protein (%)	2.0	5.5	–	–	–
Rape oil (%)	0.5	1.0	2.0	0.5	1.5
Mineral mix (%)	3.0	3.0	3.0	2.5	2.5
ME (MJ per kg DM)	13.3	13.2	12.9	13.0	13.1
Crude fibre (g per kg DM)	44.5	48.5	48.6	47.6	42.3
Crude protein (g per kg DM)	196	184	170	169	145
Lysine (g per kg DM)	11.5	11.5	10.1	9.3	7.8
Methionine + Cystine (g per kgDM)	7.5	6.7	5.3	6.7	5.1
Threonine (g per kg DM)	8.3	8.5	7.0	6.9	5.9
Tryptophan (g per kgDM)	2.7	2.3	1.9	2.4	1.7
Lys:(Meth + Cys):Thre:Tryp	1:0.7:0.7:0.2	1:0.6:0.7:0.2	1:0.5:0.7:0.2	1:0.7:0.7:0.3	1:0.7:0.8:0.2

[a] CON = control diet; FIN = diet balanced in the growing phase and unbalanced in amino acids in the finishing phase; GRO + FIN = diet unbalanced in amino acids in both the growing and the finishing phase.

[b] CP = crude protein; ME = metabolizable energy; DM = dry matter.

electrical conductivity in the loin (LF_1- and LF_{24}-values) served as a description of the meat quality. A second reflection value (opto-value 2) was also recorded 45 min after slaughter and averaged with the opto-value 1, simultaneously with the grading of the lean meat (FOM). The drip losses were quantified using the bag method 24 h after the slaughter as described by Otto et al. [19].

Muscle samples for intramuscular fat analysis were obtained from the Mld posterior to the 13th rib and frozen at $-20\,^{\circ}$C. Proximate analysis procedures for fat were conducted on homogenized muscle samples, using the near-infrared-transmission (NIT) technique. An Infratec Food and Feed Analyzer 1255 (Perstorp Analyticals, Sweden) was used for the NIT measurements with a wavelength range of 850–1050 nm. All measurements were carried out at room temperature.

2.2. Statistical analysis

The results were analysed according to the randomized complete block design. Pigs being individually penned, the experimental unit consisted of one pig. The data for each variable were analysed using the programme package SPSS, version 11.0 for Windows. The effects of diet and replicate were tested using one-way analysis of variance with the dietary treatment as classification variable. Tukey's test was used to determine statistically significant differences between treatments. The effect of the animal's sex was quantified and also compared. The correlations between IMF content and other performance parameters, carcass characteristics and meat quality attributes were calculated. To identify the most relevant factors influencing the traits, linear multiple regressions were calculated using the backward method, a method that gradually eliminates the variables that do not affect the results markedly. If $p < 0.05$, preferences were considered statistically significant. If group sizes were unequal the harmonic mean of the group was used for comparisons. Statistical calculations were carried out by using the software SAS JMP 5.1.2 with the following GLM models:

Fattening performance:

$$y_{ijk} = \mu + GT_i + D_j + b_1(\mathrm{LWS}_{ijk} - \mu\mathrm{LWS}_{ij}) + b_2(\mathrm{LWE}_{ijk} + \mu\mathrm{LWE}_{ij}) + (\mathrm{GT} \times D) + e_{ijk}$$

Slaughtering performance:

$$y_{ijk} = \mu + \mathrm{GT}_i + D_j + b_1(\mathrm{SW}_{ijk} - \mu\mathrm{SW}_{ij}) + (\mathrm{GT} \times D)_{ij} + e_{ijk}$$

where y_i = target value; μ = mean; GT_i = fixed effect of the genotype; D_j = fixed effect of the diet j; b_1 = partial linear regression of the live weight at the start of the experiment; LWS_{ijk} = live weight at the start of the experiment of animal k; $\mu\mathrm{LWS}_{ij}$ = mean live weight at the start of the experiment; b_2 = partial linear regression of the live weight at the end of the experiment; LWE_{ijk} = live weight at the end of the experiment of animal k; $\mu\mathrm{LWE}_{ij}$ = mean live weight at the end of the experiment; b_3 = partial linear regression of the slaughter weight (warm); SW_{ijk} = slaughter weight (warm) of animal k; $\mu\mathrm{SW}_{ij}$ = mean slaughter weight; $(\mathrm{GT} \times D)_{ij}$ = interaction genotype × diet; e_{ijk} = residual error.

2.3. Results

2.3.1. Performance criteria

The implications of different feeding regimes fed to pigs of different genotypes for feed intake, daily live weight gain (dlwg), carcass yield, feed conversion ratio, and net feed efficiency, taking all treatments into account, are presented in Table 2. Considering the three feeding regimes, feed intake in kg per day (average of total experimental period) did not differ significantly between the genotypes Du × DL, Pi × SH and SH, whereas the genotype Pi × (DL × DE) showed a significantly lower feed intake. The highest daily live weight gain and the best feed conversion ratio and net feed efficiency were obtained with pigs of the genotype Du × DL, and the lowest with pigs of the pure bred SH. From all genotypes included in the study the Pi × (DL × DE) pigs showed the highest carcass yield whereas the pigs of Du × DL, and SH reached a carcass yield that was 1.9% lower ($p < 0.05$) than that of the Pi × (DL × DE) pigs.

The comparison of feeding regimes, when taking the genotypes into account, showed marked differences. Performance traits were significantly higher ($p < 0.05$) with feeding regime CON than with the GRO + FIN treatment. The feeding regime FIN gave intermediate results.

While the genotype Du × DL gave the highest dlwg in both fattening phases ($p < 0.05$), the genotypes Pi × (DL × DE) and SH did not differ in dlwg in the growing nor in the finishing phase. Notable is the comparatively high growth rate of the Du × DL pigs in the finishing phase, although feed intake in the finishing phase differed only slightly when compared with those of the other genotypes.

Considering all genotypes, the highest dlwg in the growing phase was obtained with feeding regime CON and the lowest dlwg with the GRO + FIN treatment. The FIN treatment produced intermediate results. Differences in total dlwg between the feeding

Table 2
Effects of genotype[a] and feeding regime[b] on feed intake in the growing and in the total fattening period, daily live weight gain, feed conversion, and carcass yield (±SE) (Experiment 1).

Parameter		Feed intake (grow. phase) (kg per day)	Feed intake (total period) (kg per day)	Daily live weight gain (g)	Feed conversion	Carcass yield (%)
Genotype	Pi × (DL × DE) ($n = 65$)	$1.83^{b} \pm 0.23$	$2.22^{a} \pm 0.07$	$716^{c} \pm 41$	$3.13^{b} \pm 0.24$	$78.1^{a} \pm 1.1$
	Du × DL ($n = 66$)	$1.91^{a,b} \pm 0.19$	$2.32^{b} \pm 0.06$	$810^{a} \pm 38$	$2.87^{a} \pm 0.15$	$76.2^{c} \pm 0.7$
	Pi × SH ($n = 33$)	$1.97^{a} \pm 0.18$	$2.36^{b} \pm 0.03$	$752^{b} \pm 10$	$3.15^{b} \pm 0.19$	$77.1^{b} \pm 1.0$
	SH ($n = 31$)	$1.98^{a} \pm 0.16$	$2.34^{b} \pm 0.02$	$700^{c} \pm 12$	$3.37^{c} \pm 0.26$	$76.2^{c} \pm 1.2$
Feeding regime	CON ($n = 65$)	$1.98^{A} \pm 0.17$	$2.34^{B} \pm 0.10$	$776^{A} \pm 9$	$3.04^{A} \pm 0.30$	$78.1^{A} \pm 1.9$
	FIN ($n = 66$)	$1.92^{A} \pm 0.20$	$2.31^{B} \pm 0.12$	$756^{A} \pm 10$	$3.08^{A} \pm 0.30$	$76.6^{B} \pm 1.6$
	GRO + FIN ($n = 64$)	$1.81^{B} \pm 0.22$	$2.24^{A} \pm 0.16$	$720^{B} \pm 8$	$3.12^{A} \pm 0.21$	$76.2^{B} \pm 1.5$

[a,b,c] Means in the same column, followed by the same lower case letter indicates no statistically significant difference between the genotypes in that column ($p < 0.05$).

[A,B] Means in the same column, followed by the same capital letter indicates no statistically significant difference between the feeding regimes in that column ($p < 0.05$).

[a] Pi = Pietrain; DL = German Land Race; DE = Large White; Du = Duroc; SH = German Swabian Hall.

[b] For abbreviations see Table 1.

regimes were primarily due to differences in the growing phase: no differences in dlwg were found in the finishing phase.

Taking into account both genotypes (Pi × SH and SH), castrated pigs had a statistically significant higher feed intake than female pigs. In contrast, with the female pigs a higher carcass yield and a better net feed efficiency were obtained than with the castrated pigs ($p < 0.01$). Considering both sexes, pigs of the genotype Du × DL had a higher feed intake and dlwg, and a higher feed conversion ratio and net feed efficiency than the Pi × (DL × DE) pigs, in spite of the fact that the latter produced a higher carcass yield ($p < 0.05$).

The highest feed intake was found with the castrated pigs of the genotype Du × DL whereas the female pigs of the genotype Pi × (DL × DE) showed the lowest feed intake ($p < 0.05$). Dlwg was clearly higher for pigs of the genotype Du × DL than for pigs of the genotype Pi × (DL × DE) ($p < 0.01$), but no statistically significant differences between male and female animals were found. Female pigs of Pi × (DL × DE) produced the highest, and castrated pigs of the genotype Du × DL the lowest carcass yield ($p < 0.05$). Comparing selected production traits between genotypes, the pigs of the Pi × (DL × DE) genotype showed the lowest feed intake, whereas the pigs of the pure-bred SH genotype had the lowest dlwg, and the lowest values in relation to feed conversion. The Du × DL pigs obtained the highest dlwg but the lowest carcass yield whereas at the same time their feed conversion ratio was highest.

Table 3
Effect of different feeding regimes[a] on traits of carcass yield and meat composition (±SE) (Experiment 1).

Carcass and meat quality traits[b]	CON ($n = 61$)	FIN ($n = 63$)	GRO + FIN ($n = 61$)
Lean meat (%)	$54.0^{a} \pm 1.6$	$52.6^{b} \pm 1.4$	$52.2^{b} \pm 1.5$
Meat area (cm^2)	$50.1^{a} \pm 3.9$	$46.1^{b} \pm 4.1$	$42.5^{c} \pm 3.8$
Fat area (cm^2)	$21.2^{a} \pm 2.5$	$20.7^{a} \pm 2.5$	20.3 ± 2.3
IMF content of Mld (%)	$1.57^{a} \pm 0.51$	$2.10^{b} \pm 0.70$	$2.61^{c} \pm 0.61$

[a,b,c] Means in the same row, followed by the same letter are not statistically different ($p < 0.05$).

[a] For abbreviations see Table 1.

[b] IMF = intramuscular fat; Mld = *M. longissimus dorsi.*

2.3.2. Carcass and meat quality

The results of selected traits of carcass and meat composition in relation to the feeding regimes are presented in Table 3. Lean meat percentage and meat area of Mld were highest in the control treatment and significantly ($p < 0.05$) lower for pigs on the feeding regimes FIN and GRO + FIN. In contrast, the fat area was not significantly different between the feeding regimes. The IMF content was significantly higher with the feeding regimes FIN and GRO + FIN, with a difference of >0.5% with feeding regime FIN and >1% with GRO + FIN compared with the control treatment.

Differences between genotypes with respect to carcass and meat quality traits are presented in Table 4, considering only castrated pigs. The highest lean meat percentage and the largest meat area of Mld were found in the crossbred pigs of the genotypes Pi × (DL × DE) and Pi × SH. The fat area was not different between the genotypes, except for pigs of the breed SH, which showed significantly higher values. The IMF content as well as the drip losses were significantly lower for the pigs of genotype SH than for the pigs of the other genotypes. Concerning the drip losses of the Pi × (DL × DE) and Du × DL genotypes, their position was intermediate. The pigs of the pure bred SH genotype had the lowest carcass traits of all genotypes. The effect of crossing breed SH with a sire of the Pi genotype resulted in an increase in drip losses of more than 1.5% compared with the pure bred. In addition, Pi × SH showed the lowest pH$_1$values whereas the pigs of the genotype Du × DL had the highest values ($p < 0.05$).

Differences between the genotypes Pi × (DL × DE) and Du × DL in selected traits of carcass and meat composition of female and castrated pigs are presented in Table 5. Concerning lean meat percentage, the highest values were found in the female pigs of the genotype Pi × (DL × DE) and the lowest values in the castrated pigs of Du × DL ($p < 0.05$). The largest meat area of Mld was found in the female pigs of the genotype Pi × (DL × DE), the lowest in the castrated pigs of Du × DL, with a difference between the mean values of 10 cm^2 ($p < 0.05$). In both genotypes the castrated pigs had a larger fat area than the female pigs ($p < 0.05$). The pH$_1$-values did not differ between female and castrated pigs within

Table 4
Effect of genotype on carcass traits and meat composition (±SE). Only castrated pigs, and data pooled over feeding regimes) (Experiment 1).

Genotype[a]	Lean meat (%)	Meat area (cm^2)	Fat area (cm^2)	IMF content in Mld[b] (%)	Drip losses (%)
Pi x (DL × DE) ($n = 32$)	$56.9^{a} \pm 2.4$	$49.5^{a} \pm 5.8$	$20.9^{a} \pm 2.5$	$2.02^{ab} \pm 0.68$	$2.53^{ab} \pm 1.97$
Du × DL ($n = 33$)	$54.8^{b} \pm 1.7$	$42.2^{b} \pm 3.0$	$20.6^{a} \pm 2.6$	$2.29^{ab} \pm 0.76$	$2.29^{ab} \pm 1.53$
Pi × SH ($n = 33$)	$55.5^{ab} \pm 1.7$	$46.9^{a} \pm 4.3$	$21.8^{a} \pm 2.5$	$2.36^{a} \pm 0.90$	$3.04^{b} \pm 2.01$
SH ($n = 31$)	$52.9^{c} \pm 2.8$	$41.1^{b} \pm 1.6$	$25.0^{b} \pm 3.6$	$1.80^{b} \pm 0.74$	$1.44^{a} \pm 1.88$

[a,b,c] Means in the same column, followed by the same letter are not statistically different ($p < 0.05$).

[a] For abbreviations see Table 2.

[b] IMF = intramuscular fat in *M. longissimus dorsi*.

Table 5
Effect of genotype and sex on lean meat, meat area of Mld[b], fat area, IMF content and drip losses (±SE) (Experiment 1).

Genotype[a]	Sex	Lean meat (%)	Meat area (cm^2)	Fat area (cm^2)	IMF content in Mld (%)	Drip losses (%)
Pi × (DL × DE)	Females ($n = 32$)	59.1^a ± 2.3	52.1^a ± 6.8	17.9^a ± 2.6	1.81^a ± 0.70	2.32^a ± 1.79
	Castrates ($n = 33$)	56.9^b ± 2.5	49.5^a ± 7.2	20.9^b ± 2.5	2.03^a ± 0.68	2.53^a ± 1.97
Du × DL	Females ± ($n = 33$)	56.8^b ± 1.8	45.5^b ± 4.9	18.4^a ± 2.6	2.26^a ± 1.00	1.95^a ± 1.57
	Castrates ($n = 33$)	54.8^c ± 1.7	42.2^b ± 3.0	20.6^b ± 2.6	2.29^a ± 0.76	2.29^a ± 1.53

[a,b,c] Means in the same column, followed by the same letter are not statistically different ($p < 0.05$).
[a] See Table 2 for abbreviations.
[b] Mld = *M. longissimus dorsi*.

each genotype. Concerning the IMF content of the Mld no statistically significant differences were found between the genotypes Pi × (DL × DE) and Du × DL ($p = 0.06$). However, the results show a large variation within the groups. The drip losses were not significantly affected by genotype and sex ($p < 0.05$). However, drip losses tended to be higher with the female and castrated pigs of the genotype Pi × (DL × DE) than with both sexes of the genotype Du × DL ($p > 0.05$).

The model calculation showed that all traits of performance, carcass and meat composition except IMF content were primarily influenced by the genotype. The IMF content was influenced mainly by the feeding regime. Interactions between genotypes and feeding regimes were not detected.

Although IMF content varied highly across feeding regimes, the fat area differed only slightly, except for the pure-bred SH. Pigs of this breed did not attain the envisaged values of 2.5–3.0% for a high sensory pork quality with any of the feeding regimes. The results indicate that it is possible to increase the IMF content by using specific feeding regimes. The effect can be further improved by using pigs of the Du × DL genotype.

Pigs of the genotype Pi × (DL × DE) had a higher lean meat percentage and a higher meat area of the *longissimus muscle* than the pigs of the Du × DL genotype. In contrast, Du × DL pigs had higher pH$_1$-values and a higher IMF content of the *longissimus muscle* than the pigs of genotype Pi × (DL × DE). Performance and meat quality traits were lowest with the SH breed. While female pigs had a higher carcass yield and a higher lean meat percentage, castrated pigs had a better growth rate and a higher IMF content of the *longissimus muscle*.

The IMF content of the Mld was negatively correlated with lean meat percentage ($r = -20$) and meat area of the Mld ($r = -0.33$), whereas the IMF content showed no relationship with the fat area. The meat area of the female pigs was more negatively correlated with the IMF content than the meat area of the castrated pigs. Furthermore, IMF content was negatively correlated with protein and water content of the Mld, whereas drip losses were not correlated significantly with the protein, water or IMF contents.

The results emphasize the existence of an antagonistic relationship between quantitative and qualitative traits. Pigs with a different genetic capacity for protein accretion reacted differently to an imbalanced amino acid diet, which resulted in different carcass yields and meat composition. So the working hypothesis was confirmed. In contrast, the concern that imbalanced diets consequently result in an increase of back-fat thickness was refuted. In order to obtain a high IMF content of the *longissimus muscle*, the factor feeding regime clearly prevailed over the factor genotype.

2.3.3. Discussion

The preferable use of home-grown feedstuffs and limitations in the choice of purchased feedstuffs and in the availability of feed of high quality is a characteristic feature of organic pig production. The framework conditions can be the cause of a considerable variation in the composition of the feed ration, and can considerably restrict the possibilities for the adaptation of the diets to the specific requirements [20]. Due to the limited availability, especially with regard to essential amino acids, there is concern that nutritional imbalances encountered in practice might lead to a drop in pork quality.

As expected, a reduced supply of AA in the finishing phase or growing and finishing phase (GRO + FIN) resulted in a lower pig performance, which was more pronounced in the GRO + FIN treatment than in the FIN treatment. However, differences with respect to daily live weight gain, carcass yield and lean meat percentage were not very pronounced whereas feed conversion did not differ significantly between the feeding regimes.

Many experiments have demonstrated a comparable reduction in growth performance after a period of protein intake restriction compared with pigs fed a protein supply according to the requirements [21–23]. In the present study, feed intake was restricted in the finishing phase so that any potential for compensatory growth effects was limited. After a period of AA restriction, the extent and rate of compensatory growth varies with the type, degree, timing and duration of nutrient intake restriction, as well as with genotype and energy and nutrient availability after the period of nutrient intake restriction. Compensatory growth following a period of amino acid intake restriction occurs primarily during the energy dependent phase of body protein deposition so that it is unlikely to occur in growing pigs with relatively low lean tissue growth potentials [24].

Due to a comparatively high feed intake and protein deposition, the Du × DL genotype proved to be least affected by a restricted availability of high quality feedstuffs: it clearly outmatched the other genotypes with respect to daily live weight gain and feed conversion. Comparable results were obtained by Edwards et al. [25] and Gruber [26]. On the other hand, the pigs of the genotype Pi × (DL × DE) had a higher lean meat percentage, and a higher meat area of the Mld than the pigs of the genotype Du × DL whereas the latter had higher pH$_1$-values and higher IMF contents of the Mld than pigs of the genotype Pi × (DL × DE), confirming results of Gruber [26], Sutton et al. [27] and Gispert et al. [28]. Under European conditions, Pietrain (Pi), Hampshire (HA) and Duroc (DU) represent the most relevant sire breeds. According to Glodek [29], Pi has by far the highest lean meat content but is highly stress susceptible, HA is stress resistant but shows in its progeny the so-called Hampshire factor, which causes weight losses in cooked hams. DU is also stress resistant but in general produces a fatter carcass than the other two, but provides the highest IMF content [25].

In experiments of Gruber [26], castrated male pigs and female pigs of the German Federal Hybrid Pig Breeding Programme (BHZP), Du × DL, Pi × SH and SH were fed and housed according to the regulations of organic farming and compared for fattening performance, carcass and meat quality. Concerning the fattening performance, the breeds did not differ, whereas the tendentially highest daily gains were obtained by Du × Dl pigs. SH pigs put on the lowest muscle tissue and the highest fat tissue, resulting in a low lean meat content and a high back fat thickness, whereas the three other stocks did not differ. Also in the present study, the results of the SH breed were comparatively worse both in performance and in meat quality than the other genotypes.

Divergent results were obtained with respect to the sex of pigs. While female pigs had a higher carcass yield and a higher lean meat percentage, castrated pigs attained a higher growth rate and a higher IMF content of the Mld. Differences between sexes in growth, carcass and meat quality traits were generally in agreement with the results from previous studies [30,31]. These results were expected because castration favours intramuscular fattening of the meat [32]. Intramuscular fat content is generally reported to be positively correlated with the palatability of the meat [13,33,34], even though data can sometimes be controversial. Pigs fed with organically produced feedstuffs and with an imbalanced diet in relation to the AA pattern compared with the control treatment had clearly higher levels of IMF in the Mld whereas the GRO + FIN feeding regime was more successful than the FIN feeding regime. These results are in agreement with several studies [10,35,36] that showed that a lower dietary lysine content resulted in a higher IMF content and a higher rate of water loss of the *longissimus dorsi* muscle. According to Katsumata et al. [11], the higher activity of adipogenesis plays a prominent role in this promoted IMF accumulation. In studies of D'Souza et al. [34], pork from pigs fed a reduced lysine diet had not only higher IMF levels compared with control diets but was also considered to be the most juicy and tender and have the best overall acceptability. Strong correlations were also found between IMF content and shear force: the shear force decreased with increasing IMF content [37].

Pigs with different genetic capacity for protein accretion reacted differently to an imbalanced supply of amino acids, which resulted in different carcass yields and differences in meat composition. To obtain a high IMF content, the feeding regime clearly is more important than the genotype. In agreement with Cameron et al. [38], genotype × feeding interactions were not found.

According to the interrelationship between feeding strategy and IMF content, the production conditions in organic farming are favourable for the production of pork with a high quality. The concern of farmers and retailers that the fat area and the back fat thickness increase with an increase in IMF content was not confirmed. The combination of faba beans and lupines as protein sources provides a possibility to fatten pigs to an appropriate level of lean meat percentage and to a high IMF content of the Mld without increasing the amount of subcutaneous fat.

The results indicate that the feeding strategy should be more closely adapted to the genotype used on the farm and to the availability of limited resources for pork quality. The results confirm that feeding regimes based on a limited availability of essential amino acids in the diet have the potential to compensate the restrictions in performance traits by a marked increase in IMF content, thereby improving a very relevant trait in relation to the eating quality of pork. However, antagonistic relationships between factors that increase protein accretion and factors that improve IMF content make it necessary for the farmers to decide which factor should be given first priority.

3. Interactive effects of piglet birth weight and amino acid balance in the diet

Meat quality shows large variations both within and between animals and even within distinct muscles [39]. Besides the factors well known for their contribution to meat quality, such as genotype, sex, age, nutrition and slaughter treatment, morphological and metabolic properties of the skeletal muscles affect meat quality via the pattern of energy metabolism in live animals [40] as well as during the post mortem conversion of muscles to meat [41]. The total number of muscle fibres per area plays a critical role in the determination of final carcass composition. The total number of fibres in a muscle appears to be fixed at or shortly after birth, with postnatal growth of the muscle being entirely due to elongation and widening of the existing muscle fibres [16]. The relative growth rates of different fat depots varies with the stage of maturity of the animal, with the intramuscular depot being the slowest and the perirenal depot the fastest growing in pigs. So the age of the animal will affect the distribution of fat. Pigs originating from piglets of low birth weight are expected to develop a lower carcass quality in terms of higher fat deposition and lower lean meat accretion compared with their middle and heavy weight litter mates [42,43].

This study was carried out to validate the hypothesis that pigs with different birth weights react differently when fed an imbalanced supply with amino acids in the growing and the subsequent finishing phase as encountered in organic pig farming, resulting in differences in traits of pork quality. Therefore, pigs with different birth weights were fed with feed rations characterized by different essential amino acid contents.

3.1. Materials and methods

Experiment 2 included a total of 191 weaned commercial piglets of the genotype Pi × (DL × DE) with a live weight of approximately 30 kg, selected from a total number of 230 piglets and allocated to three different birth weight classes: low (average 0.95 kg, $n = 64$); medium (average 1.5 kg, $n = 64$); and high (average 2.1 kg, $n = 64$). Housing conditions and feeding regimes were similar to those of Experiment 1 described above. A total number of 9 treatments (3 feeding regimes × 3 live birth weight classes) were compared. Traits of performance, carcass and meat quality were assessed in relation to birth weight, feeding regime and sex according to the methodology described above (Section 2.1). In addition, histological characteristics were evaluated by the French Technical Centre for Meat Products (CTSCCV) in Paris, France. Muscle fibre was measured in terms of muscle area (μm^2), perimeter (μm), maximal and minimal diameter (μm) using a Calleja colouring. That is, the slice was first incubated in a 1st bath of absolute ethanol; followed by a 2nd bath of 90% ethanol. Next, the slice was put in a 1st bath of water for 2 min before being placed in a colour indicator solution (Mayer's incarmulin) for 10 min. The slice was then rinsed with water, before being stained in picro indigo carmine for 10 min. The slice was then again rinsed with water, before being later immersed for 2 min in ethanol at 50%, 70%, 90%, 95% and 100%. The slice was then soaked for 2 min in carboxylol and finally 2 min in xylene. After this a measurement was taken by microscope with the Matrox Mill programme. The total number of muscle fibres was additionally measured with a microscope three times.

3.2. Experimental design

Experiment 2 was of the randomized complete block design. The treatments consisted of the factorial combinations of three birth weight classes and three feeding regimes. The feeding regimes were identical to those used in Experiment 1 (see Section 2.1). CON = control diet, closely related to the recommendations according to GfE (1987), FIN = diet balanced supply in the growing phase, imbalanced in AA in the finishing phase, GRO + FIN = diet imbalanced in AA in both growing and finishing phase. One hundred and ninety one weaned commercial piglets of the genotype Pi × (DL × DE) with a live weight of approximately 30 kg were selected from a total number of 230 piglets and allocated to the three different birth weight classes mentioned above. Because of the occurrence of different diseases, 7 pigs from different treatments had to be excluded from the experiment.

Table 6
Composition and ingredients in the different feeding regimes[a] in the growing and the finishing phases (Experiment 2).

Ingredient[b]	Growing phase			Finishing phase	
	CON	FIN	GRO + FIN	CON	FIN and GRO + FIN
Barley (%)	35.0	29.5	23.5	43.0	32.5
Wheat (%)	34.0	29.0	22.5	32.0	32.5
Soybean meal (43% CP)	25.5	–	–	22.0	–
Faba beans (%)	–	18.0	31.0	–	16
Lupin (%)	–	14.0	18.0	–	15
Potato protein (%)	2.0	5.5	–	–	–
Rape oil (%)	0.5	1.0	2.0	0.5	1.5
Mineral mix (%)	3.0	3.0	3.0	2.5	2.5
ME (MJ per kg DM)	13.1	13.2	13.0	13.1	13.3
Crude fibre (g per kg DM)	57.6	49.0	51.0	49.6	41.8
Crude protein (g per kg DM)	195	189	181	173	146
Lysine (g per kg DM)	11.5	11.5	10.2	9.3	7.7
Methionine + Cystine (g per kgDM)	7.4	6.7	5.2	6.6	5.1
Threonine (g per kg DM)	8.3	8.4	7.0	6.9	5.9
Tryptophan (g per kg DM)	2.8	2.3	1.9	2.5	1.7
Lys: (Meth + Cys): Thre: Tryp	1:0.7: 0.7: 0.3	1:0.6: 0.7: 0.2	1:0.5: 0.7: 0.2	1:0.7: 0.7: 0.3	1:0.7: 0.8: 0.2

[a] For the abbreviations see Table 1.
[b] CP = crude protein; ME = metabolizable energy; DM = dry matter.

3.2.1. *Feeding regimes*

The ingredients and the composition of the feeding regimes are presented in Table 6. The rations were calculated to be isocaloric. The analyses of the feed mixtures, except for the energy content of feeding regimes CON and FIN, differed only slightly from the calculated data, which were based on the analysis of the single ingredients. The main differences between the diets were related to the protein sources. While the protein content of the control treatment was primarily based on soya bean meal plus potato protein, treatment FIN was composed of organic faba beans and lupines plus potato protein. The treatment GRO + FIN contained only faba beans and lupines as main protein source without further protein supplementation in both fattening phases. The use of different ingredients caused large differences between the feeding regimes in protein content and in the content of limiting amino acids. The protein content and the amino acid content were clearly lower in GRO + FIN than in FIN, and lower in FIN than in CON.

3.2.2. *Statistical analysis*

The statistical design and analysis of Experiment 2 was similar to the ones described for Experiment 1.

Statistical calculation was carried by the software SAS JMP 5.1.2 with the following GLM models:

Fattening and slaughtering performance:

$$\begin{aligned} y_{ijk} = {} & \mu + D_j + \mathrm{SEX}_j + \mathrm{LWB}_k + \mathrm{LWS}_k + (D \times \mathrm{SEX})_{ij} \\ & + (D \times \mathrm{LWB})_{ik} + (D \times \mathrm{LWS})_{ik} + (\mathrm{SEX} \times \mathrm{LWB})_{jk} \\ & + (\mathrm{SEX} \times \mathrm{LWS})_{jk} + (\mathrm{LWB} \times \mathrm{LWS})_k + e_{ijk} \end{aligned}$$

where y_i = target value; μ = mean; D_i = fixed effect of the diet i; SEX_j = fixed effect of the sex-genotype j; LWB_k = centred effect of the birth weight of animal k; LWS_k = centred effect of the weight at the start of the experiment of animal k; $(D \times \mathrm{SEX})_{ij}$ = interaction diet × sex; $(D \times \mathrm{LWB})_{ik}$ = interaction diet i × birth weight of animal k; $(D \times \mathrm{LWS})_{ik}$ = interaction diet i × start weight of animal k; $(\mathrm{SEX} \times \mathrm{LWB})_{jk}$ = interaction sex j × birth weight of animal k; $(\mathrm{SEX} \times \mathrm{LWS})_{jk}$ = interaction sex j × start weight of animal k; $(\mathrm{LWB} \times \mathrm{LWS})_k$ = interaction birth weight of animal k × start weight of animal k; e_{ijk} = residual error.

3.3. *Results*

3.3.1. *Performance traits*

Differences in performance with regard to birth weight classes are presented in Table 7. No differences were found in daily feed intake between the birth weight classes. Pigs of the high birth weight class had the highest dlwg in the total fattening period ($p < 0.05$), whereas feed conversion showed no statistically significant difference between birth weight classes. Performance traits of the fattened pigs in relation to the different feeding regimes are presented in Table 8. Across all production traits, the best results were obtained with feeding regime CON, whereas feeding regime GRO + FIN gave the worst results for all traits ($p < 0.05$). The results with pigs fed on the FIN feeding regime were intermediate.

On average, female pigs needed approximately 6 days more to reach the slaughter weight of 120 kg live weight. In contrast, their carcass yield was 0.7% higher compared with the castrates. Feed conversion was not affected by the sex. Model calculations revealed that the dlwg was affected in the first place by the feeding regime, followed by the sex and in third place by birth weight. In relation to dlwg no interactions between the factors were found.

3.3.2. *Carcass and meat quality*

Effects of birth weight on selected traits of carcass and meat quality are presented in Table 9. Carcass yield at slaughter was highest for the medium birth weight class. Pigs with a medium

Table 7
Effect of birth weight class on the production performance of the animals (Experiment 2).

Performance criterion	Birth weight class		
	Low ($n = 62$)	Medium ($n = 61$)	High ($n = 62$)
Daily feed intake (kg)	$2.39^{a} \pm 1.27$	$2.40^{a} \pm 0.12$	$2.40^{a} \pm 0.09$
Daily live weight gain (g per day)	$767^{b} \pm 91$	$776^{ab} \pm 88$	$805^{a} \pm 86$
Daily live weight gain (growing phase) (g per day)	$782^{a} \pm 139$	$813^{a} \pm 129$	$827^{a} \pm 118$
Daily live weight gain (finishing phase) (g per day)	$766^{a,b} \pm 93$	$761^{b} \pm 95$	$797^{a} \pm 103$
Feed conversion ratio	$3.07^{a} \pm 0.30$	$3.13^{a} \pm 0.30$	$3.07^{a} \pm 0.31$

[a,b,c] Means in the same row, followed by the same letter are not statistically different ($p < 0.05$).

Table 8
Effect of feeding regime^{a} on daily feed intake, daily live weight gain, and feed conversion ratio. (Experiment 2).

Performance criterion	Feeding regime		
	CON ($n = 61$)	FIN ($n = 63$)	GRO + FIN ($n = 61$)
Daily feed intake (kg)	2.44^{a} ± 0.08	2.42^{a} ± 0.10	2.34^{b} ± 0.12
Daily live weight gain (g per day)	835^{a} ± 89	791^{b} ± 69	724^{c} ± 73
Daily live weight gain (growing phase) (g perday)	908^{a} ± 94	823^{b} ± 99	694^{c} ± 94
Daily live weight gain (finishing phase) (g per day)	795^{a} ± 115	775^{ab} ± 81	755^{b} ± 95
Feed conversion ratio	2.95^{a} ± 0.33	3.07^{a} ± 0.23	3.26^{b} ± 0.27

^{a,b,c}Means in the same row, followed by the same letter are not statistically different ($p < 0.05$).
^{a}For the abbreviations see Table 1.

Table 9
Effect of birth weight on carcass and meat composition traits (±SE) (Experiment 2).

Carcass and meat quality parameter^{a}	Birth weight class		
	Low ($n = 62$)	Medium ($n = 61$)	High ($n = 62$)
Carcass yield (%)	$78.4^{a,b}$ ± 1.5	78.8^{a} ± 1.6	77.9^{b} ± 1.7
Lean meat (%)	59.0^{a} ± 2.0	59.2^{a} ± 2.1	59.2^{a} ± 1.9
Meat area (cm^2)	51.8^{a} ± 4.7	52.6^{a} ± 5.5	51.8^{a} ± 5.2
Fat area (cm^2)	17.7^{a} ± 2.8	17.6^{a} ± 2.3	17.4^{a} ± 2.2
Drip losses (%)	1.49^{a} ± 1.26	1.99^{a} ± 1.52	1.88^{a} ± 1.32
Protein content of the Mld (%)	23.2^{a} ± 4.3	22.8^{a} ± 5.2	23.0^{a} ± 4.2
IMF content of the Mld (%)	2.13^{a} ± 0.92	2.13^{a} ± 1.16	2.07^{a} ± 1.00

^{a,b,c}Means in the same row, followed by the same letter are not statistically different ($p < 0.05$).
^{a} IMF = intramuscular fat; Mld = *M. longissimus dorsi*.

birth weight attained a significantly higher carcass yield than pigs in the high birth weight class ($p < 0.05$). Birth weight of the pigs and carcass yield were negatively correlated ($r = -0.16$) ($p < 0.05$), whereas other traits showed no statistically significant correlation with birth weight. In contrast to the working hypothesis, lean meat, meat area and fat area as well as meat quality traits such as IMF content were not affected by the birth weight of the pigs.

Effects of feeding regime on traits of carcass and meat composition are presented in Table 10. Lean meat percentage and meat area of the Mld and the meat:fat ratio were markedly lower with feeding regime GRO + FIN than with the regimes FIN and CON ($p < 0.05$), whereas the fat area was not affected. Due to the large variation in drip losses after 24 h, differences between feeding regimes were not statistically significant ($p > 0.05$). In contrast, IMF content of the Mld clearly increased with feeding regime GRO + FIN compared with the CON diet from 1.22% to 2.80% ($p < 0.05$). The feeding regime FIN gave intermediate results. IMF content was negatively correlated with the lean meat percentage ($r = -0.46$), and with the meat area of the Mld ($r = -0.45$) ($p < 0.01$).

Table 10
Effects of feeding regime^{a} on carcass yield and meat composition traits (±SE). (Experiment 2).

Carcass and meat quality trait^{b}	Feeding regime		
	CON ($n = 61$)	FIN ($n = 63$)	GRO + FIN ($n = 61$)
Carcass yield (%)	79.0^{a} ± 1.5	78.1^{b} ± 1.6	77.9^{b} ± 1.6
Lean meat (%)	60.4^{a} ± 1.9	58.9^{b} ± 1.6	58.1^{c} ± 1.7
Meat area (cm^2)	56.0^{a} ± 4.2	51.4^{b} ± 4.3	48.8^{c} ± 3.9
Fat area (cm^2)	17.3^{a} ± 2.5	17.6^{a} ± 2.5	17.8^{a} ± 2.3
IMF content of the Mld (%)	1.22^{a} ± 0.50	2.30^{b} ± 0.77	2.80^{c} ± 1.01

^{a,b,c}Means in the same row, followed by the same letter are not statistically different ($p < 0.05$).
^{a} For abbreviations see Table 1.
^{b} IMF = intramuscular fat; Mld = *M. longissimus dorsi*.

The number of fibres per muscle area was not statistically different between the pigs of the birth weight classes but was affected by feeding regime. The highest numbers per cm^2 were found in pigs allocated to feeding regime FIN (28.8) and to GRO + FIN (27.4), whereas 24.3 muscle fibres per cm^2 were recorded with feeding regime CON ($p < 0.05$). No differences in the number of muscle fibres were found in relation to sire or sex. With $r = 0.28$, a positive correlation was found between the birth weight and the number of muscle fibres per cm^2. Carcass yield ($r = -0.27$), meat area ($r = -0.25$) and protein content of the Mld ($r = -0.24$) were negatively correlated with the muscle fibre number per area ($p < 0.05$).

3.4. *Discussion*

Selection for the sow's ability to give birth to a higher number of piglets has led to a larger within-litter variation in piglet birth weight [44]. While birth weight is a determining factor for weaning weight and survival at weaning [45], heavy piglets at birth have also the potential to reach higher daily live weight gains, as was shown in the present study and in other studies [46,47]. The present and previous studies also show that feeding regime affects the performance criteria more than the weight at birth.

Apart from a higher carcass yield attained by pigs with a medium birth weight than by heavier piglets at birth, carcass and meat carcass and meat quality traits did not differ between birth weight classes. Other reports also indicate that carcass fat depth and/or fat proportion were rather similar among birth weight groups [48,49]. In contrast, Gondret et al. [50] found a higher body fat and a lower lean meat content with light piglets than with heavy piglets at birth when individually reared and fed during the fattening period and slaughtered at the same live weight. At a fixed age at market weight the inferiority of light piglets and the superiority of heavy piglets are expected to become clearly apparent in carcass weight. Discrepancies in the effects of birth weight on carcass composition probably arise from differences in genotype, weight delineation, level of behavioural competition, and feeding scale.

In agreement with the results obtained by Dwyer et al. [51], the present study did not evidence any effects of birth weight (runts excluded) on total fibre number at slaughter. In contrast, Gondret et al. [49,50] presented evidence of an altered muscle cellularity with a higher cross-sectional area of fibres in pigs that were light at birth compared with larger litter mates of the same weight at slaughter.

Meat quality traits including IMF content were not influenced by birth weight classes, confirming results from previous research [50]. In contrast, other studies found higher IMF contents in pigs with a light birth weight [43,47]. However, the overall IMF values in these studies were comparatively low and were consistent with a higher degree of fatness in these pigs. Both aspects were absent in the present study. Rehfeldt et al. [47] suggest that there is an optimum in medium weight at birth, since they found a lower meat quality with pigs light at birth with respect to pH$_{45}$, drip loss, and impedance and with pigs with a high birth weight with respect to conductivity 45 min post mortem and lightness.

Concerning the implications of the feeding regime for pork quality traits, the results conclusively confirmed the knowledge gained in Experiment 1. In addition, a higher number of muscle fibres per cm^2 was found in connection with a reduced protein supply compared with a control treatment with the highest protein supply and lean meat percentage. In studies of Essén-Gustavsson [52] muscle fibre composition and the oxidative and glycolytic capacity did not differ between the pigs given a low- and a high-protein diet whereas the low-protein diet caused a higher IMF content than the pigs fed a high-protein diet. IMF values correlated with triglyceride content in the muscle, which in turn was negatively related to mean fibre area. Larzul et al. [53] did not find any relationship between IMF content and the numerical percentage of fibre types at a commercial slaughter weight of purebred Large White (DE) pigs.

Bee et al. [54] observed that feed restriction during the growing as well as during the growing and finishing period resulted in smaller myofibres in the *longissimus muscle* when pigs were slaughtered at the same age but at a lower body weight, indicating that nutrient restriction affected the growth of developing muscles. In contrast, other studies reported no effects of nutrient supply on the size and distribution of myofibres in pigs slaughtered at the same body weight [54,55]. These findings indicate that the impact of feed restriction on hypertrophic growth varies among myofibre types and muscles.

Intramuscular fat is composed of triglycerides and phospholipids, which represent 0.5–7% of the *longissimus muscle* [56]. A large amount of triglycerides is usually located in intramuscular adipocytes interspersed between myofibres and in the perimysium [57]. The amount of triglycerides located in intramuscular adipocytes is not related to fibre type composition, as has been confirmed in comparisons of genotypes [58] and in feeding experiments [17,55]. All these studies suggest that triglyceride content and fibre type composition can be manipulated independently through genetic and/or nutritional factors [53,59]. In contrast, there is a close relationship between fibre type composition and the content and nature of phospholipids, mostly located in membranes [60]. Oxidative muscles contain about twice as much phospholipids than glycolytic ones. Because phospholipids are major determinants of cooked meat flavour [61] muscle fibre type composition is likely to influence flavour through the phospholipids.

3.5. Conclusions

Because of the restricted availability of limited amino acids in organic pig production, the protein accretion capacity is lower in organic than in conventional production. Consequently, growth performance and meatiness of the carcasses are generally lower. To optimize the use of limited resources, organic farmers are challenged to adapt the supply of essential amino acids to the growth process in the various stages of life as suboptimal supply reduces performance whereas excess supply of amino acids cannot further increase performance but reduces feed efficiency, resulting in nutritional and financial losses.

In general, organic pig farming cannot compete with conventional production systems with respect to performance traits and production costs. In order to compensate for the higher production costs, organic pig farmers are well advised to put emphasis on a quality oriented production, including a high eating quality of pork to meet the expectations of consumers and respond to their willingness to pay premium prices for organic products.

On the other hand, pigs fed with organically produced feedstuffs and with an imbalanced diet in relation to the amino acid pattern have the potential to produce considerably high IMF levels in the Mld. This is expected to clearly improve the eating quality of pork for those consumers who show a positive perception of the intramuscular fat. So the production conditions in organic farming enhance the production of pork with a high eating quality.

To obtain high IMF-values, the feeding regime clearly is more important than the genotype. Concerns of farmers and retailers that fat area and back fat thickness increase with an increase in IMF content were not confirmed. In the present study, the combination of faba beans and lupines as protein sources provided the possibility to fatten pigs to an appropriate level of lean meat percentage and to a high IMF content in the Mld without increasing the amount of subcutaneous fat.

Pigs with different genetic capacity for protein accretion reacted differently to an imbalanced supply of amino acids, resulting in different carcass yields and differences in meat composition. The results indicate that the feeding regime should be more closely adapted to the genotype used on the farm and to the availability of limited resources for both pork quality and economic reasons. Antagonistic relationships between factors that increase protein accretion and factors that improve IMF content, however, make it necessary for the farmers to decide which factor should be given first priority.

Concerning birth weight, the results contradicted the initial hypothesis that the birth weight of piglets plays a relevant role in the accumulation of fat in the muscle. Under the experimental conditions the heavier piglets showed a better growth performance but not a better carcass or meat quality.

4. Implications

Currently, the economic framework conditions force the production of carcasses with a high lean meat percentage according to the current carcass grading system E-U-R-O-P. While being primarily focused on the production of lean meat and because of antagonistic relationships between several quantitative and qualitative traits, the payment system does not honour and even discourages the production of pork with a high eating quality.

Striving for a high eating quality presupposes the implementation of a system approach for an effective and efficient balancing of the multiple variables and complex interactions within each farm system. Comprehensive and accurate information about the availability of nutrients within the farm system and characteristics of the pig population on each farm with respect to nutrient partitioning for growth form the basis for a target-oriented direction of the production process, requiring a highly skilled farm management.

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