QualityLowInputFood

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QualityLowInputFood

Improving quality and safety and reduction of cost in the European organic and 'low input' supply food chains

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Food Quality and Safety

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WP4.4.2.2 In vitro and in vivo testing of promising protein rich crops

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Referaat

The effects of feeding weanling piglets diets with three different levels of field beans, lupins and quinoa on performance and health were studied. Inclusion levels up to 20% tannin-free field beans or 10% low alkaloid lupins can be recommended in diets for weanling piglets. It is difficult to draw a conclusion about the recommended level of quinoa in the diet. Piglets that were fed quinoa performed worse than the control group. A shortage of amino acids probably explains the worse performance.

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Alternative protein crops in diets of organically housed weanling pigs

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Summary

The effects of feeding weanling piglets diets with three different levels of three organic protein crops on performance and health were studied. Diets with 10, 20 or 30% field beans (Vicia faba, variety Aurelia, tannin-free), 10, 20 or 30% white lupins (Lupinus albus, variety Dieta, alkaloid-low) and 20, 40 or 60% quinoa (Chenopodium quinoa, variety Atlas, saponin-free) were compared with a control diet containing 15% soybean expeller and 2.2% soybeans. Besides, the apparent ileal digestibility and the apparent total tract digestibility of nutrients of the control diet and the diets with 30% field beans, 30% lupins and 40% quinoa were assessed. At weaning, 1,055 weanling piglets were assigned to one of the 10 experimental treatments. The piglets were monitored from weaning till four weeks after weaning. Piglets were housed in groups of 14 piglets. Diets were fed ad libitum by single-space dry feeders. At the end of the performance trial, 40 piglets were selected for the digestibility trial. At day 4 after the end of the performance trial, the 40 piglets were killed and ileal digesta and the contents of the rectum were collected. The ileal digesta of two piglets per pen were pooled and analysed for dry matter, ash, nitrogen, amino acids, crude fat, starch, sugar and chromium. The contents of the rectum, which is regarded to be similar to faeces, of two piglets per pen were pooled and analysed for dry matter, ash, nitrogen, crude fat, crude fibre, gross energy and chromium.

Main results and conclusion are:

- Daily gain, feed intake, feed conversion ratio and yield minus feeding costs were similar in piglets that were fed the control diet with 15% soybean expeller and in those that were fed diets with 10% or 20% field beans (variety Aurelia, tannin-free). Piglets that were fed the diet with 30% field beans performed worse.
- Daily gain, feed intake and yield minus feeding costs were similar in piglets that were fed the control diet and in those that were fed the diet with 10% lupins (variety Dieta, alkaloid-low). Daily gain, feed intake and yield minus feeding costs decreased with increasing level of lupins in the diet. The feed conversion ratio was not affected by the level of lupins in the diet and was similar in piglets fed the control diet or the diets with lupins.
- Daily gain and yield minus feeding costs decreased and feed conversion got worse with an increasing level of quinoa (variety Atlas, saponin-free) in the diet. Feed intake was not affected by the level of quinoa in the diet and was similar in piglets fed the control diet or the diets with quinoa. A shortage of amino acids probably explains the worse daily gain and feed conversion ratio.
- Mortality of piglets and the number of veterinary treated piglets were low and were not affected by experimental treatment.
- In all diets, the realised NE content was 8 to 12% lower than the planned NE content.
- In all diets, the realised ileally digestible lysine levels were lower than the planned levels. In the diets with field beans, and lupins and especially in the diets with quinoa, the differences between planned and realised ileally digestible lysine levels were greater than in the control diet.
- The protein content in quinoa is much lower that in other protein crops. The protein contents in soybean expeller, field beans, lupins and quinoa were 456, 286, 370 and 193 gram per kg dry matter, respectively.

Based on the results in this trial, it can be concluded that inclusion levels up to 20% tannin-free field beans or 10% low alkaloid lupins can be recommended in diets for weanling piglets. Higher levels decreased the performance of the piglets, probably as a result of a shortage of ileally digestible amino acids or because of a too high level of ANFs in the diets. It might be that higher inclusion levels of field beans and lupins can be recommended when the ileally digestible amino acids levels are assessed correctly.

It is difficult to draw a conclusion about the recommended level of quinoa in the diet. Piglets that were fed quinoa performed worse than piglets that were fed the control diet. Feed intake, however, was not affected by quinoa in the diet. It is very likely that the worse daily gain and feed conversion ratio can be explained by a shortage of amino acids in the diets with quinoa and not by a too high level of ANFs. It is not known what level can be recommended when the ileally digestible amino acids levels are assessed correctly. It is questionable if quinoa is a protein crop because the protein content in quinoa is much lower that in other protein crops.

More knowledge on the digestibility of protein, amino acids and energy in organically grown protein crops is highly required.

Contents

1 Introduction

From August 2005 onwards, 85% of the feedstuffs in diets of organically-housed pigs have to be from organically-grown sources. Every two years, this percentage will be increased by 5%. From January 2012, 100% of the feedstuffs have to be from organically-grown sources. These feedstuffs are preferably grown in the area of Western Europe. Cereals can be successfully grown in this area but the cultivation of protein crops might be a problem. Because of the climate in Western Europe, it is not possible to cultivate commonly used protein sources like soybeans. Therefore, alternative organically-grown protein crops have to be investigated as protein source in pig diets. Helsper et al. (2006) concluded that legume seeds like field beans, lupin species (Lupinus albus, Lupines luteus and Lupines angustifolius) and peas might be interesting alternative protein crops that can be cultivated under our climatic conditions. Field beans are probably more attractive to cultivate than peas due the lower sensitivity for fungal and other diseases. Usually, legume protein crops are only fed to a limited extent to piglets due to the occurrence of anti-nutritional factors (ANFs) like tannins, protease inhibiters, alkaloids and lectins. However, in recent years, plant breeding research has selected for legumes with lower levels of ANFs like tannin-free field beans and alkaloid-free lupins. Only limited information is available on the nutritional value of these low ANFs legumes. Moreover, the effects of these protein crops in pig diets on the performance and health of piglets is not known. In addition to legumes, quinoa might be an interesting protein crop due to its relatively high protein content, low levels of ANFs and high quality of the amino acid composition (Helsper et al., 2006). From quinoa, no information is available on the nutritional value in pig diets and on the effects on performance and health of piglets.

The aim of this study was:

1) To assess the effects of pig diets with three different levels of three organic protein crops on performance and health of weanling piglets. Diets with 10, 20 or 30% field beans (Vicia faba, variety Aurelia, tannin-free), 10, 20 or 30% white lupins (Lupinus albus, variety Dieta, alkaloid-low) and 20, 40 or 60% quinoa (Chenopodium quinoa, variety Atlas, saponin-free) were compared with a control diet containing 15% soybean expeller and 2.2% soybeans.
2) To assess the apparent ileal digestibility of dry matter, organic matter, ash, nitrogen, amino acids, crude fat, nitrogen-free extract, starch and sugar of the control diet and the diets with 30% field beans, 30% lupins and 40% quinoa.
3) To assess the apparent total tract digestibility of dry matter, organic matter, ash, nitrogen, crude fat, crude fibre, nitrogen-free extract and energy of the control diet and the diets with 30% field beans, 30% lupins and 40% quinoa.

2 Material and methods

2.1 Animals and experimental size

The research was conducted at Research Station Raalte (The Netherlands) with 1,055 weanling piglets of the crossbred Large White-boar x (Large White x Dutch Landrace)-sow. Forty of these piglets were used in the digestibility experiment. Piglets were raised under organic farming conditions according to SKAL. At an average age of 42 days (average weight of 13.2 kg) piglets were weaned and assigned to the experimental treatments. The piglets were monitored from weaning till four weeks after weaning. The research was conducted from December 2004 to July 2005.

2.2 Experimental treatments

Ten experimental treatments were compared. Piglets were fed a starter diet with:

1. soybean expeller (15.0%) and soybeans (2.2%) as main protein crops (control group);
2. 10% field beans (variety Aurelia, tannin-free);
3. 20% field beans (variety Aurelia, tannin-free);
4. 30% field beans (variety Aurelia, tannin-free);
5. 10% white lupins (variety Dieta, alkaloid-low);
6. 20% white lupins (variety Dieta, alkaloid-low);
7. 30% white lupins (variety Dieta, alkaloid-low);
8. 20% quinoa (variety Atlas, saponin-free);
9. 40% quinoa (variety Atlas, saponin-free);
10. 60% quinoa (variety Atlas, saponin-free).

2.3 Experimental design

At weaning, piglets were assigned to one of the 10 experimental treatments. Piglets were blocked by gender, genotype, weaning weight and weaning age. Piglets with physical abnormalities were not assigned to the experiment. For this experiment, two rooms with each 7 pens (14 piglets per pen) were available. Therefore, it was not possible to compare all ten treatments within a room. To realise a correct statistical analysis, the experiment was carried out as a balanced incomplete design with extra replicates of the control group (Appendix 1) (Cochran and Cox, 1968). To prevent a systematic overestimation or underestimation of the treatments with alternative protein crops, the control group was involved in each batch. The control group was repeated 12 times, the other experimental treatments were repeated eight times.
In some batches, there were less piglets available than 98 (7 pens x 14 piglets). Then, 10 or 12 piglets per pen were assigned to the experiment. One half of the piglets in a pen were barrows. The other half were sows.

2.4 Feeding and water supply

From day 14 onwards during the suckling period, piglets were fed a pre-starter diet. This diet was also fed during the first three days after weaning. Weaning diarrhoea is a common problem at the Research Station Raalte, and they have good experience with this feeding strategy. On day 4 and 5 after weaning, piglets were switched over to the experimental diets which were fed until day 28 after weaning (end of the trial). On day 4, piglets were fed 66.6% of the pre-starter diet and 33.3% of one of the experimental diets. On day 5, piglets were fed 33.3% of the pre-starter diet and 66.6% of one of the experimental diets. The starter diets were fed ad libitum by single-space dry feeders. The composition of the starter diets is presented in appendix 2. Only the composition of the control diet and the diets with the highest inclusion levels of field beans, lupins and quinoa are presented. The diets with the intermediate levels were realised by mixing the control diet and the diets with the highest inclusion level before pelleting. The alternative protein crops (field beans, lupins and quinoa) were exchanged against soybean expeller, soybeans, and cereals (wheat and barley). All diets were formulated to contain 9.42 MJ NE, 185 g/kg crude protein and at least 8.45, 4.65, 5.1 and 1.5 g/kg lysine, methionine + cystine, threonine and tryptophan, respectively. In the diet with 30% lupins, however, the level of ileal digestible tryptophan was 1.4 g/kg. The field beans, lupins and quinoa were grown in the Netherlands under organic conditions. All diets were produced in one batch by ABCTA (Harreveld, the Netherlands). The diets were stored in a cold-storage warehouse until needed. Drinking water was provided ad libitum by a drinking trough.

2.5 Housing and climate

Piglets were housed in two different rooms with each 7 pens for 14 piglets. Every pen was 2.0 m x 4.8 m and had an outdoor run of 7.0 m^2. The pen floor had a concrete solid floor of 2.0 m x 3.3 m and metal tri-bar slats of 2.0 m x 1.5 m. The solid floor was provided with straw. The outdoor run was 2.0 m x 3.5 m and consisted of 2.0 m x 1.75 m concrete solid floor and 2.0 m x 1.75 m concrete slats. One room was equipped with a computer-controlled heating system and a mechanical ventilation system. At weaning, the room temperature was set at 25° C. This was gradually reduced to 18° C in four weeks. The other room was ventilated naturally. In this room, all pens had a shelter to create a pleasant micro-climate for the piglets.

2.6 Data collection

Feed analysis
The four main protein crops that were used in the experiment (soybean expeller, field beans, lupins and quinoa) and four other protein crops (peas, lupins Bora, lupins Wodjil, and field beans Gloria) were analysed for dry matter, ash, nitrogen, crude fat, crude fibre, starch, sugar, minerals (Ca, P, Mg, K, Na, Cu, Zn, and Fe), and phytic acid in duplicate. Besides, in these protein crops the *in vitro* digestibility of organic matter and nitrogen was determined in duplicate. The analysed nutrient composition of the protein crops was used to formulate the experimental diets. The four protein crops were not analysed for the contents of amino acids. Therefore, for soybean expeller, field beans and lupins, the amino acid composition as published in the Dutch Feedstuffs Table (CVB, 2004) was used. The amino acid composition of quinoa was not known. We supposed that the amino acid composition in quinoa was comparable to that of wheat (CVB, 2004).

All experimental diets were analysed for dry matter, ash, and nitrogen in duplicate.

The four diets that were used in the digestibility experiment (control diet, 30% field beans, 30% lupins and 40% quinoa) were analysed for dry matter, ash, nitrogen, crude fat, crude fibre, starch, sugar, minerals (Ca, P, Mg, K, and Na), chromium, and gross energy in duplicate and for amino acids in simple. Besides, the particle size distribution of these diets was analysed. Dry matter and ash content were determined according to the AOAC (1984). Nitrogen was assayed by the Kjeldahl method (AOAC, 1984) and protein was estimated as nitrogen x 6.25. Crude fat was assayed by the Berntrop method (ISO 6492). Crude fibre was determined according to ISO/DP 6865. Sugar was assayed according to the NSP protocol (Van Gelder et al., 1992). Total P, Ca, Mg, Cu, Zn, Fe, Na, and K were determined by atomic emission spectrometry (ISO 11885: 1996). Starch was assayed by α-amylo glucosidase procedure without extraction (NEN 3574). The phytic acid content was assayed according to Bos et al. (1991). The *in vitro* organic matter digestibility was assayed according to Cone et al. (1993) and the *in vitro* crude protein digestibility according to Cone and Van Gelder (1992). The gross energy content was determined in an adiabatic bomb calorimeter (ISO 9831). The amino acids (except methionine, cysteine and tryptophan) were assayed by ion-exchange column chromatography after hydrolysis for 23 h in HCl (6 mol L^{-1}). Cysteine and methionine were determined as cysteic acid and methionine sulfone after oxidation with performic acid before hydrolysis (Schram et al., 1954). Tryptophan was determined according to Sato et al. (1984). Chromium was analysed by atomic absorption spectrophotometry after ashing the samples at 550 °C for four hours (Williams et al., 1962). The particle size distribution of the diets was analysed by using the wet sieve method. For this method 200 g of feed was dissolved in 500 ml water, soaked for 45 min, after which this solution was flushed through the sieves. The content of each sieve was dried and weighed. Five particle size fractions were distinguished by using sieves with different diameters.

Performance data
All piglets were weighed individually at the day of weaning (start of the experiment), two weeks after weaning and four weeks after weaning (end of the experimental period). The amount of feed supplied was recorded per pen on days 14 and 28. These data were used to calculate growth rate per day, feed intake per day and feed conversion ratio. Veterinary treatments were recorded per animal. When a piglet died, the date of mortality, weight of the pig, reason of mortality and total amount of feed consumed in its pen were recorded. The dead animals were not included in the analyses of the results.

Financial results
In the economic calculation the differences in performance of the pigs, the feeding costs, the costs of veterinary treatments and labour costs for treating the animals where considered. From this, the gross margin per delivered piglet and the yield minus feeding costs were calculated.

Digestibility experiment
At the end of the performance trial (day 28 after weaning), 40 piglets (16 from batch 3 and 24 from batch 7) were selected for the digestibility trial. Ten piglets on treatment 1 (control group), ten piglets on treatment 4 (30% field beans), ten piglets on treatment 7 (30% lupins) and ten piglets on treatment 9 (40% quinoa) were used in the digestibility experiment. Piglets were fed the same diets as in the performance trial but a premix of chromium (0.2 g Cr/kg diet) had been added to the diets. To prevent piglets from eating straw, straw was removed from the pens. At day 4 after the end of the performance trial, the 40 piglets were killed with T61. This was directly followed by a cut in the throat to bleed the animal. Subsequently, the abdominal cavity was opened and the last 2 m of the terminal ileum was clamped. A sample of chyme was taken and directly frozen in dry ice. In addition, the contents of the rectum were collected.
The ileal digesta of two piglets per pen were pooled and analysed for dry matter, ash, nitrogen, amino acids, crude fat, starch and sugar in simple and for chromium in duplicate. The contents of the rectum, which is regarded to be similar to faeces, of two piglets per pen were pooled and analysed for dry matter, ash, nitrogen, crude fat, crude fibre and gross energy in simple and for chromium in duplicate.

The apparent ileal digestible contents of dry matter, organic matter, ash, nitrogen, amino acids, crude fat, nitrogen-free extract (= dry matter – ash – crude protein – crude fat – crude fibre), starch and sugar and the apparent total tract digestible contents of dry matter, organic matter, ash, nitrogen, crude fat, crude fibre, nitrogen-free extract and energy of the diets were calculated using chromium as an inert marker.

2.7 Statistics

Daily gain, daily feed intake, feed conversion ratio, and the financial results were analysed by analysis of variance (Genstat, 2004), using the following model:

Y = μ + batch + control diet + control diet (protein crop x inclusion level) + error

The weight at weaning was included as a covariate.

The number of pigs that died and the number of pigs that were veterinary treated were analysed by means of a Chi-square test.

In the digestibility experiment, a set of two piglets was considered to be an experimental unit. Digestible components and energy data were subjected to analysis of variance with dietary treatment and batch as factors in the model. The statistical package Genstat (2004) was used. The *P* values for the treatment contrasts were calculated using Student's *t*-test.

3 Results

In this chapter, the analysed composition of the protein crops and of the experimental diets, the performance of the pigs and the results of the digestibility experiment are presented.

3.1 Chemical composition of the protein crops and the experimental diets

The analysed chemical composition and *in vitro* digestibility of eight protein crops (soybean expeller, field beans Aurelia, lupins Dieta, quinoa Atlas, peas, lupins Bora, lupins Wodjil and field beans Gloria) are presented in
Table 1.

Table 1 Analysed chemical composition and in vitro digestibility of eight protein crops (g/kg dry matter)

	Soybean expeller	Lupins Dieta	Field beans Aurelia	Quinoa Atlas	Peas	Lupins Bora	Lupins Wodjil	Field beans Gloria
DM (g/kg fresh)	928.2	816.8	841.4	755.9	860.6	894.6	898.3	933.3
Ash	67.6	67.2	38.8	55.4	70.4	33.4	57.6	43.9
Organic matter	932.4	932.8	961.2	944.6	929.6	966.6	942.4	956.1
Crude protein	455.7	369.9	286.1	192.8	246.0	310.2	291.5	333.1
Crude fat	119.1	78.5	18.2	75.0	26.8	63.6	100.9	15.3
Crude fibre	69.2	147.7	103.0	49.9	70.4	158.6	188.1	91.7
Starch	4.2	35.2	324.7	497.0	425.1	b.d.[a]	b.d.	343.1
Sugar	94.5	59.6	40.3	16.8	45.9	63.2	76.3	45.9
Phytic acid	16.6	14.3	16.2	12.8	n.d.[b]	9.5	31.6	10.5
Ca	4.0	2.7	1.3	2.2	1.3	2.9	2.7	1.4
Mg	3.1	2.2	1.7	3.8	1.5	1.6	3.8	1.6
P	7.2	6.4	6.1	6.3	4.0	4.5	10.7	7.4
K	24.5	17.1	13.9	19.9	11.2	9.6	16.3	16.0
Na	b.d.	0.2	b.d.	b.d.	b.d.	0.2	0.2	b.d.
Cu (mg/kg DM)	21	10	19	11	b.d.	b.d.	32	20
Zn (mg/kg DM)	65	71	88	96	36	37	96	64
Fe (mg/kg DM)	262	335	142	154	87	47	94	68
In vitro OM dig. (%)	93.8	85.4	91.9	91.1	95.1	87.3	83.3	92.9
In vitro CP dig. (%)	90.6	93.4	92.4	77.5	92.3	99.1	95.0	95.7

[a] b.d. = below detectection limit
[b] n.d. = not determined

Table 1 shows that quinoa had a low dry matter content. Ash content of the protein crops ranged from 33 g/kg DM in lupins Bora to 70 g/kg DM in peas. Quinoa had the lowest (192.8 g/kg dry matter) and soybean expeller had the highest (455.7 g/kg dry matter) crude protein content. Crude fat content ranged from 15 g/kg DM in field beans Gloria to 119 g/kg DM in soybean expeller. The crude fat content in lupins Wodjil was much higher than in lupins Dieta and lupins Bora. Quinoa had the lowest crude fibre content, while the three batches of lupins showed the highest crude fibre content. Soybean expeller and the three batches of lupins had very low starch contents, while field beans, peas and quinoa showed high starch contents. Sugar content ranged from 17 g/kg dry matter in quinoa to 94 g/kg dry matter in soybean expeller. Calcium content ranged from 1.3 g/kg dry matter in field beans and peas to 4.0 g/kg dry matter in soybean expeller. Lupins Wodjil showed a very high total P and phytic acid content of 10.7 and 32 g/kg dry matter, respectively. Total P content in the other alternative protein crops ranged from 4.0 g/kg dry matter in peas to 7.4 g/kg dry matter in field beans Gloria. Phytic acid content ranged from 10 g/kg dry matter in lupins Bora to 17 g/kg dry matter in soybean expeller. Magnesium content varied between 1.5 to 4.0 g/kg dry matter. Potassium content of all alternative protein crops was rather high and ranged from 9.6 to 24.5 g/kg dry matter. Sodium content was quite low in all protein crops. Copper content of lupins Wodjil was quite high (32 mg/kg dry matter), whereas all other protein crops had a normal copper content. Zinc and iron contents were as expected.
The *in vitro* organic matter digestibility of field beans, quinoa and peas was comparable to that of soybean expeller. The three batches of lupins showed *in vitro* organic matter digestibilities that were lower than that of soybean expeller. The *in vitro* crude protein digestibility of most alternative protein sources was superior to that of soybean expeller. Only quinoa showed a lower *in vitro* crude protein digestibility than soybean expeller.

The analysed chemical composition of the 10 experimental diets is presented in Table 2.

Table 2 Analysed chemical composition of the ten experimental diets (g/kg)

	Control	Field beans			Lupins			Quinoa		
		10%	20%	30%	10%	20%	30%	20%	40%	60%
Dry matter	890	888	886	885	887	885	879	882	870	855
Crude protein	198	191	190	189	198	199	200	193	192	192
Ash	58	60	63	77	61	67	74	63	66	69

The analysed and calculated dry matter in the diets is very similar. The dry matter content in the diets with 40 and 60% quinoa is low. This can be explained by low dry matter content of quinoa (756 g/kg). The analysed crude protein content shows only little variation among the diets (from 190 to 200 g/kg) but is in all diets higher than the calculated protein content of 185 g/kg. The analysed ash content is in all diets, except for the diet with 30% field beans, lower than the calculated ash content.

The analysed chemical composition of the four diets (control group, 30% field beans, 30% lupins, and 40% quinoa) that were used in the digestibility experiment are presented in Table 3.

Table 3 Analysed chemical composition of the four experimental diets in the digestibility experiment (g/kg dry matter)

	Control	30% Field beans	30% Lupins	40% Quinoa
DM (g/kg as fed)	870.1	863.0	856.4	855.5
Ash	64.5	87.2	79.4	73.0
Organic matter	935.5	912.8	920.6	927.0
Crude protein	219.0	210.9	222.8	219.4
Crude fat	47.8	38.8	51.1	53.0
Starch	399.3	416.9	387.0	417.4
Sugar	65.7	52.5	54.8	49.5
Crude fibre	39.4	46.9	55.0	37.1
NFE[1]	629.3	616.2	591.7	617.5
Gross energy (MJ/kg DM)	18.8	17.7	18.6	18.9
Lysine	11.1	9.9	10.5	9.4
Methionine	3.2	2.6	2.7	3.2
Cystine	3.8	3.2	3.5	3.5
Methionine + cystine	7.0	5.8	6.2	6.6
Threonine	8.9	8.9	8.9	8.9
Tryptophan	2.7	2.5	2.6	2.7
Isoleucine	9.5	8.4	9.5	9.0
Arginine	12.3	14.5	15.0	12.2
Phenylalanine	11.2	9.4	10.4	10.5
Histidine	5.6	5.5	5.5	5.4
Leucine	18.3	16.7	20.2	18.2
Tyrosine	8.5	7.7	9.8	8.6
Valine	11.0	9.9	10.6	10.5
Phenylalanine +tyrosine	19.6	17.0	20.2	19.2
Alanine	10.2	9.6	10.6	10.6
Aspartic acid	20.3	18.3	20.9	18.9
Glutamine	40.2	36.5	37.5	36.4
Glycine	9.1	8.5	8.5	9.4
Proline	15.7	12.8	13.0	13.8
Serine	10.4	9.5	10.6	9.9

[1] NFE = nitrogen-free extract (dry matter – ash - crude protein – crude fat – crude fibre)

In the diet with 30% field beans, the crude protein content is about 10 g/kg lower than in the other three diets. In the other diets, the protein contents are very similar. The contents of most amino acids are lowest in the diet with 30% field beans and highest in the control diet and the diet with 30% lupins.

The particle size of the four diets that were used in the digestibility experiment is presented in Table 4.

Table 4 Particle size distribution (%) of the four experimental diets in the digestibility experiment (g/kg)

Particle size	control	30% field beans	30% lupins	40% quinoa
> 2.0 mm	12.6	12.6	19.4	4.9
1.4 – 2.0 mm	39.8	38.7	49.1	38.6
0.6 – 1.4 mm	162.1	153.0	160.8	115.7
0.1 – 0.6 mm	243.3	239.1	246.0	251.6
< 0.1 mm[1]	542.2	556.6	524.7	589.2

[1] A particle size of less than 0.1 mm cannot be measured but it is calculated as 1000 minus the total of the other fractions

The particle size in the control diet, the diet with 30% field beans and the diet with 30% lupins are very similar. In the diet with 40% quinoa, the particle size is somewhat smaller.

3.2 Performance of the piglets

The performance of the piglets from weaning to day 14, from day 15 to day 28, and from weaning to day 28 is presented in Table 5.

From weaning to day 14, average daily gain was highest in piglets that were fed the control diet or the diets with 20% field beans, 10% lupins or 20% quinoa. Daily gain was lowest in piglets that were fed the diets with the highest inclusion levels of field beans, lupins or quinoa. Feed intake was lowest in piglets that were fed the diets with 20 or 30% lupins. It was similar in the other experimental treatments. Feed conversion ratio was worst in piglets that were fed the diets with 30% field beans, 40% quinoa or 60% quinoa. Feed conversion ratio did not significantly differ between the other experimental treatments.

From day 14 to day 28, average daily gain was highest in piglets that were fed the control diet or the diets with 10 or 20% field beans, 10% lupines or 20% quinoa. Daily gain was lowest in piglets that were fed the diets with 30% field beans, 30% lupins, or the diets with 40% or 60% quinoa. Feed intake was lowest in piglets that were fed the diets with 20 or 30% lupins. It was similar in the other experimental treatments. Feed conversion ratio was worst in piglets that were fed the diets with 30% field beans or all the diets with quinoa. Feed conversion ratio did not significantly differ between the other experimental treatments.

From weaning to day 28, average daily gain was highest in piglets that were fed the control diet or the diets with 10 or 20% field beans or 10% lupins. Daily gain was lowest in piglets that were fed the diets with 30% field beans, 30% lupins, or the diets with 40% or 60% quinoa. Feed intake was lowest in piglets that were fed the diets with 20 or 30% lupins. It was similar in the other experimental treatments. Feed conversion ratio was worst in piglets that were fed the diets with 30% field beans or all the diets with quinoa. Feed conversion ratio did not significantly differ between the other experimental treatments although it was slightly worse in the piglets that were fed the diets with 10% or 20% field beans.

3.3 Health and mortality

In Table 6, mortality of the piglets and the causes of mortality are presented. In addition, the number of veterinary treated pigs and the causes of veterinary treatments are presented.

Mortality of piglets and the number of veterinary treated piglets were not affected by experimental treatment.

Table 5 Performance of weanling piglets that were fed diets with different protein crops at different levels

	Control	Field beans			Lupins			Quinoa			P-value[1]
		10%	20%	30%	10%	20%	30%	20%	40%	60%	P x I
Number of pens	12	8	8	8	8	8	8	8	8	8	
Number of pigs	149	99	102	100	100	106	102	95	103	99	
Weaning to day 14:											
Weaning weight (kg)	13.3	13.1	13.1	13.3	13.4	13.3	13.1	13.1	13.2	13.2	
Growth (g/day)	320[a]	284[bc]	306[ab]	229[d]	293[abc]	286[bc]	261[cd]	288[abc]	276[bc]	260[cd]	0.179[2]
Feed intake (kg/day)	0.55[a]	0.52[ab]	0.54[ab]	0.51[abc]	0.52[ab]	0.49[bc]	0.47[c]	0.53[ab]	0.54[ab]	0.54[ab]	0.525[3]
Feed conversion ratio	1.73[a]	1.87[ab]	1.78[a]	2.31[d]	1.77[a]	1.75[a]	1.82[ab]	1.86[ab]	1.98[bc]	2.10[c]	<0.001
Day 14 to day 28:											
In-between weight (kg)	17.5	16.7	17.1	16.4	17.2	16.9	16.2	16.8	16.9	16.5	
Growth (g/day)	569[a]	554[ab]	576[a]	465[c]	554[ab]	512[bc]	482[c]	542[ab]	472[c]	480[c]	0.015
Feed intake (kg/day)	1.00[ab]	1.01[ab]	1.05[a]	0.96[b]	0.95[bc]	0.88[cd]	0.83[d]	1.02[ab]	0.94[bc]	0.99[ab]	0.058
Feed conversion ratio	1.76[a]	1.84[ab]	1.84[ab]	2.08[d]	1.73[a]	1.72[a]	1.72[a]	1.90[bc]	2.02[cd]	2.07[d]	0.029
Weaning to day 28:											
End weight (kg)	25.4	23.9	25.2	22.9	25.0	24.2	22.6	24.4	23.4	23.0	
Growth (g/day)	450[a]	424[abc]	446[ab]	351[e]	429[abc]	403[cd]	376[de]	419[bc]	377[de]	375[de]	0.003
Feed intake (kg/day)	0.78[ab]	0.77[ab]	0.81[a]	0.74[bc]	0.74[bc]	0.69[cd]	0.66[d]	0.78[ab]	0.75[ab]	0.77[ab]	0.085
Feed conversion ratio	1.75[ab]	1.83[bc]	1.82[bc]	2.13[e]	1.74[a]	1.72[a]	1.75[ab]	1.88[c]	1.99[d]	2.08[de]	<0.001

[1] P x I: interaction between protein crop and inclusion level
[2] There was no significant interaction between protein crop and inclusion level but there was a significant effect of inclusion level (P < 0.001)
[3] There was no significant interaction between protein crop and inclusion level but there was a significant effect of protein crop (P = 0.014)
[abcde] Different letters in a row indicate differences among the experimental treatments (P<0.05)

Table 6 Mortality and veterinary treatments of weanling piglets that were fed diets with different protein crops at different levels

	Control	Field beans			Lupines			Quinoa			Sign[1]
		10%	20%	30%	10%	20%	30%	20%	40%	60%	
Number of pens	12	8	8	8	8	8	8	8	8	8	
Number of pigs	149	99	102	100	100	106	102	95	103	99	
Mortality (number)	2	1	3	0	3	1	1	1	1	1	n.s.
Cause of death											
- respiratory disorders	0	0	1	0	1	1	1	0	0	1	[2]
- gastrointestinal disorders	1	0	0	0	1	0	0	1	0	0	[2]
- leg disorders	0	0	1	0	0	0	0	0	0	1	[2]
- bad condition	1	1	1	0	1	0	0	0	1	0	[2]
Veterinary treated (number)	3	2	3	2	2	4	2	1	1	2	n.s.
Cause of treatment											
- respiratory disorders	0	1	2	1	2	3*	1	0	0	1	[2]
- gastrointestinal disorders	2*	0	0	1	0	0	1	1	0	0	[2]
- leg disorders	1	1	1	0	0	1	0	0	1	1	[2]

[1] Sign=significance: n.s. = not significant
[2] Numbers are too small for proper statistical analysis
* Concerns piglets in the same pen

3.4 Financial results

In the economic calculation the differences in performance, in feeding costs, in the costs of veterinary treatments and in labour costs for treating the animals were considered. From this, the gross margin per delivered piglet and the yield minus feeding costs were calculated. The following assumptions were made:

- Yield per delivered organic pig: € 90.90 at a body weight of 25 kg. Pigs at a lower or higher body weight yielded € 2.06 less or more per kg difference in body weight.
- Feed costs:

starter diet with soybean expeller(control group)	€ 45.00 per 100 kg
starter diet with 10% field beans	€ 44.33 per 100 kg
starter diet with 20% field beans	€ 43.66 per 100 kg
starter diet with 30% field beans	€ 42.99 per 100 kg
starter diet with 10% lupines	€ 44.20 per 100 kg
starter diet with 20% lupines	€ 43.41 per 100 kg
starter diet with 30% lupines	€ 42.61 per 100 kg
starter diet with 20% quinoa	€ 44.87 per 100 kg
starter diet with 40% quinoa	€ 44.74 per 100 kg
starter diet with 60% quinoa	€ 44.61 per 100 kg

  The amount of pre-starter supplied in the first 3 days after weaning (about 2 kg per piglet) is calculated as starter diet.
- Medication costs: € 0.09 per ml; on average 2 ml of a medicine is injected per individual veterinary treatment.
- Labour costs for the veterinary treatments: € 18.27 per hour.
- Observations by the Research Institute for Pig Husbandry indicated that each individual veterinary treatment of weanling pigs takes 1.13 minutes. It is assumed that each treated piglet was treated two times.
- Mortality costs: the costs per dead animal are € 75.53.
- Remaining costs: costs of general health care, water, gas, electricity, and litter are € 2.09 per delivered pig.

The results of the economic calculation are presented in Table 7.

Yield of the piglets was highest in the piglets that were fed the control diet or the diets with 10 or 20% field beans, 10% lupines or 20% quinoa. Yield of the piglets was lowest in piglets that were fed the diets with 30% field beans, 30% lupins or 40% or 60% quinoa. Feeding costs were highest in piglets that were fed the control diet or the diets with 10% or 20% field beans or the diets with quinoa. Yield minus feeding costs and gross margin per delivered piglet are comparable in the groups that were fed the control diet, the diets with 10% or 20% field beans or the diets with 10% or 20% lupins. Yield minus feeding costs and gross margin per delivered piglet are lowest in groups that were fed the diet with 30% field beans or the diets with 40% or 60% quinoa.

Table 7 Financial results (€) per delivered pig of piglets that were fed diets with different protein crops at different levels

	Control	Field beans			Lupines			Quinoa			P-value[1]
		10%	20%	30%	10%	20%	30%	20%	40%	60%	P x I
Yield	91.29^{a}	89.91^{ab}	91.15^{a}	85.90^{d}	90.14^{ab}	88.74^{bc}	87.23^{cd}	89.67^{ab}	87.36^{cd}	87.17^{cd}	0.003
Feeding costs	9.38^{a}	9.12^{ab}	9.38^{a}	8.52^{bc}	8.76^{b}	8.00^{cd}	7.46^{d}	9.37^{a}	8.94^{ab}	9.16^{ab}	0.044
Health costs	0.02	0.02	0.03	0.02	0.02	0.04	0.02	0.01	0.01	0.02	
Mortality costs	1.03	0.77	2.29	0.00	2.34	0.72	0.75	0.80	0.74	0.77	
Remaining costs	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.09	
Gross margin[2]	78.77^{a}	77.91^{ab}	77.36^{b}	75.27^{c}	76.93^{b}	77.89^{ab}	76.91^{b}	77.40^{b}	75.58^{c}	75.13^{c}	0.008
Yield - feeding costs	81.91^{a}	80.79^{abc}	81.77^{a}	77.38^{d}	81.38^{ab}	80.74^{abc}	79.77^{c}	80.30^{bc}	78.42^{d}	78.01^{d}	<0.001

[1] P x I: interaction between protein crop and inclusion level

^{abcd} Different letters in a row indicate differences among the experimental treatments ($P<0.05$)

[2] Gross margin = yield – feeding costs – health costs – mortality costs – remaining costs

3.5 Apparent ileally digestible proximate components and amino acids

The apparent ileal digestible proximate components and amino acids of the control diet and the diets with 30% field beans, 30% lupins and 40% quinoa are presented in Table 8.

Table 8 Average apparent ileally digestible proximate components and amino acids and standard deviation of the observations (g/kg as fed)

	Soybean expeller	30% field beans	30% lupins	40% quinoa	SEM[1]	P-value
Di[2]dry matter	571.0	574.2	525.4	559.6	16	0.1
Di ash	20.1	25.9	19.7	17.0	3	0.4
Di organic matter	550.9	548.3	505.7	542.6	14	0.1
Di crude protein	133.0	129.9	131.9	120.6	5	0.3
Di fat	29.5^{b}	24.9^{a}	30.7	28.1^{a}	1	0.0
Di starch	334.7^{b}	345.6^{b}	299.4^{a}	342.4^{b}	5	<0.00
Di sugar	31.6	24.8	25.0	24.7	3	0.3
Di Lysine	7.56^{b}	6.81	6.8	5.73	0.	0.0
Di Methionine	2.27^{b}	1.82^{a}	1.7	2.1	0.	<0.00
Di Cystine	1.84	1.38	1.6	1.4	0.	0.1
Di Methionine + Cystine	4.11	3.20	3.4	3.5	0.	0.0
Di Threonine	5.31	5.57	5.0	4.9	0.	0.4
Di Tryptophan	1.62	1.49	1.3	1.4	0.	0.4
Di Isoleucine	6.58^{c}	5.75	6.31	5.81	0.	0.0
Di Arginine	8.97^{a}	10.90^{b}	11.14	8.47	0.	<0.00
Di Phenylalanine	7.54^{b}	6.20	6.3	6.45	0.	0.0
Di Histidine	3.71	3.69	3.6	3.4	0.	0.6
Di Leucine	12.96^{bc}	11.66^{a}	13.74	11.92	0.	0.0
Di Tyrosine	5.54^{b}	4.90	6.2	5.06	0.	<0.00
Di Valine	7.22	6.58	6.5	6.3	0.	0.1
Di Alanine	6.36	5.99	6.2	6.0	0.	0.8
Di Aspartic acid	12.99^{b}	11.92^{ab}	13.24	11.16	0.	0.0
Di Glutamine	27.99^{b}	25.49^{ab}	25.33	23.29	0.	0.0
Di Glycine	4.17	3.81	3.7	3.8	0.	0.7
Di Proline	10.42^{b}	8.18	7.9	8.53	0.	<0.00
Di Serine	6.82	6.06	6.4	5.7	0.	0.0

[1]SEM= standard error of means
[2]Di = ileal digestible
[abc] Different letters in in a row indicate differences among the experimental treatments (P<0.05)

Table 8 shows that there are no differences in the ileal digestible amounts of dry matter, ash, organic matter, crude protein and sugar among the dietary treatments. The ileal digestible amount of crude fat was lowest in the treatment with field beans, although it was not statistically different from the treatment with quinoa. The ileal digestible amount of starch was lowest in the diet with lupins and lower than that of all other dietary treatments. Although the diets were balanced to have the same ileal digestible amounts of lysine, it was lowest in the diet with quinoa. Moreover, in all diets the amount of ileal digestible lysine was well below the planned amount. The ileal digestible amounts of methionine, cystine, threonine and tryptophan were not different among treatments. However, the analysed amounts of methionine + cystine and of threonine were in all diets lower than the planned amounts. The ileal digestible amounts of isoleucine and arginine and the non-essential amino acids phenylalanine, leucine, tyrosine, aspartic acid, glutamine and proline were affected by dietary treatment but this may be due to the fact that the amounts of these amino acids were not balanced among the diets. The ileal digestible amounts of histidine, valine, alanine, glycine and serine were similar in the four diets.

3.6 Apparent total tract digestibility proximate components and energy

The apparent total tract digestible proximate components and energy of the control diet and the diets with 30% field beans, 30% lupins and 40% quinoa are presented in Table 9.

Table 9 Average apparent total tract digestible proximate components and energy and standard deviation of the observations (g/kg as fed)

	Soybean expeller	30% field beans	30% lupins	40% quinoa	s.e.	P-value
D[1] dry matter	680.0	665.0	681.	674.	17.9	0.474
D ash	25.7	32.5	32	29	5.4	0.185
D organic matter	654.4	632.5	648.	644.	14.1	0.132
D crude protein	146.8[b]	130.8	149.	135.	6.8	0.001
D fat	25.7[ab]	22.5	30.	27.	3.5	0.017
D crude fibre	6.7[a]	6.0	13.	8.	4.2	0.044
DNFE[2]	475.2[b]	473.2	455.	473.	9.0	0.009
DE[2] (MJ)	12.80[b]	11.91	12.7	12.	0.35	0.003
DNSP[2,3]	77.4	77.9	70	84	9.7	0.246
NE[2,3] (MJ)	8.63[b]	8.3	8.	8.5	0.20	0.044

[1] D = digestible
[2] DNFE = digestible nitrogen-free extract; DE = digestible energy; DNSP = digestible non-starch polysaccharides; NE = net energy
[3] Calculated assuming that total tract digestibility of starch and sugar is 100%
[abc] Different letters in a row indicate differences among the experimental treatments (P<0.05)

There are no differences in the digestible amounts of dry matter, ash, organic matter and non-starch polysaccharides among the dietary treatments (Table 9). The digestible amount of crude protein was lower in the treatments with field beans and quinoa than in those with soybean expeller and lupins. The digestible amount of crude fat was lowest in the treatment with field beans and highest in the treatment with lupins while the other treatments were in between. The digestible amount of crude fibre was lowest in the diets with field beans and soybean expeller and highest in the diet with lupins. The digestible amount of nitrogen-free extract was lowest in the diet with lupins. It was similar in the other diets. The DE and NE contents of all diets appeared to be much lower than planned. The DE and NE contents of the diet with field beans were lowest of all, although the NE content was not statistically different from that in the diet with quinoa. The DE and NE contents were not different among the other dietary treatments. In summary, the diet with 30% lupins showed a slightly higher digestible crude protein content and feeding value than the diet with soybean expeller, while the diet with quinoa showed a slightly lower digestible protein content and feeding value than the diet with soybean expeller. The diet with field beans showed the lowest digestible protein content and feeding value.

4 Discussion

Performance of the piglets

Diets with field beans
Daily gain, feed intake and feed conversion ratio were similar in piglets that were fed the control diet and in those that were the diets with 10% or 20% field beans. Piglets that were fed the diet with 30% field beans performed worse. From weaning to day 28, they grew 100 g/d less and had a 0.38 worse feed conversion ratio than piglets that were fed the control diet. Both from weaning to day 14 and from day 14 to day 28, performance was worse. These data are in contrast with the results of Böhme (1988). He gave weanling piglets diets in which soybean meal was replaced by 15 or 30% field beans. Every 15% field beans replaced 10% soybean meal. The control diet contained 27% soybean meal. Piglets that were fed the diet with 30% field beans ate 45 g/d more than piglets that were fed the control diet and their feed conversion ratio was 0.11 worse. However, these differences were not statistically significant. There are several reasons possible that might explain the worse performance of the piglets that were fed 30% field beans in our experiment. In Table 10, the planned and realised energy values and ileally digestible lysine levels are compared. The diet with 30% field beans contained about 21% less ileally digestible lysine than was planned. This means that these piglets were fed a diet that contained 0.8 g/kg (is 10.7%) less ileally digestible lysine than the piglets in the control group. This might explain the worse performance. Another explanation might be the effect of field beans on the villus height. Salgado et al. (2002) gave weanling piglets diets containing 24% soybean meal or 40% field beans. Four weeks after weaning piglets were slaughtered. The duodenal villi of piglets fed the field beans diet were much shorter than those fed the soybean meal diet (400 verus 550 µm). Shorter villi impair the digestive and absorptive function of the small intestine which is associated with poor performance of weaned piglets (Pluske et al., 1997). A third explanation might be the presence of anti-nutritional factors (ANFs) in field beans. In our experiment we used tannin-free field beans but the field beans contained some trypsin inhibitor activities (2.4 TIU/mg dry matter) (Helsper et al., 2006). Protease inhibitors can reduce the protein digestibiltity and growth rate of pigs (Jansman et al., 1995). However, the trypsin inhibitor activity of the field beans was very low, and therefore, probably had a very limited effect on the digestibility of protein (Salgado et. al., 2002).

Diets with white lupins
Daily gain and feed intake were similar in piglets that were fed the control diet and in those that were fed the diet with 10% lupins. Daily gain and feed intake decreased with increasing level of lupins in the diet. Piglets that were fed the diet with 20% and 30% lupins grew 47 and 74 g/d less, respectively, and ate 0.09 and 0.12 kg/d less, respectively, than piglets that were fed the control diet. Both from weaning to day 14 and from day 14 to day 28, feed intake and daily gain were worse. The feed conversion ratio was not affected by the level of lupins in the diet and was similar in piglets fed the control diet or the diets with lupins. These results are in agreement with results of Van Barneveld (1999). In a review, he concluded that inclusion of Lupinus albus in pig diets at levels above 100 g/kg diet results in significant reduction in growth performance, largely due to reductions in feed intake. Böhme (1988) also gave piglets diets with 0, 10, 20 or 30% sweet lupins. Daily gain, feed intake and feed conversion ratio of the piglets were similar on all diets and he concluded that 30% lupins in piglet diets can be recommended. There are several reasons that might explain the worse feed intake and daily gain of the piglets that were fed 20 or 30% lupins in the diet in our experiment. The diet with 30% lupins contained about 21% less ileally digestible lysine than was planned (Table 10). This means that these piglets were fed a diet that contained 0.8 g/kg (is 10.7%) less ileally digestible lysine than the piglets in the control group. The diet with 20% lupins contained about 14% less ileally digestible lysine than was planned. A shortage of amino acids might explain the worse performance. Another explanation might be the presence of ANFs (alkaloids, raffinose and stachyose) in lupins. Dunshea et al. (2001) concluded that in young pigs feed intake is reducing when alkaloid level rises above 200 mg/kg feed. With low alkaloid lupins, however, it is unlikely that levels will approach 200 mg/kg feed (Dunshea et al., 2001). We used the white lupin variety Dieta which is a low-alkaloid lupin (Saiko and Golovchenko, 2004). The level of alkaloids was 51 mg per 100 gram dry matter (Helsper et al., 2006). The concentration of raffinose and stachyose, however, could have reduced the feed intake of the piglets. Ferguson et al. (2003) reported that increasing the dehulled lupin content of diets from 0 to 300 g/kg caused a linear decrease in feed intake and daily gain. They used a low-alkaloid lupin and suggested that the decrease in feed intake and daily gain was caused by the level of raffinose + stachyose in the lupins. The level of raffinose +stachyose in the dehulled lupins was 49 g per kg dry matter. In our experiment it was 41 g per kg dry matter. Raffinose and stachyose are not digested in the small intestine but fermented by bacteria in the hindgut. During fermentation, gases are produced that cause flatulence. The discomfort of a distended large intestine, as a result of increased gas production, probably suppresses the feed intake and daily gain of the piglets (Ferguson et al., 2003). Another reason that might explain the worse feed intake and daily gain of the piglets that were fed 20 or 30% lupins in the diet may be the effect of lupins on the retention time. Pigs that were fed diets containing 35% Lupinus albus had an increased retention time through delayed digestion and fermentation in the hindgut resulting in a reduction in feed intake (Van Barneveld, 1999). Böhme (1988) used sweet lupins, which in general have lower raffinose + stachyose levels. This might the reason that he did not find an effect of lupins on the performance of the piglets.

Diets with quinoa
Daily gain decreased and feed conversion got worse with an increasing level of quinoa in the diet. Piglets that were fed the diets with 20, 40 or 60% quinoa grew 31, 73 and 75 g/d less, respectively, and had a 0.13, 0.24 and 0.33 worse feed conversion ratio, respectively, than piglets that were fed the control diet. Both from weaning t0 day 14 and from day 14 t0 day 28, daily gain and feed conversion ratio were worse. Feed intake was not affected by the level of quinoa in the diet and was similar in piglets fed the control diet or the diets with quinoa. The level of ANFs in quinoa is very low (Helsper et al., 2006), and therefore, daily feed intake is

probably not affected by the level of quinoa in the diet. The low level of amino acids in the diets with quinoa might explain the worse daily gain and feed conversion ratio in piglets that were fed quinoa. The diet with 40% quinoa contained about 34% less ileally digestible lysine than was planned (Table 10). This means that these piglets were fed a diet that contained 1.9 g/kg (is 25.3%) less ileally digestible lysine than the piglets in the control group. The diets with 20 and 60% quinoa contained about 17 and 51% less ileally digestible lysine, respectively, than was planned. Thus, a shortage of amino acids probably explains the worse performance.

Table 10 Comparison between planned and realised energy values and ileal digestible lysine levels

	Soybean expeller	30% field beans	30% lupins	40% quinoa
NE planned (MJ/kg)	9.40	9.40	9.40	9.40
NE realised (MJ/kg)	8.63	8.31	8.69	8.55
Difference (%)	- 8.2	- 11.6	- 7.6	- 9.0
DiLys planned (g/kg)	8.8	8.5	8.5	8.5
DiLys realised (g/kg)	7.5	6.7	6.7	5.6
Difference (%)	-14.8	-21.2	- 21.2	- 34.1
DiLys planned (g/planned EW[1])	8.2	7.9	7.9	7.9
DiLys realised (g/realised EW)	7.7	7.1	6.8	5.8
Difference (%)	-6.1	-10.2	-13.9	-26.6

[1] 1 EW = 8.8 MJ NE

Net energy and digestibility of amino acids

Table 10 shows that the realised NE content of the diets was 8 to 12 % lower than planned. Energy value data are mostly assessed in digestibility experiments with individually housed growing-finishing pigs (CVB, 2004). Digestibility, and hence also the energy value, is usually somewhat lower in younger piglets than in growing-finishing pigs, because their gastrointestinal tract is still not totally developed (Noblet and Shi, 1994). Moreover, Bakker (1996) concluded that, due to a decreased retention time of digesta in the gut, apparent faecal digestibilities are lower in group housed growing pigs than in individually housed growing pigs. It seems logical that this also applies to weaned piglets. These two aspects probably explain the lower net energy values.

Although the diets were balanced to have almost the same amounts of ileally digestible lysine, in all diets the realised levels were lower than the planned levels. Besides, the levels differed between diets. Even when the ileally digestible lysine levels were corrected for the energy values realised, major gaps existed between the planned and realised lysine levels. The differences can partly be explained by the reasons mentioned for the NE content. The feed evaluation system in the Netherlands is based on digestibility trials with individually housed growing-finishing pigs. In our experiment we used group housed weanling pigs. Moreover, digestibility experiments are conducted with conventionally housed pigs. We used organically housed pigs. There might be a difference in digestibility between conventionally and organically housed pigs. In the diets with field beans, and lupins and especially in the diets with quinoa, the differences between planned and realised ileally digestible lysine levels were greater than in the control diet. Field beans and lupins both contain ANFs and this may have reduced the ileal digestibility of amino acids. Quinoa is a brandnew product that was not tested for its ileal amino acid digestibility in pigs ever before. Therefore, we assumed that the amino acid composition and the digestibility of the amino acids in quinoa were comparable to that of wheat (CVB, 2004). It seems that we overestimated the level of ileally digestible amino acids in quinoa. The high content of weeds in quinoa might also partly explain the lower levels of ileally digestible amino acids in the diet. During the harvest of quinoa, it became clear that also a lot of weed was harvested. It was not possible to separate the weed from the quinoa. Besides it is questionable if quinoa is a protein crop. The protein content in quinoa is much lower that in other protein crops (see Table 1).
It can be concluded that more knowledge on the digestibility of protein, amino acids and energy in organically grown protein crops is highly required.

Financial results

Yield minus feeding costs were similar in piglets that were fed the control diet and in those that were fed the diets with 10 or 20% field beans or 10 or 20% lupins. In piglets that were fed the diets with 30% field beans or 30% lupins, the yield minus feeding costs were € 4.53 and € 2.14 per delivered piglet lower, respectively, than in the control group. This can be explained by the lower daily gain and therefore, lower yield of the piglets that were fed 30% field beans or 30% lupins in the diet. Piglets that were fed quinoa in the diet grew less and had, therefore, lower yield minus feeding costs than piglets that were fed the control diet. The yield minus feeding costs decreased with an increasing level of quinoa in the diet.

5 Conclusions

- Daily gain, feed intake, feed conversion ratio and yield minus feeding costs were similar in piglets that were fed the control diet with 15% soybean expeller and in those that were fed diets with 10% or 20% field beans (variety Aurelia, tannin-free). Piglets that were fed the diet with 30% field beans performed worse.
- Daily gain, feed intake and yield minus feeding costs were similar in piglets that were fed the control diet and in those that were fed the diet with 10% lupins (variety Dieta, alkaloid-low). Daily gain, feed intake and yield minus feeding costs decreased with increasing level of lupins in the diet. The feed conversion ratio was not affected by the level of lupins in the diet and was similar in piglets fed the control diet or the diets with lupins.
- Daily gain and yield minus feeding costs decreased and feed conversion got worse with an increasing level of quinoa (variety Atlas, saponin-free) in the diet. Feed intake was not affected by the level of quinoa in the diet and was similar in piglets fed the control diet or the diets with quinoa. A shortage of amino acids probably explains the worse daily gain and feed conversion ratio.
- Mortality of piglets and the number of veterinary treated piglets were low and were not affected by experimental treatment.
- In all diets, the realised NE content was 8 to 12% lower than the planned NE content.
- In all diets, the realised ileally digestible lysine levels were lower than the planned levels. In the diets with field beans, and lupins and especially in the diets with quinoa, the differences between planned and realised ileally digestible lysine levels were greater than in the control diet.
- The protein content in quinoa is much lower that in other protein crops. The protein contents in soybean expeller, field beans, lupins and quinoa were 456, 286, 370 and 193 gram per kg dry matter, respectively.

6 Practical implications

Based on the results in this trial, it can be concluded that inclusion levels up to 20% tannin-free field beans or 10% low alkaloid lupins can be recommended in diets for weanling piglets. Higher levels decreased the performance of the piglets, probably as a result of a shortage of ileally digestible amino acids or because of a too high level of ANFs in the diets. It might be that higher inclusion levels of field beans and lupins can be recommended when the ileally digestible amino acids levels are assessed correctly.

It is difficult to draw a conclusion about the recommended level of quinoa in the diet. Piglets that were fed quinoa performed worse than piglets that were fed the control diet. Feed intake, however, was not affected by quinoa in the diet. It is very likely that the worse daily gain and feed conversion ratio can be explained by a shortage of amino acids in the diets with quinoa and not by a too high level of ANFs. It is not known what level can be recommended when the ileally digestible amino acids levels are assessed correctly. It is questionable if quinoa is a protein crop because the protein content in quinoa is much lower that in other protein crops.

It can be concluded that more knowledge on the digestibility of protein, amino acids and energy in organically grown protein crops is highly required.

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Appendices

Appendix 1 Experimental design

Batch	Pen 1	Pen 2	Pen 3	Pen 4	Pen 5	Pen 6	Pen 7
1	Quinoa 20%	Control	Lupins 10%	Lupins 20%	Quinoa 40%	Beans 20%	Beans 10%
2	Beans 30%	Lupins 30%	Lupins 10%	Lupins 20%	Beans 20%	Control	Beans 10%
3	Control	Quinoa 40%	Lupins 20%	Quinoa 60%	Lupins 30%	Beans 30%	Beans 20%
4	Quinoa 60%	Beans 10%	Quinoa 20%	Beans 30%	Control	Lupins 30%	Lupins 10%
5	Beans 30%	Control	Quinoa 60%	Quinoa 40%	Quinoa 20%	Beans 20%	Beans 10%
6	Beans 10%	Lupins 30%	Lupins 20%	Control	Beans 20%	Quinoa 60%	Quinoa 20%
7	Beans 20%	Lupins 30%	Quinoa 40%	Beans 30%	Lupins 10%	Control	Quinoa 20%
8	Lupins 20%	Quinoa 60%	Quinoa 20%	Lupins 10%	Beans 20%	Beans 30%	Control
9	Quinoa 60%	Lupins 30%	Control	Lupins 10%	Quinoa 40%	Beans 10%	Beans 20%
10	Quinoa 20%	Quinoa 40%	Lupins 20%	Lupins 10%	Lupins 30%	Quinoa 60%	Control
11	Lupins 20%	Quinoa 40%	Beans 10%	Lupins 10%	Control	Quinoa 60%	Beans 30%
12	Quinoa 20%	Lupins 30%	Lupins 20%	Quinoa 40%	Control	Beans 10%	Beans 30%

Appendix 2 Calculated composition of the experimental diets (g/kg)

Ingredient	Control	30% Field beans	30% Lupins	60% Quinoa
Limestone	11.5	8.7	10.3	11.5
Monocalcium phosphate. 1 H_20	7.3	7.6	8.7	8.5
Salt	3.2	3.2	3.1	3.2
Maizegluten meal				38.3
Wheatbran	50	32		
Linseed		15		
Soybeans	22			
Cassave	12	50	44	50
Molasse, cane	10	10	10	10
Whey powder, delactosed	74	74	74	74
Wheat	189	150		37
Barley Eco	212			
Maize Eco	200.5	248	467.4	
Peas		5	6	75
Sesame expeller		50		
Soybean expeller	150			19
Sunflower oil			7	29
Quinoa				600
Lupins			300	
Potato protein	41	29	52	27
Field beans		300		
Formic and propionic acid	7.5	7.5	7.5	7.5
Premix	10	10	10	10
Dry matter	875	873	860	818
Ash	64	65	82	77
Crude protein	185	185	185	185
Crude fat	38	33	47	64
Crude fibre	35	42	47	36
Starch	372	407	350	346
Sugar	69	58	56	50
Ca	8.3	8.1	8.1	8.1
P	6.3	6.0	5.3	5.6
K	10.4	10.3	7.7	7.7
Na	2.5	2.5	2.5	2.5
Cl	5.9	5.9	5.9	5.8
EW (1 EW = 8.8 MJ NE)	1.07	1.07	1.07	1.07
Digestible P	3.30	3.25	3.25	3.25
Lysine	10.41	9.97	9.95	10.15
Ileal digestible lysine	8.75	8.45	8.45	8.45
Ileal digestible methionine	2.64	2.37	2.25	3.01
Ileal digestible cystine	2.52	2.28	2.44	2.49
Ileal digestible meth. + cyst.	5.16	4.65	4.70	5.50
Ileal digestible threonine	6.08	5.61	6.22	5.91
Ileal digestible tryptophan	1.84	1.52	1.39	1.69
NSP	162	146	210	127
Vit. E (mg/kg)	90	90	90	90