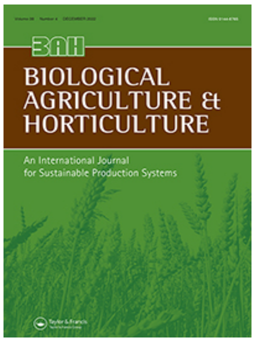

Biological Agriculture & Horticulture
An International Journal for Sustainable Production Systems

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tbah20

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To cite this article: Nele Quander-Stoll, David Bautze, Werner Zollitsch, Florian Leiber & Barbara Früh (2022) Effects of 100% organic feeding on performance, carcass composition and fat quality of fattening pigs, Biological Agriculture & Horticulture, 38:4, 271-284, DOI: 10.1080/01448765.2022.2119889

To link to this article: https://doi.org/10.1080/01448765.2022.2119889

Published online: 19 Sep 2022.

BIOLOGICAL AGRICULTURE & HORTICULTURE
2022, VOL. 38, NO. 4, 271–284
https://doi.org/10.1080/01448765.2022.2119889

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Effects of 100% organic feeding on performance, carcass composition and fat quality of fattening pigs

Nele Quander-Stoll[a], David Bautze[a], Werner Zollitsch[b], Florian Leiber[a] and Barbara Früh[a]

[a]Department of Livestock Sciences, Research Institute for Organic Agriculture (Fibl), Frick, Switzerland; [b]Department of Sustainable Agricultural Systems, University of Natural Resources and Life Sciences, Vienna (BOKU), Vienna, Austria

ABSTRACT

In organic pig production, one important aim is to achieve 100% organic feeding. This generates the challenge of achieving adequate protein quality in pig feed. Until 31st December 2021, the protein quality in organic pig feed in Europe was improved by using 5% conventional components, mainly potato protein. To investigate the effects of 100% organic feeding on growth performance, meat and fat quality in pigs, a total of 700 fattening pigs were studied in an on-farm feeding trial. The 95% organic diet fed on each farm served as the control diet (CON) and a 100% organic diet with higher proportions of soybean cake and grain legumes was used as the experimental diet (ORG). ORG-fed animals had slightly lower daily weight gains, lower carcass weight, and significantly higher iodine and PUFA values in the backfat. The feeding trial showed that the 100% organic diet led to a slightly deficient dietary amino acid profile and thus to slightly lower performance in a few traits. However, the implementation of consistent 100% organic feeding was considered valuable for organic farming even with the lower performance and change in meat and fat quality of the organic pigs.

ARTICLE HISTORY
Received 31 March 2021
Accepted 29 August 2022

KEYWORDS
Fattening pigs; livestock nutrition; on-farm research; organic diet; polyunsaturated fatty acid; potato protein

Introduction

In organic farming, numerous feed additives such as genetically modified microorganisms and synthetic amino acids are prohibited in the feeding of non-ruminants according to EU Regulation No 834/2007 (The Council of the European Union 2007). This is important in order to implement the concept of naturalness (Verhoog et al. 2003; Lund 2006) in feeding, and for the credibility towards consumers, as the aim is to increase consumer confidence in the high quality of the organic feed (Huber et al. 2003). Until 31st December 2021 in Europe, diets for organically produced non-ruminants could still contain 5% conventional components, but this was considered undesirable by the organic associations as well as by the European legislative bodies, so the introduction of 100% organic feeding has been discussed for a long time. In pig diets, conventional potato protein was usually used as this enhances the protein quality of the feed through its favourable amino acid profile (Sundrum et al. 2011; Quander-Stoll et al. 2021b). Potato (*Solanum tuberosum*) protein is a by-product from the starch industry, but it is not available from organic origin in sufficient quantities. According to the new organic regulation (2018/848), which is to be applied from

CONTACT Nele Quander-Stoll nele.quander@fibl.org Research Institute for Organic Agriculture (Fibl), 5070 Frick, Switzerland
Supplemental data for this article can be accessed online at https://doi.org/10.1080/01448765.2022.2119889.

1st January 2022, fattening pigs may no longer receive conventional feed (The Council of the European Union 2018).

Several reasons have so far prevented a renunciation of conventional potato protein. So far, the European Commission has justified the extension of the transition period with the unavailability of protein components in sufficient quality and quantity. Only few studies have investigated 100% organic feeding in fattening pigs, and these have shown that this resulted in slightly lower daily gains but with no further reductions in the performance (Hansen et al. 2006; Partanen et al. 2006; Sundrum et al. 2011). Wüstholz et al. (2017) showed that a 100% organic diet could also be realised by the use of alfalfa silage, as this has a sufficiently high protein quality, depending on the time of cutting; it may even partially replace the use of soybean cake. Fishmeal and blood- and bone meal from slaughterhouse waste are high-quality protein carriers with great potential for use in diets of monogastric animals. However, the use of fishmeal is not considered to be acceptable from an ecological point of view (Cashion et al. 2017a, 2017b) and, furthermore, organic labels predominantly prohibit the use of fishmeal in livestock feed for ethical reasons, or only allow fishmeal from sustainable fisheries. Slaughter by-products (such as blood meal or meat- and bone meal) are highly digestible sources of protein and phosphorus, and are permitted in livestock diets according to the EU Regulation No 1069/2009 for the use of animal by-products (The Council of the European Union 2009) provided certain requirements are met. However, many organic labels also prohibit the use of these products. Alternative protein sources, such as insect protein, algae protein, and fermentatively produced amino acids are continuously being researched for their suitability for pig feeding. The preparation of feed components by fermentation and germination with the aim of improving digestibility and nutrient profile has also been investigated (Scholten et al. 1999; Hong and Lindberg 2007; Koo et al. 2018; Schwediauer et al. 2018), but there appears to be no equivalent component that could replace the potato protein, which represent the most important conventional protein source currently used in organic pig nutrition in Europe (Quander-Stoll et al. 2021b). Furthermore, the production of these alternative protein sources is not yet profitable or logistically mature and there is currently no approval for their use in pig diets. If conventional potato protein is to be excluded, pig diets must be formulated with already approved organic feed components. Since the use of isolated amino acids is not permitted in organic feed, the proportion of oilseed cake in the feed will likely be increased to cover the amino acid requirements of the animals. However, oilseed cakes are rich in polyunsaturated fatty acids (PUFA) and, therefore, the animals consume more PUFA through the diet and consequently have higher PUFA contents in their adipose tissue (Quander-Stoll et al. 2021a). A study by Früh (2016) showed that organic pigs had on average more than two percentage points higher PUFA contents in the backfat than conventionally fed animals. A meta-analysis by Średnicka-Tober et al. (2016) also showed significantly higher PUFA levels in organic pork and chicken.

Although PUFA has been shown to be positive and beneficial for health in human nutrition (Butler 2014; Sanders 2014), and that the fat of organic pigs has a more favourable ratio of n3/n6 polyunsaturated fatty acids (Álvarez-Rodríguez et al. 2016), PUFA-rich fat is softer and greasier and is more prone to oxidation. This can have a detrimental effect in the processing and on product quality and shelf life (Warnants et al. 1996; Bryhni et al. 2002; Wood et al. 2004). A study by Scheeder and Müller Richli (2014) showed reduced oxidation stability and shelf life when the PUFA content was 17% and poorer consumer evaluation and willingness to buy when the PUFA content was 18%. To ensure consistent quality of processing and products, in Switzerland there are specific requirements for fat quality in pigs (Hadorn et al. 2008). These include defined limits (starting at 15.5%, Proviande 2014) for the PUFA content and iodine value at a standardised defined point in the backfat. If these thresholds are exceeded, carcass revenue is reduced, making PUFA content an economically relevant trait in Switzerland (Hadorn et al. 2008; Bee et al. 2021).

Therefore, the aim of this study was to investigate the effect of 100% organic feeding on PUFA content. The focus was to study the effects of changing from 95% to 100% organic feeding on growth performance, meat and fat quality of fattening pigs and whether compliance with Swiss fat quality requirements would still be possible under 100% organic feeding and Swiss farm conditions.

A feeding trial was performed on farms in Switzerland. The hypothesis of the study was that a 100% organic diet is feasible in fattening pigs, but an increase in PUFA content in backfat and lower daily gains can be expected.

Materials, animals and methods

To investigate the effects of a 100% organic diet on performance, carcass composition and fat quality in fattening pigs, a feeding trial was conducted on three organic farms in Switzerland (A, B, C). Farm A is located in Ederswiler (CH-2813) in the canton Jura, farm B is in Siegershausen (CH-8573) in the canton Thurgau and farm C is in Wildegg-Möriken (CH-5103) in the canton Aargau. During five consecutive replications on each farm, approximately 700 fattening pigs were examined and weighed at regular intervals until slaughter. The trial was carried out with the approval of the competent veterinary authorities (Authorisation No. AG 75719, Aarau, Switzerland). The animals were kept and managed in accordance with the Swiss guidelines for organic farming (Bio Suisse 2021). All farms obtained their feed from the same commercial feed mill. In cooperation with the feed mill, the experimental diet was produced from 100% organic components.

Diets

The 100% organic diet (ORG) shown in Table 1 was used as the experimental diet on all three farms. The experimental diet was formulated to meet the nutritional requirements of fattening pigs (from 35 kg until slaughter) taking into account economic criteria based on the feed optimisation programme of the feed mill in the best possible way. The feed consisted of the following main components: barley (*Hordeum vulgare)*, faba beans (*Vicia faba*), triticale (*Triticum aestivum L. x Secale cereale L.*), soybean cake (*Glycine max L.)*, peas (*Pisum sativum*), wheat (*Triticum aestivum*) and rapeseed cake (*Brassica napus*) (Table 1). The 95% organic diet that was already fed on the respective farm was used as the control diet (CON) (Table 1) and this consisted of the same components as the experimental diet in varying proportions and it also contained 5% conventional potato protein. The main difference between diets CON and ORG was a higher proportion of barley, peas and soybean cake in the ORG to compensate for the non-use of potato protein. The detailed compositions of the diets used are shown in Table 1. The diets were offered in dry pelleted form and were fed to the animals ad libitum.

Feed analysis

For each farm, feed samples were collected twice from CON and ORG during the experiment. To extend the durability, samples were dried for 24 h at 60°C in a drying cabinet. Afterwards samples were analysed for nutrient contents according to VDLUFA (2007) at the Agricultural Research Institute Speyer, Germany. Dry matter was determined at 105°C. The crude protein content was determined by DUMAS combustion method VDLUFA 4.1.2 (VDLUFA 2007). Ether extracts were analysed according to method A of 5.1.1 by a petroleum ether extraction (VDLUFA 2007). The crude fibre content was determined by treating the sample successively with sulphuric acid (H_2SO_4) and boiling potassium hydroxide (KOH) according to method 6.1.1 (VDLUFA 2007). To determine the ash content, the samples were incinerated at 550°C and the residue was weighed according to method 8.1 (VDLUFA 2007). After hydrolysis with hydrochloric acid the amino acids lysine, methionine, cysteine, and threonine were analysed by ion exchange chromatography following method 4.11.1 of VDLUFA (2007). The content of tryptophan was determined by HPLC-method (4.11.2, VDLUFA 2007). The digestible energy content of the diets (MJ DE) was calculated according to Agroscope (2017).

Table 1. Composition and nutrient content of the control diets (CON) and experimental diet (ORG).

Components (g 100 g^{-1} fresh matter as fed)	Control diets (95% organic) Farm A	Farm B	Farm C	Experimental diet 100% organic
Barley	16	12	17	39
Wheat	30	39	29	6
Triticale	15	15	15	15
Faba bean	17	10	16	16
Pea	2	9	2	8
Soybean cake	4	2	7	10
Rapeseed cake	3	-	-	2
Wheat starch	4	5	5	-
Potato protein (conventional)	5	5	5	-
Lime	1	1	1	1
MCP[1]	1	1	1	1
Molasses	1	-	-	1
Premix[2]	0.7	0.7	0.7	0.7
Salt	0.3	0.3	0.3	0.3
Analysed values (g 100 g^{-1} fresh matter as fed)				
Crude protein	17.0	16.2	17.1	17.5
Ether extracts	2.3	2.2	2.6	3.0
Crude fibre	3.6	3.0	3.4	4.3
Ash	5.2	4.5	4.8	5.2
MJ DE	13.8	14.0	13.8	13.3
Lysine	0.82	0.77	0.80	0.82
Methionine	0.22	0.20	0.21	0.18
Cysteine	0.29	0.29	0.28	0.28
Threonine	0.64	0.56	0.60	0.59
Tryptophan	0.18	0.18	0.17	0.14
Calculated values[3] (g 100 g^{-1} fresh matter as fed)				
SID[4] Lysine	0.77	0.70	0.77	0.73
SID Methionine	0.22	0.21	0.21	0.18
SID Met+Cys	0.45	0.43	0.44	0.41
SID Threonine	0.54	0.50	0.53	0.49
SID Tryptophan	0.16	0.15	0.16	0.15
SFA	5.7	5.1	5.8	6.6
MUFA	3.6	1.7	2.4	4.1
PUFA	8.8	7.0	8.9	11.5
PUFA/MJ DE	0.81	0.77	0.81	1.02

Notes: [1]MCP, Monocalcium phosphate. [2]Mineral premix, (g kg^{-1} dry matter):600000I.U. (international units) Vitamin A,80000I.U. Vitamin D3, 6000 mg Vitamin E, 200 mg Vitamin K3, 600 mg Vitamin B6, 3000 mcg Vitamin B12, 48 mg Folic acid 3000 mg Niacinamide, 2000 mg pantothenic acid, 4000 mg Iron, 4000 mg Iron sulphate monohydrate, 1000 mg Copper, 1000 mg Copper sulphate pentahydrate,11000mg Zinc,11000mg Zincsulphate monohydrate, 2000 mg Manganese, 2000 mg Manganese oxide, 31 mg Iodine, 31 mg Calcium iodate anhydrous, 44 mg Selenium, 44 mg Sodium selenite. [3]Values as predicted by the feed mill. [4]SID, standardised ileal digestible.

Animals

Over 700 pigs (Swiss Large White) were studied during a one-year experimental period. The piglets arrived at the fattening farm at an average age of nine weeks. The average weights (standard deviation in brackets) at the start of the trial were 26.5 kg (± 7.37) for CON and 27.7 kg (± 3.83) for ORG on farm A, 19.1 kg (± 2.47) and 18.9 kg (± 2.83) on farm B, 31.4 kg (± 6.6) and 30.8 kg (± 6.4) on farm C. On arrival at the fattening farm, the pigs were weighed, and the sex was determined. Balanced according to sex and weight, the animals were assigned to the treatment groups CON and ORG. On each farm, five runs were conducted with treatment groups running in parallel for each run. Each replicate was based on one pen with 15–30 animals, dependant on the farm (Supplemental Figures 1, 2 and 3). At 50 and 80 days of fattening, the animals were weighed again, and daily gains (ADG) were determined based on the weights recorded. ADG1 described the average daily weight gains from the start of the trial to 50 days in fattening. ADG2 represented the average daily weight gains between 50 and 80 days of fattening, and ADG3 represented the average daily weight gains over the entire trial period.

As soon as the animals reached a weight between 103 and 109 kg, they were registered for slaughter, and one week after registration, the animals were collected for slaughter by the retailers. According to the Swiss standard the optimal live weight for slaughter is 114 kg. The animals were slaughtered in groups of between 20 and 30 animals. In order to avoid mixing animals from different treatments, animals of different feed groups were always registered as separate slaughter batches.

The carcass weight was determined at the slaughterhouse. The loin muscle area (*M. longissimus dorsi*), lean meat content and the backfat thickness were recorded at the slaughterhouse by means of Auto FOM (Frontmatec, Lünen, Germany). For the determination of the contents of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA) and iodine value in the backfat of the animals, a 10 × 10 cm fat sample (including skin) of each animal was taken directly after slaughter above the shoulder ($5^{th}/6^{th}$ rib). Fat samples were then frozen for further analyses. For measurement of fatty acid contents, samples were thawed at room temperature and contents of SFA, MUFA, PUFA and iodine value were determined by near infrared spectroscopy (NIRS). This procedure was based on the standard method according to Müller Richli et al. (2016). The iodine value is a measure of the unsaturated fatty acid content of the fat and it is defined by the grams of iodine that reacts with the double bonds in 100 g of fat or oil. The PUFA is the percentage of polyunsaturated fatty acids in the total fatty acids of a tested fat sample. MUFA is the percentage of monounsaturated fatty acids and SFA of saturated fatty acids in the total fatty acids of a tested sample.

Statistical analyses

The statistical analysis of the data was performed with R (R Core Team 2019) using linear mixed models for each farm separately. 'Sex' and 'diet' were considered as fixed effects. Each pen represented a 'replicate' and was considered in the statistical model as random effect. All data collected were determined at the individual animal level. To fit linear models, function 'lmer' of the package 'lme4' (Bates et al. 2015) was used. The p – values were calculated with the function 'Anova' of the package 'lmertest' (Kuznetsova et al. 2017). The Shapiro-Wilk test and the Bartlett test were used to check the residuals for normal distribution and variance homogeneity. If one of these requirements for the analysis of variance was not met, data were transformed using the Lambda Transformation (function 'transformTukey' of the 'rcompanion' package). This function finds the lambda, which makes a single vector of values – that is one variable – as normally distributed as possible with a simple power transformation. All results were presented as model estimates ('emmeans') and standard error of means (SEM) and considered significantly different when the p – value was < 0.05.

Results

Diets

The control diets differed in composition (Table 1) and showed some nutrient content differences, especially for farm B. The control diet on this farm had a lower crude protein content, less native lysine and threonine, and higher energy content. It also had less standardised ileal digestible lysine, methionine, and threonine than the control diets on farms A and C. With regard to the recommendations for an optimal ratio of essential ileal (in the small intestine) digestible amino acids to lysine, all diets deviated slightly with regard to methionine, with the deviation being smallest for Farm B and largest for the experimental diet (Table 2). Moreover, the control diet on farm B had the lowest SFA, MUFA, and PUFA contents (Table 1). Compared to the CON diets, diet ORG had

Table 2. Comparison of the ideal ratio of digestible amino acids for growing/fattening pigs with ratio of ileal digestible amino acids in the diets used (Lindermayer et al. 2009).

	LYS	MET	M + C	THRE	TRYP
Recommendation 20–50 kg live weight	1	0.30	0.62	0.67	0.18
Recommendation 50–100 kg live weight	1	0.30	0.64	0.70	0.19
Farm A	1	0.29	0.58	0.70	0.21
Farm B	1	0.30	0.61	0.71	0.21
Farm C	1	0.27	0.57	0.69	0.21
Experimental diet (100% organic)	1	0.25	0.56	0.67	0.21

Notes: LYS, Lysine; MET, Methionine; M + C, Methionine and Cysteine; THRE, Threonine; TRYP, Tryptophan

a slightly higher crude protein content, more ether extracts, crude fibre, and (except for farm B) a lower content of ileal digestible lysine, methionine, threonine and tryptophan (Table 1).

Growth performance

While there were no differences in daily gains for the first 50 days of fattening on farm A and C between the two diets, daily gains on farm B were nearly 7.3% lower for diet ORG than for the control diet (ADG1, Table 3). During final fattening phase (ADG2), daily gains were only lower on farm C (about 7.1%) for diet ORG. For the entire fattening period (ADG3), daily gains were lower on all farms with diet ORG, the difference was on average by 46 g day^{-1}. ORG-fed groups had a significantly lower weight than the control animals at 80 days of fattening, except on farm A where comparable weights were achieved in both feed groups. Feeding diet ORG resulted in lower carcass weight on farms B and C, but not on farm A (Table 3). On farms B and C, barrows had higher daily gains than gilts (Table 4).

Carcass composition

Concerning the loin muscle area, no diet effect was found on farm A, while farms B and C had lower values for loin muscle area under diet ORG. For lean meat content and backfat thickness, no diet effects were found, but the sex of the pigs had an effect on all three farms (Table 3). Gilts consistently

Table 3. Fattening performance, carcass characteristics and fat quality of fattening pigs fed either the control diet (CON) or the experimental diet (ORG), (emmeans (SEM)).

FARM	A		B		C	
Trait/Diet	CON	ORG	CON	ORG	CON	ORG
Animal number (n)	141	109	123	109	103	115
Weight at start of trial (kg)	26.5 (0.39)	27.7 (0.32)	19.1 (0.16)	18.9 (0.56)	31.4 (0.40)	30.8 (0.48) *
ADG1 (g)	809 (0.25)	820 (0.26)	680 (0.02)	630 (0.02) **	858 (0.05	830 (0.05)
ADG2 (g)	1065 (0.03)	1042 (0.03)	981 (0.02)	977 (0.02)	1049 (0.04)	975 (0.04) ***
ADG3 (g)	884 (0.03)	843 (0.03) *	789 (0.01)	737 (0.02) *	931 (0.03)	885 (0.03) **
Fattening period (d)	95.7 (2.74)	95.0 (2.78)	113.3 (2.12)	114.7 (2.08)	97.0 (3.47)	98.0 (3.46)
Live weight at 80 days of fattening (kg)	94.5 (1.61)	97 (1.78)	81.6 (1.21)	78.7 (1.62) *	105.7 (1.69)	101.4 (1.93) ***
Live weight at slaughter (kg)	115 (1.33)	114 (1.36)	111 (0.85)	113 (0.91)	123 (1.72)	118 (1.70) ***
Carcass weight (kg)	88.3 (0.76)	87.8 (0.78)	85.7 (0.58)	84 (0.59) **	92.1 (1.43)	88.7 (1.42) ***
Loin muscle area (mm^2)	57.8 (0.63)	57.0 (0.66)	58.5 (0.92)	54.9 (0.91) ***	59.0 (0.89)	57.1 (0.88) **
Lean meat content (%)	57.2 (0.22)	56.9 (0.24)	57.8 (0.33)	57.4 (0.34)	58.4 (0.43)	58.2 (0.42)
Backfat (mm)	15 (0.21)	15.2 (0.23)	14.1 (0.27)	14.3 (0.27)	14.3 (0.37)	14.4 (0.36)
Iodine value	71.7 (0.28)	74.0 (0.30) ***	72.6 (0.57)	76.2 (0.58) ***	70.8 (0.49)	72.9 (0.48) ***
MUFA (%)	45.8 (0.35)	44.2 (0.36) ***	48 (0.18)	46.1 (0.17) ***	46.3 (0.67)	46.0 (0.66)
SFA (%)	36.9 (0.29)	36.6 (0.30)	35.1 (0.31)	34.2 (0.32) ***	36.9 (0.47)	35.9 (0.47) ***
PUFA (%)	17.7 (0.20)	19.7 (0.23) ***	16.9 (0.35)	19.9 (0.35) ***	16.9 (0.48)	18.3 (0.47) ***

Notes: ADG1- Average daily weight gains in the period from start to 50 days of fattening; ADG2- Average daily weight gains between 50 and 80 days of fattening; ADG3- Average daily weight gains over the entire trial period, start until slaughter; * significant diet effect (within a farm) * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Table 4. Fattening performance, carcass characteristics and fat quality of fattening pigs according to sex (emmeans (SEM)).

FARM	A		B		C	
Trait/Sex	Gilts	Barrows	Gilts	Barrows	Gilts	Barrows
Animal number (n)	121	129	107	125	102	116
Weight at start of trial (kg)	26.6 (0.67)	27.7 (0.34)	18.8 (0.25)	19.3 (0.24)	31.2 (0.67)	30.9 (0.57)
ADG1 (g)	776 (0.03)	853 (0.03) ***	625 (0.02)	685 (0.02) ***	812 (0.47)	878 (0.47) ***
ADG2 (g)	1029 (0.03)	1078 (0.03) *	903 (0.02)	1048 (0.02) ***	974 (0.04)	1050 (0.04) ***
ADG3 (g)	860 (0.03)	867 (0.03)	709 (0.01)	806 (0.01) ***	874 (0.03)	943 (0.03) ***
Fattening period (d)	95.4 (2.77)	95.3 (2.74)	117 (2.12)	111 (2.08) **	100 (3.48)	95 (3.46) ***
Live weight at 80 days of fattening	92.6 (1.77)	98.9 (1.56) *	76.1 (1.43)	84.2 (1.40) ***	100.4 (1.93)	106.7 (1.70) **
Live weight at slaughter (kg)	113 (1.35)	115 (1.34) *	111 (0.92)	114 (0.85) *	120 (1.74)	121 (1.69)
Carcass weight (kg)	88.4 (0.77)	88.0 (0.76)	84.3 (0.59)	85.4 (0.48) **	90.2 (1.45)	90.5 (1.42)
Loin muscle area (mm^2)	58.7 (0.64)	56.1 (0.63) ***	57.3 (0.92)	56.3 (0.91)	58.6 (0.90)	57.3 (0.87)
Lean meat content (%)	58.3 (0.23)	55.8 (0.23) ***	59.0 (0.34)	56.2 (0.33) ***	59.6 (0.43)	57.0 (0.42) ***
Backfat (mm)	14 (0.22)	16.2 (0.22) ***	13.2 (0.27)	15.3 (0.27) ***	13.1 (0.37)	15.5 (0.36) ***
Iodine value	74.1 (0.29)	71.5 (0.28) ***	76.0 (0.58)	72.8 (0.57) ***	73.7 (0.50)	70.1 (0.48) ***
MUFA (%)	44.8 (0.36)	45.2 (0.35)	46.6 (0.18)	47.5 (0.17) ***	45.9 (0.67)	46.5 (0.66) *
SFA (%)	36.2 (0.30)	37.3 (0.30) ***	34.1 (0.32)	35.3 (0.31) ***	35.8 (0.48)	37.3 (0.48) ***
PUFA (%)	19.5 (0.26)	17.9 (0.26) ***	19.6 (0.36)	17.4 (0.35) ***	18.8 (0.48)	16.6 (0.47) ***

Notes: ADG1- Average daily weight gains in the period from start to 50 days of fattening; ADG2- Average daily weight gains between 50 and 80 days of fattening; ADG3- Average daily weight gains over the entire trial period, start until slaughter; * significant sex effect (within a farm) * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

had a higher lean meat content, loin muscle area (significant different on farm A only) and a lower backfat thickness (Table 4).

Fat quality

Feeding diet ORG resulted in a significant increase in iodine value and PUFA content in backfat on every farm. Although the same ORG diet was used on all three farms, the PUFA content varied and ranged between 18.3 and 19.9%. Thereby, the iodine value was approximately 2 g 100 g^{-1} fat higher and the PUFA value was two percentage points higher under diet ORG. A reduction in MUFA was observed as a result of diet ORG on two farms (A, B) and a reduction in SFA on the farms B and C. Regarding the sex, MUFA was lower in females, and PUFA was higher than that for the barrows (Table 4).

Discussion

Study design

The present study was conducted on three different commercial organic pig farms. The real conditions on practical commercial farms producing organic pork differ from the controlled, constant, and technical environments of a research station. The results of on-farm experiments are limited to the specific and partly unpredictable conditions under which they are generated and thus have the character of a case study. Although this may appear to be a problem, this does reflect the very varying conditions that exist on organic farms. This challenge cannot be resolved in standardised research station experiments, which may be more controlled but still also represent specific cases (Richter et al. 2009). Instead, studies of the immanent diversity of organic farms requires large numbers of similar experiments or data collections under varying on-farm conditions and different on-farm practices (Leiber et al. 2017; Kapp-Bitter et al. 2021). There is a clear trade-off between a low number of farms and a high quality of variables and vice versa. If the aim is to investigate how practice copes with a change in the feeding regime, it is not sufficient to base this only on a controlled trial. Instead, different on-farm conditions are required to cover the existing variables besides feeding, as the final product is always determined by multiple factors (Delate et al. 2017; Blume et al. 2021b). Therefore, on-farm research is an essential complement to controlled trials, even if it is sometimes the case that important variables cannot be collected, such as feed intake in the present study. Due to the differences between the farms and the different control diets, the statistical evaluation was also carried out for each farm individually, as it was also a question of how each farm coped with the 100% organic feeding. The challenges and approaches discussed here, were targeted with the design of the present study.

Diets

In principle, the present feeding trial was strongly oriented towards practice. However, since some of the farms practiced continuous fattening (no in-and-out circle) and in order not to burden the farm managers with major changes, the usual feed already used on the farm was defined as the control diet in the trial. Although all farms received their feed from the same feed mill, the control diets differed in composition in so far as the components used were incorporated in different proportions in the diets, which also led to differences in the nutrient profiles.

When preparing the experimental diet (ORG), consideration was given to fulfil the needs of the growing fattening pigs as best as possible. Diet ORG differed from the control diets (CON) mainly because it did not contain conventional potato protein and had a higher soybean cake content (Table 1). The experimental diet could not completely fulfil the recommendations for an optimal ratio of essential ileal digestible amino acids (Lindermayer et al. 2009), as the ratio of methionine and tryptophan to lysine deviated (Table 2). Nevertheless, this reflected the current challenge of 100% organic feeding, as in future it will be more difficult to achieve a methionine content for pigs that is in line with the requirements.

Growth performance

Feeding the 100% organic diet had an effect on some performance and carcass characteristics and differences occurred depending on the farm. Regardless of the feeding, the growth performance achieved was at an overall high level with daily gains between 975 and 1065 g day^{-1} in the finishing phase and a lean meat percentage between 56.9 and 58.4 of the animals studied. The lower daily gains of the animals on farm B can be explained by the fact that the piglets were included in the experiment with a lower weight (and age) and were therefore in a different growth phase. This was particularly evident at the beginning of fattening (ADG1), after which the daily gains were numerically not much lower than on the other farms. In addition, farm B had the highest number of animals per m^2 (Supplemental Figure 2). According to Cho and Kim (2011), a high stocking density can act as a stressor and have a negative impact on pig performance. The lower ADG under diet ORG can be explained by the insufficient ratio of ileal digestible methionine and tryptophan to lysine. Deficits of methionine and tryptophan have been reported to restrict protein synthesis and thus muscle development (Yang et al. 2020). According to Remus et al. (2015), the minimum ratio of methionine to lysine should be 26%. A lower ratio is associated with significant loss of performance. Other studies have also shown that a deficit in digestible methionine resulted in lower daily weight gains (Sundrum et al. 2011; Conde-Aguilera et al. 2016). An adequate methionine supply has also been reported to affect specific meat quality parameters (Lebret et al. 2018; Gondret et al. 2021). This explained the lower daily weight gains under diet ORG over the entire trial period in the present study and the lower live weight at 80 days of fattening, the lower carcass weight and loin muscle area on farms B and C. However, on farm A, no losses in performance were found, even though the same 100% organic diet was used as on the other farms. This can therefore only be attributed to a farm effect, which was not apparent.

While an adequate lysine content in fattening pig diets can be easily achieved by using legumes and oil cake, the low methionine content in grain legumes (especially peas) makes it more challenging to supply organic animals according to their needs. Weißmann (2011) also mentioned further reasons why a need-based methionine supply for pigs remains a challenge: inadequate amino acid patterns of available cereals and grain legumes, lack of availability of alternative feed supplements, missing primary products of organic origin (e.g. potato protein) and explicit prohibition of other options (e.g. soybean extraction meal and free synthetic amino acids). Nevertheless, some alternatives can provide an additional source of methionine if their integration into pig diets were approved and logistically optimised, such as panicle millet (*Panicum miliaceum L.)* (Lefter et al. 2021; Vogt-Kaute and Vogt 2022), dried young alfalfa (*Medicago sativa*) leaves (Blume et al. 2021a), protein concentrate from grass-clover (Stødkilde et al. 2021), insect meal (DiGiacomo and Leury 2019), slaughter by-products (Choi et al. 2021), and some more.

Carcass composition

The reduced carcass weight and loin muscle area found on farms B and C with diet ORG can also be explained by a slight lack of digestible methionine and tryptophan, which limited muscle growth (Nørgaard and Fernández 2009; Conde-Aguilera et al. 2016). Usually, the higher feed and, thus, energy intake, as a consequence of the animals' attempt to compensate for essential amino acid deficits may be one reason for higher fat content of the carcass (Li and Patience 2017; Carcò et al. 2018; Schiavon et al. 2019). While Martinez-Ramirez et al. (2008) and Castellano et al. (2015) observed such increased fatness of the carcasses due to a deficiency in essential amino acids, this was not the case in the present study as the backfat thickness was not increased when comparing CON and ORG. Feed intake and feed conversion could not be determined in the present study, as this was not technically feasible.

Fat quality

Related to the two diets, significant differences in fatty acid composition occurred in the backfat, especially with respect to PUFA contents. Excessively high PUFA contents can impair meat processing because PUFA-rich fat is softer and greasier. Also, oxidation stability and thus product shelf life is reduced (Warnants et al. 1996; Wood et al. 2004). In Switzerland, there are limits for the PUFA content in backfat, which, if exceeded, result in deductions from the carcass value (Hadorn et al. 2008; Proviande 2014). Since the dietary PUFA content is positively correlated with the PUFA in body fat tissues (Warnants et al. 1999; Wood et al. 2008), the higher proportion of soybean cake associated with the omission of conventional potato protein could explain the high PUFA values of ORG-fed animals. Diet ORG contained twice as much soybean cake than the control diets and this is rich in dietary PUFA (Bee et al. 2002; Alonso et al. 2012). Despite the high correlation between dietary PUFA and PUFA in body fat (Warnants et al. 1999; Wood et al. 2008; Dannenberger et al. 2012), differences occurred between the farms in the present study. Although the same experimental feed was fed on all farms, the PUFA contents were different. There were also differences in the PUFA content of the control feed, which cannot be directly transferred to the real PUFA content. This may be attributed to the presence of a farm effect, which is multi-factorially determined e.g. by genotype, husbandry, management, sex, age, ambient temperature and protein content of the diet (Wood et al. 2008; Barea et al. 2013). Due to the lower fat cover, females usually have higher PUFA contents in the backfat (Table 4), as the PUFA are distributed over a smaller amount of fat (Müller Richli et al. 2016).

General discussion of 100% organic feeding

The present study showed that feeding with 100% organically produced components was feasible and that only minor differences occurred as compared to 95% organic feeding. Due to the similarly high requirements towards fattening performance and product quality of organic pork and conventional pork production, the scope of the feed components that can be used is limited. It must be questioned, whether the quality standards with regard to the marketing of organic meat can be transferred from the conventional sector as before, or whether the market criteria will have to be adapted in the future to a greater extent to diverse feeding and its effects on product quality, and also to the different animal husbandry concepts of organic farming such as different breeds, production systems (e.g. boar fattening), more roughage and longer fattening periods (Früh et al. 2013). There is also the question of whether a different production target in terms of meat and fat quality could give more scope in feeding and thus allow better use of the available resources. The prerequisite for this would be that organic consumers would be willing to accept a different quality in the knowledge that this promotes sustainability, resource conservation, naturalness and animal welfare. How could this be achieved in this context of a different information policy for consumers? Is there a willingness to accept a new product?

A change in thinking may be needed in organic pork production. High animal performance requires a high input of resources. If the high-yielding genotype can no longer be fed with organic feed in line with requirements and species-appropriateness, the feed is the limiting factor to which the genotype should adapt. Using genotypes that perform well on less intensive diets would therefore be an option. By using fewer high-yielding breeds or an adjustment of the market demands on the performance of fattening pigs and meat quality, the available organic feed resources for pigs can be better utilised. In any case, the present study has shown that conventional components can be carefully dispensed of in organic diets for fattening pigs if a slightly reduced fattening performance and a higher content of PUFA in backfat are accepted.

Conclusions

The use of a 100% organic diet resulted in reduced daily gains and carcass weights, and significantly higher iodine values and PUFA contents in the backfat of the pigs. The elimination of conventional potato protein increased the challenge of achieving adequate amino acid levels in the diet. Compensation solely with soybean cake increased the protein content of the diet and a slight deficit of essential limiting amino acids (such as methionine) still remained. With the requirements for fast growing organic pork being equally as high as in conventional production, the variety of feed components that can be used is limited. An adjustment of the quality requirements for organic meat and the acceptance of a slightly lower growth performance would promote the feasibility of 100% organic feeding.

Acknowledgments

The authors would like to sincerely thank the practical farms for the opportunity to conduct the trials on their farms and the Swiss Federal Office for Agriculture (FOAG) and BioSuisse for the financial support of the project Bioschwein100.0.

Disclosure statement

The authors are not affiliated with any organisation that has a direct or indirect financial interest in the subject matter covered in the manuscript.

Funding

This work was supported by the Federal Office for Agriculture (FOAG) of Switzerland [627000764].

ORCID

Florian Leiber http://orcid.org/0000-0002-1434-6155

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