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Sire-feed interactions for fattening performance and meat quality traits in growing-finishing pigs under a conventional and an organic feeding regimen

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ABSTRACT

In a two-factorial feeding trial 120 growing-finishing pigs from eleven sires were fed on an organic (ORG) or a conventional (CON) diet. Diet ORG contained mainly oil press cakes and legume grains as protein source containing higher protein and crude fiber content along with slight deficiencies of limiting amino acids. Pigs were allocated to treatments balanced according to litter, sex and initial weight. Feed was offered ad libitum. Feed consumption, weight gain as well as carcass, meat and fat quality traits were recorded. ORG fed animals had lower weight gain, poorer feed conversion, lower loin muscle area, higher intramuscular fat content, higher ultimate pH (loin, ham), and a higher PUFA content in backfat. Despite for cook loss and dressing percentage, no sire-feed interactions were found. This indicates no need for a performance test, specifically designed for organic production. However, weight of the breeding values for the various traits and selection criteria should be adapted to the needs of organic production.

1. Introduction

Pigs of a genotype performing best under conventional conditions are not necessarily best adapted to the conditions in organic production systems (Boelling, Groen, Sørensen, Madsen, & Jensen, 2003; Reuter, 2007). Requests for specific breeding programs for organic pork production are based on the assumption that the performance of pigs kept under organic conditions needs to be assessed against different traits than for conventional pigs (Brandt, Werner, Baulain, Brade, & Weissmann, 2010). Maximizing production performance may be less important than high adaptability to the organic feeding and husbandry conditions (Reuter, 2007). Among several factors that distinguish organic livestock farming from conventional, feeding has a strong influence on performance and meat quality. Restrictions regarding feed components (The Council of the European Union, 2007) include a ban of free amino acid supplements, solvent-extracted oilseed meals and conventional by-products such as potato protein, which is not available from organic sources. Thus, a dietary amino acid pattern similar to that of conventional feed can hardly be achieved in organic feed formulations for pigs (Quander-Stoll, Holinger, Früh, Zollitsch, & Leiber, 2020). Therefore, organic pig diets are often characterized by a deficiency in the most limiting amino acids lysine and methionine, despite their higher protein content (Millet et al., 2004; Sundrum et al., 2011).

Various studies which investigated the effects of organic feeding on pig performance and meat quality, show that organically fed pigs have lower average daily weight gains (ADG), poorer feed conversion ratio (FCR), lower carcass weight, lower dressing percentage, higher intramuscular fat content (ImF), fatter carcasses and higher contents of polyunsaturated fatty acids (PUFA) in backfat (Hansen, Claudi-Magnussen, Jensen, & Andersen, 2006; Martino et al., 2014; Partanen, Siljander-Rasi, & Alaviuhkola, 2006). This can be explained by a deficiency of the essential amino acids (EAA) lysine and methionine, which limits overall growth, and particularly muscle development (Lambe et al., 2013; Lebret, Batonon-Alavo, Perruchot, Mercier, & Gondret, 2018; Liao, Wang, & Regmi, 2015). A slight deficit of EAA can also increase the feed intake (FI) (Carcò et al., 2018; Li & Patience, 2017;

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Schiavon et al., 2018). Feed intake is affected by several factors, although pigs' feed consumption is primarily orientated towards energy saturation (Henry, 1985; Nyachoti, Zijlstra, De Lange, & Patience, 2004). Due to the access to open-air runs available to organic pigs, their energy requirement is higher than those of conventionally kept pigs without access to open-air runs, due to their higher activity and greater strain on thermoregulation (Tomažin, Batorek-Lukač, Škrlep, Prevolnik-Povše, & Čandek-Potokar, 2019). Furthermore, in addition to concentrate, roughage must be offered to organic pigs (The Council of the European Union, 2007). This can reduce the total feed intake due to the bulk effect of the fiber it contains (Bee, Ampuero Kragten, Früh, & Girard, 2021; Montagne et al., 2014). Basically, the feed composition influences growth performance and several meat and fat quality characteristics such as ImF, pH and the associated water holding capacity (WHC), as well as fat quality and the content of polyunsaturated fatty acids (PUFA) in the backfat (Hamill et al., 2013; Li et al., 2015; Sundrum et al., 2011).

However, at the market, organic pork is subject to the same quality requirements as conventionally produced pork. Since several studies (Godinho et al., 2018; Latorre, Pomar, Faucitano, Gariépy, & Méthot, 2008; Rivera-Ferre, Nieto, & Aguilera, 2003) revealed a relevant genetic influence on performance, meat quality and fat composition, the additional investigation of genotype-environment interactions could help to determine whether the requirements of organic pork production need to be reflected in specific breeding goals. A study of genotype-environment interactions showed that the seven different genotypes, including high performing modern breeds as well as more extensive, local strains, tested, all performed better under conventional feeding. Although genotype-environment interactions were found, no significant shift in ranking within environment between genotypes occurred (Brandt et al., 2010). In most cases, there was no re-ranking of sires within breed under organic conditions (Kelly et al., 2007; Wallenbeck, Rydhmer, & Lundeheim, 2009) or only for a few characteristics (Godinho et al., 2018). Genotype-environment interactions are only relevant if they would affect selection decisions (Werner, 2009). In this sense relevant genotype-feed interactions were found for growth performance and feed efficiency when pigs were fed diets containing only 85% of the recommended lysine compared with a lysine content slightly above recommendations (Agroscope, 2017; Hofer, Spring, & Stoll, 2018).

Because under organic conditions the supply with essential amino acids often is insufficient, the aim of this study was to specifically investigate sire-feed interactions regarding conventional and organic feed. The present study should contribute to answering the question whether it would be beneficial to test boars under typical conditions of organic nutrition. This should also show whether sire lines selected under conventional feeding regimes are equally suitable for the production of piglets to be fattened with organic diets.

Our hypothesis was that progeny groups from different boars react differently to organic feed and that sire-feed interactions occur for some growth performance, carcass composition as well as meat and fat quality traits.

2. Animals, materials and methods

A feeding trial was performed at the Swiss pig performance testing station (Suisag, https://www.suisag.ch/; approval of the veterinary authority in Lucerne, Switzerland no. LU 04/17, 29020).

2.1. Animals

A total of 120 F2-piglets were allocated to the two treatments control (CON) or 100 % organic feed (ORG), balanced according to litter, sex, and weight. The animals originated from 11 sires, nine Swiss Large White, sire line (LW-S) and two Duroc (D), mated to a total of 28 Swiss Landrace x Swiss Large White crossbred sows. All animals came from private pig producers affiliated to the Swiss pig breeding program of Suisag. A maximum of 10 animals was housed per pen and feeder. In total eight pens of 12.1 m^2 with 6.6 m^2 solid and 5.5 m^2 slatted floor were used for each treatment. Feed consumption records started when the animals had reached 35 kg. The animals received a grower diet (CON-1/ORG-1, Tables 1 and 2) until they reached a live weight of 80 kg (average per pen) and were subsequently switched to the finisher diets (CON-2/ORG-2, Tables 1 and 2).

Table 1
Composition and nutritional values of the experimental diets[1]

Item (g/100g as fed)	Grower diet		Finisher diet	
	CON-1	ORG-1	CON-2	ORG-2
Barley	48.0	8.0	52.35	12.8
Triticale	-	23.94	-	30.07
Wheat	24.0	12.5	24.87	14.5
Faba bean *(Vicia faba)*	-	10.7	-	17.5
Pea *(Pisum sativum)*	-	19.3	-	7.5
Soybean meal HP	17.6	-	8.66	-
Soybean cake	-	8.6	-	7
Rapeseed cake	2.5	5.1	4.97	-
Lucerne meal	-	10.0	-	8.6
Limestone	1.27	-	1.29	-
MCP	0.38	0.53	0.3	0.49
Calcium carbonate	-	0.51	-	0.74
Molasses	3.0	-	2.49	-
Fat RS 65	0.85	-	0.99	-
Wheat starch	-	-	0.99	-
Lignin sulfonate	-	-	0.99	-
Sodium chloride	0.26	0.32	0.34	0.3
L-Lysine (Lys)	0.23	-	0.42	-
DL-Methionine	0.08	-	0.09	-
L-Threonine	0.06	-	0.13	-
Vitamin-mineral mix	1.16	0.5	0.25	0.5
Phytase/enzymes	0.1	-	0.01	-
Organic acids	-	-	0.86	-
Preservative	0.5	-	-	-
Digestible energy (MJ DE)	13.5	13.1	13.5	13.1
Lys:MJ DE ratio	0.74	0.69	0.7	0.59
SID[2] Lys:MJ DE ratio	0.67	0.59	0.51	0.51

[1] CON=conventional; ORG=organic
[2] SID=standardized ileal digestible

Table 2
Analyzed nutrient content (g/100g as fed)

	Grower diet		Finisher Diet	
	CON-1	ORG-1	CON-2	ORG-2
Crude protein	18.2	18.6	15.4	16.7
Ether extracts	3.3	3.2	3.1	2.5
Crude fiber	3.6	6.3	3.9	6
Ash	5.5	5	4.7	4.6
Lysine	0.98	1	0.92	0.82
Methionine	0.30	0.23	0.27	0.19
Cystine	0.35	0.33	0.32	0.30
Threonine	0.63	0.64	0.61	0.54
Tryptophane	0.19	0.18	0.16	0.16

2.2. Diets

The control diets (CON-1 and CON-2) corresponded to the standard used in the Swiss pig performance test (Suisag, 2019, technical report), the amino acid requirements being met by using high-protein soybean meal and synthetic free amino acids. The experimental diets ORG-1 and ORG-2 represented 100% organic pig diets with a higher protein content but an imbalanced amino acid composition (lack of sulfur-containing EAA and threonine). Under Swiss organic production rules, pigs must have permanent access to roughage in addition to the concentrate. Since it was not possible to offer extra roughage under the experimental conditions, 10% (ORG1) and 8.6% (ORG2) alfalfa meal was added to the

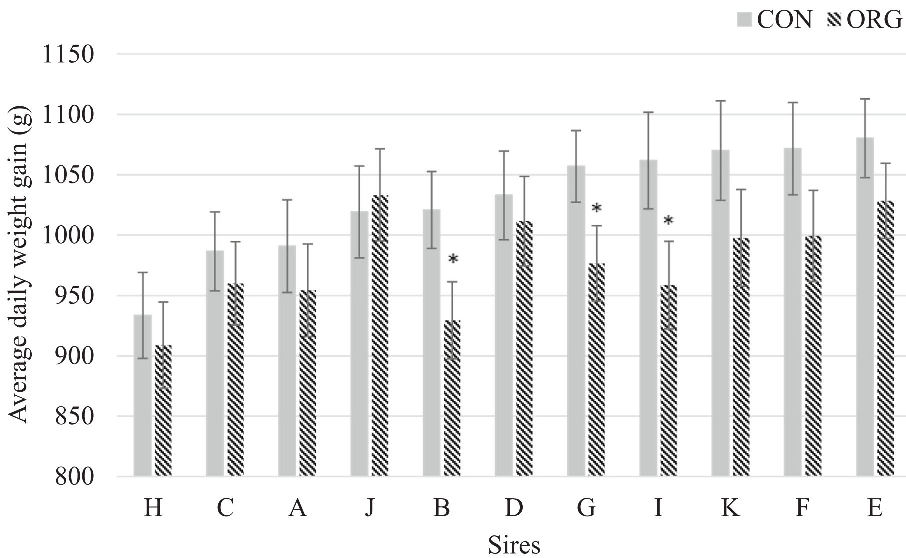

Fig. 1. Average daily weight gain (ADG) of boar offspring fed either a conventional control or a 100% organic diet (emmeans, SE). *boar offspring with significantly lower ADG, fed diet ORG.

ORG-diets to reach the suggested crude fiber content of the complete diet. Thus, the crude fiber content was higher in diet ORG than in CON (Table 2).

Feed samples were taken directly from the feeders of different pens twice during the grower and finisher phase, and samples from two pens per feed were pooled for later analysis. Two pooled samples were analyzed for each of the four diets. The samples were examined for nutrient content at the Agricultural Research Institute Speyer Germany, according to VDLUFA (2020). The crude protein content was determined by the DUMAS combustion method (VDLUFA, 4.1.2, 2020). Ether extracts were analyzed according to method A of 5.1.1 by a petroleum ether extraction (VDLUFA, 2020). The crude fiber content was determined by treating the sample successively with sulfuric acid and boiling potash lyse according to 6.1.1 (VDLUFA, 2020). To determine the ash content, the samples were incinerated at 550 °C and the residue was weighed according to 8.1 (VDLUFA, 2020). After hydrolysis with hydrochloric acid the amino acids lysine, methionine, cysteine, and threonine were analyzed by ion exchange chromatography following method 4.11.1 of VDLUFA (2020). The content of tryptophan was determined by HPLC-method (4.11.2, VDLUFA, 1988). The energy content of the diets (MJ DE) was calculated according to Agroscope (2017). The feed composition is shown in Table 1, the analyzed nutrient contents in Table 2.

2.3. Performance and quality traits

Feed intake (FI) was recorded individually for each animal using a transponder (FIRE pig feeder, Osborne Industries, Inc., Osborne, Kansas 67473, USA) in the ear tag. The animals were weighed every Thursday when they approached the target weight and were assigned for slaughter in the following week when they exceeded a live weight of 103 kg. On the basis of the weight at slaughter and the weight at start of the performance test, average daily weight gains (ADG) were calculated. Feed conversion ratio (FCR) as kg feed consumed per kg weight gain, was calculated based on feed intake and daily weight gains. Fattening performance, carcass composition as well as meat and fat quality traits were measured according to the Swiss pig performance test guidelines (Suisag, Sempach, Switzerland, https://www.suisag.ch).

The animals had unlimited access to feed until they were loaded around 3:00 a.m. and transported (approx. 20 min.) to the lairage pens of the slaughterhouse. CO_2-stunning started at 6:00 a.m. The carcass weight was recorded approximately 50 min. after stunning. The lean meat content was measured using an AutoFOM III (Frontmatec, Kolding, Denmark). The pH measurements were carried out 90 minutes and 24 h p.m. in the loin muscle (*L. thoracis*, LT) between the 2nd and 3rd last rib and *M. semimembranosus* (6 cm above the aitch bone) of the left carcass side, using a pH-Star device (Matthäus, Eckelsheim, Germany). Dressing percentage was determined by calculating the live weight at slaughter using the live weight five days before slaughter plus the extrapolated daily gains and dividing the carcass weight by the calculated live weight.

The left carcass side was cut between the second and third last rib at a right angle to the spine 24 h p.m. A picture of the cross-section was taken with a camera (Canon lxus 130) to measure the loin muscle area as well as the backfat area using the ScanStar program (Matthäus GmbH & CO. KG, Eckelsheim, Germany). A piece of the loin, three ribs cranial from the cut, including the loin muscle and the overlying backfat, was taken from every carcass and carried to the Suisag laboratory (Sempach, Switzerland). A slice of the LT was used to determine the intramuscular fat content (ImF) after all adhering connective and adipose tissue had been removed. The sample was homogenized and the ImF was determined with an NIR-FIex N-500 (Büchi, Flawil, Switzerland). The drip loss (DL) was determined by cutting a piece of 80-85 g out of a 3-cm-thick slice of LT suspended in a plastic bag for 48 h at 2 °C. The weight of the sample was collected before and after the 48 h had elapsed.

The same piece of meat was used to determine the cook loss, sealed under vacuum in a plastic bag and cooked at 72 °C in a water bath for 45 minutes. The meat sample was then cooled for 15 minutes in a water bath at 20 °C, rinsed with water and then dabbed dry with paper towels and weighed back (Scheeder & Müller Richli, 2017).

The cooked meat sample was kept deep-frozen until defrosted at 20 °C for the shear force measurement. Four cores (1.3 cm in diameter) were drilled out in the direction of the fibers. Shear force was measured using a texture analyzer (Nexygen plus 3, Lloyd instruments) equipped with a modified Warner-Bratzler shear force cell (blade thickness 1 mm, slot width 1.2 mm) perpendicular to the muscle fibers (cross-head speed 120 mm/s).

The proportion of mono- and polyunsaturated fatty acids (MUFA, PUFA) in the backfat overlaying the LT was determined as fatty acid methyl esther (FAME) using the NIR-Flex N-500 (Büchi, Flawil, Switzerland). The backfat was separated from the meat and the rind was carefully removed from the outer layer of the backfat. NIR scans were taken directly from the surface of the outer layer using a fiber-optic probe (FOP) (Müller Richli, Kaufmann, & Scheeder, 2016).

The meat color (meat brightness and pigment content) was measured

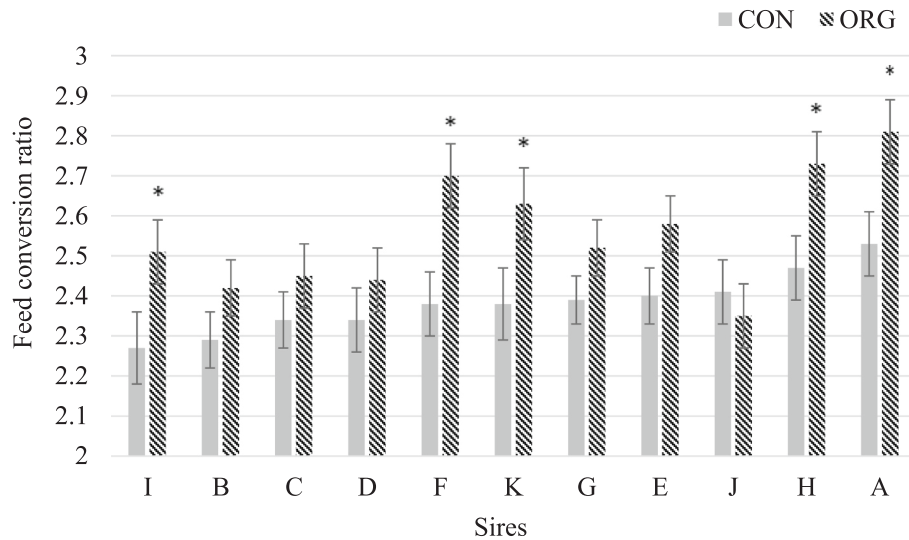

Fig. 2. Feed conversion ratio (FCR) of boar offspring fed either a conventional control or a 100% organic diet (emmeans, SE).
*boar offspring with significantly inferior FCR, fed diet ORG.

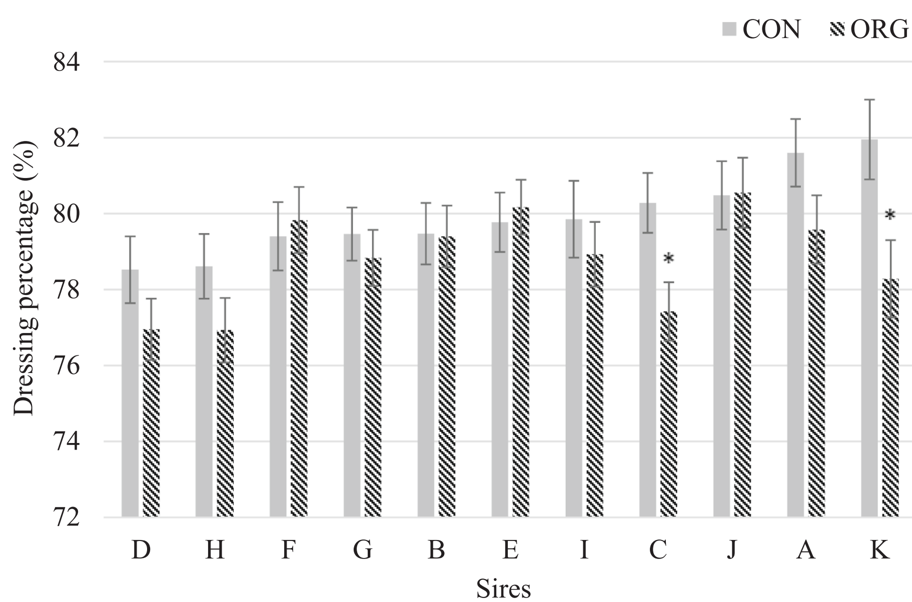

Fig. 3. Dressing percentage of boar offspring fed either a conventional control or a 100% organic diet (emmeans, SE).
*boar offspring with significantly different dressing percentage, fed diet ORG.

with a CM-2500d Spectrophotometer (Konica Minolta, Sensing Europe B.V., Swiss Branch, Dietikon). The measurement was performed at three points distributed over the cross section of the LT after 20 minutes of blooming. Meat brightness is given as L* value, pigment content was estimated from the difference in absorption at 525 nm and 730 nm (Lindahl, 2005).

2.4. Statistical analysis

The statistical analyses were conducted with the software R, version 3.6.1 (R Core Team, 2019). Linear mixed-effects models were applied, considering sex, diet and sire as well as the interaction of diet and sire as fixed effects. As random effects, sow and pen were considered. To fit linear models, function “lmer” of the package “lme4” (Bates, Mächler, Bolker, & Walker, 2015) was used. P-values were calculated with the function “Anova” of the package "lmertest" (Kuznetsova, Brockhoff, & Christensen, 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. Multiple comparisons were conducted using the “pairs” function of the package “emmeans” (Lenth, 2019) in order to compare the sires within diet and the diets CON and ORG within boar. The term “sire-feed interaction” is used in the sense of “genotype-feed interaction”. 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. For the Fig. 1-6, a multiple comparison of means was made for the different boars within diet.

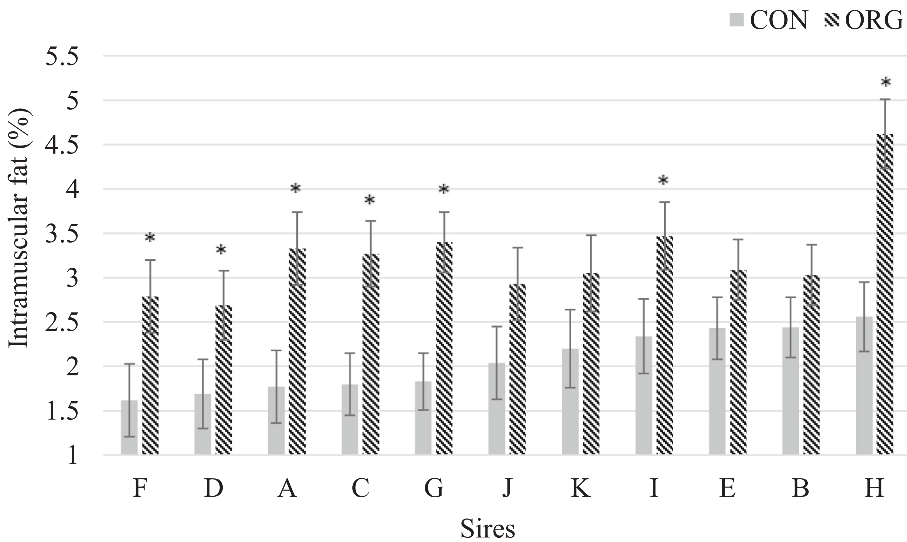

Fig. 4. Intramuscular fat content (ImF) of boar offspring fed either a conventional control or a 100% organic diet (emmeans, SE). *boar offspring with significantly higher ImF, fed diet ORG.

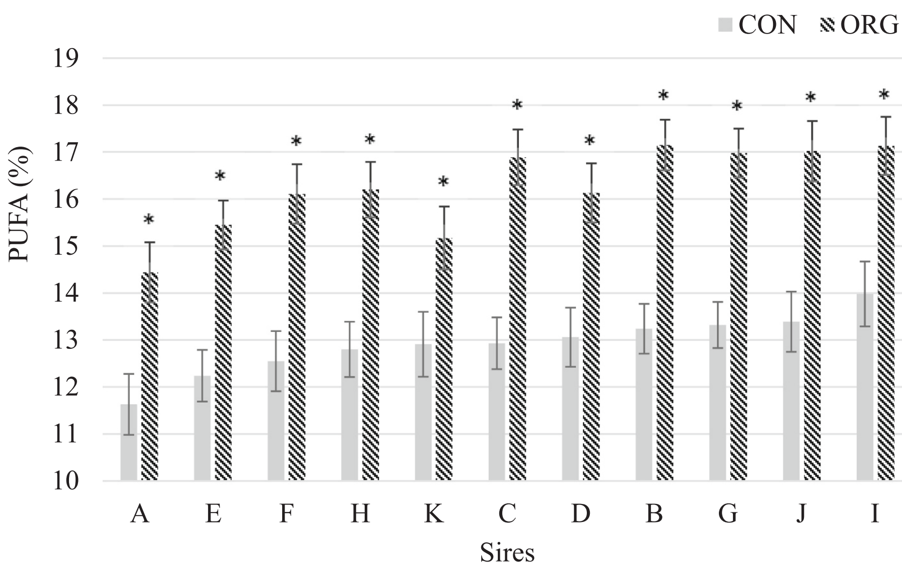

Fig. 5. PUFA content in backfat of boar offspring fed either a conventional control or a 100% organic diet (emmeans, SE). *boar offspring with significantly higher PUFA content, fed diet ORG.

3. Results & discussion

3.1. Performance traits

The ADG of animals fed diet CON was higher than of the animals that received diet ORG (P<0.001; Table 3). In pigs, lysine is the first limiting amino acid and a deficit limits protein synthesis and consequently muscle growth. As shown in Table 1, diet ORG had a lower lysine:energy (MJ DE) ratio than diet CON in the grower and in the finisher period, which partly explains the lower ADG in the ORG group (Cho et al., 2012; Li et al., 2012). The methionine content was also lower in diet ORG than in CON in both fattening phases (Table 2). A methionine deficiency reduces growth performance resulting in lower ADG, muscle growth and carcass weight with an increased fat deposition (Castellano et al., 2015; Lebret et al., 2018; Zhou et al., 2016). The addition of free amino acids is not permitted in organic feeding (The Council of the European Union, 2007). Legumes and oil press cakes are used as protein rich dietary components. Due to the high residual fat content (including PUFA), oil press cakes can only be used to a limited extent to avoid high PUFA contents in the backfat of pigs. At present, conventional potato protein is still used to improve the protein quality in organic pig diets (Sundrum, Bütfering, Henning, & Hoppenbrock, 2000). When 100% organic feeding will be mandatory (in Europe from 2023) (The Council of the European Union, 2018), this is no longer feasible and potato protein of organic origin is not available in sufficient quantities. Therefore, an EAA supply meeting the requirements is usually the biggest challenge in organic pig feeding and the first limiting amino acids for pigs, lysine and methionine, are often deficient. Organic fattening pigs therefore usually have lower ADG than conventional pigs (Hansen et al., 2006; Martino et al., 2014; Sundrum et al., 2011). In addition, the inclusion of alfalfa meal in diet ORG may have further reduced the amino acid digestibility (Freire, Guerreiro, Cunha, & Aumaitre, 2000; Liang, Gao, Li, Ding, & Zhang, 2015). Today's fast-growing pigs, bred for a high lean meat content, cope less well with an EAA deficit than slow-growing breeds (Barea, Nieto, Vitari, Domeneghini, & Aguilera, 2011; Martino et al., 2014). No significant sire-feed interactions occurred regarding ADG.

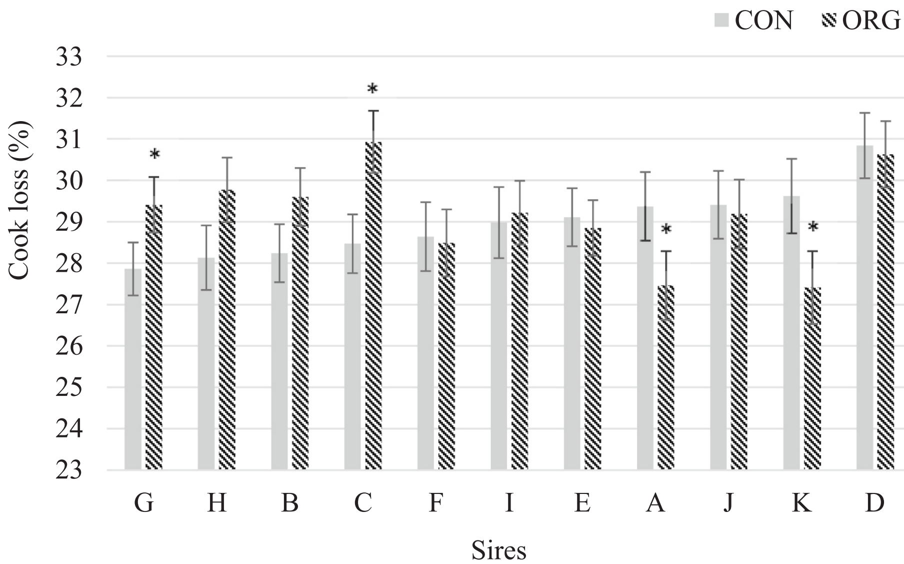

Fig. 6. Cook loss of boar offspring fed either a conventional control or a 100% organic diet (emmeans, SE). *boar offspring with significantly different cook loss, fed diet ORG.

Table 3
Growth performance and carcass quality traits of pigs fed either a conventional control (n=53) or a 100% organic (n=52) diet (emmeans (SEM)).

Item	Treatment		P values (fixed effects)		
	CON	ORG	Feed (F)	Sire (S)	SxF interaction
Age at slaughter (d)	153.9 (1.88)	157.6 (1.95)	0.095	0.011	0.096
Live weight 5 days before slaughter (kg)	106.5 (0.45)	106.8 (0.43)	0.476	0.109	0.178
Carcass weight (kg)	85.1 (0.50)	84.2 (0.49)	0.070	0.013	0.733
Dressing percentage (%)	77.7 (0.31)	76.7 (0.30)	<0.001	<0.001	0.026
Weight gain (g/day)	1029 (11)	978 (10.8)	<0.001	0.006	0.549
Feed intake (kg/day)	2.43 (0.04)	2.50 (0.04)	0.105	0.013	0.419
Energy intake (MJ ME/day)	30.4 (2.07)	27.5 (2.2)	0.197	0.001	0.232
Feed conversion ratio (kg/kg)	2.38 (0.03)	2.55 (0.03)	<0.001	<0.001	0.143

Table 4
Meat and fat quality traits of pigs fed either a conventional control (n=53) or a 100% organic (n=52) diet (emmeans (SEM)).

Item	Treatment		P values (fixed effects)		
	CON	ORG	Feed (F)	Sire (S)	SxF-interaction
Lean meat content (%)	58 (0.22)	58.1 (0.22)	0.679	<0.001	0.507
Intramuscular fat (%)	2.1 (0.12)	3.2 (0.12)	<0.001	0.040	0.110
Loin muscle area (cm^2)	45 (0.44)	43 (0.44)	<0.001	0.001	0.246
Backfat area (cm^2)	15.2 (0.38)	14.9 (0.37)	0.367	<0.001	0.565
Meat brightness (L*)	52.1 (0.4)	52.1 (0.4)	0.963	<0.001	0.086
Pigment content	0.72 (0.03)	0.79 (0.03)	0.031	<0.001	0.160
pH1 loin	6.34 (0.05)	6.32 (0.05)	0.615	0.302	0.630
pH1 ham	6.27 (0.04)	6.28 (0.04)	0.731	<0.001	0.440
pH24 loin	5.41 (0.01)	5.46 (0.01)	<0.001	0.050	0.320
pH24 ham	5.48 (0.01)	5.53 (0.01)	0.002	0.185	0.260
Drip loss (%)	2.97 (0.23)	3.10 (0.23)	0.623	0.022	0.832
Cook loss (%)	29 (0.25)	29.2 (0.24)	0.383	0.090	<0.001
Shear force (N)	37.9 (0.86)	37.1 (0.84)	0.454	0.001	0.189
MUFA (% of total FAME)	49.0 (0.18)	48.1 (0.18)	<0.001	0.001	0.455
PUFA (% of total FAME)	12.9 (0.18)	16.2 (0.18)	<0.001	0.001	0.846

However, Fig. 1 illustrates that the offspring of three boars showed significantly lower ADG under ORG-conditions, while other progeny groups were less affected (Fig. 1).

Feed intake of pigs is strongly, but not only regulated by energy saturation (Henry, 1985; Nyachoti et al., 2004). According to Schiavon et al. (2018) and Carcò et al. (2018) feed intake can also increase with an amino acid deficiency. This was not observed in the present study. Despite the slightly lower energy content and the lower proportion of the first limiting amino acids (lysine and methionine) in diet ORG (Table 1 and 2), there was no significant difference in feed consumption (kg/day; MJ ME/day, Table 3). This can be explained with the findings of Kallabis and Kaufmann (2012) and Lengling et al. (2020), who observed a decreased daily feed intake with a higher crude fiber content in the feed. The swelling of dietary fibers in the digestive tract has an effect on saturation and consequently on feed intake. The alfalfa meal in diet ORG therefore provides an explanation as to why the animals did not consume more feed, despite the EAA deficit (Slama, Schedle, Wurzer, & Gierus, 2019; Tan, Wei, Zhao, Xu, & Peng, 2017). In addition, animals generally avoid metabolic stress in unbalanced rations. Reduced protein synthesis reduces energy requirements, which can also reduce feed intake (Harper, 1959; Li & Patience, 2017). Due to the lower ADG, ORG-fed animals showed a FCR inferior to that of CON-fed animals (P<0.001, Table 3). According to Reckmann and Krieter (2015) FCR (next to ADG) is one of the most important parameters influencing the environmental impact of pig production. Beside the optimization of feed composition to improve FCR, genetic improvement of this trait can help to increase the meat unit produced per feed unit and reduce the environmental impact of pork production (Ali, de Mey, Bastiaansen, & Oude Lansink, 2018). For a more sustainable use of resources, the targeted choice of boars with high feed efficiency would therefore be advisable, regardless of the production system.

Despite the lower ADG of the ORG-fed animals, the numerical difference in slaughter age of 3.7 days was not significant. Since the aim was to slaughter all animals at a similar live weight, they also did not differ in their final weight when they were assigned for slaughter, while the dressing percentage was lower for the ORG-animals (P<0.001). A sire-feed interaction (P=0.03) was found for this trait. As diet ORG contained twice as much crude fiber than the CON diet (Table 2) it can be assumed that the high water-binding and swelling capacity of dietary fibers led to more fiber-bound water in the intestines of ORG animals, contributing to a lower dressing percentage (Chaplin, 2003; Jha & Berrocoso, 2015). An enlargement and a higher capacity of the digestive organs as a result of a fiber-rich diet can also occur (Coble et al., 2018; Whittemore, Emmans, & Kyriazakis, 2003) and thus contribute as well to the lower dressing percentage in ORG-fed animals. As shown in Fig. 3, offspring of two boars (C, K) had a lower dressing percentage with diet ORG. However, offspring of some ORG-fed boars (F, E, J) showed numerically even higher dressing percentages, which obviously led to the sire-feed interaction for this trait.

3.2. Meat and fat quality traits

The animals of both treatments achieved similar lean meat percentages of 58.0 and 58.1 % (Table 4). The loin muscle area, however, was higher in CON than in ORG fed animals (P<0.001), which can be attributed to the lysine deficiency in diet ORG. Conde-Aguilera, Cobo-Ortega, Mercier, Tesseraud, and van Milgen (2014), Martínez-Ramírez, Jeaurond, and De Lange (2008) and Castellano et al. (2015) reported a higher fat accretion in animals fed an EAA-deficient diet. We found no difference in the backfat area (P=0.361) between the treatments, but animals fed ORG had a higher intramuscular fat content (3.2 vs. 2.1, P<0.001). Former studies (Fischer, Lindner, & Baulain, 2009; Sundrum et al., 2011; Wood et al., 2013) have also shown that a lysine deficit results in an increased ImF. The ImF is important for some economically valuable processed products (such as dry-cured ham) and their sensory properties (Suárez-Belloch, Latorre, & Guada, 2016). Several studies found a higher sensory acceptance and preference for pork with higher ImF (Fernandez, Monin, Talmant, Mourot, & Lebret, 1999; Font-i-Furnols, Tous, Esteve-Garcia, & Gispert, 2012; Fortin, Robertson, & Tong, 2005). In tastings, consumers rate meat with a high ImF better (up to 3.25%) but from an ImF of 3.5% the marbling becomes visually perceptible, which may reduce the willingness to buy, since a large proportion of the consumers still prefer lean meat (Brewer, Zhu, & McKeith, 2001; Fernandez et al., 1999). In Switzerland, an average ImF of 2% has been set as a breeding goal. To ensure a high sensory acceptance Font-i-Furnols et al. (2012) recommend an ImF between 2.2 and 3.4% and Fernandez et al. (1999) recommend not to exceed an ImF of 3.5% to avoid a rejection by consumers. In our study, the offspring of seven boars had significantly higher intramuscular fat contents (Fig. 4) under diet ORG compared to CON, which can be rated as advantage for the eating quality. Nevertheless, all boar offspring except for one boar (H) were below or just up to the threshold of 3.5% mentioned by Fernandez et al. (1999). The offspring of boar H had an average ImF of 4.6% and was thus in a range, which can result in a poor visual acceptance by consumers. This boar also had the highest ImF under conventional feeding. In order to avoid excessive ImF it may be recommended for organic piglet production not to use boars with high breeding values for ImF.

No treatment effect was found for pH 90 minutes p.m. in loin and ham, but animals of CON had a lower pH 24h p.m. than ORG (P<0.001) in both muscles. The pH value is linked to the water holding capacity (drip and cook loss) of meat. A higher pH 24h p.m. indicates a lower glycolytic potential (GP) in the muscle, which can be explained by the higher crude fiber content in diet ORG (Li et al., 2015). The observation of Conde-Aguilera et al. (2014) and Lebret et al. (2018) that a methionine deficit leads to an increase in GP and thus a stronger pH decrease could not be confirmed by our results. The pH for both diets CON and ORG was within the usual range (Aaslyng & Hviid, 2020; Scheeder, Gläser, Eichenberger, & Wenk, 2000; Xu et al., 2020) and did not affect other meat quality characteristics such as drip and cook loss.

Regarding meat color, we found no difference in meat brightness. The estimated pigment content in the meat of ORG-fed animals was slightly higher (Table 4). This could be explained by the fact that diet ORG may have had a higher iron content due to the alfalfa meal it contained, which may in turn affect the myoglobin content in muscle (Reichardt, Müller, & Leiterer, 2002). Also, no difference was found due to treatment in drip and cook loss (P=0.603; P=0.383), but in cook loss there was a significant sire-feed interaction (P<0.001). However, the total range of effects was negligibly small (Table 4). We also found no difference in meat tenderness (shear force) between treatments.

Regarding monounsaturated and polyunsaturated fatty acids in backfat, the treatments differed with 48.1% (CON) and 49% (ORG) for MUFA (P<0.001), and with 12.8% (CON) and 16.3% (ORG) also for PUFA (P<0.001). The content of MUFA and PUFA in backfat is of great and contradictive importance for the nutritional and technological value of pig meat (Wood et al., 2008). PUFA are rated as beneficial for human health (Butler, 2014; Sanders, 2014). However, high PUFA amounts can be disadvantageous for meat processing, as the fat is softer and due to the lower oxidation stability, the shelf life can be reduced (Warnants, Van Oeckel, & Boucqué, 1996; Wood et al., 2008). It is well known that the PUFA content in pig fat correlates strongly with the PUFA content in the diet (Kouba, Enser, Whittington, Nute, & Wood, 2003; Pascual et al., 2006; Scheeder, Gumy, Messikommer, Wenk, & Lambelet, 2003). Compared to extracted soybean meal, soybean cake has a higher residual fat content with a high PUFA level. The use of press cake (rapeseed, soybean) in diet ORG can therefore explain the high PUFA content in the backfat. According to Arkfeld et al. (2015), a high dietary crude fiber content can also promote a higher proportion of PUFA in the adipose tissue, so that the inclusion of alfalfa meal, which itself comes along with some PUFA, in diet ORG may also have contributed to a higher PUFA. Several studies found a positive correlation between PUFA and lean meat content and a negative correlation between PUFA and backfat thickness (Davoli et al., 2019; Müller Richli et al., 2016; Sellier, Maignel, & Bidanel, 2010). The deposited lipids in the adipose tissue originate from dietary and *de novo*-synthesized fatty acids. The lower the *de novo* fat synthesis, which depends on genotype, sex and nutritive energy supply, the greater the influence of the diet on the fatty acid composition in adipose tissues (Kloareg, Noblet, & van Milgen, 2007). In recent years, breeding aimed at a high lean meat content, so that modern pigs have a low fat cover. The lower the fat content of the carcass, the higher the proportion of PUFA, which also explains that gilts usually have higher PUFA values than barrows (Table 6). The high contrast between CON and ORG in PUFA content indicates that breeding values for PUFA should be taken into account when choosing breeding boars for organic piglets, especially if markets are supplied where fat quality requirements exist and deductions are made for PUFA levels exceeding 15.5% (e.g. in Switzerland). Fig. 5 shows that all boar offspring showed significantly higher PUFA contents in backfat under diet ORG, and most of them do not meet the fat quality requirements, at least for Switzerland.

The PUFA content in backfat is influenced by various factors. While the PUFA content in the diet and the total amount of PUFA ingested during a pig's life has a great influence on the storage in the adipose tissue, breed and husbandry are also influential (Wood et al., 2008). Furthermore, medium to high heritabilities are reported for MUFA and PUFA, indicating the possibility to breed for fat composition (Müller Richli et al., 2016). According to the EU Organic Regulation, organic pigs must have access to outdoor areas and in some cases, animals also have access to pasture. Pigs that are kept outdoors are exposed to seasonal temperature fluctuations. The incorporation of PUFA also has a

Table 5
Sex differences in growth performance and carcass quality traits (emmeans (SEM)).

Item	Gilts	Barrows	P values
Number of animals (n)	51	56	
Age at slaughter (d)	157.7 (1.61)	153.7 (1.64)	<0.001
Live weight 5 days before slaughter (kg)	106.7 (0.44)	106.6 (0.42)	0.830
Carcass weight (kg)	84.9 (0.45)	84.4 (0.45)	0.410
Dressing percentage (%)	79.5 (0.27)	79.2 (0.27)	0.302
Weight gain (g/day)	976 (10.8)	1031 (10.6)	<0.001
Feed intake (kg/day)	2.34 (0.03)	2.59 (0.03)	<0.001
Feed intake (MJ ME/day)	27.5 (1.73)	30.4 (1.73)	<0.001
Feed conversion ratio (kg/kg)	2.41 (0.02)	2.53 (0.02)	<0.001

Table 6
Sex differences in meat and fat quality traits (emmeans (SEM)).

Item	Gilts	Barrows	P values
Number of animals (n)	51	56	
Lean meat content (%)	59.1 (0.22)	57.0 (0.21)	<0.001
Intramuscular fat (%)	2.3 (0.12)	3.0 (0.11)	<0.001
Loin muscle area (mm^2)	45.1 (0.43)	42.9 (0.42)	<0.001
Backfat area (mm^2)	13.9 (0.37)	16.2 (0.36)	<0.001
Meat brightness (L*)	51.6 (0.38)	52.6 (0.37)	0.018
Pigment content	0.77 (0.03)	0.74 (0.03)	0.273
pH1 loin	6.31 (0.04)	6.36 (0.04)	0.238
pH24 loin	5.43 (0.01)	5.43 (0.01)	0.860
pH1 ham	6.27 (0.03)	6.28 (0.03)	0.660
pH24 ham	5.49 (0.01)	5.52 (0.01)	0.059
Drip loss (%)	3.33 (0.23)	2.74 (0.22)	0.029
Cook loss (%)	29.3 (0.24)	28.8 (0.23)	0.043
Shear force (N)	39.1 (0.84)	35.9 (0.83)	0.002
MUFA (% of total FAME)	48.5 (0.17)	48.6 (0.17)	0.537
PUFA (% of total FAME)	15.3 (0.18)	13.9 (0.18)	<0.001

physiological significance. Two factors determine the relationship between PUFA and exposure to low temperatures: Desaturase activity and reduced fat deposition. The desaturase activity and proportion of unsaturated fatty acids increase as outdoor temperature decreases in order to maintain the viscosity of the subcutaneous adipose tissue due to their low melting point (Fuller, Duncan, & Boyne, 1974; Lefaucheur et al., 1991). Bee, Guex, and Herzog (2004) and Martins et al. (2018) observed higher PUFA contents in the backfat layer of outdoor reared pigs, as a result of reduced fat deposition, which can be explained by the need of energy for thermoregulation and less for fat deposition. Because of the organic pig production conditions, which lead to high PUFA in the backfat, and regarding the variation between progeny groups (Fig. 5), it may be recommended to specifically choose boars with low breeding values for PUFA.

3.3. Barrows and gilts

Between the sexes the expected differences appeared. Barrows had higher daily gains than gilts (1024 g and 966 g, respectively; Table 5). Gilts consumed about 10% less feed and energy (kg/day; MJ ME/day) than barrows and had a better feed conversion ratio. Barrows were ready for slaughter five days earlier than gilts. As expected, gilts achieved a higher lean meat percentage than barrows (59.1% and 57%, respectively) and had a larger loin muscle area (42.9 and 45.1 mm^2, respectively; Table 6). Barrows, in general, showed a higher fat accretion than gilts, indicated by the higher backfat thickness and ImF. Barrows had lighter meat, but no difference in the meat pigment content was found. Also, no difference was found in the pH, but barrows had more tender meat as well as a lower drip and cook loss compared to females. No difference was found for MUFA, but gilts had higher PUFA values than barrows (15.4% and 13.8%, respectively; Table 6), which can be explained by their lower backfat thickness. These sex differences are usually observed and correspond well with a number of other studies (Arkfeld et al., 2015; Li & Patience, 2017; NRC, 2012).

4. Conclusion

Significant sire-feed interactions were only found for dressing percentage and cook loss, but not for more important and economically relevant production and quality traits. The animals of both feed groups (CON, ORG) achieved a high fattening performance and a carcass composition well in line with market requirements, with exception of the PUFA content in the backfat of ORG animals, which was beyond the threshold of the Swiss fat quality requirements in nine out of eleven progeny groups in the ORG treatment. Beside PUFA, significant differences between the feed groups were also found in the traits ADG, feed conversion, loin muscle area and ImF, which are also of economic relevance. Because the 100% organic feed already promotes a high ImF (desirable) but also high PUFA in backfat (undesirable), it is recommended to select breeding boars for the production of organic fattening piglets more specifically according to the distinctive requirements, which differ from conventional production. Because no sire-feed interaction was found for these traits, this selection may be based on breeding values derived from performance tests under conventional conditions. However, it should be considered that an effective selection for a high protein and specifically amino acid efficiency should be carried out under restricted amino acid availability.

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Declaration of Competing Interest

None.

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