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Effect of feeding *Alphitobius diaperinus* meal on fattening performance and meat quality of growing-finishing pigs

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ABSTRACT

A total of 48 piglets with an average weight of 26 kg were allocated to 4 experimental groups of 12 animals, balanced according to litter, sex and weight, and fattened on feed containing 0, 3, 6, or 9% of Alphitobius diaperinus meal (ADM) replacing soybean meal (SOY) as protein source. The control feed contained 10.7% SOY while in the 9% ADM feed SOY was completely replaced. Feed was accessible *ad libitum* in transponder-controlled feeders. Feed consumption and fattening performance records started when the animals reached 35 kg. The 3-way crossbred animals (Landrace x Large White sows mated to Duroc, Pietrain, or Large White sire line bores) were slaughtered at a target carcass weight of 86 kg. No linear effect of ADM on daily gain and feed consumption was found. No effect on lean meat content nor on any of the meat quality traits was observed. The content of polyunsaturated fatty acids (PUFA) in the backfat increased with increasing amount of ADM in the feed. It is concluded that ADM may replace SOY in pig feed without exerting detrimental effects on growth performance, carcass composition and meat quality except for a higher PUFA-content in the adipose tissue.

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Introduction

Alphitobius diaperinus, commonly called the 'lesser meal worm', is probably better known as a pest than as a beneficial organism. It is one of the most common insect pests in commercial poultry farms and may serve as reservoir and vector for various avian pathogens (Rumbos et al., 2019). On the other hand, *A. diaperinus* belongs to those species that have the biggest potential to be used as food and feed and is listed as one of the eight insect species that are so far registered for this use in the EU.

Basic property for both, making it a nasty bug as well as a useful insect: its larvae is not very picky in terms of the substrate to feed on. Thus, it can be used to convert less valuable by-products of the agro-food and -feed industry into valuable protein and fat compounds. *A. diaperinus* has a shorter development time in comparison to the common mealworm *Tenebrio molitor* (van Broekoven et al., 2015) and the meal made from its larvae provides a high amount of protein and essential amino acids, particularly lysine, even exceeding the values of soybean meal (Table 1). *A. diaperinus* meal (ADM) therefore has the potential to be used as protein concentrate in feed and thus to partly reduce the ecological burden of soybean production.

However, pig feeding experiments with insect meal are still rare, mainly focusing on piglets and short periods of administration. Håkenåsen et al. (2021) fed full fat black soldier fly larvae meal in increasing amounts up to 19% of the diet to weaned piglets and reported only minor effects on growth performance, gut function and health as well as colon microbiota. Various reviews showed variable results for digestibility and growth performance, depending on the insect species used, their life stages, and dietary inclusion levels (DiGiacomo & Leury, 2019; Gasco et al., 2020; Veldkamp & Vernooij, 2021; Hong & Kim, 2022). Experiments focused on effects of insects as protein source on carcass composition and meat quality of pigs are scarce. Dankwa et al. (2000) reported a higher subcutaneous fat layer in growing pigs fed house-fly-larvae instead of fishmeal, though it remained unclear if the diets were isoenergetic. In contrast, Yu et al. (2019) reported a higher loin muscle area, though with higher marbling scores, in finishing pigs fed *Hermetia illucens* meal replacing soybean meal. Meyer et al. (2020) investigated potential effects of a *Tenbrio molitor* larvae meal on the metabolism of growing pigs in a 4-week feeding trial while Ringseis et al. (2021) specifically analysed the antioxidant status and oxidative stress in tissues of these animals. The insects used in all of these experiments were either *Tenebrio molitor, Hermetia illucens, Musca domestica* or *Bombyx morii*. *A. diaperinus* was used in a feeding experiment with broiler chicken, resulting in a higher body weight of chicken fed on starter feed and larvae compared to chicken consuming the feed only (Despins & Axtell 1995). It was also shown that *A. diaperinus* increases food intake in rats (Miguéns-Gómez et al., 2020). However, to our knowledge no

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Table 1. Compositional data of *Alphitobius diaperinus* larvae and soybean meal.

	Alphitobius diaperinus[a]	*Alphitobius diaperinus* meal (ADM)[b]	Soybean meal (48% CP)[c]
Dry matter (g/100 g)	30.0–35.5	94.9	
Crude protein (g/100 g DM)	58.0–64.8	57.7	56.3
Crude lipid (g/100 g DM)	13.4–29.0	26.3	
Lysine (g/kg DM)	35.4–42.1	37.5	30
Methionine + Cystein (g/kg DM)	15.5	14.6	13.3
Threonine (g/kg DM)	22.6–26.0	22.4	18.1
Tryptophan (g/kg DM)	7	5.8	6.34
SFA (% of total fatty acids)	27.6–40.6	34.2	
MUFA (% of total fatty acids)	21.3–44.9	32.5	
PUFA (% of total fatty acids)	18.5–40.8	33.2	

[a]Adámková et al. (2016); Bosch et al. (2014); Tzompa-Sosa et al. (2014); van Broekhoven et al. (2015); Yi et al. (2013).
[b]AGROLAB, 2021, analytical results.
[c]Feedbase 2022, https://www.feedbase.ch

pig-feeding experiment with *A. diaperinus* has been conducted so far. Furthermore, data on the sensory perception of meat from animals fed insects are rare (Dalle Zotte, 2021). Only one study using partly defatted *Hermetia illucens* meal in pig feed has been reported, showing a higher odor intensity and juiciness compared with the meat of control animals (Altmann et al., 2019). Here we report the effects of using an *A. diaperinus* meal as protein compound in pig feed, aimed to replace soybean meal, on fattening performance and meat quality including the sensory perception.

Animals, material and methods

In order to evaluate effects of increasing amounts of ADM, replacing soybean meal as protein concentrate in pig feed, a feeding experiment was performed at the Swiss pig performance testing station (Suisag, https://www.suisag.ch/; approval of the veterinary authority in Lucerne, Switzerland no. LU 06/2021, 33809).

Animals

A total of 48 piglets, always four out of 12 litters, were allocated to four treatments, balanced according to litter, sex, and weight (Table 2). Thus, twelve animals were housed per pen and feeder. The animals originated from eight sires, three Swiss Large White, sire line (LW-S), three Duroc, and two Piétrain, mated to Swiss Landrace x Swiss Large White crossbred sows. All animals came from private pig producers affiliated to the Swiss pig breeding program of Suisag, were individually tagged and furnished with a transponder to record the individual feed intake.

Diets

In the experimental diets soybean meal was replaced at increasing amounts with a meal made from *Alphitobius diaperinus* larvae (ADM). The ADM used contained 59.6 g/100 g Protein and 28.7 g/100 g fat of which 31% were polyunsaturated fatty acids (PUFA; Table 1), mainly linoleic acid (28.9% 18:2n-6). The control diet contained no ADM while 3, 6 and 9% ADM were added to the three experimental diets. With the highest amount of ADM, soybean meal could be completely replaced (Table 3). The free amino acids lysine, threonine, methionine, tryptophan, valine, and isoleucine were added to meet the amino acid requirements. By adding appropriate amounts of animal fat (RS 65; a mix of beef and pork fat) the fat in the ADM was compensated for in order to achieve similar nutrient contents in all diets. The fatty acid composition of the diets, however, changed according to the composition of the fat sources. Feed samples were taken directly from the feeders four times during the fattening phase. The four samples per treatment were pooled and analysed at the

Table 2. Allocation of the animals to the experimental groups according to breed, sex, and live weight.

		Feeding treatment[a]			
		9%	6%	3%	0%
n		12	12	11	12
sire breed	Duroc	4	4	3[b]	4
	LW-S[c]	4	4	4	4
	Piétrain	4	4	4	4
sex	female	6	6	6	6
	barrow	6	6	5	6
live weight (kg)		25.8 ± 3.8	26.0 ± 3.8	26.2 ± 4.2	26.1 ± 3.7

[a]amount of *Alphitobius diaperinus* meal in the diet.
[b]one animal has been excluded due to health problems.
[c]LW-S: Large White-Sire line.

Table 3. Composition of the experimental diets (g/100 g).

	Feeding treatment			
	9%	6%	3%	0%
Item				
Alphitobius diaperinus meal	9	6	3	0
Soybean meal	0	4.0	7.5	10.7
Barley	30.0	28.4	28.0	28.0
Rice	16.0	16.0	16.0	16.0
Wheat	16.0	16.0	16.0	14.5
Corn	13.0	13.0	12.2	12.0
Wheat bran	7.4	7.3	7.3	7.7
Molasses	3.0	3.0	3.0	3.0
Animal fat RS 65[a]	0.2	0.9	1.5	2.6
Oat bran	1.6	1.6	1.6	1.6
Diatomite	0.7	0.7	0.7	0.7
Amino acids	0.9	0.9	1.0	1.0
Mineral-vitamin mix	2.2	2.2	2.2	2.2
Calculated energy and nutrients				
Digestible energy (MJ/kg)	14.2	14.2	14.2	14.2
Crude protein	14.5	14.5	14.5	14.5
Ether extract	4.8	4.8	4.8	4.8
Crude fibre	4.0	3.9	3.7	3.6
Analysed nutrient content				
Crude protein	14.6	14.6	14.5	14.0
Ether extract	4.9	5.1	5.1	5.2
Crude fibre	4.4	4.4	4.4	4.1
Lysin	0.96	0.90	0.97	0.95
Methionine	0.34	0.30	0.32	0.32
Calcium	0.6	0.57	0.52	0.52
Phosphorus	0.43	0.42	0.41	0.41
Saturated fatty acids	1.16	1.5	1.58	1.74
Monounsaturated fatty acids	1.2	1.48	1.55	1.72
Polyunsaturated fatty acids	1.67	1.68	1.44	1.3

[a]RS 65: Blend of animal fat (cattle and pig) with about 65 g polyunsaturated fatty acids per kg

Agricultural Research Institute LUFA Nord-West (Oldenburg, Germany).

The animals had *ad libitum* access to the feed and the individual feed intake was recorded by the transponder-controlled feeders (Compident MLP II Station, Schauer Agrotronic AG, Schötz, Switzerland). Feed consumption records started when the animals reached 35 kg.

Fattening performance and physico-chemical quality traits

The animals were weighed weekly, every Thursday. They were assigned for slaughter in the following week when they reached a live weight of 102 kg. The animals were slaughtered in five batches together with regular performance testing animals during five consecutive weeks, after transportation over a distance of 12 km, a lairage time of approx. 2 h followed by CO_2-stunning in groups of four animals.

Based on 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 weight gain. 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).

In brief, the lean meat content was measured using an AutoFOM III (Frontmatec, Kolding, Denmark). The pH measurements were carried out 90 min and 24 h p.m. in the loin muscle (*L. thoracis*, LT) and *M. semimembranosus* (SM) of the left carcass side, using a pH-Star device (Matthäus, Eckelsheim, Germany) calibrated with pH 4.01 and 7.00 buffer solutions (InLab Solution, Mettler Toledo, Greifensee, Switzerland) at 20 °C.

The left carcass side was cut between the second and third last rib at a right angle to the spine 24 h p.m. Meat brightness and pigment content were measured with a CM-2500d Spectrophotometer with 8 mm aperture and using D65 light source and 10° observer (Konica Minolta, Sensing Europe B.V., Swiss Branch, Dietikon, Switzerland). The measurement was performed at three points over the cross section of the LT after 20 min of blooming. Meat brightness is given as L^*-value, pigment content was estimated from the difference in absorption at 525 and 730 nm (Lindahl, 2005).

A picture of the cross-section was taken with a digital camera (Canon Ixus 130) to measure the loin muscle area as well as the backfat area using the ScanStar program (Matthäus, Eckelsheim, Germany). A piece of the loin, three ribs cranial of 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 using a NIR-FIex N-500 (Büchi, Flawil, Switzerland). The drip loss (DL) was determined in a piece of 80-85 g cut from a 3-cm-thick slice of LT and suspended in a plastic bag for 48 h at 2 °C.

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

The cooked meat sample was kept deep-frozen until defrosted at 20 °C for the shear force measurement. Thus, the meat had not been frozen before cooking, which turned out to give the most reliable results for cook loss in a previous study (Scheeder and Müller Richli 2017). Four cores (1.3 cm in diameter) were drilled out in the direction of the fibers. Shear force was measured by cutting perpendicular to the muscle fibers using a texture analyzer (Nexygen plus 3, Lloyd instruments) equipped with a modified Warner-Bratzler shear force cell. The blade speed was set to 120 mm/min.

The proportion of mono- and polyunsaturated fatty acids (MUFA, PUFA) in the backfat overlaying the LT was determined using the NIR-Flex N-500. 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) and a calibration based on the GC-FID method described below (Müller Richli et al., 2016). In order to get more detailed information on the fatty acid composition, backfat samples of the females and of the castrates within feeding treatment were pooled and analyzed by gas chromatography. After dissolving 150 mg homogenized adipose tissue in 8 ml hexane, an aliquot of 4 ml was taken for transesterification with 2 ml 2N KOH in methanol. The gas-chromatograph used (GC-2010, Shimadzu, Reinach, Switzerland) was equipped with a Supelcowax-10™ column (30 m x 0.32 mm, df 0.25; Sigma-Aldrich, VWR Dietikon, Switzerland). Hydrogen was used as carrier gas with a constant flow of 2.4 ml/min and a split ratio of 50:1. The oven was programmed from 160 °C, held for 1 min., to 200 °C at 20 °C/min., held for 5 min., to 230 °C at 10 °C/min., held fo 5.5 min. followed by a final heating period of 2.5 min. at 250 °C. With this temperature program it was ascertained that remaining cholesterol eluted in the heating phase between samples. The oxidative stability was determined in the pooled samples as induction period with a Rancimat 892 (Metrohm Schweiz AG, Zofingen, Switzerland) at 120 °C and an air flow of 20 l/min.

Sensory analysis

The sensory analysis was performed as duo-trio-test (ISO 10399, 2017) with pan-fried ground meat to identify overall sensory differences between the samples. Lean meat from the shoulder (400 g per animal, 87%) and adipose tissue (60 g per animal, 13%), to ensure a similar fat content and contribution per animal, were pooled per experimental group, mixed, ground, vacuum sealed and kept frozen until used for the sensory evaluation. The ground meat was fried in a Teflon coated pan without additional fat under permanent stirring to avoid browning. The fried meat of the control was served as reference to 36 semi-trained panelists. The samples were kept in a water bath at 58°C until tasting in covered glasses for 5 min to 15 min. The panelists were served with the reference and samples blinded with a randomly generated 3-digit code. The comparisons were randomly assigned across test persons in a forced-choice procedure. Overall, four sensory sessions were held, and all panelists tested samples from all treatments randomly

arranged in the forced choice duo-trio-test. The task of the panelists was to identify the reference samples in a pair of samples consisting of a control sample and a sample of one of the experimental groups.

Statistical analyses

Statistical analyses were performed using the GLM procedure of NCSS (NCSS 2020 Statistical Software. NCSS, LLC. Kaysville, Utah, USA). Three statistical models were applied to analyze 1. the performance traits (daily gain, feed intake and conversion, carcass composition traits) and ImF (Table 4), 2. meat quality (pH-values, colour, drip and cook loss, shear force; Table 5), and 3. fat quality (proportion of MUFA and PUFA; Table 7). All these models comprised feed, sex and sire-breed as fixed effects. The model 1. for the performance traits (excluding carcass weight) and ImF additionally included carcass weight as covariate. In the model 2. for the meat quality traits, slaughter date was included as random factor.

In the model 3. for the proportion of PUFA and MUFA, backfat area was included as covariate, to account for the effect of the amount of fat synthesized on the proportion of PUFA.

Interactions of the fixed effects were included in the models in a first instance. As no significant interactions were found, the interactions were removed to simplify the models for the final runs.

In the Tables 4, 5, and 7 least square means, the standard error of the mean (of the feeding treatments), and the *p*-values for the effects considered in the models are shown. Additionally, preplanned comparisons of the experimental groups with the control group were performed and significant differences are indicated with an asterisk.

The sensory duo-trio test was analyzed using SPSS® 27.0 (SPSS Inc., USA). Data were obtained as correct or incorrect answers and statistically significant differences were identified using binomial distribution at a *p*-value level of <0.05.

Results

Fattening performance and carcass composition

Statistically significant effects of the feed were observed for daily weight gain, feed intake and backfat area, with backfat thickness being borderline significant (Table 4). However, only the daily weight gain of the 3% ADM treatment was significantly different from control. Overall, the variability between ADM treatments was bigger than the difference to the control and no linear dose response effect with increasing amount of ADM in the diet was to be observed.

The expected sex effects were clearly pronounced with higher daily gains and higher fat accretion of the barrows. The effect of the sire breeds was as well as expected with the lowest daily gain but the highest loin muscle area for the Piétrain-progeny.

Meat quality

No feed effects were observed in any of the examined meat quality traits, covering pH, color, water holding capacity and

Table 4. Effect of feeding treatment, sex and sire breed on fattening performance, carcass composition, and intramuscular fat content of pigs fed diets with different amounts of *Alphitobius diaperinus* meal. Least square means, standard error of the mean (SEM), and level of significance (*P*-value) are given.

	Feeding treatment (% ADM)[a]					Sex		Sire breed			*P*-value			
	9	6	3	0	SEM	Female	Barrow	Duroc	LW-S[b]	Piétrain	C.weight[c]	Feed	Sex	Sire breed
n	12	12	11	12		24	23	15	16	16				
Carcass weight, kg	87.2	86.5	86.3	86.5	0.95	85.9	87.3	86.8	86.2	86.9	-	0.934	0.331	0.670
Daily gain, g/d	1081	1005	1111*	1034	21.56	1024	1091	1135	1042	997	0.000	0.000	0.005	0.000
Feed conversion, kg/kg	2.41	2.34	2.36	2.41	0.04	2.29	2.48	2.38	2.34	2.42	0.317	0.510	0.006	0.409
Feed intake, kg/d	2.61	2.35	2.62	2.49	0.06	2.34	2.69	2.70	2.44	2.42	0.070	0.002	0.000	0.001
Lean meat content, %	57.7	58.9	57.5	57.8	0.45	59.5	56.4	56.5	58.6	58.8	0.126	0.127	0.000	0.002
Loin muscle area, cm^2	46.9	48.6	46.9	47.0	1.18	48.2	46.5	45.4	46.4	50.3	0.004	0.631	0.319	0.003
Backfat area, cm^2	15.3	13.4	15.7	15.6	0.73	13.4	16.6	15.9	14.0	15.2	0.000	0.027	0.001	0.217
Backfat thickness, cm^2	1.11	0.94	1.15	1.11	0.06	0.92	1.23	1.17	0.99	1.06	0.003	0.051	0.001	0.186
Intramuscular fat content, %	2.28	1.78	1.85	1.98	0.21	1.75	2.19	2.12	2.10	1.69	0.674	0.430	0.217	0.242

[a]ADM: *Alphitobius diaperinus* meal.
[b]LW-S: Large White sire-line.
[c]C.weight: carcass weight as covariate.
*-significantly different from control (0% ADM.)

Table 5. Effect of feeding treatment, sex and sire breed on meat quality traits of pigs fed diets with different amounts of *Alphitobius diaperinus* meal. Least square means, standard error of the mean (SEM), and level of significance (*P*-value) are given.

	Feeding treatment (% ADM) [a]					Sex		Sire breed			*P*-value			
	9	6	3	0	SEM	Female	Barrow	Duroc	LW-S [b]	Piétrain	Feed	Sex	Sire breed	Kill date
n	12	12	11	12		24	23	15	16	16				
pH 90′ *p*.m, LD	6.26	6.33	6.34	6.15	0.067	6.31	6.23	6.30	6.34	6.17	0.134	0.162	0.088	0.010
pH 90′ *p*.m, SM	6.05	5.99	6.10	6.02	0.054	6.07	6.00	6.07	6.14	5.91	0.564	0.155	0.002	0.018
pH 24 h *p*.m. LD	5.39	5.34	5.32	5.37	0.024	5.32	5.38	5.34	5.35	5.38	0.189	0.015	0.511	0.070
pH 24 h *p*.m. SM	5.43	5.47	5.46	5.47	0.023	5.45	5.46	5.46	5.48	5.43	0.497	0.484	0.171	0.000
Brightness [*L**]	51.0	50.1	51.8	51.0	0.611	51.0	50.9	51.8	50.6	50.5	0.347	0.900	0.271	0.101
Pigment content	0.86	0.86	0.83	0.89	0.040	0.84	0.88	0.79	0.89	0.90	0.715	0.203	0.112	0.010
Driploss [%]	3.82	4.59	4.13	4.66	0.518	4.27	4.33	4.00	3.82	5.07	0.760	0.916	0.177	0.838
Cookloss [%]	28.1	29.1	28.5	29.4	0.403	28.9	28.7	28.3	29.3	28.8	0.101	0.492	0.147	0.009
Shear force [N]	34.7	37.5	34.1	38.9	1.590	39.2	33.4	35.6	36.1	37.2	0.200	0.001	0.746	0.106

[a]ADM: *Alphitobius diaperinus* meal.
[b]LW-S: Large White sire-line.

Table 6. Identification of the control sample in a sensory duo-trio-test of ground meat from pigs fed diets with different amounts of *Alphitobius diaperinus* meal.

	Feeding treatment (% ADM)[a]		
	9	6	3
n (panelists)	36	36	36
Correct	20	19	23
Incorrect	16	17	13
p-value	0.617	0.868	0.134

[a]ADM: *Alphitobius diaperinus* meal.

shear force (Table 5). The breed effects, however, were again as expected with the lowest early p.m. pH and highest, though not significant, driploss for the heavy muscled Piétrain-progeny.

In the sensory analysis the panelists were not able to identify the control sample, which served as reference, in a pair of unknown samples to a significant extent. Thus, the sensory analysis revealed no significant differences between the control and any of the ADM treatments (Table 6).

Backfat composition

According to the high PUFA content in the ADM, the proportion of PUFA in the backfat was highest in the 6 and 9% ADM treatments, significantly different from control (Table 7). Vice versa the proportion of MUFA linearly declined with increasing amount of ADM in the feed. With all ADM-treatments being significantly different from control. The detailed analysis of the fatty acid composition in the pooled samples confirmed these findings and additionally showed the higher proportion of SFA and the lower proportion of PUFA and concomitantly lower iodine value in the backfat of barrows compared with females (Table 8). The n-6/n-3-ratio was above ten in all treatments, which well reflects the predominant role of the n-6 fatty acid linoleic acid in the PUFA-fraction of the diets. The Induction period, a measure of the oxidative stability of the fat, however, did not correlate with the proportion of PUFA in the backfat.

Discussion

The fact that the fattening performance and carcass composition traits of the control group were well within the range covered by the ADM treatments and the lack of a linear relation between these traits and the increasing amount of ADM in the diets indicates that ADM in the diet did not cause any detrimental effects of on the performance of the animals. It should be mentioned that in the 6% ADM-group five out of the 12 animals had to be treated due to health problems while it was four in the control, two in the 3%, and three in the 9% treatment. Part of the lower performance in the 6% ADM-group may therefore be explained by the somewhat lower health status of the animals in this experimental group. This, however, may not be attributed to the administration of ADM as the lowest number of treated animals were observed in the 3% and 9% group. Overall, the fattening performance was well within the range observed in the common performance tests run at the same station. The higher subcutaneous fat layer in growing pigs fed house-fly-larvae instead of fishmeal as reported by Dankwa et al. (2000), may be explained by a higher energy density, as indicated by the higher ether extract in the fly-diet in that experiment.

Table 7. Effect of feeding treatment, sex and sire breed on the fatty acid type composition of the backfat of pigs fed diets with different amounts of *Alphitobius diaperinus* meal. Least square means, standard error of the mean (SEM), and level of significance (*P*-value) are given.

	Feeding treatment (% ADM) [a]				SEM	Sex		Sire breed			*P*-value			
	9	6	3	0		Female	Barrow	Duroc	LW-S [b]	Piétrain	Fat area [c]	Feed	Sex	Sire breed
n	12	12	11	12		24	23	15	16	16				
MUFA[d], %	48.6*	49.2*	50.1*	50.9	0.26	49.7	49.8	48.9	50.0	50.3	0.790	0.000	0.763	0.000
PUFA[e], %	15.6*	15.8*	14.1	13.4	0.36	15.1	14.4	14.3	14.7	15.1	0.018	0.000	0.075	0.148

[a]ADM: *Alphitobius diaperinus* meal.
[b]LW-S: Large White sire-line.
[c]Fat area.-backfat area as covariate.
[d]MUFA-monounsaturated fatty acids.
[e]PUFA-polyunsaturated fatty acids.
*-significantly different from control (0% ADM.).

Table 8. Quality characteristics of the backfat (subcutanous layer, pooled samples) of pigs fed diets with different amounts of *Alphitobius diaperinus* meal.

Sex	Female				Barrow			
Feeding treatment[a]	9%	6%	3%	0%	9%	6%	3%	0%
SFA[b]	33.8	32	34.1	34.3	35.7	36.1	34.8	35.3
MUFA[c]	48	48.7	49.9	50.1	47.8	47.4	50	50.9
PUFA[d]	18.1	19.2	15.8	15.5	16.4	16.4	15.1	13.7
n-6/n-3[e]	12.3	12.9	12.2	11.6	12.4	13.4	12.4	11.9
iodine-value	74.4	77	72.1	71.7	71.2	70.8	70.8	69
induction period	3.8	4.02	3.61	3.89	3.64	3.98	3.89	4.27

[a]proportion of Alphitobius diaperinus meal in the feed.
[b]SFA-saturated fatty acids.
[c]MUFA-monounsaturated fatty acids.
[d]PUFA-polyunsaturated fatty acids.
[e]n-6/n-3 – omega-6:omega-3 ratio.

Similarly, no effect of the ADM in the feed was observed on any of the meat quality traits measured (Table 5). This is well in accordance with the findings of Yu et al. (2019) and could be expected as the protein-related meat quality traits can hardly be affected by the feed composition, once the nutritional requirements are met. Not surprising, the fried ground meat from the ADM-fed animals could not be distinguished from the control by the panelists. Interestingly, the highest, though not significant, discrimination was against the lowest ADM supplementation group, supporting the absence of any dose dependent effect on sensory properties of the meat from ADM-fed pigs. Thus, ADM could be applied as protein source in pig feed up to an amount completely replacing soybean meal without detrimental effects on fattening performance and meat quality.

Regarding the fat quality, however, clear effects of the ADM could be observed. This was expected as the amount of fat in the ADM, of which close to one third are PUFA, predominantly linoleic acid, was high. It is well known that the fat composition of the feed is well reflected in pigs' adipose tissue (Gläser et al., 2002). The PUFA are largely deposited at the expense of MUFA which might be explained by the inhibitory effect of PUFA on the activity of steaoryl-CoA-desaturase (Kouba & Mourot 1998; Kouba et al., 2003). Nevertheless, the increasing amount of PUFA and concomitantly increased iodine number (Table 7) will result in a softer consistency of the lard (Gläser et al., 2004) which is not desirable regarding the fabrication of processed meat products. In Switzerland, pig producers have to face price reductions once the proportion of PUFA exceeds 15.5% (Müller Richli & Scheeder, 2014) which would be the case for the 6 and 9% ADM groups. Under such conditions the fat content and composition of the ADM would limit its use in pig feed and a complete replacement of soybean meal would not be possible. It can be assumed that the fat composition of ADM also depends on the fat composition of the substrate the larvae are fed on, as was shown for other insect species (Rumpold & Schlüter, 2013; van Broekhoven et al., 2015). Thus, the resulting fat quality in the pigs could be controlled to a certain extent already in the production of the larvae ADM is produced from. Another approach would be to decrease the fat content of the ADM. This would also facilitate the calculation and fabrication of the feed but increase the production cost.

Interestingly, the oxidative stability, measured as induction period, was not impaired by the higher proportion of PUFA in the lard of the ADM-fed pigs. Ringseis et al. (2021) did not find differences in TBARS and tocopherols in liver, muscle, or plasma of growing pigs fed diets with 0, 5, or 10% defatted *Tenebrio molitor* larvae meal, nor did they find differences in the activity of the antioxidant enzymes superoxide dismutase and glutathione peroxidase. In this study whole ADM, including the lipids from larvae fed entirely on plant-based feed stocks and plant-based side-streams such as wheat bran and draff, was fed. Wheat bran not only contains a high proportion of PUFA but also tocopherols and further potentially antioxidative compounds (Onipe et al., 2015). It remains matter of conjecture if the - relative to the amount of PUFA - increased oxidative stability could be explained by specific antioxidants in the ADM.

The substrate used to feed insects, will not only affect the composition and thus nutritive value of the insects, but also its potential advantage in terms of sustainability. As long as feedstuffs, which could also be fed directly to farm animals, are used to produce insects, any ecological advantage will be limited, unless the insect products are also consumed directly as food, e.g. as part of meat products (Zhang et al., 2022), or the insect-based feedstuffs have significant net benefits that offset the nutritive losses and emissions that occur during conversion. For example, the applicability of the feedstuffs in animal feed may be limited due to the presence of mycotoxins. The conversion through insects reduces or remove these compounds (Camenzuli et al., 2018; Schrögel & Wätjen 2019). Feeding insects to pigs can also be a feasible approach particularly when they are raised on substrates, which are not suitable as human food or even animal feed. However, to date, substrates fed to insects in the EU have to meet the same requirements as any animal feed (VO (EG) Nr. 1069/2009, Art. 3, Nr. 6; VO (EG) Nr. 1069/2009 und VO (EU) Nr. 142/2011) (EU, 14.11.2009, 25.02.2011). The limitations for this particular approach, however, currently are more of legal than of biological or scientific nature.

Overall, the results of our feeding experiment indicate that meal from *Alphitobius diaperinus* larvae could well replace soybean meal in growing-finishing pig diets without affecting fattening performance, carcass composition or meat quality. Various experiments with the black soldier fly in growing-finishing pig diets show a similar picture (Hong & Kim, 2022). The fat content and composition of the ADM, however, deserves attention, because it directly affects the lipid composition in the adipose tissue of the pigs.

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Author contributions

M. Müller Richli: submission of the approval for animal experiments and supervision of the feeding experiment regarding animal welfare and health aspects; data recording, sampling and part of the meat and fat quality analyses in the feeding experiment.

F. Weinlaender: project development, project management, stakeholder management, permitting process, supply chain management and financial accountability

M. Wallner: conducting of the sensory analysis and statistical analysis of the sensory data

B. Pöllinger-Zierler: conducting of the sensory analysis and statistical analysis of the sensory data

J. Kern: strategic and scientific support in both project development and stakeholder management.

M. Scheeder: Development of the detailed experimental design and supervision of the feeding experiment; contributions to data recording and meat quality analyses; validation of the data and statistical analysis of the feeding experiment.

All authors contributed to the discussion of the results and to writing the manuscript and approved the submitted version.

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