Livestock Science 302 (2025) 105830

Contents lists available at ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

Whole plant silage of vetch in growing-finishing pigs: Effect on growth performance and carcass characteristics, and determination of its apparent total tract digestibility

J. Wiskandt [a,*], K. Aulrich [a], M. Bochnia [b,1], R. Bussemas [a], H. Kluth [b], M.-T. Machner [a], A. Zeyner [b], S. Witten [a]

[a] *Institute of Organic Farming, Johann Heinrich von Thünen Institute, 23847 Westerau, Germany*
[b] *Institute of Agricultural and Nutritional Sciences, Martin-Luther-University Halle-Wittenberg, 06120 Halle (Saale), Germany*

HIGHLIGHTS

- It was studied if whole plant silage of vetch is a contribution to pig diets.
- Vetch silage is a suitable roughage for growing-finishing pigs.
- When compared to triticale straw, vetch silage improves body mass gain of pigs.
- Triticale straw and vetch silage lead to the same carcass characteristics of pigs.
- The digestibility of vetch silage in pigs is comparable to other legume silages.

ARTICLE INFO

Keywords:
Organic farming
Roughage
Silage
Vicia pannonica
Vicia sativa
Vicia villosa

ABSTRACT

A study was conducted to investigate, if 3 different vetch species contribute to the protein supply of growing-finishing pigs while maintaining carcass composition. In a feeding trial with 2 consecutive replications, 140 mixed sex pigs (females and castrates, (Landrace x Large White) × Piétrain)) with an initial body mass of 51.7 ± 6.78 kg were provided with an organic on-farm formulated compound feed for growing-finishing pigs and either triticale straw or a silage derived from 1 of 3 vetch species (*Vicia sativa, Vicia pannonica* and *Vicia villosa*). Experimental unit was individual pig for body mass gain and carcass characteristics and pen (10 pigs) for data related to feed intake. The total tract nutrient digestibility of the vetch species was studied using the difference method with 16 pigs of the same origin in 2 replications with 8 animals each. In each replication 2 animals were subjected to either a control diet or a diet with 1 of the 3 silages. Experimental unit for the digestibility trial was the individual pig. Pigs fed additional silage to a compound feed had a greater average body mass gain and gain:feed in the finishing phase than pigs fed triticale straw as roughage ($P < 0.05$), while total crude protein needed to achieve a kilogram of body mass gain increased ($P < 0.05$). Carcass characteristics were not affected by the type of roughage. The apparent total tract digestibility of organic matter and crude protein ranged from 51 to 66 % and 55 to 70 %, respectively, and did not differ among vetch species. The findings of this study indicate that whole plant silage of vetch serves as a valuable roughage for growing-finishing pigs and contributes to the animals' protein supply.

1. Introduction

Including a forage legume in the diet of pigs can reduce the environmental impact of pork production as well as the feed-food competition (Zira et al., 2023) by supplying energy, crude protein (CP) and amino acids (AA) and reducing compound feed consumption. This was observed with clover-grass silage (Friman et al., 2021; Wallenbeck et al., 2014) and alfalfa silage (Wüstholz et al., 2017). Furthermore,

* Corresponding author.
E-mail address: julika.wiskandt@thuenen.de (J. Wiskandt).
[1] Present address: Saxony-Anhalt Federal Administration Authority, 06118 Halle (Saale), Germany.

https://doi.org/10.1016/j.livsci.2025.105830
Received 3 April 2025; Received in revised form 22 July 2025; Accepted 5 October 2025
Available online 6 October 2025
1871-1413/

roughage serves as enrichment material, fulfils the animals' need for rooting and has a satiating effect (Holinger et al., 2018; Høøk Presto et al., 2009). Different legume species in pure stand, like alfalfa (Nguyen et al., 2022) or red clover (Messinger et al., 2021), or as mixed crops with cereals (Olsen et al., 2000) or grasses (Wallenbeck et al., 2014) are actually used as roughage (fresh, dried or ensiled) for pigs. Their apparent total tract digestibility (TTAD) of organic matter (OM) and of CP is in a range of 50 to 69 % (DLG, 2014; Messinger et al., 2021). To our knowledge there are no existing studies focussing on the use of pure vetch, which has advantages as winter catch crop (Büchi et al., 2015; Toom et al., 2019), as whole plant silage for pigs and its effects on growth performance, slaughter characteristics or meat quality.

Olsen et al. (2000) showed, that a mixed whole crop silage of oats, vetch (*Vicia sativa*) and lupin is a preferable rooting material and serves as enrichment for pigs. However, this study only focused on the behavior of the animals and did not consider the nutritional value. Therefore, no information on the effects on growth performance and carcass characteristics nor on the digestibility of vetch forages is available. Vetch plants of the species *Vicia pannonica, Vicia sativa* and *Vicia villosa* contain high amounts (170 to 229 g/kg) of CP in the whole plant (Rahmati et al., 2012; Parissi et al., 2022) and are promising forage plants. Yet, secondary plant metabolites with antinutritional or toxic effects may restrict their use in the nutrition of monogastric animals, especially after the beginning of pod formation (Enneking, 1994; Farran et al., 2002).

The aim of the present study was to test the growth performance and slaughter characteristics of pigs fed vetch silage. In addition, we aimed to investigate the feed value of vetch silage for growing-finishing pigs based on the TTAD. It was hypothesized, that vetch silage, added to a protein reduced diet, could contribute to the protein supply of growing-finishing pigs without affecting the dressing percentage and lean meat percentage of the carcass. Furthermore, it was hypothesized, that this roughage has digestibility values for growing-finishing pigs comparable to other whole plant silages. For this purpose, a feeding and a digestibility trial with three different vetch species (*V. sativa, V. pannonica* and *V. villosa*) took place.

2. Material and methods

All animals used in this study were bred using crossover sows of Norwegian Landrace (Topigs Norsvin l-Line) × Norwegian Large White (Topigs Norsvin Z-Line) paired with Piétrain (PIC 408) boars. They were born and raised on the research station of the Thünen Institute of Organic Farming in Northern Germany, which is certified according to EU regulations for organic farming (European Union, 2018). All areas of the pig stalls were littered with triticale straw. Male pigs were surgically castrated within the first days of live. All pigs had access to triticale straw as roughage in racks from birth until trial start. They were weaned at 48 ± 5.1 days of age and afterwards kept in group pens until the formation of the trial groups. A total of 156 pigs from 24 litters were subjected to the digestibility and feeding trial.

In the trial, three different vetch species were tested: *V. pannonica* (cv. Beta), *V. sativa* (cv. Carbure), and *V. villosa* (cv. Latigo). The vetches for the trials were sown in August 2021 and harvested in June 2022 with a disc mower (Easy Cut F 320 CR and R 280 CR, Krone, Spelle, Germany). *V. pannonica* and *V. villosa* were at the mid flowering (BBCH 65) and *V. sativa* at the end of the flowering stage (BBCH 69). The plant matter was wilted to a dry matter content (DM) of at least 28 % for optimal ensiling and pressing and then picked up with a loader wagon (Cargos 8500, Claas, Harsewinkel, Germany). Afterwards, the silage additives were added in a feed mixer with one vertical mixing auger (MP 13, SILOKING Mayer Maschinenbau GmbH, Tittmoning, Germany). First, formic acid (10 L/t, Amasil-NA, BASF SE, Ludwigshafen am Rhein, Germany) was added continuously using watering cans to lower the pH value. In a next step, a homofermentative lactic acid bacteria inoculant, comprised of *Lactobacillus plantarum* DSM 8866 and 8862 (Biosil, Dr. Pieper Technologie- und Produktentwicklung GmbH, Wuthenow, Germany) was added using backpack sprayers and mixed in. For this purpose, 1.2 g lactic acid bacteria inoculant were diluted in 1 L water to obtain a concentration of 3.6×10^{11} cfu/g of fresh forage. The material was put on plain ground, picked up with a round baler and pressed in round bales weighing 400 - 600 kg each. The round bales were not opened for at least 90 days. Table 1 shows the analyzed concentrations of crude nutrients and AA in the silages. Further silage characteristics (pH and fermentation acids) can be found in the Supplementary material (Table S1).

2.1. Feeding trial

The feeding trial was conducted under EU regulations for organic farming (European Union, 2018) on the research station, where the pigs were born. The animal trial considered the EU Directive 2010/63/EU (European Union, 2010) and the ARRIVE guidelines and was approved by the local authorities (Schleswig-Holstein Ministry for Energy Transition, Agriculture, Environment, Nature and Digitalization; V242 - 24822/2021). The trial was carried out parallel to the digestibility trial in two consecutive replications (replication 1 and replication 2).

Table 1
Analyzed concentrations of crude nutrients, energy, amino acids and minerals in the roughage fed in the feeding trial.

Item (g/kg dry matter unless stated otherwise)	Silage			Straw
	V. pannonica	*V. sativa*	*V. villosa*	Triticale
Dry matter (g/kg in fresh matter)	296	314	324	916
Crude ash	136	121	147	73
Crude protein	178	205	192	24
Ether extract	19.3	14.8	16.6	5.5
Starch	21.0	79.4	udl[6]	n.a.[7]
Crude fiber	308	219	283	469
aNDFom[1]	450	340	431	837
ADFom[2]	374	269	365	557
Amino acids (g/kg dry matter)				
Lys	8.7	10.4	9.1	n.a.
Met	2.3	2.5	2.4	n.a.
Cys	1.5	1.7	1.7	n.a.
Thr	7.2	8.3	7.6	n.a.
Trp	1.7	2.1	1.4	n.a.
Amino acids (g/100 g crude protein)				
Lys	4.9	5.1	4.7	n.a.
Met	1.3	1.2	1.3	n.a.
Cys	0.8	0.8	0.9	n.a.
Thr	4.0	4.0	4.0	n.a.
Trp	1.0	1.0	0.7	n.a.
Minerals				
Ca	10.6	10.1	10.6	n.a.
P	3.4	3.5	3.7	n.a.
Mg	2.5	2.3	2.0	n.a.
K	33.8	24.7	34.3	n.a.
Na	2.6	2.7	1.7	n.a.
Ca:P	3.2	2.9	2.9	
Secondary plant metabolites				
Vicin	udl	udl	udl	n.a.
Convicin	udl	udl	udl	n.a.
BCA[3]	udl	0.031	udl	n.a.
GCA[4]	udl	0.018	udl	n.a.
Metabolizable energy (MJ/kg)[5]	7.4	9.9	8.6	

[1] aNDFom = amylase-treated neutral detergent fiber on organic matter basis.
[2] ADFom = acid detergent fiber on organic matter basis.
[3] BCA= β-cyanoalanine.
[4] GCA= γ-glutamyl-β-cyanoalanine.
[5] Calculated according to GfE 2006.
[6] udl = under determination limit.
[7] n.a. = not analyzed.

2.2. Animals and housing

Replication 1 included 60 and replication 2 included 80 pigs. With an average age of 70 ± 6.1 days (replication 1: 73 ± 8.2 d, replication 2: 67 ± 1.1 d) and a mean body mass (BM) of 29.2 ± 3.78 kg (replication 1: 29.0 ± 3.39 kg, replication 2: 29.4 ± 4.07 kg) pigs of both sexes, female and castrated males, were evenly distributed based on sex and BM among pens. In each of the pens (6 in replication 1 and 8 in replication 2) 10 pigs were housed. The stables had solid concrete floors with straw bedding and were not heated. To prevent cold stress, pigs were offered covered and littered resting areas, which were closed with curtains to provide a microclimate. Every pen had access to an outdoor run with a roughage rack and a bowl drinker. The total indoor area of each pen was 13.6 m^2 and the outdoor area 11.05 m^2. Compound feed was offered in a trough (Length: 4 m) with an animal-to-place ratio of 1:1. Detailed information on housing arrangements can be found in Höne et al. (2023).

2.3. Dietary treatments and experimental diets

All treatments received the same amount (according to mean BM) of the same compound feed per animal and day. The silages in the treatments were fed additionally, while the control treatment received triticale straw as roughage.

The feeding trial was conducted in three phases, habituation phase (29 to 49.5 kg BM), growing phase (50 to 74.5 kg BM) and finishing phase (75 to 121 kg BM) with habituation phase not belonging to the trial, but being used to ensure familiarization with the housing and other animals. The pigs were fed a pelleted compound feed with the amount following a feeding curve. The allowance was adjusted every week based on the mean BM of the animals in each pen according to a feeding curve (Supplementary material Table S2). Because no official supply recommendations for pigs under the conditions of organic farming (outdoor climate, more movement, lower performance goals) are existing, different supply recommendations were reviewed. The Brazilian supply recommendations use equations, which allow the correction for BM gain (BMG) and ambient temperature and might, therefore, be used in organic farming. The diet was formulated to be low in nitrogen and cover the German (GfE, 2006) as well as the Brazilian (Rostagno et al., 2011) AA and CP supply recommendations for pigs weighing 65 kg for growing phase and 110 kg for finishing phase. We aimed to formulate growing and finishing diets containing 8.2 and 5.7 g standardized ileal digestible lysine/kg DM (equivalent to 9.6 g and 6.7 g total lysine), respectively. The CP concentrations were calculated to be ≤ 176 g/kg DM in the growing and ≤ 134 g/kg DM in the finishing phase. The ingredients and nutrient composition of the compound feed are shown in Table 2. Compound feed was fed two times a day.

With the beginning of the growing phase (> 50 kg mean BM/animal and pen) the pens were allocated to one of the four treatments, which differed in the kind of roughage. The control treatment (CON) was provided triticale straw as roughage. The treatments VP, VS and VV were named after the provided silages derived from *V. pannonica*, *V. sativa* and *V. villosa*, respectively. The VP and VS treatment were included in both replications, while VV was only used in the second replication owing to a production related shortage of this silage. The silage was portioned weekly and the opened round bales as well as the portioned roughage were stored in a cooled container at 1°C. Pigs of the VP, VS and VV treatment were fed 0.9 kg fresh matter (FM) of the respective roughage per animal and day in the growing phase. In the finishing phase, silage quantity was increased to 1.4 kg FM/animal and day. Animals of CON were provided with ad libitum triticale straw, of which remains were removed twice a week. Both, silage and straw, were provided manually in the morning in the racks located in the outdoor run after feeding of the compound feed. Because of allocating of the silage based on FM (0.9 kg FM in growing, 1.4 kg FM in finishing phase), the DM consumption of the different treatments was not the same. In the growing phase, VP received an average amount of 0.28, VS of 0.27 and VV of 0.33 kg DM per animal and day. In the finishing phase VS and VV received averagely 0.45 kg DM, while VP received averagely 0.4 kg DM per animal and day.

Table 2
Ingredients and analyzed chemical composition of the compound feed in the growing and finishing phase of the feeding trial in the two consecutive replications.

Item	Feed in the phases			
	Growing [1]		Finishing [2]	
	Replication 1	Replication 2	Replication 1	Replication 2
Ingredient (g/kg as fed)				
Wheat	100	100	150	150
Barley	200	200	250	340
Oats	272	272	400	400
Peas	200	200	–	–
Field beans	200	200	172	82
Mineral premix [3]	28	28	28	28
Analyzed concentrations (g/kg dry matter unless stated otherwise)				
Dry matter (g/kg in fresh matter)	896	881	890	890
Crude ash	63.1	55.4	53.3	51.7
Crude protein	161	168	138	128
Ether extract	21.4	18.2	18.4	21.3
Starch	505	542	518	564
Sugar	33.7	43.1	26.1	25.0
Crude fiber	70.7	61.4	77.9	57.9
aNDFom[4]	147	155	202	220
ADFom[5]	86.9	80.3	101	79.6
Amino acids (g/kg dry matter)				
Lys	8.8	9.6	6.9	6.3
Met	1.5	1.6	1.6	1.6
Cys	2.9	2.5	2.6	2.4
Thr	5.8	5.9	4.6	4.4
Trp	1.7	1.5	1.2	1.2
Amino acids (g/100 g crude protein)				
Lys	5.5	5.7	5.0	4.9
Met	0.9	1.0	1.2	1.3
Cys	1.8	1.5	1.9	1.9
Thr	3.6	3.5	3.3	3.4
Trp	1.1	0.9	0.9	0.9
Minerals (g/kg dry matter)				
Ca	11.4	8.5	8.4	7.3
P	6.9	6.2	6.1	6.2
Ca:P	1.7	1.4	1.4	1.2
Metabolizable energy (MJ/kg)[6]	13.5	14.0	13.2	14.0

[1] Growing = phase from 50 to 74.9 kg body mass.
[2] Finishing = phase from 75 kg body mass to slaughter.
[3] Detaphos M plus, premix providing the following per kg: 216,000 IU vitamin A, 57,000 IU vitamin D3, 4000 mg vitamin E, 1500 mg Fe (Fe (II) sulphate), 1500 mg Mn (Mn(II) oxide), 400 mg Cu (Cu(II) sulphate), 80 mg Zn (Zn oxide), 50 mg I (Ca iodate, $Ca(IO_3)_2$), 14 mg Se (Na selenite)(H. Wilhelm Schaumann GmbH, Pinneberg, Germany).
[4] aNDFom = amylase-treated neutral detergent fiber on organic matter basis.
[5] ADFom = acid detergent fiber on organic matter basis.
[6] Calculated according to GfE (2008).

2.3.1. Data collection and calculations

During the study, two pigs were withdrawn from the experiment because of lameness. One in replication 1 (from VS treatment, four weeks after begin of the finishing phase) and one in replication 2 (VS, two weeks after begin of the finishing phase). Data from these animals were included in the dataset until the week in which they were removed from the trial.

2.3.2. Growth performance and feed consumption

Pigs were weighed individually each week. Average daily BMG was calculated for each animal by dividing the gain per period by the sum of days in that period. The compound feed offers and refusals were measured daily on a pen basis. Feed consumption (kg DM/kg BMG) was computed pen wise by dividing the sum of feed per phase of each pen by the sum of BMG of the animals in this pen. The CP consumption from compound feed was calculated per pen and period by dividing CP intake from compound feed by BMG. Offered total CP (from compound feed and silage) was calculated as CP from compound feed plus CP concentration of each silage multiplied with silage DM offered per day. Although the results were calculated on a pen basis, they are given as mean per animal of the respective pen.

2.3.3. Carcass composition

The day after a pig reached or surpassed the target live BM of 119 kg it was transported to the nearby slaughterhouse (11 km distance) and stunned electrically. Warm carcass mass was recorded for calculation of dressing percentage. All subsequent measurements were taken on the left half of the carcass. Lean meat percentage was measured with a Fat-O-Meater (FOM S89, SFK systems, Copenhagen, Denmark).

2.3.4. Chemical analysis

A sample of each silage round bale was collected and stored at −20°C until analysis. The compound feed was sampled at the beginning of each phase. Each sample was split to be ground (CT 293 Cyclotec, Foss, Hilleroed, Denmark) either through a 0.5 mm (for analysis of AA and secondary plant metabolites) or a 1.0 mm sieve (for the analysis of crude nutrients). Pooled samples for each silage/mixed feed and phase were created for further analysis. The DM and crude nutrient concentrations were analyzed according to standard procedures of the Association of German Agricultural Analytic and Research Institutes (DM: method 3.1; CP: 4.1.1; crude ash: 8.1; ether extract (EE): 5.1.1 procedure B; starch: 7.2.1; sugar: 7.1.3, VDLUFA, 2012). Fiber fractions were analyzed by filter bag techniques with the digestion instrument ANKOM^{2000} (ANKOM Technology, Macedon, NY, USA) (crude fiber (CF): approved method 6.1.1 (VDLUFA, 2012; Ankom Technology, 2010), ADFom (acid detergent fiber on organic matter basis): Ankom Technology (2010); aNDFom (amylase-treated neutral detergent fiber on organic matter basis): Ankom Technology (2010)). Minerals were analyzed after microwave assisted digestion (method 10.8.1.2; VDLUFA, 2012) by UV–Vis-spectroscopy for phosphorus (method 10.6.1, VDLUFA, 2012) and by atomic absorption spectrometry (CS-AAS contra 300, Analytic Jena GmbH, Jena, Germany) for calcium (method 968.08; AOAC, 2016). Concentrations of AA were analyzed according to Directive (EC) No 152/2009 (European Commission, 2009) regarding sample preparation *via* oxidation and hydrolysis. The subsequent derivatization and high-performance liquid chromatography (HPLC) were performed according to Cohen and Michaud (1993). The detailed description can be found in Witten et al. (2020). Secondary plant metabolites were analyzed as follows: The analysis of the cyanoalanine toxins γ-glutamyl-β-cyano-alanine (GCA) and β-cyanoalanine (BCA) was performed with HPLC and mass spectrometry detection (1260 Infinity, InfinityLab LC/MSD, Agilent Technologies GmbH, Waldbronn, Germany) according to Thavarajah et al. (2012). The separation was carried out on a core shell column (C18-Kinetex 5 μm XB-C18,150 × 4.6 mm, Phenomenex, Aschaffenburg, Germany). Pyrimidine glycosides vicine and convicine were analyzed after separation on a core shell column (C18-Kinetex 5 μm XB-C18,150 × 4.6 mm, Phenomenex, Aschaffenburg, Germany) using HPLC and detection via diode array detection (1260 DAD, 1260 InfinityII, Agilent Technologies GmbH), according to Pulkkinen et al. (2015). The metabolizable energy (ME) in the compound feed was calculated according to the formula of the GfE (GfE, 2008). However, the CP concentration of the compound feed used in the finishing phase was lower than proposed by the limitations of this formula. Thus, the interpretation of the energy value for this phase needs to be considered carefully.

2.3.5. Statistics

The statistical analyses were performed in R 4.2.3 (R Core Team, 2024) using linear and linear mixed models with the packages lmerTest and emmeans (Kuznetsova et al., 2017; Lenth, 2024). The BM and slaughter traits were analyzed with individual pig as experimental unit while feed and CP consumption were analyzed pen wise. The results are presented as estimated marginal means (EMmeans), formerly known as least square means (LSmeans). Group differences were evaluated with the package multcomp (Hothorn et al., 2008) as multiple comparisons with sidak *P*-value adjustment and the statistical significance level was set as $P< 0.05$. For performance parameters (BMG, trial duration) the model included the fixed effects treatment, replication and sex and BM at the start of the respective period as covariable. The mother was included as random variable. Interactions were not significant and therefore excluded from the model. Dressing percentage was estimated using following formula:

$$Y = \mu + \text{treatment} + \text{carcass weight} + \text{sex} + \text{replication} + (1|\text{sow}).$$

Lean meat percentage was calculated with the same formula, incorporating the animal's age as an additional covariate. Pen was tested as random variable in all of the models, but excluded, because no effect was observed.

The compound feed and CP consumption were estimated using a linear model:

$$Y = \mu + \text{treatment} + \text{replication} + \varepsilon, \text{ with } Y = \text{pen as target variable}.$$

2.4. Digestibility trial

The digestibility trial was conducted on the research station of the Martin-Luther-University Halle-Wittenberg under the supervision of the animal welfare officer, who ensured the compliance with the EU Directive 2010/63/EU (European Union, 2010) and the ARRIVE guidelines. The sacrifice of the pigs was registered under the number H1–5 / T1–22. The digestibility trial was carried out parallel to the feeding trial also in two consecutive replications (replication 1 and replication 2). The TTAD of the silages was assessed according to the difference method, whereby the silages were fed as test components proportionally in combination with a basic mixture containing acid-insoluble ash as an indigestible marker (GfE, 2005).

2.5. Animals and housing

For each replication, 8 castrated male pigs weighing 58.4 ± 6.9 kg in the first replication and 52.4 ± 4.8 kg in the second replication were transported from the research station in Trenthorst to the research facility (Agrar- und Ernährungswissenschaftliches Versuchszentrum of the Martin Luther University Halle-Wittenberg in Merbitz, Germany), where the digestibility trial took place. The pigs were adapted to vetch silage two weeks prior to the relocation. In Merbitz, the pigs were housed in pairs in enriched pens of 2.0 × 2.4 m on slatted floors and provided chains, teething rings and balls as well as chopped straw in hanging racks (the latter with exception of the feces collection period). At mealtimes only, the pigs housed in pairs were separated by a mobile partition. Each pig had its own trough and nipple drinker.

2.5.1. Dietary treatments and experimental diets

The silages used in the feeding trial were also tested in the digestibility trial. The chemical analysis of the specific bales tested in the digestibility trial can be found Table 3. With the first pig transport, silage bales were also transported to the research facility, weighed into plastic bags containing the daily required silage amount per animal, stored at −20°C and thawed on the day before feeding. During each of the two replications, the 8 pigs per replication were allocated to four diets (diet 1: basal mixture only; diets 2 to 4: proportional basal mixture, supplemented with one of the three silages each). Thus, the digestibility of each silage was determined on four pigs using the difference method. The composition of the basal diet is given in Table 4. As a marker, 3 % of silica (Sipernat, Evonik, Essen, Germany) were added to the diet. Each feeding time, the basal diet was given first, followed by the silage. To avoid losses, the respective amount of silage per meal was divided into several smaller portions. It was generally consumed quickly and with great appetite. Only in the first replication two pigs left larger silage residuals (average over five days: 283 g/d, *V. sativa*; 236 g/d, *V. villosa*). The average BMG ranged from 557 (*V. sativa*) to 443 g/d (*V. villosa*) and from 674 (*V. villosa*) to 539 g/d (*V. pannonica*) in replication 1 and 2, respectively. The pigs were supplied with 1.29 kg FM of *V. sativa* (0.323 kg DM), 1.11 kg FM of *V. pannonica* (0.327 kg DM) or 0.91 kg FM of *V. villosa* (0.330 kg DM) per animal and day. Thus, 20 % of the DM of the ration was comprised of silage.

2.5.2. Data collection and calculations

The pigs were weighed on Fridays. The pens were cleaned daily in the mornings. Feces collection for the determination of the TTAD started when the pigs weighed averagely 70.5 ± 8.2 kg and 79.9 ± 4.8 kg in the first and second replication, respectively. After a 5-day adaption period on the trial diet, the freshly deposited feces were collected individually of each pig three to four times a day mainly around feeding time. This period lasted five consecutive days (Monday - Friday) and feces were stored at −20°C before freeze drying at around −85°C. After freeze drying, the samples were stored at room temperature.

The difference procedure for calculating the nutrient digestibility based on an indigestible marker is described by GfE (2005). The following equations were used:

1. TTAD (%) = 100 – 100 × ((marker T_{diet} × $nutrient_{feces}$) / ($indicator_{feces}$ × nutrient T_{diet})), with: T_{diet} = test diet
2. $TTAD_{Tingr}$ (%) = ($TTAD_{Tdiet}$ – $TTAD_{basaldiet}$ × (1-a)) / a, with: T_{ingr} = test ingredient and *a* = analyzed nutrient concentration in T_{ingr} (g/kgDM) × inclusion rate of T_{ingr} in T_{diet} (kg/kg, on a DM basis) / analyzed nutrient concentration in T_{diet} (g/kg DM)

Table 3
Analyzed concentrations of crude nutrients, energy, amino acids and minerals in vetch whole plant silage fed in the digestibility trial.

Item (g/kg dry matter unless stated otherwise)	Silage *Vicia pannonica*	*Vicia sativa*	*Vicia villosa*
Dry matter (g/kg in fresh matter)	295	250	363
Crude ash	141	127	154
Crude protein	169	211	194
Ether extract	20	20	22
Starch	32	80	23
Crude fiber	305	211	194
aNDFom[1]	434	324	424
ADFom[2]	392	271	372
ADL[3]	79	67	87
Lignification (%)[4]	20.2	24.7	23.4
Acid insoluble ash	18.5	20.0	24.2
Minerals			
Ca	11.2	10.9	11.1
P	3.6	3.7	3.6
Mg	2.5	2.4	2.0
K	36.0	26.9	34.0
Na	1.9	2.6	1.7
Trace elements (mg/kg)			
Zn	47	42	58
Mn	35	33	44
Cu	8	8	9
Fe	851	1,007	1,052
Gross energy (MJ/kg)	17.2	17.7	17.2

[1] aNDFom = amylase-treated neutral detergent fiber on organic matter basis.
[2] ADFom = acid detergent fiber on organic matter basis.
[3] ADL = acid detergent lignin.
[4] Calculated as 100 ADL/ADFom.

Table 4
Analyzed chemical composition of the basal diet[1] used in the digestibility trial.

Item (g/kg dry matter unless stated otherwise)	Basal diet
Dry matter (g/kg in fresh matter)	917
Crude ash	60
Acid insoluble ash	10.6
Crude protein	164
Ether extract	30
Starch	447
Crude fiber	55
aNDFom[2]	173
ADFom[3]	73
Amino acids	
Lys	9.5
Met	2.9
Cys	3.1
Thr	6.4
Trp	2.1
Minerals	
Ca	8.1
P	5.4
Gross energy (MJ/kg)	18.1

[1] Diet consisting of barley, triticale, rapeseed meal, wheat, steam-treated soybean meal from dehulled seeds, wheat bran, calcium carbonate, soybean oil, monocalcium phosphate, and sodium chloride, providing the following per kg: 6500 IU vitamin A, 813 IU vitamin D3, 26 mg vitamin E, 64 mg Fe (Fe (II) sulfate monohydrate), 41 mg Mn (Mn(II) oxide), 71 mg Zn (Zn oxide), 0.55 mg I (Ca iodate; $Ca(IO_3)_2$), 0.26 mg Se (Na selenite)(Mischfutter und Landhandel GmbH, Südliches Anhalt, Germany).
[2] aNDFom = amylase-treated neutral detergent fiber on organic matter basis.
[3] ADFom = acid detergent fiber on organic matter basis.

2.5.3. Chemical analysis

Samples were taken of the silages and compound feed and freeze-dried. For chemical analyses the freeze-dried feed and feces samples were ground to pass a 1 mm screen. Feed and feces were analyzed for DM and crude nutrients according to VDLUFA official methods (Method numbers: DM: 3.1, crude ash: 8.1, CP: 4.1.1, EE: 5.1.1, CF: 6.1.1, aNDFom: 6.5.1, ADFom: 6.5.2, ADL: 6.5.3, CA: 8.1; VDLUFA, 2012). Starch and sugar were analyzed in the feed according to Salomonsson et al. (1984). The concentrations of the marker (acid-insoluble ash), minerals and AA were analyzed according to the VDLUFA methods 8.2, 10.8.1.2 (VDLUFA, 2012) and Rodehutscord et al. (2004). The gross energy content was determined as heat of combustion using an adiabatic bomb calorimeter (C7000, IKA-Werke GmbH & Co. KG, Staufen im Breisgau, Germany).

2.5.4. Statistics

For the statistical evaluation the data derived from 3 animals per treatment were used. A one-way analysis of variance was used to evaluate the effect on TTAD of energy, CP, EE, CF, aNDFom and NfE for every single silage (Statistica 9.0 for Windows, StatSoft, 2009). The Tukey HSD test was applied as post hoc test. Results are presented as arithmetic means. The significance level was set at $P < 0.05$.

3. Results

3.1. Feeding trial

3.1.1. Feed consumption

The gain:feed of the compound feed did not differ in the growing phase and was greater in VP, VS and VV compared to CON in the finishing phase ($P< 0.05$). The CP and energy consumption from compound feed did not differ among treatments in the growing phase (Table 5). In the finishing phase, VP, VS and VV had a lower CP and energy consumption from compound feed per kilogram BMG than CON ($P< 0.05$). The CP consumption from the silage ranged from 59 to 75 g/kg BMG in the growing and 84 to 108 g/kg BMG in the finishing phase and differed among the treatments, with VP receiving the least amount of CP from silage per kilogram BMG ($P< 0.05$). Animals of the VP treatment received less energy from silage compared to VS and VV in the growing phase ($P< 0.05$), while in the finishing phase all 3 treatments differed ($P< 0.05$).

3.1.2. Performance of the animals

During the growing phase there was no effect of feeding group on the animals' average daily BMG, which ranged from 812 to 894 g/d. However, the BMG of the pigs in the silage treatments was numerically greater and the duration of the growing phase (time until reaching a medium pen BM of 75 kg) of the pigs was shorter in the silage treatments than in CON ($P< 0.05$). In the finishing phase the BMG of the animals in the VP and VS treatment was increased by about 11 % (91 g/d) compared to the animals in CON, which gained 795 g/d ($P< 0.05$).

3.1.3. Carcass characteristics

The lean meat percentage did not differ among the pigs of the different treatments. The dressing percentage of the animals in the VS treatment was greater than of VV ($P< 0.05$) but no differences among the other treatments occurred (Table 5).

3.2. Digestibility trial

The TTAD of OM, CP, CF, aNDFom and energy did not differ among the vetch whole plant silages (Table 6). However, the digestibility of EE and NfE of the *V. sativa* silage was greater than of the silages of the other vetch species ($P< 0.05$).

4. Discussion

The performance data of the animals in the feeding trial clearly showed, that silage was taken in, was converted into BMG and improved the animals' performance compared to the CON animals. This was confirmed by the results of the digestibility trial. Still, there are some limitations of the feeding trial: While the silage of *V. pannonica* and *V. sativa* was tested in two pens each in two replications of the feeding trial, the silage of *V. villosa* could only be tested in two pens in one

Table 5

Estimated Marginal Means (EMMeans)[1] of growth performance, CP and energy consumption per kilogram body mass gain, as well as carcass characteristics of pigs fed silage made of *Vicia pannonica* (VP), *Vicia sativa* (VS) or *Vicia villosa* (VV) or triticale straw as control (CON) as roughage.

Item	Treatment					
	VP	VS	VV	CON	SEM [11]	*P*-value
Number of pens	4	4	2	4		
Number of animals	40	40 (38[2])	20	40		
Initial body mass (kg) [3, 4]	52.6 ± 6.3	51.6 ± 7.4	51.0 ± 6.4	51.2 ± 6.9		
Final body mass (kg) [3, 4]	121.6 ± 5.9	120.7 ± 4.1	121.2 ± 7.7	121.3 ± 4.0		
Growing phase [5]						
Duration (d) [4]	28.0 [a]	29.8 [b]	30.4 [b]	33.3 [c]	0.5	<0.001
BMG (g/d) [4, 6]	823	831	894	812	27	0.261
Gain:feed (g/kg) [7]	0.405	0.403	0.421	0.382	0.010	0.156
Consumption [5]						
CP[8] (g/kg BMG) from feed[9]	404	406	388	429	10	0.140
CP (g/kg BMG) from silage	59 [a]	67 [b]	75 [c]	–	1	<0.001
ME (MJ/kg BMG) from feed	34.0	34.1	32.7	36.1	0.8	0.142
ME (MJ/kg BMG) from silage	2.5 [a]	3.3 [b]	3.3 [b]	–	0.1	<0.001
Finishing phase [10]						
Duration (d) [4]	53.1 [ab]	52.2 [a]	54.6 [ab]	57.7 [b]	1.4	0.011
BMG (g/d) [4]	886 [b]	886 [b]	845 [ab]	795 [a]	23	<0.001
Gain:feed (g/kg) [7]	0.344 [b]	0.342 [b]	0.336 [b]	0.316 [a]	0.003	<0.001
Consumption [7]						
CP (g/kg BMG) from feed	386 [a]	388 [a]	396 [a]	420 [b]	3	<0.001
CP (g/kg BMG) from silage	8 [a]	108 [b]	103 [b]	–	1	<0.001
ME (MJ/kg BMG) from feed	39.5 [a]	39.8 [a]	40.5 [a]	43.0 [b]	0.3	<0.001
ME (MJ/kg BMG) from silage	3.5 [a]	5.1 [c]	4.6 [b]	–	0.1	<0.001
BMG gowing+finishing (g/d) [4]	855	868	873	814	22	0.119
Carcass characteristics [4]						
Carcass mass (warm, kg)	96.4	96.7	96.0	96.9	0.9	0.912
Dressing percentage (%)	79.3 [ab]	80.0 [b]	79.0 [a]	79.8 [ab]	0.2	0.007
Lean meat percentage (%)	58.2	57.7	58.3	56.9	0.4	0.036

[a-c] Means with different superscript on the same row differ significantly ($P < 0.05$).
[1] Obtained from linear and linear mixed models.
[2] Animals which completed the finishing phase and were included in the carcass characteristics.
[3] Mean and standard deviation.
[4] Experimental unit: individual animal.
[5] Growing = phase from 50 to 74.9 kg body mass.
[6] BMG = body mass gain.
[7] Experimental unit: pen (group).
[8] CP = crude protein.
[9] Feed = compound feed (DM).
[10] Finishing = phase from 75 kg body mass to slaughter.
[11] SEM = pooled standard error.

Table 6
Arithmetic means of apparent total tract digestibility coefficients (TTAD) of crude nutrients and energy of the vetch species *Vicia pannonica* (VP), *V. sativa* (VS) and *V. villosa* (VV) in growing-finishing pigs.

TTAD of	Treatment				
	VP	VS	VV	SEM[1]	*P*-value
Organic matter	0.51	0.66	0.60	0.03	0.194
Crude protein	0.55	0.70	0.65	0.03	0.228
Ether extract	0.75 [b]	0.98 [a]	0.75 [b]	0.04	0.007
Crude fiber	0.43	0.37	0.50	0.03	0.290
aNDFom[2]	0.52	0.51	0.52	0.03	0.995
NfE[3]	0.69 [b]	0.81 [a]	0.72 [b]	0.02	0.014
Gross energy	0.55	0.67	0.61	0.03	0.168

[a,b] Means with different superscript on the same row differ significantly ($P < 0.05$).
[1] SEM = pooled standard error.
[2] aNDFom = amylase-treated neutral detergent fiber on organic matter basis.
[3] NfE = Nitrogen-free extractives.

replication. To our knowledge there is no data published regarding the use of *V. villosa* silage in pig feeding. Thus, the valuable data was evaluated in the dataset together with the data of the other vetch species and corrected for the effect of replication. Because of the poor statistic validity, the results must be interpreted with caution. Moreover, spilling of the silage could not be estimated (as a result of straw bedding) in the feeding trial. Machner et al. (2025) roughly estimated silage intake of the animals in the present study by collecting leftovers in the outdoor runs. They estimated that an average of 71 - 80 % in replication 1 and 65 - 67 % in replication 2 of the *V. sativa* and *V. pannonica* silage (no treatment effect) was taken in by the animals. However, the amount could not be exactly determined and no conclusions can be drawn on possible selection of leaves from stems, which was observed by Wallenbeck et al. (2014). Hence only the silage consumption, and not the conversion, can be discussed.

The used vetch silages can be characterized as protein-rich roughage. The CP concentrations of the tested vetch silages were in the range stated for other leguminous silages (DLG, 2014; Messinger et al., 2021; Pleger et al., 2021; Purwin et al., 2015). Weber et al. (2024) estimated 8.7 MJ ME in alfalfa silage, which is also comparable to our results. While none of the silages in this study contained vicine or convicine, BCA and GCA were detected in *V. sativa* silage in low concentrations. Because of their antinutritive components the feeding of vetch grains can have a negative impact on pigs BMG (Collins et al., 2005). However, the concentration of the investigated secondary plant metabolites in the whole plant are lower than in the grains and ensiling reduces their amount additionally (Aulrich and Böhm, 2023; Enneking 1994; Rizzello et al., 2016). The pigs of the VS treatment in the present study ingested only a medium of 1.0 g BCA and 0.6 g GCA over the whole feeding trial, which is a low amount compared to the amount of 397 g GCA originating out of vetch grains in a study of Collins et al. (2005), when 11.6 g/kg GCA are assumed (Aulrich 2024, pers. communication). It was shown that, in contrast to vetch grains, vetch whole plant silage can be fed without complications.

The additional offer of vetch silage improved the gain:feed and led to a greater compound feed efficiency. This indicates, that the silages contributed to the supply of nutrients of the pigs, which was also stated by Messinger et al. (2022), who found an improved compound feed conversion ratio with 20 to 30 % inclusion of alfalfa silage and Wallenbeck et al. (2014), who replaced 20 % of the CP from compound feed with silage. Despite the varying amount of CP and energy per animal and day, no significant difference in BMG was observed among the vetch treatments. Even if less CP from compound feed was expended in the silage treatments, the total amount of CP per kilogram BMG in these treatments was greater than in CON. Likely this fact is combined with an increased nitrogen excretion of the animal, i.e., an excess of nitrogen in the system with additional silage. However, Friman et al. (2023) determined the volatile nitrogen losses in housing systems with silage offering to be lower than without. Feeding fiber-rich diets leads to a shift from urinal to fecal nitrogen, which tends to have lower gaseous nitrogen losses. In a land- based circular livestock production system, like it is specified in the EU regulation for organic agriculture (European Union, 2018), nitrogen from manure is a valuable fertilizer and is an essential for plant nutrition.

The feeding of roughage can lead to less dressing percentage, which can be explained by a larger or a more filled intestinal tract (Bellof et al., 1998; Friman et al., 2021; Messinger et al., 2022). In the present study this effect could not be observed. This may have been owing to the fact, that all animals had access to straw, either from the racks or from the litter until the transport to the abattoir. A restricted feeding strategy that includes silage during the growing-finishing period can increase the lean meat proportion in the carcass (Hansen et al., 2006; Strudsholm and Hermansen, 2005; Wallenbeck et al., 2014). This is not consistent with observations of Friman et al. (2021) and Wüstholz et al. (2017), who detected no difference in lean meat percentage between pigs fed alfalfa or clover-grass silage compared to those in the control treatments. In the present study, lean meat percentage did not differ among the treatments.

The digestibility trial allowed for precise measurement of roughage intake. The mean values for the digestibility of the respective nutrients show a high scattering. This is owing to the difference method for determining digestibility and should be taken into account when interpreting the results. The level of digestibility was typical for such coarse forages and silages. To our knowledge there are no other studies focusing on the digestibility of vetch whole plant silages in pigs, but there are some studies on other leguminous silages. Pigs have a certain ability to digest fiber-rich feedstuffs, like roughage (Carlson et al., 1999; Jørgensen et al., 2012; Messinger et al., 2021). The feed value of clover-grass forage and silage was found to be depending on the CF concentration (Roth and Reents, 2001). The authors showed, that with increasing plant maturity (from before bud formation to begin of flowering) each percent increased CF decreased the TTAD of OM by 1.11 % and the ME concentration by 0.18 MJ/kg DM (Roth and Reents, 2001). In the present study, the CF concentration was lowest in *V. sativa* silage, followed by *V. villosa* and being highest in *V. pannonica*. Despite this difference, the TTAD of OM did not differ significantly. However, numerically it was highest in *V. sativa*. With an increasing level of NDF in feedstuffs for pigs the digestibility of OM, NDF and ADF decreases (Kanengoni et al., 2002). This can also be found in the comparison of the three vetch species of the present study, where VS with the lowest aNDFom concentrations showed significantly the highest digestibility of EE and NfE and numerically of OM, CP and GE. The low CF digestibility of the *V. sativa* silage may be corresponding with an increased lignification of the fiber.

When interpreting the TTAD of CP, it should be considered that the digestibility of CP measured in feces is of limited value for protein evaluation. The digestibility of CP from the actual test component is corrupted by nitrogen of endogenous origin, which cannot be recorded separately for methodological reasons. The digestible CP is nevertheless included as an independent variable in the equation for estimating the content of ME in pig feed (GfE, 2006). An above-average digestibility of 65 % (*V. villosa*) and 70 % (*V. sativa*) for CP was measured for the silages, which in turn is greater than the value of 50 % recorded for ensiled grass and legume plants in the German feed value tables (DLG, 2014). The standardized ileal digestibility of protein nitrogen is of high importance for monogastric feed evaluation and should be studied further. Renaudeau et al. (2022) estimated the protein nitrogen of red clover silage and alfalfa silage to be digestible by 54.7 and 21.6 %. However, no information for vetch silages is accessible.

The digestibility of NfE from fresh alfalfa decreases with increasing maturity from 75 to 67 % (DLG, 1991), which is in good agreement with the silages from the vetch varieties *V. pannonica* and *V. villosa*. The decrease in NfE digestibility with increasing plant maturity was also described by Roth and Reents (2001) who stated a decrease in TTAD from 68.2 % to 63.8 % from the first to the third cutting stage of clover grass silage. However, despite the most advanced maturity (pod formation) of *V. sativa* in the present study, NfE digestibility was significantly greater.

5. Conclusion

It can be concluded that vetch whole plant silage from different species shows potential as a protein source for growing-finishing pigs. Further research should explore the impact of harvest stages, increased inclusion rates, and its potential to replace conventional protein-rich feed components.

Financial support statement

The project is supported by funds of the Federal Ministry of Agriculture, Food and Regional Identity (BMLEH) based on a decision of the Parliament of the Federal Republic of Germany via the Federal Office for Agriculture and Food (BLE) under the Protein Crop Strategy; Project 2818EPS2019 WickGanz: „Winter vetch as whole plant: Potential as preceding crop to maize and in the feeding of fattening pigs“.

CRediT authorship contribution statement

J. Wiskandt: Writing – original draft, Investigation, Formal analysis, Data curation. **K. Aulrich:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Data curation, Conceptualization. **M. Bochnia:** Methodology, Conceptualization. **R. Bussemas:** Conceptualization. **H. Kluth:** Writing – review & editing, Methodology, Data curation, Conceptualization. **M.-T. Machner:** Investigation, Formal analysis, Data curation. **A. Zeyner:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **S. Witten:** Writing – review & editing, Supervision, Methodology, Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to express our gratitude to the staff at the experimental station of the Thünen Institute of Organic Farming in Westerau for supporting the study and to the Federal Ministry of Food and Agriculture (BMEL) for funding the study.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.livsci.2025.105830.

References

AOAC, 2016. Official Methods of Analysis of AOAC International, 20th ed. AOAC International, Rockville, MD, USA.

Ankom Technology, 2010. Ankom200 Fiber Analyzer Operator's Manual. Ankom Technology, Macedon, NY, USA.

Aulrich, K., Böhm, H., 2023. Chemical composition (main ingredients and anti-nutritional factors) of common vetch (Vicia sativa L.) varieties. In: Fourth International Legume Society Conference ILS4. Granada, Spain, p. 78.

Bellof, G., Gaul, C., Fischer, K., Lindermayer, H., 1998. Der Einsatz von Grassilage in der Schweinemast [The use of grass silage in pig finishing]. Zuechtungskunde 70, 327–388.

Büchi, L., Gebhard, C.-A., Liebisch, F., Sinaj, S., Ramseier, H., Charles, R., 2015. Accumulation of biologically fixed nitrogen by legumes cultivated as cover crops in Switzerland. Plant Soil. 393, 163–175. https://doi.org/10.1007/s11104-015-2476-7.

Carlson, D., Lærke, H.N., Poulsen, H.D., Jørgensen, H., 1999. Roughages for Growing Pigs, with Emphasis on Chemical Composition, Ingestion and Faecal Digestibility. Acta Agr. Scand. A - Anim. Sci. 49, 129–136. https://doi.org/10.1080/090647099424033.

Cohen, S.A., Michaud, D.P., 1993. Synthesis of a fluorescent derivatizing reagent, 6-aminoquinolyl-N-hydroxysuccinimidyl carbamate, and its application for the analysis of hydrolysate amino acids via high-performance liquid chromatography. Anal. Biochem. 211, 279–287. https://doi.org/10.1006/abio.1993.1270.

Collins, C.L., Dunshea, F.R., Henman, D.J., King, R.H., 2005. Evaluation of common vetch (Vicia sativa cv. Morava) for growing pigs. Aust. J. Exp. Agr. 45, 699–703. https://doi.org/10.1071/EA04111.

Core Team, R., R, 2024. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing (version 4.4.0), Vienna, Austria. https://www.R-project.org/.

DLG, 1991. DLG-Futterwerttabellen Schweine [German feed value tables for pigs]. sixth ed. DLG e.V, Frankfurt am Main, Germany.

DLG, 2014. DLG-Futterwerttabelle Schweine [German feed value tables for pigs]. seventh ed. DLG e.V., Frankfurt am Main, Germany.

European Commission, 2009. Commission Regulation (EC) No 152/2009 of 27 January 2009 laying down the methods of sampling and analysis for the official control of feed. Off. J. EU L54/1-L54/130, 26.02.2009.

Enneking, D., 1994. The toxicity of Vicia species and their utilisation as grain legumes. PhD thesis. University of Adelaide, Adelaide, Australia. https://digital.library.adelaide.edu.au/items/642064b3-07a7-4bc5-b7c9-ff60d5bf7aa4.

European Union, 2010. Directive 2010/63/EU of the European Parliament and of the Council of 22 September 2010 on the protection of animals used for scientific purposes 10.2010. https://eur-lex.europa.eu/eli/dir/2010/63/oj/eng. L276/33-L276/79, 20.

European Union, 2018. Regulation 2018/848/EU of the European Parliament and of the Council of 30 th May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007. Off. J. EU L150/1-L150/92, 14.06.2018.

Farran, M.T., Darwish, A.H., Uwayjan, M.G., Sleiman, F.T., Ashkarian, V.M., 2002. Vicine and convicine in common vetch (Vicia sativa) seeds enhance beta-cyanoalanine toxicity in male broiler chicks. Int. J. Toxicol. 21, 201–209. https://doi.org/10.1080/10915810290096333.

Friman, J., Lundh, T., Presto Åkerfeldt, M., 2021. Grass/clover silage for growing/finishing pigs – effect of silage pre-treatment and feeding strategy on growth performance and carcass traits. Acta Agr. Scand. A - Anim. Sci. 70, 151–160. https://doi.org/10.1080/09064702.2021.1993319.

Friman, J., Mjöfors, K., Salomon, E., Presto Åkerfeldt, M., 2023. Feeding silage to fattening pigs – effects on nitrogen utilization and ammonia losses from fresh manure. Acta Agr. Scand. A - Anim. Sci. 72, 111–122. https://doi.org/10.1080/09064702.2023.2225517.

GfE, 2005. Determination of digestibility as the basis for energy evaluation of feedstuffs for pigs. Proc. Soc. Nutr. Physiol. 14, 207–213.

GfE, 2006. Empfehlungen zur Energie- und Nährstoffversorgung von Schweinen [Recommendations for the energy and nutrient supply of pigs]. DLG-Verlag, Frankfurt am Main, Germany.

GfE, 2008. Prediction of Metabolisable Energy of compound feeds for pigs. Proc. Soc. Nutr. Physiol. 17, 199–204.

Hansen, L.L., Claudi-Magnussen, C., Jensen, S.K., Andersen, H.J., 2006. Effect of organic pig production systems on performance and meat quality. Meat. Sci. 74, 605–615. https://doi.org/10.1016/j.meatsci.2006.02.014.

Holinger, M., Früh, B., Stoll, P., Kreuzer, M., Hillmann, E., 2018. Grass silage for growing-finishing pigs in addition to straw bedding: effects on behaviour and gastric health. Livest. Sci. 218, 50–57. https://doi.org/10.1016/j.livsci.2018.10.012.

Höne, U., Krause, E.T., Bussemas, R., Traulsen, I., Schrader, L., 2023. Usage of outdoor runs and defaecation behaviour of fattening pigs. Appl. Anim. Behav. Sci. 258, 105821. https://doi.org/10.1016/j.applanim.2022.105821.

Høøk Presto, M., Algers, B., Persson, E., Andersson, H.K., 2009. Different roughages to organic growing/finishing pigs — Influence on activity behaviour and social interactions. Livest. Sci. 123, 55–62. https://doi.org/10.1016/j.livsci.2008.10.007.

Hothorn, T., Bretz, F., Westfall, P., 2008. Simultaneous inference in general parametric models. Biom. J. 50, 346–363. https://doi.org/10.1002/bimj.200810425.

Jørgensen, H., Carlson, D., Lærke, H.N., 2012. Influence of forage inclusion in the diet on ileal and total tract digestibility. J. Anim. Sci. 90 (Suppl 4), 176–178. https://doi.org/10.2527/jas.53886.

Kanengoni, A.T., Dzama, K., Chimonyo, M., Kusina, J., Maswaure, S.M., 2002. Influence of level of maize cob meal on nutrient digestibility and nitrogen balance in Large White, Mukota and LW × M F1 crossbred pigs. Anim. Sci. 74, 127–134. https://doi.org/10.1017/S1357729800052292.

Kuznetsova, A., Brockhoff, P.B., Christensen, R.H.B., 2017. lmerTest Package: tests in Linear Mixed Effects Models. J. Stat. Softw. 82. https://doi.org/10.18637/jss.v082.i13.

Lenth, R., 2024. emmeans: Estimated Marginal Means, aka Least-Square Means. https://CRAN.R-project.org/package=emmeans.

Machner, M.-T., Aulrich, K., Bussemas, R., Wiskandt, J., Witten, S., 2025. Usage of outdoor run and health aspects of fattening pigs fed whole plant vetch silage or straw as roughage. Appl. Anim. Behav. Sci., 106742 https://doi.org/10.1016/j.applanim.2025.106742.

Messinger, D., Weindl, P.A., Aulrich, K., Pleger, L., Bellof, G., 2022. Growth performance and carcass traits of growing pigs consuming different alfalfa (Medicago sativa) products in organic farming systems. Acta Agric. Scand. – A Anim. Sci. 71, 58–73. https://doi.org/10.1080/09064702.2022.2141309.

Messinger, D., Weindl, P.A., Aulrich, K., Pleger, L., Weindl, P.N., Bellof, G., 2021. Determination of apparent total tract digestibility of nutrients of lucerne (Medicago sativa) and red clover (Trifolium pratense) products in growing pigs. Zuechtungskunde 93, 389–405.

Nguyen, T.T., Chidgey, K.L., Wester, T.J., Morel, P.C.H., 2022. Provision of lucerne in the diet or as a manipulable enrichment material enhances feed efficiency and welfare status for growing-finishing pigs. Livest. Sci. 264, 105065. https://doi.org/10.1016/j.livsci.2022.105065.

Olsen, A.W., Vestergaard, E.M., Dybkjær, L., 2000. Roughage as additional rooting substrates for pigs. Anim. Sci. 70, 451–456. https://doi.org/10.1017/S1357729800051808.

Parissi, Z., Irakli, M., Tigka, E., Papastylianou, P., Dordas, C., Tani, E., Abraham, E.M., Theodoropoulos, A., Kargiotidou, A., Kougiteas, L., Kousta, A., Koskosidis, A., Kostoula, S., Beslemes, D., Vlachostergios, D.N., 2022. Analysis of genotypic and environmental effects on biomass yield, nutritional and antinutritional factors in common vetch. Agronomy 12, 1678. https://doi.org/10.3390/agronomy12071678.

Pleger, L., Weindl, P.N., Weindl, P.A., Carrasco, L.S., Leitao, C., Zhao, M., Aulrich, K., Bellof, G., 2021. Precaecal digestibility of crude protein and amino acids from alfalfa (Medicago sativa) and red clover (Trifolium pratense) leaves and silages in broilers. Anim. Feed Sci. Tech. 275, 114856. https://doi.org/10.1016/j.anifeedsci.2021.114856.

Pulkkinen, M., Gautam, M., Lampi, A.-M., Ollilainen, V., Stoddard, F., Sontag-Strohm, T., Salovaara, H., Piironen, V., 2015. Determination of vicine and convicine from faba bean with an optimized high-performance liquid chromatographic method. Food Res. Int. 76, 168–177. https://doi.org/10.1016/j.foodres.2015.05.031.

Purwin, C., Fijałkowska, M., Wierzbowska, J., Lipiński, K., Fijałkowska, M., Michalski, J. P., Kobzhassarov, T., 2015. Changes in the amino acid composition during the ensiling of lucerne and red clover in round bales. J. Elementol. 20, 965–973. https://doi.org/10.5601/jelem.2015.20.1.863.

Rahmati, T., Azarfar, A., Mahdavi, A., Khademi, K., Fatahnia, F., Shaikhahmadi, H., Darabighane, B., 2012. Chemical composition and forage yield of three Vicia varieties (Vicia spp.) at full blooming stage. Ital. J. Anim. Sci. 11, e57. https://doi.org/10.4081/ijas.2012.e57.

Renaudeau, D., Jensen, S.K., Ambye-Jensen, M., Adler, S., Bani, P., Juncker, E., Stodkilde, L., 2022. Nutritional values of forage-legume-based silages and protein concentrates for growing pigs. Animal. 16, 100572. https://doi.org/10.1016/j.animal.2022.100572.

Rizzello, C.G., Losito, I., Facchini, L., Katina, K., Palmisano, F., Gobbetti, M., Coda, R., 2016. Degradation of vicine, convicine and their aglycones during fermentation of faba bean flour. Sci. Rep. 6, 32452. https://doi.org/10.1038/srep32452.

Rodehutscord, M., Kapocius, M., Timmler, R., Dieckmann, A., 2004. Linear regression approach to study amino acid digestibility in broiler chickens. Br. Poult. Sci. 45, 85–92. https://doi.org/10.1080/00071660410001668905.

Rostagno, H.S., Teixeira Albino, L.F., Donzele, J.L., Gomes, P.C., de Oliveira, R.F., Lopes, D.C., Ferreira, A.S., de Toledo Barreto, S.L., Euclides, R.F., 2011. Brazilian Tables for Poultry and Swine: composition of feedstuffs and nutritional requirements, third ed. Animal Science Department UFV, Viçosa, MG, Brazil.

Roth, F.X., Reents, H.J., 2001. Futterwert von frischem und siliertem Kleegras aus ökologischem Anbau für Mastschweine [Feed value of fresh and ensiled red clover grass for growing pigs from organic farming]. In: Reents, H.J. (Ed.), Von Leitbildern zu Leitlinien. Beiträge zur 6. Wissenschaftstagung Ökologischer Landbau, 6−8. März 2001. Weihenstephan, Verlag Dr. Köster, Berlin, pp. 461–464. https://scholar.google.de/scholar?hl=de&as_sdt=0%2C5&q=Roth%2C+F.X.%2C+Reents%2C+H.J.%2C+2001.+Futterwert+von+frischem+und+siliertem+Kleegras+aus+%C3%B6kologischem+Anbau+f%C3%BCr+Mastschweine+%5BFeed+value+of+fresh+and+ensiled+red+clover+grass+for+growing+pigs+from+organic+farming%5D.+In%3A+Reents%2C+H.J.+%28Ed.%29%2C+Von+Leitbildern+zu+Leitlinien.+Beitr%C3%A4ge+zur+6.+Wissenschaftstagung+%C3%96kologischer+Landbau%2C+6%E2%88%928.+M%C3%A4rz+2001.+Weihenstephan%2C+Verlag+Dr.+K%C3%B6ster%2C+Berlin%2C+pp.+461%E2%80%93464.&btnG=.

Salomonsson, A.C., Theander, O., E, W., 1984. Chemical characterization of some swedish cereal whole meal and bran fractions. Swed. J. Agric. Res. 14, 111–117.

StatSoft, Inc., 2009. Statistica for Windows (Data Analysis Software System), version 9.0. www.statsoft.com. https://www.statsoft.de/en/data-science-applications/tibco-statistica/.

Strudsholm, K., Hermansen, J.E., 2005. Performance and carcass quality of fully or partly outdoor reared pigs in organic production. Livest. Prod. Sci. 96, 261–268. https://doi.org/10.1016/j.livprodsci.2005.02.008.

Thavarajah, P., Thavarajah, D., Premakumara, G.A., Vandenberg, A., 2012. Detection of common vetch (Vicia sativa L.) in Lentil (Lens culinaris L.) using unique chemical fingerprint markers. Food Chem. 135, 2203–2206. https://doi.org/10.1016/j.foodchem.2012.06.124.

Toom, M., Talgre, L., Mäe, A., Tamm, S., Narits, L., Edesi, L., Haljak, M., Lauringson, E., 2019. Selecting winter cover crop species for northern climatic conditions. Biol. Agric. Hortic. 35, 263–274. https://doi.org/10.1080/01448765.2019.1627908.

VDLUFA, 2012. VDLUFA Methodenbuch Band III Die Chemische Untersuchung von Futtermitteln einschl. 1.-8. Ergänzungslieferung [VDLUFA method book volume III The chemical analysis of feedstuffs incl. 1st-8th supplementary delivery]. VDLUFA Verlag, Darmstadt.

Wallenbeck, A., Rundgren, M., Presto, M., 2014. Inclusion of grass/clover silage in diets to growing/finishing pigs – Influence on performance and carcass quality. Acta Agr. Scand. A - Anim. Sci. 64, 145–153. https://doi.org/10.1080/09064702.2015.1006668.

Weber, M.E., Weindl, P., Bellof, G., 2024. Apparent digestibility of crude nutrients from protein-rich lucerne products for growing pigs. Zuechtungskunde 96, 432–444.

Witten, S., Böhm, H., Aulrich, K., 2020. Effect of variety and environment on the contents of crude nutrients and amino acids in organically produced cereal and legume grains. Org. Agric. 10, 199–219. https://doi.org/10.1007/s13165-019-00261-7.

Wüstholz, J., Carrasco, S., Berger, U., Sundrum, A., Bellof, G., 2017. Fattening and slaughtering performance of growing pigs consuming high levels of alfalfa silage (Medicago sativa) in organic pig production. Livest. Sci. 200, 46–52. https://doi.org/10.1016/j.livsci.2017.04.004.

Zira, S., Salomon, E., Åkerfeldt, M., Röös, E., 2023. Environmental consequences of pig production scenarios using biomass from rotational grass-clover leys as feed. Environ. Technol. Innov. 30. https://doi.org/10.1016/j.eti.2023.103068.