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Grass/clover silage for growing/finishing pigs – effect of silage pre-treatment and feeding strategy on growth performance and carcass traits

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ABSTRACT
This study evaluated the influence of feeding strategy and grass/clover silage pre-treatment on pig growth performance and carcass traits. In total, 128 pigs weighing 30–110 kg were fed either a commercial control feed or received silage in a pellet (SP) or in a total mixed ratio (TMR) containing chopped silage (SC) or intensively treated silage (SE). Silage replaced 20% of dietary crude protein content (g/kg). Diet affected weight gain ($P = 0.001$), with pigs fed the SP diet showing best overall growth performance. Pigs fed the SC diet had the lowest weight gain ($P = 0.001$), while pigs fed the SE diet performed similarly to those fed the control diet. Carcass weight and dressing percentage differed between the diets ($P = 0.016$ and $P = 0.018$), but there was no difference in lean meat content ($P = 0.832$). The results show satisfactory growth performance and carcass traits, indicating that silage can replace other protein sources in growing/finishing pig diets.

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Growing/finishing pig; silage; legumes; TMR; growth performance; carcass traits

Introduction

Increasing demand for sustainable animal protein and increasing competition for agricultural land for food production makes it essential to find alternative feed proteins for farm animals (Kim et al., 2019; Stødkilde et al., 2019). One key challenge to enhanced sustainable pig production is finding viable feed sources that have a low environmental impact, can tolerate climate change and meet the nutritional requirements of pigs. Limited access to high-quality feed protein, especially in organic production where synthetic amino acids are banned, has made it necessary to evaluate alternative protein sources for organically reared pigs. Green legumes are high-yielding and their ability to fix atmospheric nitrogen (N) makes them an important component of crop rotations in organic production (Hermansen et al., 2017; Manevski et al., 2018). Interest in using silage from ley crops as a protein source for pigs is increasing due to its possibility for use as a local, year-round protein feed (Kambashi et al., 2014; Kim et al., 2019) and the amino acid composition of grass and clovers are comparable to those of e.g. soybean meal (Hermansen et al., 2017). Despite well-known positive effects of feeding roughage on pig behaviour and welfare (Olsen, 2001; Kallabis & Kaufmann, 2012; Holinger et al., 2018; Presto Åkerfeldt et al., 2019) silage from grasses and clover are seldom used as an ingredient in formulation of pig feed rations. However, silage has potential for use as a protein ingredient in feed rations for growing/finishing pigs (Wallenbeck et al., 2014; Wüstholz et al., 2017; Presto Åkerfeldt et al., 2019). Previous research indicates that feeding technique, type of roughage and pre-treatment of the silage (e.g. mechanical shortening of straw length, minimising the particle size of the silage) strongly influence the capacity of pigs to consume silage (Wallenbeck et al., 2014; Presto Åkerfeldt et al., 2018).

Research on the effects of feeding technique and pre-treatment on the nutritive value of silage is still limited, but studies to date have shown that inclusion of silage in commercial pelleted pig diets does not reduce daily weight gain (DWG) or impair carcass conformation of growing/finishing pigs (Wallenbeck et al., 2014). Feeding pigs intact (whole stem length) and chopped (3–5 cm stem length) silage has been found to reduce DWG, as a result of silage residuals and lower energy intake (Bikker et al., 2014; Wallenbeck et al., 2014). Reducing the particle length to < 0.5 cm by intensive processing in a bioextruder, where the cellulose structure is broken down, increased silage intake and reduced silage residuals, however, bioextrusion did not improve

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silage nutrient digestibility in that study (Presto Åkerfeldt et al., 2018). Wüstholz et al. (2017) concluded that chopped and extruded alfalfa silage can supply pigs with protein, although pigs fed extruded alfalfa silage showed lower growth and poorer carcass performance than pigs fed chopped alfalfa. Studies in which pigs were fed silage mixed with commercial feed as a total mixed ratio (TMR) report high potential of this as a feeding strategy applicable at farm level. Feeding silage in a TMR can prevent the pigs from sorting out feed compounds, but silage structure (straw length, particle size) affects silage intake and the ability of pigs to select more favourable compounds (Bikker et al., 2014; Wallenbeck et al., 2014; Presto Åkerfeldt et al., 2018).

The effect of silage pre-treatment before feeding to pigs needs to be further evaluated in terms of how it affects nutrient utilisation, feed intake and overall pig performance. The aim of this study was thus to evaluate the effects of pre-treatment and inclusion of silage in diets to growing/finishing pigs on pig performance and carcass traits. The starting hypothesis was that reducing the particle size of silage and feeding it as a TMR or pellets increases silage intake by limiting the ability of pigs to exclude less desirable feed components, resulting in comparable growth and carcass performance to that in pigs fed a commercial compound feed.

Material and methods

The study was performed at the pig research facility at the Swedish Livestock Research Centre, Funbo Lövsta, Uppsala, Sweden, during January–May 2020. The study was approved by the Uppsala Ethics Committee on Animal Research (ethics approval number Dnr 5.8.18-14309/2019), which is in compliance with EC Directive 86/609/EEC on animal studies.

Animals and housing

A total of 128 growing/finishing pigs (Swedish Yorkshire × Hampshire) from two production batches in a batch-wise production system with two weeks between batches were included in the study. Each batch (1 and 2) included 64 pigs. At 8 weeks of age, the pigs in each batch were mixed into new groups and allocated to one of eight pens, with eight pigs per pen. The distribution of the pigs was balanced regarding birth litter, sex and birth weight. No siblings were included in the same pen and each pen included four gilts and four male pigs with mean weaning weight 12.3 (±1.42) kg for batch 1 and 13.2 (±1.97) kg for batch 2. The male pigs were immunocastrated with Improvac™, with their first injection at 77 days of age and their second at 105 days. After seven days of acclimatisation to the new group, each group was moved to a new pen at the start of the study. The pigs were then 66 days of age (±1 d) and weighed on average 32 kg (32.5 ± 4.2 kg), and the study continued until slaughter. Pigs were sent to slaughter on three occasions for each batch, at an average live weight (LW) of 115 kg (114.3 ± 6.5 kg) and 150 days of age (147 ± 7.2 d).

The total area of the pen was 11 m^2, with a concrete floor in the feeding and lying area and a slatted dunging area in the back of the pen (1/3 of pen area), giving a floor area of 1.4 m^2 per pig. The pens were divided by metal bars in the dunging area and solid walls in the eating and lying area. A feed through 4.5 m long was provided along the front of the pen and two water nipples were provided in the slatted area. During the study period, the pigs did not have access to straw, but all pens were provided daily with wood shavings as bedding material.

Diets and feeding

Green crop silage

The silage used in the study was from the second cut, harvested in July 2019, of a first-year grass ley with a high proportion of clover. The biomass consisted of a mixture of red clover (*Trifolium pratense*) (10%), white clover (*Trifolium repens*) (5%), timothy (*Phleum pratense*) (50%), meadow fescue (*Festuca pratensis*) (20%) and perennial ryegrass (*Lolium perenne*) (15%). The grass was cut in the field with a forage harvester and chopped to 4–15 mm particle size. During harvesting, a silage additive (ProMyr NT570, Perstorp Holding AB, Malmo, Sweden) was added at a rate of 5 litres per 1000 kg of fresh matter. Using additives to improve silage quality is a standard procedure in conventional production and emerging in organic production, due to increased variation in conditions at harvest. The crop was ensiled in a silage bun, with plastic wrap covering the ground, directly after harvesting.

Dietary treatments

The pigs in each batch were allocated to one of four diets: a control diet with commercial feed for growing/finishing pigs or one of three experimental diets in which silage was mixed with commercial feed as pellets (SP), or fed as part of a TMR as chopped (SC) or intensively treated silage (SE). There were two replicates for each diet and batch, resulting in a total of four pens, i.e. 32 pigs, per diet. In all experimental diets, the same green crop silage was included to replace 20% of the dietary crude protein (CP) content (g/kg).

Formulation of diets and preparation of feed rations

The control diet was a commercial complete feed, optimised according to the nutritional recommendations for growing/finishing pigs, produced at a commercial feed plant (Swedish Agro, Kalmar, Sweden). To produce the feed for the SP diet, silage was sent to a dry feed producer (Genevads Grönfodertork, Laholm, Sweden), where it was heat-dried, pelleted into pure silage pellets and then sent to the commercial feed plant. The pure silage pellets were mixed with commercial feed to produce a pelleted feed with silage inclusion, optimised according to nutritional recommendations for growing/finishing pigs. The TMR consisted of a commercial basal feed mixed with either SC or SE silage. The basal feed for the TMR mixture was optimised to meet the nutritional recommendations for growing/finishing pigs when included in the TMR at a 60:40 ratio and was produced at the same commercial feed plant as the control and SP feeds (Swedish Agro, Kalmar, Sweden). The ingredient composition in the control feed, the SP feed and the basal feed for the TMR diets are shown in Table 1.

Once a week during the study, silage was collected from the silage bun for preparation of daily rations of the SC and SE diets. DM content of the silage was determined to ensure that silage (kg) constituted 40% of the TMR. When collecting silage, half of the total amount of silage was kept intact (chopped 4–15 mm) for the SC diet and the other half was intensively treated in a bioextruder (model MSZ-B15e, LEHMANN Maschinenbau GmbH) for the SE diet. The bioextruder was equipped with rotating double-screws and set at 60% rotation speed to get a structure of 1–3 mm of the silage. The SC and SE silages were then weighed, packed into rations per pen and feeding event, and stored in a chilled container (Cooltainer, Isolett Panelbyggen AB, Uppsala, Sweden) at approximately +4°C until feeding.

Table 1. Ingredient composition (% of ingredients per kg feed), estimated energy content (MJ kg^{-1} DM) and crude protein content (g kg^{-1} DM) of the control feed, the silage pellet feed (SP) and the basal feed for the total mixed ration (TMR) diets.

	Control feed	SP feed	Basal feed
Wheat	43	51.83	30
Barley	25.53	–	–
Rye	–	–	12.69
Field beans	13.38	20.3	20
Peas	–	–	10
Rapeseed meal	12	–	–
Rapeseed	–	–	7.96
Soybean meal	0.95	–	–
Potato protein	–	4.37	5.2
Maize meal	–	–	10
Silage pellet	–	20	–
Limestone	1.11	0.89	0.6
Premix finishing pigs	0.12	0.12	0.22
Estimated energy and crude protein content			
Dry matter, %	87	88	87
Net energy	10.8	10	12.2
Crude protein	184	198	207

Feeding

Feeding was carried out twice daily (morning and afternoon) according to the Swedish nutrient recommendations for growing/finishing pigs, based on the average pen LW. The rearing period was divided into two growing phases with a restricted feeding regimen (Andersson et al., 1997). During growing phase 1, when the pigs had an average LW between 30 and 65 kg, the feed allowances in MJ of NE was 14.5, 18.3, 22.1 and 25.9 at 30, 40, 50 and 60 kg, thus corresponding to an ad libitum feeding strategy, until they reached an average LW of 65.7 (±7.9) kg. During growing phase 2, from 65.7 kg until slaughter, the pigs were provided with a maximum feed ration of 25.9 MJ NE per day. The control and SP diets were fed by an automatic computerised feeding system, while the SE and SC diets were fed manually as a TMR. For the TMR, the silage was mixed with basal feed in a mixer (Syntesi 140, Epox Maskin AB, Sollentuna, Sweden) and the TMR was then transferred by hand to the feed troughs. Silage intake accounted for 20.5% of total dry matter intake (DMI) of the SC and SE diets. Chemical composition and energy value of the control diet, SP diet, the basal feed and TMR as fed is shown in Table 2.

Chemical analyses

Feed samples of the control diet, the SP diet and the basal feed used in the TMR diets were collected at the start of the study. Feed samples of the intact (SC) and intensively treated (SE) silage were collected on four occasions during the study period, frozen (−20°C) and then pooled to one representative sample. All feed samples were freeze-dried, milled through a 1-mm sieve and dried at 103°C for 16 h for determination of DM content. Ash content was determined after combustion at 550°C for 3 h. Nitrogen content was analysed according to Kjeldahl (Nordic Committee on Food Analysis, 1976) using a 2520 Digestor and a Kjeltec 8400 Kjeltec Analyser Unit (FOSS Analytical A/S Hilleröd, Denmark). CP was calculated as N x 6.25. Gross energy (GE) content was measured with an Isoperibol bomb calorimeter (Parr 6300, Parr Instrument Company, Moline, IL, USA). Water-soluble carbohydrates (WSC) content was determined using an enzymatic method (Larsson & Bengtsson, 1983). To analyse the hygiene quality and influence of storage, silage samples were collected and stored for 7 days at +4°C. One sample was

Table 2. Chemical composition (g kg^{-1} DM), energy content (MJ kg^{-1} DM) and amino acid content (% feed) of the control feed, the silage pellet (SP) feed, the basal feed for the total mixed ration (TMR) and the chopped (SC) and intensively treated (SE) silage, and TMR as fed (SC and SE). TMR as fed represents the composition in a 40:60 ratio of silage and basal feed.

	Control feed	SP feed[a]	Basal feed[b]	Chopped silage, SC	Intensively treated silage, SE	TMR as fed SC	TMR as fed SE
Dry matter, %	88	89	88	34	35	66	67
Gross energy	18.3	18.9	19.5	16.7	17.2	18.4	18.6
Net energy[c]	11.0	11.0	11.8	8.1	8.9	10.3	10.6
Crude protein	191	202	205	183	178	196	194
Crude fat	36	51	69	–	–	41	41
Ash	51	59	42	95	97	63	64
Neutral detergent fibre	126	157	117	384	361	224	215
Lysine	0.945	0.890	1.02	0.727	0.690	0.903	0.888
Methonine	0.270	0.247	0.282	0.288	0.269	0.284	0.277
Threonine	0.629	0.713	0.765	0.720	0.684	0.747	0.733
Valine	0.742	0.846	0.857	0.880	0.895	0.866	0.872

[a]Commercial feed + ground silage, mixed and pelleted.
[b]Basal feed optimised for mixing with silage in a TMR.
[c]Estimated according to Lindberg and Andersson (1998), where energy digestibility (dE%) = 94.8 + (− 0.93 × NDF %). Digestible energy (DE) = dE × GE, ME = 0.95 × DE and NE = 0.75 × ME.

taken for analysis on day 1 and a second sample on day 7, and frozen (−20°C) and stored until analysis. The analysis involved squeezing the liquid from the thawed silage and then determining the concentration of volatile fatty acids (VFA), lactic acid, ethanol, formic acid and butandiol using the methods of Andersson and Hedlund (1983). Ammonia-N concentration (% of total-N) was analysed using the flow injection technique according to the manufacturer's instructions (Tecator, Application Note, ASN 50-01/92). Silage pH was measured using a standard pH meter (Metrohm 654 pH meter, Herisau, Switzerland). Amino acids were analysed according to ISO 13903:2005 (Eurofins Agro Testing Sweden, Kristianstad, Sweden).

Measurements and calculations

Feed intake

Average daily feed, energy and protein intake, feed conversion ratio (FCR) and protein conversion ratio (PCR) were recorded pen-wise and presented as mean values per pig. Number of days in the study was recorded separately for growing phase 1, growing phase 2 and the total growth period. FCR was calculated as: Energy intake per kg weight gain = (Mean total energy intake/(Sum of final LW – Sum of initial LW)). PCR was calculated as: Protein intake per kg weight gain = (Mean total protein intake/(Sum of final LW – Sum of initial LW)).

Weighing and carcass assessment

All pigs were weighed at the start of the study, then every second week until an approximate LW of 90 kg and thereafter once a week until slaughter. In each batch, pigs were sent to slaughter on three occasions, with two weeks between the first and second occasion and one week between the second and third occasion. When the pigs reached an average LW of 107.7 kg (107.7 ± 5.5 kg), they were registered for slaughter and sent to the abattoir one week later. Thus, the final LW was calculated as: LW one week prior to slaughter + ADG × 7 days. At slaughter, carcass weight was recorded and lean meat content was determined with the Hennessy Grading Probe (Hennessy Grading Systems, Auckland, New Zealand) (Sather et al., 1991). The dressing percentage was calculated as: ((Carcass weight/Final LW) × 100). Daily growth from start of the study to slaughter was calculated as: (Final LW – Initial LW)/(Days in the study).

Daily lean meat growth was calculated as: (Percentage lean meat content × (Carcass weight – (Initial LW × 0.72))/Days in the study), with a value of 0.72 representing hypothetical dressing percentage at the start (Andersson et al., 2012).

Statistical analyses

Of the 128 pigs that entered the study, five were culled or died during the study period, due to illness unrelated to the study. Data on the culled pigs were excluded from the statistical analysis, and the results are based on 124 pigs for feed consumption and growth parameters and 123 pigs for the carcass parameters. The statistical analyses were performed with SAS, version 9.4 (SAS, 2021). Descriptive statistics were produced using Proc MEANS and the effect of diet was evaluated using Proc MIXED. Pig performance and carcass traits were analysed using a model (with pig as experimental unit) including the fixed effects of diet (SE, SC, SP, control), batch (1 and 2), sex (male and female) and the random effects of pen nested within batch (pens 1–16, 8 pens/batch, i.e. including the effect of the unique pig group) and birth litter nested within the batch. When analysing DWG, initial weight was included as a continuous covariate in growing phase 1 and for the total growth period. Carcass weight was included as a covariate when lean meat content was analysed. For feed, energy and protein intake, FCR and PCR the model included diet (control, SP, SC and SE) and batch (1 and 2) as fixed effects, with pen as the experimental unit. Level of significance was set at $P < 0.05$. All variables were tested for two-way interactions, but interactions were found to be non-significant and therefore excluded from the model. Results are presented as least square means (LS-means) with pooled standard error (SEM) unless otherwise stated.

Results

Feed analysis and feed intake

The feed rations for all four diets were based on the estimated energy content (MJ kg^{-1} feed) optimised by the commercial feed plant (Table 1). Extrusion of the silage resulted in lower CP content and neutral detergent fibre (NDF) content compared with the SC, while DM content and energy value of the silage were not affected by the extrusion process (Table 2). The content of essential amino acids are presented in Table 2.

Throughout the study, the provided feed rations were totally consumed by the pigs in all four treatments. Daily inspections of the silage indicated satisfactory hygiene quality and signs of mould growth were not found at any time. Storage did not influence the hygiene quality of the silage (Table 3). Regarding average daily feed intake, it was found that pigs on the SP diet consumed a higher amount of feed per day, compared with pigs on the control diet in all growing phases (Table 4). The average daily feed intake in pigs fed the SC and SE diets was on average 1.9 kg basal feed and 1.3 kg silage (Table 4).

During growing phase 1, average daily intake of energy (MJ NE) and crude protein (g CP) was higher in pigs fed the SP diet compared to pigs in the control, SC and SE diets ($P = 0.003$ and $P = 0.002$ for energy and protein) (Table 4). Energy intake was similar in growing phase 2 for all diets, except for pigs in the SP and SC diets ($P = 0.02$) and protein intake only differed between pigs on the control and SP diet ($P = 0.01$). The overall average intake of energy and protein was higher in pigs on the SP diet ($P = 0.001$ and 0.001). Pigs on the SE diet had similar energy and protein intake as pigs on the SC and control diets, however, pigs on the control diet had significantly higher energy intake and lower protein intake compared to pigs on the SC diet ($P = 0.003$ and 0.02).

Table 3. Chemical composition and hygiene quality of fresh silage used in the chopped (SC) and intensively treated (SE) silage diets, and of the same silage after one week of storage at 4°C.

	Fresh silage	Silage stored for 1 week
Dry matter %	35	34
Crude protein (CP, g kg^{-1} DM)	183	184
Gross energy (GE, MJ kg^{-1} DM)	16.7	17.4
Water-soluble carbohydrates (g kg^{-1} DM)	118	122
pH	4.22	4.15
Fermentation products, % of dry matter		
Lactic acid	4.7	4.8
Formic acid	1.2	1.2
Acetic acid	0.8	0.9
Propionic acid	0.2	0.2
Butyric acid	< 0.02	<0.02
2,3-butandiol	0.04	0.06
Ethanol	0.1	0.1
Ammonia-nitrogen (% of total nitrogen)	3.3	3.4

Performance

Pigs on the SC and SE diet had lower FCR compared to pigs on the control and SP diet in growing phase 1, however, the difference was not significant ($P = 0.15$). No significant difference in FCR was found in growing phase 2 ($P = 0.99$) or when compared for the overall study period ($P = 0.145$) (Table 4). Overall, PCR was highest in pigs on the SC diet and lowest in pigs on the control diet ($P = 0.001$). Pigs on the SP and SC diets had significantly higher PCR in growing phase 1 than pigs on the control diet ($P = 0.046$ and 0.01), but in growing phase 2 no difference in PCR was found between diets ($P = 0.154$)

Diet had a significant effect on growth performance of the pigs ($P = 0.001$) (Table 5). During growing phase 1 (pig LW 30–60 kg), pigs on the SC and SE diet had significantly lower DWG than pigs on the SP diet ($P = 0.001$ and $P = 0.049$). However, pigs on the SE diet had comparable DWG to pigs on the control diet. Pigs fed the SC diet had the lowest DWG, which also differed from the pigs on the control diet ($P = 0.001$) (Table 5). During growing phase 2 (pig LW 60–110 kg), pigs on the SP diet had higher DWG than pigs on all other diets ($P = 0.001$) (Table 5). This difference was reflected in DWG during the total period, where pigs on the SP diet had the highest DWG and pigs on the SC diet had the lowest ($P = 0.001$) (Table 5). No significant difference in total DWG was found between pigs on the SE and control diets ($P = 0.333$) (Table 5).

Final weight was lowest in pigs on the SC diet (111.5 kg), followed by pigs on the SE, control and SP diets (113.4, 114.7 and 117.7 kg) (Table 5), with a

Table 4. Difference in daily average feed (kg), energy (MJ NE) and protein (g CP) intake between diets (SP = pellet with silage inclusion, SC = Basal feed + chopped silage fed as TMR, SE = Basal feed + intensively treated silage fed as TMR) and effect of diet on feed- and protein conversion ratio (MJ NE kg^{-1} growth and g CP kg^{-1} growth), presented for growing phase 1, 2 and all phases. The results are presented as least square means and pooled standard error (SEM). Level of significance was set at $P < 0.05$.

	Control (N = 32)	SP (N = 30)	SC (N = 31)	SE (N = 31)	*SEM*	$P^{\#}$
Phase 1 30–65 kg						
Days in phase 1	28.5	28.5	28.5	28.5	0.02	0.42
Feed intake	2.52^{a}	2.78^{a}	3.35^{b}	3.35^{b}	0.06	0.001
Energy intake	24.4^{a}	27.2^{b}	23.1^{a}	23.8^{a}	0.85	0.003
Protein intake	423.1^{a}	499.6^{b}	436.3^{a}	434.3^{a}	11.02	0.002
Feed conversion ratio	25.6	28.2	28.6	26.8	0.93	0.15
Protein conversion ratio	443.7^{a}	517.4^{b}	540.2^{b}	490.4^{ab}	17	0.01
Phase 2 65–110 kg						
Days in phase 2	51.7^{ab}	50.2^{b}	55.3^{a}	53.4^{ab}	1.53	0.01
Feed intake	2.40^{a}	2.53^{a}	3.22^{b}	3.22^{b}	0.05	0.001
Energy intake	23.4^{ab}	24.8^{b}	22.2^{a}	22.9^{ab}	0.49	0.02
Protein intake	403.2^{a}	455.4^{b}	420.1^{ab}	417.8^{ab}	9.04	0.01
Feed conversion ratio	21.9	21.7	21.7	21.7	0.48	0.99
Protein conversion ratio	379.2	397.6	410.6	396.5	8.83	0.15
All phases 30–110 kg						
Total days in study	80.2^{ab}	78.7^{a}	83.8^{b}	81.9^{ab}	1.53	0.01
Feed intake	2.43^{a}	2.61^{a}	3.25^{b}	3.25^{b}	0.02	0.001
Energy intake	23.6^{a}	25.6^{c}	22.4^{b}	23.1^{ab}	0.17	0.001
Protein intake	408.2^{b}	469.8^{c}	423.8^{a}	421.1^{ab}	3.03	0.001
Feed conversion ratio	23.0	23.6	23.6	23.1	0.23	0.145
Protein conversion ratio	398.7^{c}	433.8^{ab}	446^{b}	421.8^{a}	4.23	0.001

#Probability: Different superscript letters within rows indicate pairwise differences at $P < 0.05$.

significant difference between pigs on the SC diet and the SP diet (P = 0.05). A similar pattern of differences between diets was found for carcass weight ($P = 0.018$), where pigs on the SC diet differed significantly from pigs on the SP diet ($P = 0.025$) (Table 5). Pigs on the control diet had a higher dressing percentage than pigs on the SC and SE diets ($P = 0.022$ and $P = 0.047$) but a similar value to pigs on the SP diet ($P = 0.10$) (Table 5). Diet did not affect lean meat content (P = 0.832), but had a significant effect on daily lean meat growth ($P = 0.001$), with lower growth among pigs on the SC and SE diets than pigs on the control and SP diets ($P = 0.001$) (Table 5).

No differences were found between batches, but sex influenced some growth traits. Castrates had better DWG in phase 2 (1.14 kg) and in the total period (1.057 kg) than gilts (1.0 kg in phase 2, 0.970 kg in total) ($P = 0.001$) (Table 5). Dressing percentage was 72.2% for castrates and 73.7% for gilts ($P = 0.001$) (Table 5).

Discussion

Silage has the potential to function as an energy and protein supply for growing/finishing pigs, but the capacity of pigs to utilise the nutrients in silage is affected by their age and LW, the structure and nutritive composition of the silage, and the feeding technique (Dierick et al., 1989; Noblet & Henry, 1993; Carlson et al., 1999). The present study evaluated the effect of feeding technique and pre-treatment of the silage on feed intake, growth and carcass traits. The overall

Table 5. Effect of sex and effect of diet (SP = pellet with silage inclusion, SC = Basal feed + chopped silage fed as TMR, SE = Basal feed + intensively treated silage fed as TMR) on weight gain and carcass traits. The results are presented as least square means and pooled standard error (SEM). Level of significance was set at $P < 0.05$.

	Diet						Sex†			
	Control (N = 32)	SP (N = 30)	SC (N = 31)	SE (N = 31)	*SEM*	$P^{\#}$	m	f	*SEM*	$P^{\#}$
Initial weight (kg)	32.7	32.4	32.8	32.5	0.74	0.95	32.9	32.2	0.7	0.217
Final weight (kg)	114.7^{ab}	117.7^{b}	111.5^{a}	113.4^{ab}	1.5	0.014	116.6	112.1	1.02	0.001
Daily weight gain 30–65 kg (g)	952^{bc}	966^{c}	811^{a}	887^{ab}	24.4	0.001	905	904	14	0.956
Daily weight gain 65–110 kg (g)	1064^{a}	1148^{b}	1022^{a}	1054^{a}	19	0.001	1141	1003	17	0.001
Daily weight gain 30–110 kg (g)	1023^{a}	1084^{b}	951^{c}	996^{a}	14.8	0.001	1056	971	11.6	0.001
Carcass weight (kg)	84.6^{bc}	85.3^{b}	81.1^{ac}	82.5^{ab}	1.1	0.018	83.8	82.9	0.95	0.183
Dressing percentage (%)	73.8^{c}	72.8^{bc}	72.5^{ab}	72.7^{ab}	0.41	0.016	72.2	73.7	0.32	0.001
Lean meat content (%)	60.7	60.8	61.5	60.9	0.5	0.832	60.0	61.8	0.26	0.001
Lean meat growth 30–110 (g day^{-1})	465.5^{b}	481.0^{b}	422.2^{a}	442.2^{a}	8.1	0.001	0.460	0.446	0.01	0.01

N = number of pigs in each treatment diet group.
†m = castrated male (immunocastrated with Improvac™), f = gilt.
#Probability: Different superscript letters within rows indicate pairwise differences at $P < 0.05$.

results showed satisfactory growth performance regardless of diet, with DWG ranging from 951 to 1084 g/day, which is in compliance with national (973 g/day) and international (914 g/day) standards on pig growth performance (Gård & Djurhälsan, 2020).

In the present study, silage accounted for an estimated 20.5% of the pigs' total DM intake/day, which is similar to that in other studies, where grass/clover silage has been included at up to 19% of DMI (Bellof et al., 1998; Carlson et al., 1999; Bikker & Binnendijk, 2014; Wüstholz et al., 2017; Presto Åkerfeldt et al., 2018).

To avoid possible silage residuals and compare the effect of the silage intake per se, silage was included in pelleted form (SP diet). In the study by Wallenbeck et al. (2014), pigs fed pelleted feed with silage inclusion (20% on metabolisable energy (ME) basis) consumed all feed and performed similarly to control pigs that did not receive any silage. In the present study, overall performance was similar or improved in pigs fed the SP diet than in pigs on the control diet, despite a lower intake of lysine and methionine. Ingredient composition differed between the SP and control diets, with inclusion of potato protein in the SP diet, which provides a high amount of digestible amino acids. It is conceivable that the improved growth performance was due to higher nutrient digestibility and improved nutrient absorption in the SP diet. Pigs on the SP diet had higher energy and protein intake per day, which might be an additional explanation for the improved performance on the SP diet.

FCR was numerically higher for the silage-fed pigs in growing phase 1. Interestingly, all diets had similar FCR in growing phase 2 and did not differ in general. This indicates that utilisation of the silage increase with age and higher LW. These findings suggest that freshly processed silage with a finer structure and fed as a complete feed can supply nutrients to growing pigs. However, PCR was higher in pigs fed the control diet than in silage-fed pigs. This could be explained by increased passage rate of the digesta and binding of proteins to the fibre in silage, limiting absorption and digestion of proteins in the small intestine (Dierick et al., 1989; Varel & Yen, 1997; Andersson & Lindberg, 1997; Lindberg & Andersson, 1998). It has been suggested that feeding fine-structured silage mixed with commercial feed impedes the ability of pigs to sort out more palatable parts of the feed (Bikker et al., 2014; Presto Åkerfeldt et al., 2018). In the study by Presto Åkerfeldt et al. (2018), feeding chopped (1–3 cm) and intensively treated (<0.5 cm) silage in a TMR resulted in complete or near-complete consumption of silage. The particle size of the SC used in the TMR diets in the present study was even smaller (4–15 mm) than that evaluated in previous research, while the particle size of the intensively treated (SE) silage was similar to that in e.g. Presto Åkerfeldt et al. (2018). The finer structure of the silage and the strategy of feeding a TMR might be the reasons for the improved silage consumption in our study. In the present study, pigs fed a TMR with SC diet had the lowest DWG over the total study period even though they consumed all silage in the diet. However, feeding pigs a TMR with intensively treated silage (SE diet) improved the DWG. The extrusion process might increase the digestibility of nutrients in the silage, which could explain the improved growth performance in pigs on the SE diet compared with pigs on the SC diet. Mechanical reduction of particle size in lupin (*Lupinus angustifolius*) has been shown to increase the digestibility of amino acids in growing pigs, due to improved interaction between digestive enzymes and microbes responsible for digestion of nutrients (Kim et al., 2009). In a study by Acosta et al. (2019), reducing the particle size by milling improved the energy and nutrient digestibility of maize (*Zea mays*). The higher weight gain in pigs fed intensively treated silage (SE) in the present study further indicates that destroying the cell structure and reducing the particle size by extrusion could improve the availability of nutrients, as suggested by Wüstholz et al. (2017). However, in the digestibility study by Presto Åkerfeldt et al. (2018) this could not be proven. Interestingly, the pigs fed a TMR with intensively treated silage (SE diet) had similar weight gain for the whole period as pigs on the control diet, which did not receive any silage.

Silage inclusion in the diet did not affect the leanness of the carcass and lean meat content was similar for all four diets (range 72.5%–73.8%). This supports findings by Wüstholz et al. (2017) and indicates that all pigs were able to consume and utilise sufficient amounts of energy for deposition of adipose tissue, regardless of diet. However, pigs on the SC diet required a longer period to reach slaughter weight. Leaner carcasses in silage-fed pigs have been reported in previous studies (Hansen et al., 2006; Wallenbeck et al., 2014; Hermansen et al., 2017), where they were explained by insufficient energy intake and reduced capability to gain adipose tissue. In accordance with earlier studies, pigs fed silage in the present study had a lower dressing percentage than pigs on the control diet, as reflected by greater size of the gastrointestinal tract and higher gut fill at slaughter (Dierick et al., 1989; Wallenbeck et al., 2014).

With a growing demand for sustainably produced animal protein with high animal welfare standards finding alternative protein sources is important to maintain and improve sustainable pig production (Jakobsen et al., 2015; Hermansen et al., 2017; Damborg et al., 2018; DiGiacomo & Leury, 2019; Kim et al., 2019). Perennial grasses, clovers and legumes have the capacity to increase soil conditions and carbon storage and lower the risk of field N and phosphorus losses compared with annual crops (Aronsson et al., 2007; Franzluebbers & Stuedemann, 2008; Eriksson et al., 2010; Aronsson et al., 2014). Furthermore, ley crops increase biodiversity and reduce pests and weeds (Nemecek et al., 2008; Kambashi et al., 2014).

When replacing other feed ingredients with silage and using it as a source of nutrients, it is essential that the pigs consume all the silage provided, to ensure efficient energy and protein intake. In the present study, all silage provided was consumed, showing that it can replace other ingredients in the diet and supply energy and protein with maintained growth performance of the pigs. The potential of silage as a valuable feed ingredient and enrichment substrate for pig behaviour makes it an interesting option in conventional production systems too, as a strategy for improving the environmental footprint and pig welfare. Lowering the inclusion of imported protein, such as soybean, and using more locally produced feed ingredients could reduce the total environmental impact from feed production, through reduced transport (Cederberg & Flysjö, 2004; Stern et al., 2005). Silage can therefore function as an economically and environmentally sustainable protein ingredient in all pig production (Kim et al., 2019). Further studies are needed to confirm the role of silage production on the environmental impact and overall production economics of conventional and organic pig production.

Conclusions

Feeding silage with finer particle size as part of a TMR can improve silage intake in pigs and prevent them sorting out less desirable parts of the diet. Provided that pigs consume all silage allocated in the feed ration, inclusion of silage at 20% of dietary CP can replace other feed ingredients and supply the pigs with sufficient energy and protein for high performance. A pig feeding strategy involving silage can be an interesting option to increase the proportion of ley crops in a rotation, with benefits for the climate and biodiversity, while also serving as a local year-round nutrient resource and enhancing animal welfare in pig production.

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Disclosure statement

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