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Digestibility, metabolic utilisation and effects on growth and slaughter traits of diets containing whole plant maize silage in heavy pigs

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ABSTRACT
Two experiments were conducted to investigate the inclusion of high cut whole plant corn silage (HCCS) in diets for finishing heavy pigs on digestibility, metabolic utilisation, growth performance and slaughter traits. A control diet (CTR, containing maize meal, barley meal, extracted soybean meal and wheat bran, 550, 250, 90 and 80 g/kg DM, respectively) was compared with diet (CS) containing 200 g/kg DM of HCCS. The HCCS replaced wheat bran and part of maize meal in the CTR diet. In the first experiment, eight barrows were used in a two periods cross over design with periods of 21 d, included 7 d of total collection and three cycles of 24 h each in a respiratory chamber. In the second experiment, 28 barrows were divided into pairs on the basis of BW, kept in 14 pens and fed with the experimental diets until slaughter. Lower DM, OM, CP and energy total tract apparent digestibility was measured for the CS diet. Overall P retention as percentage of P intake was higher for CS diet, while N retention was similar for the two diets. Pigs fed CS tended to have a lower retained energy and the estimated NE of maize silage was 8.47 MJ/kg DM. Pigs fed the CS diets had a lower daily gain, a lower BW at slaughter and a reduction in the weight of back fat. The inclusion of HCCS increased the size of the stomach, the aNDFom concentration of stomach content and reduced the incidence of follicular gastritis.

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Introduction

In Italy pigs are mainly slaughtered at high BW (160–170 kg) for cured ham production (Bosi & Russo 2004). The current feeding system for heavy pigs is based on finely milled mixtures of cereal grains, protein sources and by-products, which ensure high growth rate and efficient feed conversion. However, there may be advantages to modify the diets fed during the last phase of growth (above 80 kg) using on farm ensiled forages. Heavy pigs can digest fibre rather efficiently (Galassi et al. 2005a, 2007, 2010) having a well-developed gut, similarly to sows. In addition, heavy pigs have to moderate the growth rate to ensure an optimal meat quality and this should be obtained using fibrous diets rather than adopting restrict feeding systems, which reduce the sense of satiety of the animals and cause damages to the gastric mucosa (Di Martino et al. 2013; Mason et al. 2013). Finally, on farm ensiled forages are generally cheaper than the dry concentrates and can be produced with less energy expenses (e.g. energy for drying and transport).

A potential on farm forage is whole plant maize silage, which is generally considered too fibrous and coarse for pig diets. In previous studies (Capraro et al. 2014; Zanfi et al. 2014) we demonstrated the potential to use of high levels (up to 400 g/kg of dietary DM) of whole ear corn silage (WECS) in the diets of fattening pigs. Maize silage has a higher fibre content and also a larger average particle size than WECS and a way to improve its nutritional quality is to cut it, at harvest, at a higher height than usual (e.g. high cut whole plant corn silage, HCCS), thus avoiding the basal part of the stalk, which is highly lignified and it is a site of accumulation of nitrates. In the present trial the objectives were to evaluate the digestibility, the balances of P, N and energy, the growth and slaughter traits of heavy pigs fed a diet containing 200 g/kg DM of HCCS in the last fattening phase (above 80 kg of BW). The results can be useful also to implement the accuracy of models aimed at predicting the tissue composition of heavy pigs (Mordenti et al. 2003).

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Material and methods

Maize silage, diets, and planning of the experiments

In two experiments a control diet (CTR, containing maize meal, barley meal, extracted soybean meal and wheat bran, 550, 250, 90 and 80 g/kg DM, respectively) was compared with an experimental diet containing 200 g/kg HCCS on a DM basis (CS). The HCCS replaced the wheat bran and of part of the maize meal in the CTR diet. The HCCS was obtained cutting the plants, at harvest, at an average height of 60 cm from the soil, instead of the classic 20–25 cm. The diets were fed to finishing heavy pigs in a digestibility and metabolic trial (Exp. 1) aimed to determine the coefficient of total tract apparent digestibility (CTTAD) and N, P, and energy balance and in a fattening and slaughter trial (Exp. 2). In both the experiments the same ingredients were used.

All animals of both experiments were Italian Large White × Italian Duroc barrows and were cared for in accordance to the guidelines on animal welfare in animal research of the Italian Legislative decree no. 116/1992 (Italian Ministry of Health 1992).

Digestibility and metabolic trial (Exp. 1)

The two experimental diets were fed to eight barrows, divided into two homogeneous groups, in a 2 × 2 crossover design. Feed was restricted to allow a daily DMI of 63 g/kgBW$^{0.75}$ and pigs were fed at 08:00 and at 18:00 h and had free access to water.

In order to determine CTTAD, and P, N and energy balance, the animals were housed in individual metabolic cages, in two consecutive periods. Each period lasted 21 days and consisted of 14 d of diet adaptation and 7 d of separate collection of excreta (testing period). During each testing period, barrows in the cages were placed individually in an open-circuit respiration chamber described by Crovetto (1984) to measure respiratory exchange over three 24-h cycles. The animals were weighed at the start of the first testing period and at the end of the second testing period (134.2 ± 5.8 and 152.6 ± 5.5 kg BW, respectively).

Heat production (HP) for each animal was calculated from Brouwer's equation (Brouwer 1965):

$$HP(kJ/d) = (16.175\ O_2) + (5.021\ CO_2) - (2.167\ CH_4) - (5.987\ N)$$

where O_2, CO_2 and CH_4 are the volumes (l/d) of the gases at standard temperature (0 °C) and pressure (760 mm Hg) conditions, consumed or produced during respiration and N is the urinary nitrogen (g/d). Heat production includes NE for maintenance and the heat increment for production.

The ME and the NE of the maize silage were predicted from the calorimetric measurements taking into account the corresponding values of maize meal (NRC 2012) and wheat bran (Crovetto et al. 2007) and the NE requirement for maintenance (261 kJ/kg BW$^{0.75}$) reported by Noblet et al. (1993), value that, to our knowledge, is the most appropriate among those found in literature for heavy pigs allocated in individual metabolic cages.

The ME content of the maize silage was computed by two steps as follows:

1. ME other = MECTR diet – (ME maize + ME bran)
2. ME maize silage = MECS diet – (ME maize + ME bran + ME other)

where ME other is the ME content of the other ingredients (included in the same amounts in all diets), MECTR diet is the ME content of CTR diet, ME maize is the ME content of maize meal, ME bran is the ME content of wheat bran, ME maize silage is the ME content of maize silage, and MECS diet is the ME content of CS diet.

For the NE content of maize silage we followed the same procedure considering, instead of ME, the corresponding total NE values of feed ingredients; for the calculation of the total NE of the diets we added the NE for maintenance (NEm) requirement (Noblet et al. 1993) to the NE content for production (NEp = ME – HP) of the diets determined by calorimetric measurements.

The diets were collected daily to determine the DM content after 72 h of drying at 55 °C in a forced ventilation oven. Diet samples were pooled for each period for further analysis. Before feeding, all the remaining feed was removed from the trough, weighed and chemically analysed.

During each testing period, urine was collected individually in a vessel containing 150 ml of a 20% (vol/vol) H_2SO_4 solution to maintain the pH below 2.5 and avoid ammonia loss. Urine was weighed daily, sampled (10% of total weight), pooled per pig and frozen (−20 °C) for subsequent chemical analysis. Individual faces were weighed daily and sampled (20% of total weight), pooled per pig and frozen (−20 °C) for subsequent chemical analysis.

Fattening and slaughter trial (Exp. 2)

Twenty-eight barrows (89.5 ± 4.9 kg BW) were divided into pairs on the basis of BW and kept in 14 partially slatted pens to house 2 barrows (1.2 × 3 m). Pigs had free access to water and each pen was equipped with two separate troughs to avoid competition for feeding.

During an adaptation phase (10 d) pigs received a unique commercial compound feed (Electa; Consorzio Agrario, Udine, Italy), containing mainly maize meal, wheat bran, and soybean meal (155, 44 and 52 g/kg DM of CP, fat and ash, respectively) and supplemented with antibiotics (575 and 200 mg/kg of amoxicillin and colistin, respectively) for 5 days to prevent intestinal disease and subsequently were adapted to the experimental diets (5 d). The individual daily amounts of each experimental diet were prepared daily.

Daily amount of DMI per pig ranged from about 80 to 62 g/kg $BW^{0.75}$ during the whole growth from 90 to 170 kg BW and the diets were distributed in equal portions at 09.00 and 17.00 daily. Pigs were weighed every two weeks to monitor the growth and feed samples were collected at each weighing. The animals were slaughtered at an average BW of 170.9 ± 6.2 kg by electrical stunning and after evisceration, the carcases were weighed. Back fat was measured at 8 cm to the side of the central line of the carcase between the third and the fourth last ribs, using a calliper. The carcases were processed and the weight of the commercial cuts of hams, loins (muscle *Longissimus dorsi*, LD) and back fat were recorded before cooling. Samples of LD muscle were collected and used for the following measures:

- the pH of meat, taken on LD muscle sections by a glass piercing electrode (Crison 52-32) connected to a pH metre at 120 min (pH120) after slaughter;
- the drip loss of meat, measured on cylinders of LD muscle (25-mm diam.) inserted in EZ-Driploss containers (Rasmussen & Andersson 1996) and maintained at 4 °C for 72 h;
- the cooking loss, measured in 5 LD muscle slices (20 mm thickness) by cooking samples in plastic bags until reaching 75° C for 45 min using a water bath (Honikel 1998);
- the maximum shear force, measured on cooked cylinders (20-mm diam.) of LD muscle, using a Warner–Bratzler device with a triangular hole of 60° in the shear blade, mounted on a texture analyser (Lloyd TA Plus; Lloyd Materials Testing, Leicester, UK) at a test speed of 100 mm/min (Honikel 1998);
- the colour values, measured using a spectrophotometer Minolta CM 2600 d (Ramsey, NJ) with a 1 cm aperture, using Standard Illuminant D65 light source and 10 viewing angle geometry (the values recorded included L*, a*, b*, Chroma* and Hue* scores (CIE, 1976), and were taken on 10 points per slice of LD muscle sample).

Subsequently, samples of LD muscle were rapidly frozen and lyophilised (ASPA 1996) for analysis of meat (DM, CP and ash). Fat content (g/kg DM) was calculated by difference: 1000-(CP + Ash), with CP and Ash expressed as g/kg DM.

The stomachs were collected at slaughter and stored at −20 °C. After thawing was manipulated following the procedures described by Mason et al. (2013). Once opened along the greater curvature (curvature ventricles major) the organs were emptied, gently rinsed and weighed. The material in the stomach was sampled and analysed for DM content and neutral detergent fibre assayed with amylase and expressed exclusive of residual ash (amylase NDF organic matter, aNDFom).

Orthogonal photos of the outstretched stomach were taken in the same condition of brightness and the images were used to measure four anatomical areas: oesophageal, fundic, cardia and pyloric area by a dedicated software open source (ImageJ 1.48r, source freely available developed by Rasband W., National Institute of Mental Health, Bethesda, MD).

Finally, a macroscopic pathological examination was carried out on the internal mucosa of each stomach and lesions were grouped into four categories (hyperplastic, atrophic, follicular and simple gastritis).

Chemical analysis of feeds

Samples of HCCS, experimental diets containing HCCS and faecal samples were dried in a forced air oven (72 h at 55 °C) and all the samples were then milled through 1 mm screen (Pulverisette, Fritsch, Idar-Oberstein Germany). All the samples were assayed in two replications for DM (method 930.15, AOAC 2000), CP (method 976.05, AOAC 2000), ether extract (EE, method 954.02, AOAC 2000), total ash content (method 942.05, AOAC 2000). The aNDFom content was measured by a fibre analyser (Ankom II Fibre Analyser, Ankom Technology Corporation, Fairport, NY) following the procedure of Mertens (2002).

Phosphorus was determined in feeds, faces and urine samples by atomic absorption spectrometer Unicam Model Solar 969 (Unicam Ltd., Cambridge, UK) (AOAC 1995, method 965.17). Samples of HCCS were also analysed for the starch content using the Megazyme kit K-TSTA (Megazyme International Ireland Ltd., Wicklow, Ireland) for total starch assay procedure according to the method 996.11 (AOAC 2000).

Gross energy of feeds, faces and urine was measured using an adiabatic bomb calorimeter (IKA 4000, Staufen, Germany).

During the feeding trial fresh samples of maize silage (approximately 500 g each one) were fractionated using a particle separator (NASCO®, Nasco, Fort Atkinson, WI) composed of three sieves (mesh diam. of 19, 8 and 2 mm) and a collector at the bottom. Samples were inserted in the upper sieve and the apparatus was shaken for a total of 40 horizontal movements in four directions (Kononoff et al. 2003).

Statistical analysis

Data from Exp. 1 were analysed using the PROC GLM procedure of SAS (SAS Inst. Inc., Cary, NC) using the following model:

$$Y_{ijkl} = \mu + S_i + A_j(S) + P_k + T_l + e_{ijkl}$$

where Y_{ijkl} = dependent variable; μ = general mean; S_i ($i = 1,2$) = sequence of treatment effect; A_j ($j = 1,4$) = animal effect nested in sequence; P_k ($k = 1,2$) = period effect; T_l ($l = 1,2$) = treatment effect; e_{ijkl} = residual error.

Data from Exp. 2 were analysed according to a monofactorial design by using the pen as the experimental unit.

For all statistical analyses, significance was declared at $p \leq .05$ and trend at $p \leq .10$.

Results

Diets

Table 1 shows the ingredient composition of the compound feeds, chemical composition of whole plant maize silage and the two experimental diets. The main chemical differences between the CTR and the CS diets were related to the CP content (137 vs. 128 g/kg DM, respectively), the aNDFom content (138 vs. 188 g/kg DM, respectively) and the P content (5.6 vs. 5.0 g/kg DM, respectively).

The particle distribution of the silage (results not in table) showed the highest presence of material at the 8–19 mm sieve (592 g/kg), followed by the 2.0–7.9 mm fraction (368 g/kg) with very low amounts both at top and the bottom (24 and 16 g/kg, respectively). The above particle distribution allowed to calculate an average particle size of 7.7 mm.

Table 1. Composition, chemical analysis and energy contents of high cut maize silage and the experimental diets.

	HCCS	Diet[a] CTR	CS
Composition, g/kg DM			
Maize meal		550	430
Barley meal		250	250
Soya bean meal, extracted		90	90
Wheat bran		80	0
Maize silage		0	200
NaCl		4	4
$CaCO_3$		12	12
$CaHPO_4$		8	8
L-lys HCL		1	1
Supplement[b]		5	5
Chemical analysis, g/kg DM			
DM, g/kg	443	880	730
CP	66.3	137	128
EE[c]	26.2	27.4	25.5
aNDFom[d]	387	138	188
ADFom[e]	221.0	46.3	78.4
Ash	36.1	49.8	51.2
Starch	339	495	501
P	3.7	5.6	5.0
Total lysine[f]		6.9	6.7
Energy contents, MJ/kg DM			
Gross energy	18.45	17.89	17.99
Metabolisable energy	11.66	14.86	14.41
Net energy	8.47	10.77	10.42

[a]Diet CTR and CS: diets with 0 and 200 g/kg of high cut whole plant corn silage on a DM basis, respectively.
[b]Supplied per kilogram DM of complete diet: vitamin A, 9400 IU; vitamin D_3, 1880 IU; vitamin E, 47 mg; vitamin K_3, 1.0 mg; vitamin B_1, 0.9 mg; vitamin B_2, 4.7 mg; vitamin B_3, 23.5 mg; vitamin B_6, 0.9 mg; vitamin B_{12}, 0.024 mg; pantothenic acid, 12 mg; biotin, 0.19 mg; choline chloride, 118 mg; Fe, 126 mg from $FeSO_4.H_2O$; Cu, 21 mg from $CuSO_4.5H_2O$; Zn, 127 mg from ZnO; Mn, 42 mg from MnO_2; I, 0.7 mg from $Ca(IO_3)_2$; Co, 0.2 mg from $2CoCO_3$ $3Co(OH)_2.H_2O$; Se, 0.2 mg from Na_2SeO_3 (Pig supplement 0.5%, Consorzio Agrario, Udine, Italy).
[c]EE = ether extract.
[d]aNDFom = neutral detergent fibre assayed with amylase and expressed exclusive of residual ash.
[e]ADFom = acid detergent fibre expressed exclusive of residual ash.
[f]Computed by NRC (2012).

Digestibility and metabolic trial (Exp. 1)

Feed rests were almost negligible and their analyses revealed no feed selection by the animals. The average individual feed intake in the two testing periods was 2560 and 2490 g DM/d for diets CTR and CS, respectively.

Significant differences between the diets were observed for DM, OM, CP and energy CTTAD (Table 2) with higher values for the CTR diet in comparison with CS diet. In contrast P CTTAD was higher for the CS diet in comparison with CTR ($p = .013$).

Phosphorus intake (Table 3) was higher for the CTR diet ($p = .003$). This determined a lower faecal P excretion (g/d) for CS diet ($p = .001$) in comparison with CTR. Urinary P excretion was also higher for the CTR diet ($p = .009$) in absolute values (g/d) and when expressed as percentage of P intake ($p = .049$). Overall P retention was similar in absolute values for the two diets (5.69 and 6.26 g/d for diets CTR and CS, respectively) but higher for the CS diet ($p = .007$) when expressed as percentage of P intake.

Table 2. The effects of including 200 g/kg DM high cut maize silage in the diet fed pigs weighing 143 kg on the coefficients of total tract apparent digestibility of nutrients (8 animals in cross-over design).

	Diet[a]			
	CTR	CS	SEM	*p* value
Item				
DM	0.862	0.826	0.005	.003
OM	0.884	0.847	0.004	.002
CP	0.852	0.811	0.007	.012
EE[b]	0.755	0.733	0.040	.138
aNDFom[c]	0.552	0.509	0.019	.174
ADFom[d]	0.448	0.404	0.024	.252
Ash	0.445	0.431	0.013	.512
P	0.450	0.537	0.016	.013
Energy	0.860	0.824	0.006	.009

[a]Diet CTR and CS: diets with 0 and 200 g/kg of high cut whole plant corn silage on a DM basis, respectively; SEM: standard error of the mean.
[b]EE = ether extract.
[c]aNDFom = neutral detergent fibre assayed with amylase and expressed exclusive of residual ash.
[d]ADFom = acid detergent fibre expressed exclusive of residual ash.

Table 3. The effects of including 200 g/kg DM high cut maize silage in the diet fed pigs weighing 143 kg on P and N balance (8 animals in cross-over design).

	Diet[a]			
	CTR	CS	SEM	*p* value
Item				
P intake (PI), g/d	14.5	12.3	0.3	.003
Faecal P				
g/d	7.98	5.69	0.25	.001
% PI	55.0	46.3	1.6	.013
Urinary P				
g/d	0.84	0.42	0.07	.009
% PI	5.77	3.51	0.62	.049
P retained				
g/d	5.69	6.26	0.32	.265
% PI	39.2	50.2	1.8	.007
N intake (NI), g/d	56.4	50.9	1.1	.022
Faecal N				
g/d	8.37	9.61	0.46	.116
% NI	14.8	18.9	0.7	.012
Urinary N				
g/d	26.6	21.6	0.7	.004
% NI	47.2	43.2	2.3	.267
N retained				
g/d	21.4	19.7	1.5	.461
% NI	38.0	37.9	2.4	.991

[a]Diet CTR and CS: diets with 0 and 200 g/kg of high cut whole plant corn silage on a DM basis, respectively; SEM: standard error of the mean.

Nitrogen intake (Table 3) was higher for the CTR diet ($p = .022$). Faecal N excretion was similar in terms of g/d, but higher for the CS diet when expressed as percentage of N intake ($p = .012$). Urinary N was higher for the CTR diet in absolute values ($p = .004$) although not significantly when expressed as percentage of N intake (47.2 and 43.2% for CTR and CS diets, respectively). Consequently, N retention was similar in the two treatments and resulted on average 38.0% of N intake.

Table 4. The effects of including 200 g/kg DM high cut maize silage in the diet fed pigs weighing 143 kg on energy utilisation (8 animals in cross-over design).

	Diet[a]			
Item	CTR	CS	SEM	*p* value
Gross energy intake (EI), MJ/d	46.1	44.6	1.1	.365
Energy in faeces				
MJ/d	6.47	7.87	0.36	.041
% EI	14.0	17.6	0.6	.009
Energy in urine				
MJ/d	1.03	0.85	0.02	.004
% EI	2.23	1.93	0.08	.044
Energy in CH_4				
MJ/d	0.30	0.17	0.03	.035
% EI	0.65	0.39	0.06	.030
Energy metabolised				
MJ/d	38.3	35.7	0.9	.085
% EI	83.1	80.1	0.6	.013
Heat production				
MJ/d	21.3	20.7	0.3	.167
% EI	46.3	46.5	0.7	.817
Energy retained				
MJ/d	17.0	15.1	0.6	.074
% EI	36.8	33.6	0.7	.024
Respiratory quotient (RQ)	1.11	1.05	0.02	.064

[a]Diet CTR and CS: diets with 0 and 200 g/kg of high cut whole plant corn silage on a DM basis, respectively; SEM: standard error of the mean.

The daily energy utilisation associated with each diet is shown in Table 4. As expected from the digestibility data, faecal energy losses were higher for the CS diet both in terms of g/d ($p = .041$) and when expressed as percentage of gross energy intake (EI, $p = .009$). The ME intake of pigs fed the CS diet averaged 35.7 MJ/d and tended ($p = .085$) to be lower than that of pigs fed the control diet (38.3 MJ/d). The ME intake of pigs fed the CS resulted significantly lower than that of the CTR diet when expressed as percentage of EI ($p = .013$). Retained energy (RE) was tendentially higher for the CTR diet ($p = .074$) in absolute values (MJ/d) and significantly higher ($p = .024$) when expressed as percentage of EI. The respiratory quotient (CO_2/O_2) of the C diet (1.11) tended to be higher ($p = .064$) than that of the CS diet (1.05).

The ME of the maize silage resulted to be 11.66 MJ/kg DM and the NE 8.47 MJ/kg DM. For the diets CTR and CS the ME resulted to be 14.86 and 14.41, and the NE 10.77 and 10.42 MJ/kg DM, respectively.

Fattening and slaughter trial (Exp. 2)

The average individual feed intake in the fattening period was 2747 and 2754 g DM/d for diets CTR and CS, respectively.

Pigs fed the CS diets in the fattening range between 90 to 170 kg of BW had (Tables 5 and 6) a lower daily gain (700 vs. 765 g/d, $p = .023$), a lower BW

Table 5. Effects of including 200 g/kg DM high cut maize silage in the diet fed heavy finishing pigs on growth performance (2 pigs/pen and 7 pens/diet; pens as experimental units).

	Diet[a]			
	CTR	CS	SEM	*p* value
Item				
Initial BW, kg	90.1	88.9	1.9	.662
Final BW, kg	175.1	166.6	2.4	.026
DM intake, g/kg $BW^{0.75}$	70.3	72.5	0.8	.099
ADG, g	765	700	17	.023
G:F, g/g DM	0.28	0.25	0.01	.018

[a]Diet CTR and CS: diets with 0 and 200 g/kg of high cut whole plant corn silage on a DM basis, respectively; SEM: standard error of the mean.

Table 6. The effects of including 200 g/kg DM high cut maize silage in the diet fed heavy pigs on carcase and meat traits (2 pigs/pen and 7 pens/diet; pens as experimental units).

	Diets[a]			
	CTR	CS	SEM	*p* value
Slaughter traits				
Carcase weight, kg	140.8	133.6	2.2	.037
Dressing, %	80.4	80.1	0.3	.596
Back fat thickness (mm)	29.2	27.3	1.3	.300
Joints weight and percentage				
Ham weight, kg	35.4	34.2	0.6	.155
Ham, %	25.1	25.6	0.2	.078
Loin weight, kg	14.1	13.7	0.3	.355
Loin, %	10.0	10.3	0.2	.337
Back fat weight, kg	10.8	9.0	0.5	.021
Back fat, %	7.7	6.7	0.2	.038
pH 120[b]	5.83	5.81	0.02	.549
Drip loss, %	5.96	6.46	0.40	.382
Cooking loss, %	31.2	30.3	0.4	.117
Shear force (N)	32.2	26.1	1.9	.045
Colorimetric profile				
L*	50.0	49.0	1.3	.349
a*	−0.91	−0.29	0.30	.168
b*	10.6	11.5	0.3	.099
Chroma*	10.7	11.6	0.3	.090
Hue*	95.3	91.8	1.7	.169
Chemical composition				
DM, g/kg	324	321	4.0	.500
Ash, g/kg DM	39.6	40.0	0.7	.719
CP, g/kg DM	808	799	11	.572
Calculated fat[c], g/kg DM	152	161	12	.606

[a]Diet CTR and CS: diets with 0 and 200 g/kg of high cut whole plant corn silage on a DM basis, respectively; SEM: standard error of the mean.
[b]Measured 120 min after the slaughtering.
[c]NFE: Nitrogen free extract, obtained by difference: 100−(PG + Ash).
*CIElab system.

at slaughter (167 vs. 175 kg, $p = .026$) and a reduction in the back fat percentage (6.7 vs. 7.7, $p = .038$). The CS diet determined a lower value of shear force (26.1 vs. 32.2 N, $p = .045$), while there were no other modifications among the other *Longissimus dorsi* physical, colorimetric and chemical analyses. The inclusion of silage increased (Table 7) the size of the stomach (779 vs. 692 g, $p = .028$ and 1403 vs. 1168 cm^2, $p = .005$, respectively of weight and surface), the aNDFom concentration of stomach content (499 vs. 277 g/kg DM, $p < .001$) and reduced the proportion of the fundic surface (0.371 vs. 0.404, $p = .029$) and the incidence of follicular gastritis (0.29 vs. 1.14 n/pig, $p = .010$).

Table 7. The effects of including 200 g/kg DM high cut maize silage in the diet fed to heavy pigs on stomach traits and gastric mucosal disease (2 pigs/pen and 7 pens/diet; pens as experimental units).

	Diets[a]			
	CTR	CS	SEM	*p* value
Stomach weight full, g	2032	2706	271	.106
Stomach weight, g	692	779	25	.028
Stomach content and composition				
Content weight, g	1346	1928	267	.149
DM, g/kg	268	231	15	.103
aNDFom[b], g/kg DM	277	499	23	<.001
Area				
Total, cm^2	1168	1403	49	.005
Oesophageal, cm^2	50.1	65.0	3.4	.010
Oesophageal proportion	0.043	0.047	0.002	.278
Fundic, cm^2	471	519	15	.045
Fundic proportion	0.404	0.371	0.009	.029
Pyloric, cm^2	251	312	11	.002
Pyloric proportion	0.223	0.214	0.007	.369
Cardiac, cm^2	396	507	30	.022
Cardiac proportion	0.339	0.358	0.011	.243
Stomach weight/stomach area, g/cm^2	0.60	0.56	0.03	.388
Gastritis, *n*/pig				
Hyperplastic	2.57	3.97	0.48	.069
Follicular	1.14	0.29	0.20	.010
Atrophic	0.07	0.00	0.05	.337
Simple	0.02	0.00	0.11	.175
Total	4.00	4.21	0.43	.730

[a]Diet CTR and CS: diets with 0 and 200 g/kg of high cut whole plant corn silage on a DM basis, respectively; SEM: standard error of the mean.
[b]aNDFom = neutral detergent fibre assayed with amylase and expressed exclusive of residual ash.

Discussion

Diets

In previous experiments our research groups have tested the inclusion of WECS in diets for finishing heavy pigs (Zanfi & Spanghero 2012; Capraro et al. 2014; Zanfi et al. 2014) in substitution of all the wheat bran and of part of the maize meal. The overall result was that WECS can be included up to 400 g/kg of DM without any detriment on in vivo performance, slaughter traits and meat characteristics when compared with traditional soy-maize based diets. The present trial is a continuation of previous researches and is focussed on the whole plant maize silage, which mainly differs from WECS for a double content of NDF (approx. 400 vs. 200 g/kg DM). As we demonstrated that WECS can be used at high levels we decided to include the whole plant maize silage at the level of 200 g/kg DM in substitution of all the wheat bran and of part of the maize meal in a soy-maize based diet. The silage used was a high cut maize silage (60 cm from the soil on average) with low aNDFom and high starch contents (387 and 339 g/kg DM, respectively) and with a very low fraction of coarse particles (less than 3% of the >19 mm fraction). The high cut silage was preferred to a normal cut silage because in the basal part of the stalk there is a high concentration of lignin, which depress fibre digestibility, and a high nitrate accumulation (Masoero et al. 2011). As reported in Table 1 the main chemical differences between the two diets were the aNDFom and the CP contents which were, respectively, increased (by about 5 percentage points) and reduced (by about 1 percentage point) with the HCCS inclusion. We did not balance the CP content between the diets to simulate what could happen in practice and to avoid the inclusion of other ingredients in the CS diet, which would have made it impossible to compute the NE of maize silage by difference with the other ingredients, as previously described. Moreover, we believe that a dietary CP content of 128 g/kg DM for a heavy pig is compatible with a good lean tissue deposition.

Digestibility and metabolic trial (Exp. 1)

Digestibility coefficients of the CTR diet (Table 2) are consistent with those reported recently by Galassi et al. (2015) in heavy pigs of two different genetic lines. The lower CTTAD of DM, OM, CP and energy for pigs fed the CS diet are in line with the differences in growth performance and likely associated with the relatively high aNDFom level of the CS diet (18.8% on DM). In our previous studies including 30% WECS in the diet with an NDF level of 15.2% on DM had no effect the CTTAD of these nutrients. Several studies report a trend for a reduction of digestibility with increasing fibre content (Yin et al. 2000; Galassi et al. 2010). On the other hand, in a review by Souffrant (2001) it was concluded that the effect of dietary fibre on digestibility is variable due to the high variability in the physico/chemical characteristics of this nutrient.

The higher CTTAD of P with the CS diet can be attributable to the fact that in the grain fraction of silage the phytic P is degraded and the mineral can therefore be better utilised, than no silage products, by monogastrics (Niven et al. 2007). A higher P digestibility with high moisture maize meal in comparison with dried maize meal was also reported in fattening pigs by Humer et al. (2013). The present results for CTTAD of P in the CTR diet are consistent with those of Jolliff and Mahan (2012) and Zanfi et al. (2014) in growing pigs fed a diet based on maize and soybean meal. Moreover, the amount of P added with the mineral supplementation was the same for both diets, but the CS diet had lower P content in comparison with CTR diet. This resulted in a higher relative inclusion of added P on total dietary P in CS diet than CTR diet. The higher availability of P mineral sources can partially explain the higher P digestibility.

The P intake of pigs fed CS diet was consistent with NRC recommendation (12.0 g/d) for maize and soybean meal-based diets. For growing pig from 100 to 135 kg BW the NRC (2012) reports that apparent total tract digestible P requirement is 4.98 g/d; the 2 diets tested in this trial allowed an amount of digestible P higher than this requirement (6.5 g/d for both CTR and CS diets). This confirms the high digestibility and utilisation of P with the CS diet: with this diet P retained was 6.26 g/d (equal to 50.2% of P intake). As regards pigs fed the CTR diet, the CTTAD of P registered was similar to that reported by NRC (2012) (about 0.40).

Our results showed that including 20% HCCS in the diet significantly reduced the CTTAD of N but the fact that N retention did not differ suggests that both diets met the animals requirement for N. Nevertheless, the adverse effect of HCCS on N digestibility would need to be taken into account when formulating diets using this ingredient.

Our results showed that the ME and NE of the CS diet was lower than the CTR diet and this was in line with the reduction in energy CTTAD by pigs fed the CS diet. This was reflected in the relative ME and NE values of the two diets (14.86 and 14.41 MJ ME/kg DM and 10.77 and 10.42 MJ NE/kg DM, for CTR and CS diets, respectively) and again would need to be taken into account when using HCCS in pig diets. The calculated ME and NE values for the HCCS used in this study (11.66 and the 8.47 MJ/kg DM, respectively) will assist with this. The ME value of the HCCS in our study was higher than that reported for a maize silage with a higher fibre content by INRA (1989) (9.45 MJ/kg DM). The difference probably reflects the fibre content of the materials used and the fact that the pigs used in our study were considerably heavier and better able to digest fibre than those used by INRA.

The conversion of ME to NE in our study was 0.724 which is between the minimum (0.690) and maximum (0.772) values reported by Noblet et al. (1994a) for 61 diets fed to growing pigs.

Despite differences in particle size and fibre content between the diets, HP was similar for the two diets. Generally, high-fibre diets increase HP (Ramonet et al. 2000). The lack of an effect in our study might have been due to the fact that the pigs were fed restrictively and/or that the higher fibre content of the CS diet might have reduced activity and the HP associated with this. Indeed, according to Ramonet et al. (2000) for pregnant sows, and Schrama et al. (1998) for growing pigs, the use of high-fibre diets is often associated with a reduced physical activity and it may partially compensate for the increase in HP due to the long-term metabolic processes related to fermentation.

The tendency for pigs fed the CS diet to retain less energy than their control counterparts was probably associated with their lower fat deposition. The RE values obtained in this trial are consistent with those reported for finishing pigs in other experiments (Noblet et al. 1994b; Galassi et al. 2004, 2005b). The RQ is correlated to fat deposition with higher values for animals that have higher fat deposition: the lower RQ registered with the CS diet ($p = .064$) confirms therefore the lower fat deposition of the pigs fed the CS diet.

Fattening and slaughter trial (Exp. 2)

Animals showed good health conditions and there were no refusals of the diets, which were consumed at the same level. The BW gain was approximately 8–9% lower for the pigs fed the CS diet and this caused a reduction in slaughter BW and in carcase weight (9 and 7 kg respectively). However, the carcase weights were within the range (131–142 kg) found recently for different genetic types of heavy pigs (Schiavon et al. 2015). The reduction of the growth performance (approximately 8–9%) of the pigs fed the CS diet was greater than that expected on the basis of the measured difference in the digestibility and energy content (approximately 3–4%). The metabolic utilisation of the diets was measured at a very late growth stage of animals (134–153 kg of BW), when fibre digestibility reaches very high levels (Galassi et al. 2005a, 2005b), while the growth was tested in a larger range of BW (90–160 kg), therefore, it is possible that in the initial part of the growing period the differences in digestion and metabolic utilisation between the diets were larger than those measured later. The weights of the main carcase cuts and several physic-chemical parameters measured on the *Longissimus dorsi* muscle were similar between diets, but the use of silage determined a lower deposition of the back fat in the body. On the contrary, in our previous trials (Capraro et al. 2014; Zanfi et al. 2014), where WECS was introduced in diets, we only observed a reduction in the dimension of the *Longissimus dorsi*. However, it has to be considered that in the present trial the energy concentration (e.g. DE, ME and NE) of the CS diet was lowered with a direct impact on the performance of animals (e.g. lower growth rate and fat deposition). Nevertheless, whole plant maize silage contains a different fibre than WECS, because stalks have a less degradable fibre in comparison with that of the cob and the husks (Masoero et al. 2011) and, perhaps more important, has a larger dimension of particles. The inclusion of a coarse and a fibrous ingredient, such as the maize silage, induced a relevant modification in the development of the stomach in terms of total weight and total surface, which is due to the capacity to retain the more fibrous and coarse particles of the diet for a longer period. In fact pigs fed the CS diet doubled the aNDFom concentration of the gastric material in comparison with those fed the CTR diet.

The relative partition of stomach in different areas was not markedly modified by dietary treatments with the only exception being of the fundic area, which was reduced in pigs fed the CS diet. A tendency for a reduction in the proportion of the fundic area was also previously observed by feeding a diet containing WECS to pigs (Mason et al. 2013). These results are not easy to interpreter, but in both our trials, the diets that have induced a reduction of fundic area contained ensiled feeds (WECS or CS): we speculate that these diets, being moderately acidic, could induce a limited development of the fundic area, which is involved in gastric acid production.

The repletion of the stomach with coarse material has an impact on the incidence of the damages of the stomach mucosa and the hyperplastic and the follicular gastritis are the more frequent lesions in heavy pigs with a prevalent localisation in the fundic and pyloric areas (Pascotto et al. 2016). In the present trial, we observed a tendency to increase the hyperplastic gastritis in pigs fed the CS diet and this could be interpreted as a reaction of the mucosa to the presence of coarse materials in the gastric contents. By contrast, the significant reduction of follicular gastritis, which confirms our previous finding by including WECS in the pig diets (Mason et al. 2013), is probably the positive effect of a repletion of the stomach and a lower damage of mucosa by the gastric acidity.

Conclusions

The inclusion of 20% on a DM basis of HCCS in the diet fed to heavy finishing pigs reduced energy digestibility and dietary ME and NE and resulted in reduced growth performance. Further research is required to determine the optimum level of inclusion and the economics of using this feed in pig diets. Consideration should also be given to the role HCCS might have in respect to animal welfare due to its effects on gastric repletion and possibly satiety.

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