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Digestibility and metabolic utilization of diets containing whole-ear corn silage and their effects on growth and slaughter traits of heavy pigs[1]

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ABSTRACT: The aim was to evaluate 2 levels of dietary inclusion of chopped whole-ear corn silage (WECS) on energy and nutrient utilization, growth, and slaughter performances of heavy pigs. Two in vivo experiments were conducted to determine digestibility and metabolic utilization of WECS using 18 barrows weighing 118 ± 8 kg BW on average, metabolic cages and respiration chambers (Exp. 1), and the effect of WECS on the growth performance and carcass traits on 42 barrows from 90 to 170 kg BW (Exp. 2). In both experiments, pigs were fed 3 experimental diets: a control diet (CON) containing cereal meals, extracted soybean meal, and wheat bran (80%, 9%, and 8% of DM, respectively) and 2 diets containing 15% (15WECS) or 30% WECS (30WECS) on a DM basis in place of wheat bran and corn meal. The diets were prepared daily by mixing the WECS to a suitable compound feed. Feed intake was always restricted to allow a daily DMI of 7.2% $BW^{0.75}$ in Exp. 1 and from 8.0% to 6.5% $BW^{0.75}$ in Exp. 2. Diets had similar NDF contents (15.2% to 15.8% of DM), and WECS inclusion resulted in a slight reduction in CP content (from 14.0% to 13.6% of DM) and a considerable decrease in P content (from 0.47% to 0.30% of DM). Digestibility of OM, CP, and fat was similar among diets, whereas P digestibility was lower ($P < 0.05$) for the 30WECS diet (33.5%) in comparison with the CON and 15WECS diets (45.5% and 44.1%, respectively). Nitrogen lost in feces and urine and N retained were not different among diets, whereas P retained decreased with the increase of WECS (5.4, 3.7, and 2.2 g/d for the CON, 15WECS, and 30WECS diets, respectively; $P < 0.05$). No difference among diets was observed for energy balance. The WECS contained 13.48 MJ ME and 9.39 MJ NE/kg DM. In Exp. 2, feed intake was not depressed by WECS inclusion, and the ADG for the whole experiment was not different among dietary treatments (from 737 to 774 g/d). Fecal pH was lower ($P < 0.05$) for the WECS diets than the control diet (7.10 and 7.00 vs. 7.40) and for the sampling at 150 kg BW than that at 130 and 110 kg BW (6.96 vs. 7.29 and 7.24). At slaughter, lean percentage in the carcass was lower in the 30WECS diet than those of the other 2 diets (46.8% vs. 48.3% and 48.6%, $P = 0.05$). The overall experimental data obtained in both trials indicate that substitution of wheat bran and corn meal for WECS (up to 30% of DM) does not affect, with the exception of P utilization and carcass leanness, energy and nutrient utilization and performance of heavy pigs in the last phase of growing.

Key words: corn silage, digestibility, nitrogen, phosphorous, pigs, slaughter traits

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INTRODUCTION

Dry corn meal is the main ingredient of growing pig diets in areas of intensive corn crop cultivation and pig production, such as northern Italy (Bosi and Russo, 2004). Recently, the increases in corn grain prices and grain drying cost have raised interest in silage corn products, not only for ruminants but also for pig diets. Moreover, a larger usage of farmland grown

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and ensiled corn feeds can increase farm sustainability by limiting off-farm transport of feeds for processing and drying.

High-moisture corn (**HMC**) is largely used in pig diets as an alternative to dry corn. It can contain variable proportions of cob fraction, with a NDF content of 12% to 14% of DM. In contrast, whole-ear corn silage (**WECS**), resulting from harvesting and chopping the cob, kernels, and husks of the ear, has a greater NDF content (from 17% to 19% of DM) and is not commonly used in pig feeding systems because of its high fiber content and an average particle size greater than corn meal. However, its digestibility is fairly high when fed to pigs in the last part of the growing period or above 80 kg BW (Zanfi and Spanghero, 2012). In Italy, more than 80% of pig production consists of "heavy" pigs as required by the guidelines of the Italian Consortia of ham ("prosciutto") production, which state that the pigs must be slaughtered after 9 mo of age at a BW of 160 kg ± 10% (Bosi and Russo, 2004).

The interest in WECS derives from its higher crop yield in comparison to dry corn (15% to 20% more DM) and the simultaneous supply of starch and fiber, thus reducing the need to purchase fiber ingredients such as wheat bran or beet pulps. Finally, WECS could be an appropriate ingredient to increase the fiber content of the diet to satisfy recent issues related to pig welfare (EFSA, 2007, 2012). The present research aimed at evaluating the effects of partial substitution of dry corn and wheat bran with WECS in diets for heavy pigs on nutrient utilization and growth and slaughter performances.

MATERIAL AND METHODS

All animals were cared for in accordance to the guidelines on animal welfare in animal research of Italian Legislative Decree 116/1992 (Italian Ministry of Health, 1992).

Whole-Ear Corn Silage, Diets, and Planning of the Experiments

Two corn hybrids (DKL 6903, Dekalb-Monsanto Agricoltura, S.P.A., Milan, Italy; PR31Y43, Pioneer Hi-Bred Italia, S.r.l., Gadesco Pieve Delmona, Cremona, Italy) belonging to the same maturity class (131- to 140-d cycle) were grown in homogeneous fields at the same farm in the Friuli Venezia Giulia Region (Udine province, Italy). The silt loam soil was fertilized with N (300 kg N/ha), P (100 kg P_2O_5/ha), and K (80 kg K_2O/ha). Both hybrids were harvested on the same day (September 1, 2011) and immediately ensiled in equal proportions (50:50) in the same bunk silo (2 m high and 5 m wide). The HMC products can be composed of only kernels, kernels with some parts of the cob, or the whole ear, composed of kernels, cobs, and husks plus some of the upper part of the corn plant (called "snaplage"; Bucholtz, 2012). In this experiment, we used a HMC represented by the whole ear, harvested with a forage chopper, which was equipped with a kernel processor and a snapper head, and the silage was directly used in the diets without any process to reduce particle size.

Three experimental diets (Table 1) were fed to pigs in both experiments: a control diet (**CON**) containing cereal meals (corn, barley, and wheat; 80% DM in total), soybean meal (9% DM), wheat bran (8% DM), minerals, and a vitamin–trace mineral premix and 2 diets containing 15% (**15WECS**) or 30% WECS (**30WECS**) on a DM basis, replacing wheat bran and corn meal partly or completely. The diets were prepared daily by mixing the WECS to a compound feed (1 for 15WECS and another for 30WECS) specifically formulated to attain a diet with the desired analytical characteristics. Two experiments were conducted on growing heavy pigs to test the digestibility and the metabolic utilization (Exp. 1) and the effects on growth and slaughter performance (Exp. 2) of the experimental diets.

Digestibility and Metabolism Study (Exp. 1)

Eighteen barrows (Italian Large White × Italian Duroc) with an average BW of 95 ± 3.5 kg were randomly housed in 6 pens (3 × 3 m) with 2 pens per treatment and 3 barrows per pen. To determine total tract apparent digestibility, P, N, and energy balance, 1 pig per pen was moved from the pen to an individual metabolism cage in 3 consecutive periods. Each period lasted 14 d, 7 d of cage adaptation and 7 d of separate collection of excreta (testing period). Consequently, in Exp.1, 6 barrows were used for each of the 3 dietary treatments. 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.

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

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

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 N (g/d).

The ME and NE of WECS were predicted from the calorimetric measurements, taking into account the corresponding values of corn meal (NRC, 2012) and wheat bran (Crovetto et al., 2007) and the NE requirements for maintenance (261 kJ/kg $BW^{0.75}$) reported by Noblet et al. (1993).

Table 1. Composition and analysis of the experimental diets

Item	Diet[1]		
	CON	15WECS	30WECS
Ingredient, g/kg DM			
Corn meal	471	361	251
Barley meal	231	231	231
Wheat meal	100	100	100
Soya bean meal, extracted	90	90	90
Wheat bran	80	40	0
WECS	0	150	300
NaCl	3.6	3.6	3.6
$CaCO_3$	11.3	11.3	11.3
$CaHPO_4$	7.5	7.5	7.5
L-Lys×HCl	0.9	0.9	0.9
Vitamin–trace mineral premix[2]	4.7	4.7	4.7
Chemical analysis			
DM, %	91.5	86.5	81.8
CP, % DM	14.0	13.7	13.6
NDF, % DM	15.8	15.4	15.2
ADF, % DM	4.9	5.2	5.5
Ether extract, % DM	2.7	2.7	2.6
Ash, % DM	5.5	4.8	4.5
P, % DM	0.47	0.37	0.30
Lys, % DM	0.60	0.57	0.55
GE, MJ/kg DM	17.82	17.98	18.09

[1]CON: control diet with 0% whole-ear corn silage (WECS); 15WECS: diet with 15% WECS on a DM basis; 30WECS: diet with 30% WECS on a DM basis.

[2]Supplied per kilogram DM of complete diet: vitamin A, 9,400 IU; vitamin D_3, 1,880 IU; vitamin E, 47 mg; vitamin K_3, 1.0 mg; thiamin, 0.9 mg; riboflavin, 4.7 mg; niacin, 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).

The ME content of WECS was computed by 2 steps as follows: 1) MEother = MEdietCON – (MEcorn + MEbran) and 2) MEWECS = MEWECSdiets– (MEcorn + MEbran+ MEother), where MEother is the ME content of the other ingredients (included in the same amounts in all diets), MEdietCON is the ME content of the CON diet, MEcorn is the ME content of corn meal, MEbran is the ME content of wheat bran, MEWECS is the ME content of WECS, and MEWECSdiets is the ME content of the WECS diets.

For the NE content of WECS, we followed the same procedure, considering the corresponding NE values of feed ingredients and adding the NE maintenance requirement to the NE content for production of the diets determined by calorimetric measurements. During the digestibility and metabolism study, barrows weighed, on average, 118 ± 8 kg. Feed was restricted to allow a daily DMI of 7.2% $BW^{0.75}$, and pigs were fed at 0800 and at 1700 h and had free access to water.

All 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 remaining feed was removed from the trough, weighed, and analyzed for DM content.

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 a 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 feces were weighed and sampled (20% of total weight) daily, pooled per pig, and frozen (–20°C) for subsequent chemical analysis.

Feeding Study and Slaughter Measurements (Exp. 2)

Forty-two Italian Large White × Italian Duroc barrows (84.0 ± 9.0 kg BW and approximately 5 mo of age) were divided into pairs on the basis of BW and kept in 21 partially slatted pens suitable to house 2 barrows (1.2 × 3 m) and equipped with individual feeding and free access to water. A unique commercial compound feed (Electa; Consorzio Agrario, Udine, Italy), containing mainly corn meal, wheat bran, and soybean meal (15.5% CP, 4.4% fat, and 5.2% ash; as-fed basis) and supplemented with antibiotics (575 mg amoxicillin and 200 mg colistin/kg), was fed to barrows for 10 d after arrival at the experimental farm to prevent intestinal disease. The pigs were then weighed, and mixtures of the commercial compound feed and the experimental diets were fed to barrows (14 d) to allow a progressive adaptation to the experimental diets. Pigs were then weighed at wk 2, 6, and 10 and the day before slaughter (wk 15) to divide the whole growth into a transition period (wk 1 to 2) and 3 subsequent growing periods (i.e., wk 3 to 6, 7 to 10, and 11 to 15). Samples of WECS and experimental diets were collected during each growing period to be analyzed accordingly.

During the feeding study, the individual daily amounts of each experimental diet were prepared daily; the pigs were fed at a restricted level (daily DMI from about 8.0% to 6.5% $BW^{0.75}$ during the whole growth from 90 to 170 kg BW) and received 2 equal meals per day at 0900 and 1700 h. The indoor barn temperature was recorded daily, and fresh fecal samples were collected in the middle of each growing period and were immediately stored at –20°C. After thawing, 1 g of fecal sample was diluted 1:25 with distilled water for the pH measurement, and 100 g were used for DM analysis (72 h in a forced-air oven at 55°C).

The animals were slaughtered at an average BW of 168.8 ± 3.6 kg by electrical stunning and were exsanguinated, scalded at 65°C, skinned, eviscerated, and split at the center of the vertebral column according to standard slaughtering procedures. The weights of carcasses, hams, loins, and back fat were recorded before cooling. Back fat and LM thickness (**BT** and **LMT**, respectively) were measured before cooling using a Fat-O-Meater equipped with a probe of 6-mm diam. with a photodiode (SFH 950/960 Type; Siemens, Munich, Germany) at

8 cm to the side of the central line of the carcass between the third and the fourth last ribs (European Commission, 2001). Carcass lean percentage (**CLP**) was calculated from BT and LMT (both in mm) using the following European Union equation for heavy pigs (European Commission, 2001):

$$CLP = 45.371951 - 0.221432\ BT + 0.055939\ LMT + 2.554674\ BT/LMT.$$

The drip loss of meat was measured on cylinders of LM (25-mm diam.), which were inserted in containers (EZ-Driploss Containers, Kabe Labortechnik, Germany; Rasmussen and Andersson, 1996) and maintained for 72 h at 4°C. The cooking loss was measured in 5 LM slices with a thickness of 20 mm, which were cooked in plastic bags at 75°C for 45 min using a water bath (Honikel, 1998). The maximum shear force was measured on cooked cylinders (20-mm diam.) of LM, using a Warner-Bratzler device with a triangular hole of 60° in the shear blade, mounted on a texture analyzer (Lloyd TA Plus; Lloyd Materials Testing, Leicester, UK) at a test speed of 100 mm/min. The pH measurement of meat was taken on LM sections by a glass-piercing electrode (Crison 52-32) connected to a pH meter at 120 min ($\mathbf{pH_{120}}$) after slaughter. Finally, samples of LM were vacuum-packed, rapidly frozen, and stored at –20°C until the proximate analysis of meat (DM, N, ether extract, and ash), which was performed on the freeze-dried samples (Animal Science and Production Association, 1996). Hams were sent to a dry-curing ham factory (San Daniele, Italy) for the seasoning process and were weighed after 120 d to calculate the ham loss of weight during seasoning.

Chemical Analysis of Feeds, Feces, and Urine

Fresh samples of WECS (approximately 500 g) were fractionated using the Penn State Particle Separator (Nasco, Fort Atkinson, WI), composed of 3 sieves (mesh diam. of 19, 8, and 2 mm) with a collector at the bottom. Samples were inserted in the upper sieve, and the apparatus was shaken horizontally 5 times in 1 direction, then rotated a quarter turn, and again shaken 5 times; this procedure was repeated to obtain a complete rotation of the apparatus, and then the process was repeated (for a total of 40 shakes; Kononoff et al., 2003). The material collected in each sieve and in the bottom pan was weighed.

Samples of WECS, experimental diets containing WECS, and fecal samples were dried in a forced-air oven (72 h at 55°C), and all samples were then milled with a 1-mm screen (Pulverisette; Fritsch, Idar-Oberstein, Germany). Samples were determined for DM by heating at 105°C for 3 h (method 945.15; AOAC, 1995), ash by incineration at 550°C for 2 h (method 942.05; AOAC, 1995), ether extract by solvent extraction (method 920.29; AOAC, 1995), N (wet fecal samples and urine) by the Kjeldahl method (method 984.13; AOAC, 1995), and NDF and ADF by a fiber analyzer (Ankom^{II} Fiber Analyzer; Ankom Technology Corporation, Fairport, NY) following the procedure of Mertens (2002) for NDF and Van Soest et al. (1991) for ADF. Phosphorus in feeds, feces, and urine samples was determined by atomic absorption spectrometer (Unicam Model Solar 969; Unicam Ltd., Cambridge, UK; method 965.17; AOAC 1995). The WECS samples were also analyzed for lactic and acetic acids using the method of Fussell and McCalley (1987) and for the starch content using a kit (Megazyme Kit K-TSTA; Megazyme International Ireland Ltd., Wicklow, Ireland) for the total starch assay procedure (method 996.11; AOAC, 1998). The GE of feeds, feces, and urine was measured using an adiabatic bomb calorimeter (IKA 4000; IKA Werke GmbH and Co., Staufen, Germany).

Statistical Analysis

Data from Exp. 1 were analyzed using the PROC GLM procedure of SAS (SAS Inst. Inc., Cary, NC). For all data, the model initially included dietary treatment and period and their interaction. Later, the effects of the period and the interaction were excluded from the model because they were not significant. The main part of the data from Exp. 2 (DMI, ADG, G:F, and slaughter and meat quality traits) were analyzed with a model, which included dietary treatment and used the pen as the experimental unit. Data for pH and DM content of feces collected in 3 subsequent periods (3 samples from each pen) were analyzed as a repeated measurement (PROC MIXED procedure of SAS) according to the following linear model:

$$y_{ijk} = \mu + \alpha_i + (\beta_j)_i + \delta_k + (\alpha\delta)_{ik} + \varepsilon_{ijk},$$

where y_{ijk} is the response at sampling period k (k=1,…,3), on pen j (j=1,…,7) in dietary treatment group i (i=1,…3), μ is the overall mean, α_i is a fixed effect of the dietary treatment i, βij is a random effect of pen j in dietary treatment group i, δ_k is a fixed effect of time k, $(\alpha\delta)_{ik}$ is a fixed interaction effect of treatment i with time k, and ε_{ijk} is random error at time k on pen j in treatment i. A comparison of the treatment means was conducted at $\alpha = 0.05$ using the PDIFF option in the LSMEANS statement.

RESULTS AND DISCUSSION

Diets

Contamination with the upper parts of stalks was very limited because of the 2 hybrids used showed great resistance to stalk ruptures because of mechanical traction during harvesting. The particle size measured showed

that the greatest amount of WECS was retained by the 2-mm sieve (about 73%), whereas limited amounts were collected at the bottom and by the 8-mm sieve (14% and 12%, respectively). A minor fraction (<1%) was collected by the 19-mm sieve. The distribution of data fractions allowed the mean particle size to be calculated (3.4 to 3.5 mm). Average particle size was less than that used in the studies reported by Zanfi and Spanghero (2012), where the fraction retained by the 8-mm sieve was about one-third of the total while the amount retained by the 2-mm sieve was lower (51% to 55% vs. 73%). The feed was harvested in a bunker silo, and the quality of the silage was excellent, given the high level of lactic acid (1.5% of DM) and low acetic acid (<0.5% of DM) with a pH of 4.5. The DM content ranged between 60% and 65%. The average protein, starch, and NDF contents were 9.3%, 52.3%, and 16.7% of DM, respectively. The NDF content was intermediate between those reported by Bucholtz (2012) for high-moisture ear corn (9.5% of DM) and snaplage products (24% of DM).

The WECS was well accepted by the pigs. High palatability of corn silage was also reported by Zanfi and Spanghero (2012), and no differences in DM intake were detected among diets. In Exp. 1, DM intake was, on average, 2,630, 2,550, and 2,575 g/d for the CON, 15WECS, and 30WECS diets, respectively. This was expected, considering the restricted feeding system.

Table 1 shows the analysis of the experimental diets. The high CP content of WECS used in this study, compared to the content reported in literature (8.4% of DM; NRC, 2001), led to differences in CP content among the 3 diets, which were lower than expected. Ash and P contents decreased from the CON diet to the 30WECS diet. This was due to the high ash and P contents of wheat bran, which was partially or totally replaced by WECS in the 15WECS and 30WECS diets, respectively. The NDF diet content slightly decreased, and ADF slightly increased in the 30WECS diet compared to the CON diet. Both NDF and ADF values were very close among the 3 diets, confirming the possibility to substitute wheat bran with WECS to maintain a certain content of dietetic fiber in the diet. In agreement with the ash content of the diets, GE content was lowest for the CON diet and greatest for the 30WECS diet.

Digestibility, N and P Balances, and Energy Utilization

No difference among treatments was observed for the digestibility criteria studied (Table 2) with the exception of P digestibility, which was lower for the 30WECS diet compared to the CON ($P < 0.05$) and 15WECS ($P < 0.05$) diets. This was probably due to a lack of wheat bran in the 30WECS diet. Wheat bran is known for high endogenous phytase activity (Harland and Harland, 1980; Cavalcanti and Behnke, 2004); hence, wheat bran has a greater phytase concentration than cereals (Viveros et al., 2000) and WECS. This has, perhaps, resulted in a lower digestibility of phytic P and, consequently, to a lower absorption of P for the 30WECS diet.

Table 2. Apparent digestibility coefficients (%) of diets containing different proportions of whole-ear corn silage (WECS) for pigs weighing 118 kg (18 animals with 6 replications per diet)

	Diet[1]				
Item	CON	15WECS	30WECS	SEM	*P*-value
DM	86.5	87.4	85.8	0.6	0.17
OM	88.5	89.1	87.7	0.5	0.13
CP	85.1	85.6	83.2	1.0	0.21
Ether extract	71.1	72.8	71.1	1.6	0.40
NDF	59.6	59.8	55.3	2.0	0.19
ADF	35.0	38.6	34.4	3.6	0.66
Ash	51.0	51.0	46.4	2.7	0.36
P	45.5[a]	44.1[a]	33.5[b]	3.2	0.03
Energy	86.2	86.8	85.1	0.7	0.15

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

[1]CON: control diet with 0% WECS; 15WECS: diet with 15% WECS on a DM basis; and 30WECS: diet with 30% WECS on a DM basis.

Phytic P and phytase are not accumulated in the corn ear and cob (Laboure et al., 1993). Phytic P accumulates in the grain during the ripening stage (Maga, 1982); hence, WECS, which is harvested before the grain completely ripens, is characterized by a lower phytic P content than corn grain. The data obtained for P digestibility for the CON diet in the present experiment are consistent with those determined by Jolliff and Mahan (2012) in growing pigs fed a diet based on corn and soybean meal. For the 30WECS diet (free of wheat bran), P digestibility was similar (on average, 33.5% vs. 29.1%) to that reported by Akinmusire and Adeola (2009) for younger animals fed diets free of cereal by-products, corn, and phytase. The data obtained for DM, energy, and NDF digestibility are consistent with those reported by Urriola and Stein (2010) in growing pigs.

Phosphorus intake (Table 3) was greatest for the CON diet, intermediate for the 15WECS diet, and lowest for the 30WECS diet ($P < 0.01$) because of the different contents of dietary P. This resulted in a lower fecal P excretion (g/d) for the 15WECS ($P < 0.05$) and 30WECS ($P < 0.05$) diets than for the CON diet. However, when fecal P excretion is considered as a percentage of P intake, the 30WECS diet had greater fecal P excretion than the CON ($P < 0.05$) and 15WECS ($P < 0.05$) diets. Urinary P excretion was not affected by dietary treatment in absolute values (g/d). However, because of the lower P intake for the 30WECS diet, urinary P excretion expressed as a percentage of P intake was greater for the 30WECS diet than the CON diet ($P < 0.05$). Overall P retention decreased

Table 3. The effects of dietary whole-ear corn silage (WECS) level on P and N balance in heavy pigs (18 animals with 6 replications per diet)

	Diet[1]				
Item	C	15WECS	30WECS	SEM	*P*-value
P					
P intake (PI), g/d	12.5[a]	9.3[b]	7.9[c]	0.2	<0.01
Fecal P					
g/d	6.8[a]	5.1[b]	5.3[b]	0.4	0.02
% PI	54.5[b]	55.9[b]	66.5[a]	3.2	0.03
Urinary P					
g/d	0.23	0.36	0.42	0.1	0.20
% PI	1.8[b]	3.9[a,b]	5.3[a]	0.8	0.02
P retained					
g/d	5.4[a]	3.7[b]	2.2[c]	0.4	<0.01
% PI	43.7[a]	40.2[a]	28.2[b]	3.5	0.01
N					
N intake, g/d	58.9	55.8	56.0	1.0	0.08
Fecal N					
g/d	8.8	8.0	9.4	0.6	0.26
% PI	14.9	14.4	16.8	1.0	0.21
Urinary N					
g/d	24.6	22.2	22.0	1.6	0.38
% PI	41.6	39.7	39.2	2.5	0.71
N retained					
g/d	25.6	25.6	24.6	1.6	0.83
% PI	43.5	45.9	44.0	2.9	0.76

[a–c]Within a row, means without a common superscript differ ($P < 0.05$).

[1]CON: control diet with 0% WECS; 15WECS: diet with 15% WECS on a DM basis; and 30WECS: diet with 30% WECS on a DM basis.

Table 4. Effects of dietary whole-ear corn silage (WECS) level on energy utilization in heavy pigs (18 animals with 6 replications per diet)

	Diet[1]				
Item	CON	15WECS	30WECS	SEM	*P*-value
Energy intake (EI), MJ/d	46.94	45.88	46.59	0.84	0.64
Energy in feces					
MJ/d	6.49	6.06	6.98	0.37	0.19
% EI	13.8	13.2	14.9	0.6	0.14
Energy in urine					
MJ/d	0.92	0.85	0.87	0.06	0.69
% EI	1.96	1.86	1.85	0.12	0.77
Energy in CH_4					
MJ/d	0.26	0.26	0.25	0.04	0.95
% EI	0.56	0.58	0.53	0.03	0.85
Energy metabolized					
MJ/d	39.27	38.70	38.50	0.66	0.68
% EI	83.7	84.4	82.7	0.7	0.19
Heat production					
MJ/d	20.40	20.87	20.26	0.39	0.60
% EI	43.3	45.7	43.5	0.1	0.17
Energy retained					
MJ/d	18.95	17.78	18.26	0.72	0.50
% EI	40.4	38.7	39.2	1.2	0.60

[1]CON: control diet with 0% WECS; 15WECS: diet with 15% WECS on a DM basis; and 30WECS: diet with 30% WECS on a DM basis.

with the increase of the WECS level, 5.4, 3.7, and 2.2 g/d for the CON, 15WECS, and 30WECS diets, respectively ($P < 0.01$). The available P requirement (NRC, 2012) for a barrow of 120 kg BW is 4.8 g/d. The WECS30 diet resulted in a P retention lower than the requirement, and the WECS15 diet resulted in a retention slightly lower than the requirement, whereas the CON diet resulted in a P retention rate slightly above the estimated requirement.

Daily N balance is reported in Table 3. No differences were found between the diets. As indicated by the similar DM and N contents of the diets, daily N intake (**NI**) was similar for all treatments. Fecal N excretion was similar for the 3 diets and was about 15% of NI. The urinary N was about 40% of NI for all treatments. Consequently, N retention was similar in the 3 treatments and resulted in greater than 40% of NI. These results are in agreement with those reported by Zanfi and Spanghero (2012) for diets based on WECS for pigs at different stages of growth during the heavy finishing cycle.

The daily energy utilization associated with each diet is shown in Table 4. As expected from the digestibility data, fecal energy losses were similar for the 3 treatments. No difference in urinary energy was found among treatments. The ME of the WECS diets did not differ from that of the CON diet. The respiratory quotient (CO_2/O_2) data were similar among treatments (1.18 to 1.20), as expected for heavy pigs with a high rate of fat deposition. Retained energy was slightly lower than 40% of the intake energy on average for all diets, with no difference among treatments. The values obtained are consistent with those reported for finishing pigs (Noblet et al., 1994b; Galassi et al., 2004, 2011).

The ME of WECS was 13.48 MJ/kg DM, a value slightly greater than that reported by INRA (1989; 13.04 MJ/kg DM) for a WECS characterized by greater fiber content. The NE of WECS was 9.39 MJ/kg DM. From the values of ME and NE obtained for WECS, the efficiency of transformation of ME to NE was 0.697. This was within the range (0.690 to 0.772) reported by Noblet et al. (1994a) for 61 diets for growing pigs.

Growth and Slaughter Performances

All pigs had excellent health during the study; the feed intake was not depressed by silage inclusion, and no feed residual was observed during the entire study. The growth performance of pigs (Table 5) was not affected by treatment except between wk 7 and 10 when pigs fed the diets containing WECS grew slower and had a lower G:F than those fed the CON diet ($P < 0.05$). Overall growth rate in the whole trial (from 737 to 774 g/d) was greater than that reported by Galassi et al. (2010) for pigs of the same weight

Table 5. Effects of dietary whole-ear corn silage (WECS) level on the growth performance of pigs between 90 and 170 kg BW (42 barrows with 7 replications per diet and 2 barrows per pen)

	Diet[1]			SEM	*P*-value
Item	CON	15WECS	30WECS		
Initial BW, kg	90.1	91.1	89.0	3.6	0.92
Final BW, kg	170.9	168.9	166.5	3.6	0.70
wk 1 to 2 (dietary transition period)					
DMI, g/(kg BW$^{0.75}$·d)	81.4	81.4	80.3	2.7	0.95
ADG, g/d	740	722	745	79	0.98
G:F,[2] g/g	0.300	0.296	0.304	0.032	0.98
wk 3 to 6					
DMI, g/(kg BW$^{0.75}$·d)	76.1	75.2	76.4	2.2	0.94
ADG, g/d	785	760	750	27	0.62
G:F, g/g	0.302	0.296	0.290	0.010	0.68
wk 7 to 10					
DMI, g/(kg BW$^{0.75}$·d)	70.6	70.7	71.2	1.6	0.96
ADG, g/d	738[a]	680[b]	675[b]	17	0.03
G:F, g/g	0.268[a]	0.248[b]	0.247[b]	0.006	0.04
wk 11 to 15					
DMI, g/(kg BW$^{0.75}$·d)	63.6	64.4	64.8	1.2	0.79
ADG, g/d	794	782	777	17	0.76
G:F, g/g	0.282	0.277	0.276	0.006	0.76
wk 3 to 15 (whole feeding trial)					
DMI, g/(kg BW$^{0.75}$·d)	68.9	68.9	69.6	1.6	0.93
ADG, g/d	774	745	737	13	0.14
G:F, g/g	0.283	0.274	0.271	0.005	0.18

[a–b]Within a row, means without a common superscript differ ($P < 0.05$).

[1]CON: control diet with 0% WECS; 15WECS: diet with 15% WECS on a DM basis; and 30WECS: diet with 30% WECS on a DM basis.

[2]ADG:DMI.

Table 6. Slaughter traits and physical-chemical characteristics of the meat (42 barrows with 7 replications per diet and 2 barrows per pen)

	Diet[1]				
Item	CON	15WECS	30WECS	SEM	*P*-value
Slaughter traits					
HCW, kg	140.4	139.1	137.2	3.4	0.79
Dressing proportion, %	82.1	82.3	82.4	0.5	0.97
Back fat thickness, mm	28.1	28.1	30.5	1.6	0.05
LM thickness, mm	62.3	63.9	58.0	0.8	0.06
Carcass lean, %	48.3[a]	48.6[a]	46.8[b]	0.4	0.02
Ham weight, kg	35.8	34.3	34.5	0.8	0.36
Ham proportion, %	25.5	24.7	25.1	0.2	0.07
Ham weight loss,[2] %	20.8	20.5	20.4	0.3	0.64
Loin weight, kg	16.5	16.4	15.7	0.5	0.41
Loin proportion, %	11.8	11.7	11.4	0.2	0.24
Back fat weight, kg	10.3	10.5	10.7	0.3	0.71
Back fat proportion, %	7.3	7.5	7.8	0.2	0.25
Physical-chemical characteristics[3]					
pH 120 min after slaughter	5.5	5.6	5.6	0.1	0.35
Drip loss, %	8.5[b]	8.5[b]	9.5[a]	0.3	0.02
Shear force, N	61.4	60.2	55.0	4.0	0.51
Cooking loss, %	24.1	23.6	24.6	0.7	0.59
Chemical composition					
DM, %	27.1	28.0	27.0	0.4	0.16
CP, % DM	80.5	78.2	80.3	1.5	0.51
Ether extract, % DM	12.8	14.5	11.6	1.6	0.46
Ash, % DM	4.6	4.9	5.0	0.1	0.07

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

[1]CON: control diet with 0% WECS; 15WECS: diet with 15% WECS on a DM basis; and 30WECS: diet with 30% WECS on a DM basis.

[2]Ham weight loss during the first 120 d of seasoning.

[3]On a sample of LM.

and has to be considered very satisfactory considering the intense fat deposition of the final phase of growth.

Fecal samples collected in each pen from animals at 110, 130, and 150 kg BW (with a barn indoor temperature of 16.9°C, 24.6°C, and 23.4°C, respectively) were used to monitor the DM contents and pH of feces. The fecal DM was not different among diets, whereas it slightly increased in the third sampling with respect to the previous collections (28.9% vs. 26.0% and 27.0%, $P < 0.05$; pooled SEM, 1.0%). The 15WECS and 30WECS diets determined a lower fecal pH than the CON diet (7.10 and 7.00 vs. 7.40, $P < 0.05$; pooled SEM, 0.10), and the pH of feces sampled at 150 kg BW was lower than that measured at 130 and 110 kg of BW (6.96 vs. 7.29 and 7.24, $P < 0.05$).

The lower pH of the feces associated with the WECS diets is probably due to intensive fermentation activity in the lower tract of the intestine. Because of the large particle size of the silage, the passage rate of undigested material in the gut may have increased. This could have some implications for the pollution from pig slurry because a lower pH can fix more ammonia, thus reducing its volatilization. The reduction of fecal pH of the heaviest weight of pigs could be due to more intensive fermentation activity in the gut as pigs grow. Indeed, previous studies with heavy pigs (Le Goff and Noblet, 2001; Noblet and Le Goff, 2001; Le Goff et al., 2003; Galassi et al., 2004, 2005, 2007, 2010) demonstrated better fiber utilization in the final part of the growth of finishing pigs.

The slaughter characteristics and the physical-chemical measures of meat samples are reported in Table 6. The carcass proportion was similar among diets, and the average values (82.1% to 83.4%) were close to those found by Galassi et al. (2010) in heavy pigs fed diets with a NDF content ranging from 17.5% to 19.0% DM. The average back fat was similar to that observed in other studies with Italian heavy pigs (Renaville et al., 2010), and the diet with the greatest WECS tended to lead to a higher back fat compared with the other 2 diets (30.5 vs. 28.1 and 28.0 mm, $P < 0.05$). The LMT tended to be lower for the 30WECS diet ($P < 0.05$), and the overall calculated carcass lean proportion for pigs fed the 30WECS diet was lower ($P < 0.05$) than for the other 2 diets (46.8% vs.

48.3% to 48.6%). A greater fat and a lower lean-meat deposition in pigs fed the silage is not easy to interpret, and it could be due to a shortage of AA for protein synthesis.

There were no differences in the weight of the main carcass cuts and proportion. The loss of ham weight at 120 d of seasoning was similar among diets (20% to 21%), and the dietary treatments did not affect physical-chemical characteristics of meat except for a greater drip loss (9.5%; $P < 0.05$) in pigs fed the 30WECS diet compared with the other 2 groups (8.5%). The overall experimental data obtained in both studies indicate that the substitution of corn meal and wheat bran for WECS (up to 30% of DM) to obtain diets with the same fibrous content does not affect, with the exception of P utilization and carcass leanness, nutrient utilization and performance of heavy pigs in the last phase of growth (from 90 to 170 kg BW). By taking care to meet the requirements for P, the use of WECS in the heavy-pig finishing diet can therefore be positively considered in view of a possible reduction of feeding costs.

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