Effect of feeding cereals–alternative ingredients diets or corn–soybean meal diets on performance and carcass characteristics of growing–finishing gilts and boars

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ABSTRACT: Pig-breeding businesses have resulted in global breeding programs that select pigs to perform well on high-energy high-protein diets, which are traditionally based on corn and soybean meal. Nowadays, there is a shift toward diets based on cereals and co-products, therefore, high dietary inclusion of co-products can modify the expected performance of these pigs. The objective of this study was to evaluate the effect of feeding a cereals–alternative ingredients diet (**CA-diet**) compared to a corn–soybean meal diet (**CS-diet**) on the growth performance, feed efficiency, and carcass characteristics of genetically similar growing–finishing gilts and boars. In total, 160 pigs, 80 gilts and 80 boars, coming from 18 litters were used. The pigs were blocked based on litter, to ensure no genetic differences between the 2 treatments. For the starter phase, pigs fed the CA-diet performed in terms of growth, and feed efficiency, as good as the pigs fed CS-diet ($P > 0.05$). For the grower phase, pigs fed the CA-diet had the same ADFI ($P > 0.05$), but a lower daily energy intake (**ADEI**) ($P < 0.001$), and same growth performance ($P > 0.05$) than pig fed the CS-diet, therefore pigs fed the CA-diet were more efficient in terms of residual energy intake (**REI**) ($P < 0.001$). For the finisher phase, interaction between diet and sex had an effect on ADFI ($P < 0.001$), ADEI ($P < 0.001$), ADG ($P = 0.010$), and lipid deposition (**Ld**) ($P = 0.016$). Pigs fed the CA-diet were less efficient than pigs fed the CS-diet, i.e., G:F ($P < 0.001$), RFI ($P < 0.001$), and REI ($P = 0.007$). In general, feeding a CA-diet to pigs showed to improve the ratio between Pd and Ld, especially for boars. Also, pigs fed the CA-diet showed thinner back fat thickness ($P < 0.001$), same loin depth thickness ($P > 0.05$), but lower dressing percentage ($P < 0.001$), than pigs fed the CS-diet.

Key words: carcass characteristics, co-products, feed efficiency, growth performance, pigs

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INTRODUCTION

Corn and soybean meal are the main ingredients in high-energy and high-protein diets for pigs, especially in North and South America, and India, countries where the increment of pork production will predominantly happen (Robinson and Pozzi, 2011). As corn is increasingly used in food and in biofuels, and soybean can be used directly for human consumption and in other growing sectors such as aqua feed, these main ingredients face an increasing demand on the global market, which increases their cost to be used in pork production (Woyengo et al., 2014). On the other hand, Europe due to environmental awareness is looking for strategies to reduce its low self-sufficiency in protein-rich feedstuffs for monogastric feeds (Cooper and Weber, 2012). Different research groups in EU are assessing the potential of relevant crops,

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agro industrial feedstuffs, or biofuels co-products that are rich in protein. Some of the candidates as alternative ingredients are pulses (faba bean, lupins, and pea), forages (alfalfa and clover), and oilseeds (rapeseed and sunflower seed meals). Following this trend, we expected that at least 2 different diets for pigs remain worldwide in the next 5 to 10 yr, a) A corn–soybean meal based diet as it is used nowadays in North and South America, and b) A cereals–alternative ingredients diet (**CA-diet**) as it is common used in EU.

Consolidation of pig-breeding businesses has resulted in global breeding programs that select pigs to perform well on high-input diets. A number of questions arise when the aim is to produce pork by efficiently growing pigs that are fed diets with high inclusions of alternative ingredients. High dietary inclusions of alternative ingredients can modify the expected performance of these pigs. The objective of this study, therefore, was to compare the growth performance, feed efficiency, and carcass characteristics between genetically similar growing–finishing gilts and boars fed a corn–soybean meal diet (**CS-diet**) or a CA-diet.

MATERIALS AND METHODS

Ethic Statement

The data used for this study was collected as part of routine data recording in a commercial breeding program. The Schothorst Feed Research farm is strictly operating in line with the regulations of the Dutch law on protection of animals (Gezondheids- en welzijnswet voor dieren).

Husbandry and Diets

To compare the growth performance, feed efficiency, and carcass characteristics, between pigs fed a CS-diet or a CA-diet (wheat, barley, peas, rapeseed, and sunflower seed meal), 160 pigs, 78 gilts and 82 intact boars, coming from 18 litters were used. Pigs originated from a 3-way crossbreeding structure, where Landrace pigs are crossed with Large White pigs to produce F1 crossbred sows. These crossbred sows in turn are crossed with "synthetic" sires, originated from a Dutch Large White breed, to produce 3-way cross growing–finishing pigs. The 160 pigs were blocked based on litter to ensure no genetic differences between the two treatments, such as that phenotypes are observed on different pigs of the same genetic group under 2 different treatments, in that way genotypic variance is removed and phenotypic variance contains variation due to the environment (i.e., diet) and sex. The 160 pigs were also blocked based on BW and were randomly allocated to the 2 treatments and put on test in 2 batches. Distribution was as follow: 10 pigs per pen (5 gilts and 5 intact boars when possible) and 8 pens per compartment, 1 compartment was used per entrance batch. Resulting in 80 pigs fed the CS-diet and 80 pigs fed the CA-diet. Pigs were allowed a minimal space of 1 m^2 per pigs, and the pens were equipped with 60% concrete floor and 40% slatted floor. All 160 pigs were kept at the experimental facilities of Schothorst Feed Research (Lelystad, the Netherlands).

The diet (CS-diet or CA-diet) was applied to all pigs in a pen according to a 3-phase feeding program and was given *ad libitum*: starter from days 0 to 25 of the trial, grower from days 26 to 67 of the trial, and finisher from days 68 to 107 of the trial.

Experimental diets were produced in the feed plant ABZ Diervoeding, Nijkerk, the Netherlands. CS-diets and CA-diets were formulated on a similar SID Lys:NE ratio (Table 1), the decrease of the SID Lys:NE ratio in grower and finisher diets was mainly achieved by exchanging peas with wheat middlings for the CA-diet, and soybean meal with corn for the CS-diet. Diets were formulated to supply sufficient digestible amino acids in each phase to meet or exceed the nutrient requirements of growing—finishing pigs according to CVB (2011). The provided diets were analyzed to determinate the content of CP, crude fat, and starch, using the following methods: NEN-EN-ISO 16634:2004, NEN-ISO 6492:1999, NEN-ISO 15914:2005, respectively. Net energy (NE) of the diets were estimated according to the NE_v equation described by CVB (2011) based on the analyzed nutrient contents in the diets. Table 1 shows the ingredients and the nutritional content for CS-diet and CA-diet at each phase.

Growth Performance, Feed Efficiency, and Carcass Characteristics

In this study, we evaluated growth performance as ADG (g/d), protein deposition (**Pd**, g/d), and lipid deposition (**Ld**, g/d). For feed efficiency, different definitions to calculate the growth rate accounting for the intake of feed or energy exist, therefore, in this study, we evaluated feed efficiency as G:F, residual feed intake (**RFI**, g/d), and residual energy intake (**REI**, g/d). Carcass characteristics included HCW (kg), back fat thickness (**BF**, mm), loin depth thickness (**LDT**, mm), and dressing percentage (%). Body weight (kg), ADFI (g/d), average daily energy intake (**ADEI**, MJ/d) were also measured or

Table 1. Formulated diet composition and nutrient content for the corn–soybean meal diet (CS-diet) and cereals–alternative ingredients diet (CA-diet) at each of the three phases of the trial, e.g., starter, grower, and finisher (as-fed basis)

	Starter (days 0 to 25)		Grower (days 26 to 67)		Finisher (days 68 to 107)	
Item	CS	CA	CS	CA	CS	CA
Ingredient, g/kg						
Corn	647.1	—	698.4	—	755.1	—
Wheat	—	321.9	—	400.0	—	350.0
Soybean meal (48% CP)	240.5	100.0	180.5	21.5	98.3	—
Barley	—	200.0	—	100.0	—	150.0
Wheat middlings	—	—	—	50.0	—	125.0
Peas	—	120.0	—	29.4	—	—
Rapeseed meal (34% CP)	—	63.0	—	80.0	—	100.0
Sunflower meal (38% CP)	—	80.0	—	80.0	—	21.9
Molasses cane	40.0	30.0	50.0	50.0	50.0	50.0
Corn gluten feed	18.1	—	25.0	50.0	50.0	50.0
Palm kernel meal	—	—	—	50.0	—	50.0
Soybean oil	—	25.0	—	—	—	—
Poultry fat	—	—	—	27.5	—	29.4
Soybean hulls	—	—	—	14.3	—	50.0
AA premix[1]	17.3	12.5	17.3	10.2	16.7	6.7
Limestone	11.6	10.9	9.4	8.9	9.9	4.0
Lys + Trp premix	7.8	4.3	8.3	3.6	9.2	—
Lys HCl (L 79%)	2.4	3.8	2.2	4.3	1.9	3.3
Met (DL 99%)	1.6	1.3	1.4	0.7	0.8	0.1
Thr (L 98%)	1.5	1.7	1.5	1.6	1.5	0.9
Val 10%	—	1.4	—	—	—	—
Monocalcium phosphate	6.7	5.3	2.0	—	0.7	—
Palm oil	5.0	17.3	5.0	16.0	5.0	5.0
Phytase premix[2]	5.0	5.0	5.0	5.0	5.0	1.9
Vitamin-trace mineral premix 1[3]	4.0	4.0	4.0	4.0	4.0	4.0
Salt	2.7	2.1	2.4	1.8	1.8	2.1
Sodium bicarbonate	—	1.1	1.0	1.0	3.4	—
Vitamin-trace mineral premix 2[4]	1.0	1.0	—	—	—	—
Vitamin premix[5]	1.0	1.0	—	—	—	—
Analyzed content, g/kg						
Moisture	117.0	120.0	120.0	119.0	123.0	115.0
Ash	50.5	51.7	41.9	47.0	38.2	42.2
CP	188.0	186.8	164.0	163.0	136.0	144.0
Crude fat	37.0	55.0	41.0	66.0	43.0	60.0
Starch	419.0	366.0	445.0	304.0	479.0	338.0
Calculated composition						
NE, MJ/kg	9.96	9.94	10.14	9.51	10.27	9.50
NSP, g/kg[6]	145.6	171.9	143.6	245.2	141.2	243.6
SID Lys, g/kg	11.10	11.10	9.53	9.10	7.47	6.78
SID Lys:NE	1.11	1.12	0.94	0.96	0.73	0.71
SID Met + Cys, g/kg	6.62	6.62	5.88	5.61	4.62	4.56
SID Thr, g/kg	7.09	7.09	6.31	6.04	5.16	4.71
Dig. P, g/kg	2.99	2.99	2.00	1.94	1.68	1.53
Ca, g/kg	6.89	6.89	5.20	5.50	5.00	3.80

[1]Provided Lys, Met, Thr, Trp, and Val to equalize the dietary contents.

[2]Provided 500 phytase unit phytase/kg.

[3]Supplied per kilogram of premix: 0.4 g of Ca, 15 mg of Cu (copper sulfate), 80 mg of Fe (ferrous sulfate), 24 mg of Mn (manganous oxide), 62 mg of Zn (zinc oxide), 0.04 mg of Co (cobalt oxide), 0.4 mg of I (potassium iodide), 0.2 mg of Se (sodium selenite), 7,500 IU of vitamin A, 1,500 IU of vitamin D_3, 25 IU of vitamin E, 4 mg of vitamin B_2, 6 mg of pantothenate, 30 mg of niacin, 0.02 mg of vitamin B_{12}, and 0.752 mg of vitamin K_3 (Mervit START M220; NuScience, Utrecht, the Netherlands).

[4]Supplied per kilogram of feed: 12 mg of Fe (ferrous sulfate), 10 mg of Mn (manganous oxide), 0.04 mg of Co cobalt oxide), 0.12 g of Ca, 0.0501 g of P, 0.04 mg of I (potassium iodide), 1,000 IU of vitamin A, 100 IU of vitamin D_3, 5 IU of vitamin E, 0.4 mg of vitamin B_1, 0.8 mg of vitamin B_2, 2 mg of pantothenic acid, 4 mg of niacine, 0.4 mg of vitamin B_6, 0.2 mg of folate, 0.003 mg of vitamin B_{12}, 10 mg of vitamin C, 0.01 mg of biotine, 0.2 mg of vitamin K_3, and 40 mg of choline (Mervit Sporavit; PreMervo).

[5]Supplied per kilogram of feed: 2,500 IU of vitamin A, 500 IU of vitamin D_3, and 5 IU of vitamin E (Mervit AD3E; PreMervo, Utrecht, the Netherlands).

[6]NSP (g/kg) = 1,000 − ash − CP − crude fat − starch − sugar * 0.97 − moisture.

calculated. All the traits were measured or calculated for each individual pig.

The experimental facilities of Schothorst Feed Research were equipped with IVOG stations (INSENTEC, Marknesse, the Netherlands), and all the pigs had radio frequency identification ear tags with unique numbering, therefore, individual feed intake records were available for each day of the trial. Body weight was measured at days 0, 26, 54, 68, and 107 of the trial. Back fat thickness measurements were recorded at days 54 and 107 of the trial using an ultrasound instrument (Renco Lean Meater; Renco Corp., Minneapolis, USA). On the day of slaughter, pigs were weighed, transported to a commercial abattoir, and slaughtered according to standard procedures. Carcasses were weighted to determine HCW. Back fat thickness and LDT were measured using a probe named "capteur gras maigre" (**CGM**; Sydel, France), and dressing percentage was calculated as:

$$\text{dressing, \%} = \frac{BW_{end} - BW_{slaughter}}{BW_{end}} \times 100.$$

ADG was calculated as the difference between BW at the beginning and end of each of the phases divided by the length of the phase. Average daily feed intake was calculated as cumulative individual feed intake during the corresponding phase divided by the length of the phase. Average daily energy intake was calculated as ADFI multiplied by the NE provided by the diet. The Pd and Ld were calculated as the increment in protein and lipid mass content between the beginning and the end of each phase. The protein and lipid mass at the beginning and end of each phase was calculated based on individual BW and back fat measurements, as derived by De Greef et al. (1994) and Bergsma et al. (2013):

$$\text{fat}_{end}, \% = \frac{\text{Back fat} - 1.87}{53.3},$$

$$\text{fat}_{start}, \% = \text{fat}_{end} \times \frac{-0.000005(BW_{start})^2 + 0.0019(BW_{start}) + 0.0665}{-0.000005(BW_{end})^2 + 0.0019(BW_{end}) + 0.0665},$$

$$\text{Protein water ratio} = 5.39\,(BW \times 0.14)^{-0.145},$$

$$\text{Ash, g} = 0.03 \times BW,$$

$$\text{Lipid mass, g} = \text{fat} \times 0.95 \times BW,$$

$$\text{Protein mass, g} = \frac{0.95 \times BW - \text{Lipid mass} - \text{Ash}}{\text{Protein water ratio} + 1},$$

$$\text{Ld, g/d} = \frac{(\text{Lipid mass}_{end} - \text{Lipid mass}_{start}) \times 1000}{\text{Test length, d}},$$

$$\text{Pd, g/d} = \frac{(\text{Protein mass}_{end} - \text{Protein mass}_{start}) \times 1000}{\text{Test length, d}}.$$

Gain-to-feed ratio was calculated as the ratio between ADG and ADFI. RFI was obtained as the residual term of the regression (Cai et al., 2008):

$$ADFI = \mu + b_1 BW_{on} + b_2 BW_{off} + b_3 BF + b_4 ADG + b_5 O_{age} + e,$$

in which *ADFI*, *BF*, and *ADG* are described previously, μ is the mean of the pigs, BW_{on} is the BW at the start of each phase, BW_{off} is the BW at the end of each phase, O_{age} is the age at the start of the trial, b_1, b_2, b_3, b_4, and b_5 are the linear coefficients of the regression on covariates, and *e* is the RFI. Residual energy intake represents the efficiency of the energy metabolism and was calculated as a linear function of feed intake, production (Pd and Ld), and maintenance of live weight (Bergsma et al., 2013):

$$\text{Maintenance, kJ/d} = \frac{(BW_{end}^{1.75} - BW_{start}^{1.75}) \times 420}{(BW_{end} - BW_{start}) \times 1.75},$$

$$\text{Production, kJ/d} = (Pd + Ld) \times 53,$$

$$\text{REI, g/d} = \text{Feed intake} - \frac{\text{Maintenance} + \text{Production}}{ME_{diet}, \text{kJ/g}},$$

where ME_{diet} was calculated as (NE_{diet}, kJ/gr)/74 * 100.

Gut Fill

Computation of protein mass or lipid mass of an animal assumes a constant gut fill across experimental treatments. If this assumption is violated, conclusions might not be valid. Different diets might show different water-binding characteristics and different passage rates, yielding a different gut fill. By converting the BW at the end of the trial to an expected body weight (**EBW**) at slaughter, the gut fill is standardized across diets. For that purpose, we corrected the BW at the end of the trial by the dressing percentage ($EBW = BW_{end} \times \text{dressing percentage}/100$). Analysis of the overall period has been performed twice, once using the BW at the end of the trial and once using EBW instead.

Experimental Design and Statistical Analysis

The study was performed as a split-plot design in a 2 × 2 factorial arrangement, factors being diet (CS-diet vs. CA-diet) and sex (intact boars and gilts). Sixteen pens of 10 pigs (5 boars and 5 gilts, when possible) were randomly allocated to the dietary treatments to provide 8 pens for each diet. Individual pigs were considered as the experimental unit. At the beginning of the experiment, pigs were blocked based on litter and based on BW and were randomly allocated to the treatments. At the start of the trial (day 0), the pigs had an average body weight of 22.2 ± 3.1 kg and were 61.5 ± 1.9 days old, and were kept in the facilities until they achieved a slaughter weight of approximately 123 kg.

Observations from individual pigs with studentized residuals greater than |3.5| were considered as outliers and were removed from the analysis. Individual observations were analyzed by analysis of covariance using the following models:

$$X_{ijklm} = \mu + sex_i + diet_j + sex.diet_{ij} + batch_k + b_a OW + pen_l + litter_m + e_{ijklm} \quad (1)$$

$$Y_{ijklm} = \mu + sex_i + diet_j + sex.diet_{ij} + batch_k + b_b BW + pen_l + litter_m + e_{ijklm} \quad (2)$$

$$Z_{ijklm} = \mu + sex_i + diet_j + sex.diet_{ij} + batch_k + b_c HCW + pen_l + litter_m + e_{ijklm} \quad (3)$$

where X_{ijklm} was observed ADG, Pd, or Ld, Y_{ijklm} was observed ADFI, ADEI, G:F, REI, or RFI, Z_{ijklm} was observed BF, LDT, or dressing percentage, for each pig with known *sex i* (*i* = gilt or boar), *batch j* (*j* = 1 or 2), and *diet k* (*k* = CS-diet or CA-diet). μ is the mean across pigs. b_a, b_b, b_c are the regression coefficients for birth weight (*OW*), BW at start of each phase (*BW*), and *HCW*, respectively. Pen_l is the random effect of the l^{th} housing pen assumed to be normally distributed $\sim N(0, \mathbf{I}\sigma^2_{pen})$, $litter_m$ is the random effect of the m^{th} common litter assumed to be normally distributed $\sim N(0, \mathbf{I}\sigma^2_{litter})$, and e_{ijklm} is the random residual term assumed to be normally distributed $\sim N(0, \mathbf{I}\sigma^2_e)$. The R package "lme4" (Bates et al., 2015) was used to fit the linear mixed models and the R package "car" (Fox and Weisberg, 2011) for estimating the *P* values. Least squares means were computed using the R package "lsmeans" (Lenth, 2016) and least squares means were separated by Tukey test using the R package "multcomp" (Hothorn et al., 2008). *P* values lower or equal to 0.05 were considered significant.

RESULTS

From the analyzed content of the diets (Table 1), some differences between the diets were observed. For the starter phase, the CA-diet contained 1.2 g/kg less CP, 18.0 g/kg more crude fat, 53 g/kg less starch, and 0.02 MJ/kg less calculated NE than the CS-diet. At grower phase, the CA-diet contained 1.0 g/kg less CP, 15.0 g/kg more crude fat, 141 g/kg less starch, and 0.63 MJ/kg less calculated NE than the CS-diet. At finisher phase, the CA-diet contained 8.0 g/kg more CP, 17.0 g/kg more crude fat, 141 g/kg less starch, and 0.77 MJ/kg less calculated NE than the CS-diet.

Effects of diet and sex on performance and number of observations per trait are given in Table 2. On average, pigs started the trial at 61.5 days of age and 22.2 kg of BW and finished the trial at 168.9 days of age and 123.0 kg of BW. Pigs put on the CA-diet started on average with 0.5 kg heavier and 0.2 days younger than pigs put on the CS-diet. At the start of the trial, sex had an effect (P = 0.036) on BW, gilts were heavier than boars. For the starter phase, type of diet had an effect on ADEI (P = 0.048), pigs fed the CA-diet was lower than pigs fed the CS-diet. Also, pigs fed the CA-diet had a slightly lower ADFI (P = 0.053). However, we did not observe an effect of type of diet on the growth performance and feed efficiency of pigs. Except for Pd, where interaction between type of diet and sex had an effect (P = 0.011). The gilts fed the CS-diet deposited more protein than the gilts fed the CA-diet, while for the boars, no difference was observed. Sex had an effect on feed efficiency traits, boars had a better G:F (P = 0.02), RFI (P = 0.01), and REI (P = 0.02), than gilts.

For the grower phase, BW was affected (P = 0.041) by the interaction between diet and sex, gilts fed the CS-diet were 1.6 kg heavier than the gilts fed the CA-diet, while for the boars the opposite was observed, boars fed the CA-diet were 0.7 kg heavier than boars fed the CS-diet. No difference was observed between pigs fed the CA-diet and the pigs fed the CS-diet on ADFI. However, NE value of the CA-diet was 0.63 MJ/kg lower than the CS-diet, resulting that type of diet had an effect on ADEI (P < 0.001). Moreover, we did not observe an effect of type of diet on growth performance (i.e., ADG, Pd, Ld). Therefore, feed efficiency in terms of G:F and RFI was not significantly different for both groups of pigs. But, feed efficiency in terms of REI was better (P < 0.001) for pigs fed the CA-diet than pigs fed the CS-diet. Similar to the starter phase, boars were more efficient than gilts, as they showed a greater G:F (P < 0.001) and a lower RFI (P = 0.002), and REI (P = 0.006).

When pigs entered the finisher phase there was no difference in BW between pigs fed the CA-diet or CS-diet, neither between gilts and boars. At the end of the finisher phase there was no difference in BW between pigs fed the CA-diet or CS-diet, neither between gilts and boars, however, pigs put on the CA-diet finished on average with 1.9 days older than pigs put on the CS-diet, and gilts were on

Table 2. Least squares means for type of diet and sex on growth performance and feed efficiency on live weight basis for the starter, grower, finisher phase, and overall, and carcass characteristics at slaughter

	Gilts		Boars		*P* value			
	CS-diet	CA-diet	CS-diet	CA-diet	Diet	Sex	Diet × sex	*n*
Starter phase								
$BW_{starter}$, kg	22.5[a]	22.5[ab]	21.5[b]	22.2[ab]	0.786	**0.036**	0.289	160
ADFI, g/d	1,444	1,325	1,394	1,311	0.053	0.208	0.492	156
ADEI, MJ/d	14.39[a]	13.18[b]	13.89[ab]	13.03[b]	**0.048**	0.208	0.491	156
ADG, g/d	810	759	781	783	0.394	0.827	0.058	157
Pd, g/d	135[a]	125[ab]	128[b]	131[ab]	0.490	0.748	**0.011**	155
Ld, g/d	109	99	111	99	0.142	0.830	0.793	156
G:F	0.57[a]	0.57[a]	0.57[ab]	0.60[b]	0.241	**0.019**	0.240	155
RFI, g/d	49[a]	23[a]	23[a]	−43[b]	0.116	**0.014**	0.309	156
REI, g/d	62[a]	38[ab]	12[ab]	−16[b]	0.312	**0.020**	0.907	154
Grower phase								
BW_{grower}, kg	43.5[a]	41.9[ab]	41.8[b]	42.5[ab]	0.780	0.293	**0.041**	158
ADFI, g/d	2,195	2,210	2,187	2,119	0.463	0.151	0.252	157
ADEI, MJ/d	22.27[a]	21.02[b]	22.19[a]	20.15[b]	**<0.001**	0.156	0.278	157
ADG, g/d	970	963	980	991	0.951	0.252	0.586	155
Pd, g/d	162	161	160	166	0.483	0.418	0.268	155
Ld, g/d	183	180	198	171	0.175	0.747	0.129	156
G:F	0.44[a]	0.44[ab]	0.46[bc]	0.46[c]	0.272	**<0.001**	0.791	156
RFI, g/d	38[ab]	49[a]	−23[ab]	−32[b]	0.958	**0.002**	0.689	157
REI, g/d	191[a]	70[bc]	94[b]	11[c]	**<0.001**	**0.006**	0.482	155
Finisher phase								
$BW_{finisher}$, kg	84.2	82.4	82.8	83.3	0.754	0.845	0.300	158
ADFI, g/d	2,579[a]	3,083[b]	2,829[c]	2,901[c]	**<0.001**	0.560	**<0.001**	155
ADEI, MJ/d	26.51[a]	29.30[b]	29.05[b]	27.55[a]	0.167	0.477	**<0.001**	155
ADG, g/d	931[a]	986[a,b]	1089[c]	1018[b]	0.807	**<0.001**	**0.010**	155
Pd, g/d	155[a]	165[a]	177[b]	174[ab]	0.393	**<0.001**	0.103	155
Ld, g/d	216[a]	226[a]	261[b]	218[a]	0.213	0.086	**0.016**	156
G:F	0.36[a]	0.32[b]	0.39[c]	0.35[a]	**<0.001**	**<0.001**	0.887	157
RFI, g/d	−150[a]	219[b]	−149[a]	98[c]	**<0.001**	0.080	0.067	154
REI, g/d	200[a]	403[b]	130[a]	235[a]	**0.007**	**0.003**	0.213	155
BW_{end}, kg	120.9	123.1	121.6	122.8	0.215	0.853	0.698	156
Overall								
ADFI, g/d	2,180[a]	2,312[b]	2,205[a,b]	2,202[a,c]	0.949	0.582	**0.037**	155
ADEI, MJ/d	22.12[a]	22.22[a]	22.35[a]	21.16[b]	0.100	0.160	**0.044**	155
ADG, g/d	920	920	957	947	0.782	**0.027**	0.742	155
Pd, g/d	153	153	156	159	0.554	**0.049**	0.604	156
Ld, g/d	177[a]	178[ab]	197[b]	170[a]	0.100	0.410	**0.050**	156
G:F	0.42[a]	0.40[b]	0.44[c]	0.43[a]	**0.002**	**<0.001**	0.360	153
RFI, g/d	−20[a]	107[b]	−59[a]	−4[a]	**<0.001**	**<0.001**	0.082	155
REI, g/d	153[a]	181[a]	60[b]	79[b]	0.332	**<0.001**	0.855	155
At slaughter								
HCW, kg	94.36[a]	93.96[a]	92.51[b]	91.59[b]	0.131	**<0.001**	0.495	152
Dressing, %	77.26[a]	75.26[b]	75.09[b]	73.69[c]	**<0.001**	**<0.001**	0.198	146
Back fat, mm	14.47[ab]	14.33[a]	15.12[b]	13.55[c]	**<0.001**	0.966	0.106	151
Loin depth, mm	64.40[a]	65.62[a]	62.64[a]	59.22[b]	0.351	**<0.001**	**0.045**	152

[a–d]Different superscripts in the same row denote a significantly difference between least square means ($P \le 0.05$). The difference was caused by variables with significant effects ($P \le 0.05$) shown as bold values.

ADEI = average daily energy intake, CA-diet = cereals–alternative ingredients diet; CS-diet = corn–soybean meal diet; Pd = protein deposition; Ld = lipid deposition; REI = residual energy intake; RFI = residual feed intake .

BW measurements at the start of each of the three feeding phases: starter ($BW_{starter}$), grower (BW_{grower}), and finisher ($BW_{finisher}$). BW measurements at the end of the trial (BW_{end}). Total number of observations per trait (*n*).

average 2.4 days older than boars. For the finisher phase, interaction between diet and sex had an effect on ADFI ($P < 0.001$), ADEI ($P < 0.001$), ADG ($P = 0.010$), and Ld ($P = 0.016$). Gilts fed the CA-diet consumed more feed, therefore had a higher ADEI than gilts fed the CS-diet. However, ADG and Ld for gilts fed the CA-diet were not greater than for gilts fed the CS-diet. Boars fed the CA-diet did not consume more feed. Because the CS-diet had a higher NE value than the CA-diet, ADEI was greater for boars fed the CS-diet. This difference in ADEI resulted in a higher ADG and Ld of boars fed the CS-diet than boars fed the CA-diet. Only sex had an effect on Pd, boars showed a higher Pd than gilts ($P < 0.001$). Regarding feed efficiency, pigs fed the CS-diet had a better feed efficiency than pigs fed the CA-diet, i.e., G:F ($P < 0.001$), RFI ($P < 0.001$), and REI ($P = 0.007$). Boars were more efficient than gilts, as they showed a higher G:F ($P < 0.001$), and REI ($P = 0.003$).

Considering the overall trial period, interactions between diet and sex were observed. Gilts fed the CA-diet consumed 132 g/d more feed than gilts fed the CS-diet, but there was no difference for ADEI. On the other hand, there was no difference in feed consumption between boars fed the CS-diet and boars fed the CA-diet, therefore ADEI of boars fed the CS-diet was 1.37 MJ/d higher than the boars fed the CA-diet. As a result, interactions between diet and sex had also an effect on Ld ($P = 0.050$), gilts fed the CA-diet only deposited 1 g/d more lipid than gilts fed the CS-diet. While boars fed the CA-diet deposited 27 g/d less lipid than boars fed the CS-diet. For ADG and Pd only sex had an effect, boars showed higher ADG ($P = 0.027$) and Pd ($P = 0.049$) than gilts. For feed efficiency, CS-diet had a positive effect on efficiency when measured as G:F ($P = 0.002$) and RFI ($P < 0.001$), but no effect when feed efficiency was measured as REI. And boars showed a better efficiency, i.e., G:F ($P < 0.001$), RFI ($P < 0.001$), and REI ($P < 0.001$), than gilts.

At slaughter, pigs fed the CA-diet had 1.22 kg heavier HCW, although not significantly different to pigs fed the CS-diet, and 1.7% less dressing percentage ($P < 0.001$) than pigs fed the CS-diet. Regarding the carcass composition, pigs fed the CA-diet had on average 0.3 mm less BF ($P < 0.001$), but no difference in loin depth compared to pigs fed the CS-diet. As mentioned before, CS-diet fed pigs tend to have a higher Ld, and therefore at slaughter we observed a significantly thicker BF ($P < 0.001$). Regarding sex, gilts showed heavier HCW ($P = 0.015$), higher dressing percentage ($P < 0.001$), and thicker loin depth ($P < 0.001$) than boars.

Effects of diet and sex on performance when BW were corrected for gut fill for the overall trial period are given in Table 3. When corrected for gut fill, significant differences were observed for BW between sexes ($P = 0.030$), and sex had no longer an effect on ADG, Pd, G:F, and REI. However, when BW were corrected for gut fill, we observed a significant improvement in ADG and REI when feeding the CS-diet compared to CA-diet, i.e., ADG ($P = 0.031$) and REI ($P < 0.001$). The interaction between type of diet and sex remained having an effect on Ld ($P = 0.011$).

DISCUSSION

For the starter phase, the crude fat content in the CA-diet was greater than in the CS-diet because of the addition of soybean oil and palm oil in the CA-diet to increase its NE value and to achieve a similar NE value to the CS-diet. Even both diets having similar NE values at the starter phase, the ADEI of pigs fed the CA-diet was lower than pigs fed the CS-diet. The ADEI was limited because pigs fed the CA-diet had a slightly lower ADFI. A reason for the lower ADFI by the pigs fed the CA-diet,

Table 3. Least squares means for type of diet and sex on growth performance and feed efficiency on dressed weight basis for the overall trial

	Gilts		Boars		*P* value			
	CS-diet	CA-diet	CS-diet	CA-diet	Diet	Sex	Diet × sex	*n*
Overall								
EBW, kg	93.26[a,b]	93.92[a]	92.35[a,b]	91.04[b]	0.747	**0.030**	0.263	148
ADG, g/d	662[a,b]	655[a,b]	681[a]	643[b]	**0.031**	0.723	0.149	148
Pd, g/d	110	108	110	108	0.344	0.883	0.881	148
Ld, g/d	131[a]	133[a,b]	146[b]	122[a]	0.170	0.735	**0.011**	148
G:F	0.31[a]	0.28[b]	0.31[c]	0.29[a]	**<0.001**	0.197	0.269	148
REI, g/d	585[a]	707[b]	575[a]	640[a,b]	**<0.001**	0.162	0.284	148

[a–d]Different superscripts in the same row denote a significantly difference between least square means ($P \leq 0.05$). The difference was caused by variables with significant effects ($P \leq 0.05$) shown as bold values.

Total number of observations per trait (*n*). CS-diet = corn–soybean meal diet; CA-diet = cereals–alternative ingredients diet; EBW = expected live weight, Ld = lipid deposition; Pd = protein deposition; REI = residual energy intake.

could be the limited gut capacity. According to Whittemore et al. (2001), the capacity of the gut is a function of its size and the rate of throughput of digesta. Gut size is related to the extent of habituation of the intestine to diets of low nutrient density and the size of the animal (Whittemore et al., 2001). Tybirk (1989) suggested that at 20 kg live weight pigs will be able to eat to 0.95 of their energy capacity when offered a diet of 13 MJ ME/kg. Corn–soybean meal diet provided 13.46 MJ ME/kg and CA-diet provided 13.43 MJ ME/kg, therefore, at this age pigs are not able to accommodate feed intake to satisfy their energy capacity because of size limitations. Rate of throughput of digesta is related to diet digestibility (Whittemore et al., 2001). Cereals–alternative ingredients diet had higher content of nonstarch polysaccharides (**NSP**), 26.3 g/kg more than the CS-diet, which can limit feeding capacity as soluble fiber sources increase digesta retention time, although, it has not been proven that high levels of NSP in diets reduces voluntary feed intake (Pluske et al., 1998; Molist et al., 2014).

The growth performance results indicate that the lower energy intake of the pigs fed the CA-diet was enough to cover for maintenance and production. We observed no difference in Pd for the pigs fed the CA-diet compared to the Pd achieved by the pigs fed the CS-diet, indicating that a maximum Pd was achieved by both diets, and the extra energy available in the CS-diet was deposited as lipid, although Ld was not significantly higher than for the CA-diet. Availability of digestible lysine and other essential amino acids were similar between the two diets; therefore, there were no limiting factors for causing differences in Pd (Susenbeth, 1995). Pigs fed the CA-diet used the energy supplied more efficiently. However, when feed efficiency is measured as G:F and RFI, no significant difference can be observed between the diets.

For the finisher phase, growth performance was similar to the grower phase, when extra energy was available it was deposited as lipid. However, gilts fed the CA-diet had the highest ADFI and ADEI, but they did not have the greatest growth performance. The high content of NSP provided by the CA-diet could reduce lipid absorption due to a partial inhibition of both lipolysis and intestinal fat absorption (Kerr and Shurson, 2013). Energetic efficiency of utilization of different ingredients varies in growing pigs. For starch and lipid, the proportion of ME used for Ld is 0.84 and 0.88, respectively (van Milgen et al., 2001). Similar, for starch and NSP, the proportion of DE used to Ld was 0.52 and 0.44, respectively (Halas et al., 2010). Energy for both diets came mainly from starch, however, CA-diets contained less than CS-diet, but contained higher NSP and crude fat compared to the CS-diet.

For carcass characteristics, we observed lower dressing percentage in pigs fed the CA-diet. Similar, Siljander-Rasi et al. (1996) observed that the dressing percentage of the pigs decreased linearly when soybean meal was replaced by rapeseed meal. The lower dressing percentage observed in pigs fed the CA-diet might be related to the fact that CA-diet stimulates more the growth of the gastrointestinal tract (**GIT**) due to a greater content of NSP. This means that, at slaughter, the GIT of pigs fed the CA-diet was larger than the GIT of pigs fed the CS-diet. Similar, Pluske et al. (1998) observed that NSP content of a wheat/barley diet compared to a diet based on sorghum/animal-protein/soybean meal, had an effect on digesta viscosity increasing intestinal growth and decreasing dressing percentage. As explained by Whittemore et al. (2001), the size of the gut is related to the extent of habituation of the intestine to diets of low nutrient density and low rate through output. Moreover, CS-diet fed pigs tend to have a higher Ld, and therefore at slaughter we observed a significantly thicker BF. Siljander-Rasi et al. (1996) did not observe differences in BF and LDT when soybean meal was replaced by rapeseed meal. Even after correcting for gut fill, no difference was observed for Pd and boars fed the CS-diet remained having a larger Ld than boars fed the CA-diet.

Although diets were formulated to have a similar nutritional level, and pigs allocated in the two treatments were genetically similar, we observed different responses of the pigs when fed different diets. In general, we observed that boars fed the CA-diet had a higher ratio between Pd and Ld than boars fed de CS-diet, while for gilts there was no difference in the ratio between Pd and Ld. Boars fed the CS-diet tend to have a reduced Pd, although not significant, but a significantly higher Ld, and therefore at slaughter they had a significantly greater BF. These results show that once a maximum of Pd is achieved no more protein is deposited although more energy is available. Because the minimal requirement in CP, NE, and amino acids was met during the whole trial in both diets, we expect that the maximum Pd was always achieved and, depending on the diet, the extra energy was deposited as lipid following the expectation of protein and Ld observed by De Greef et al. (1994) and Quiniou et al. (1996) in growing pigs. From the grower and finisher phase, we observed that if pigs are fed a CS-diet, the extra energy is easily deposited as lipid, while for pigs fed a CA-diet this deposition is limited. At the end, these differences from the diets are reflected in thicker BF when pigs are fed the CS-diet, and in a lower dressing percentage when pigs are fed the CA-diet.

CONCLUSION

We concluded that feeding a diet with high inclusion of alternative ingredients to growing–finishing pigs showed to improve the proportion of Pd to Ld, especially for boars. Inclusion of alternative ingredients during the grower phase improved REI, but not during the finisher phase. Pigs fed the diet with high inclusion of alternative ingredients showed thinner BF, but lower dressing percentage, than pigs fed the CS-diet. For all feed-efficiency traits and during all the phases, boars were significantly more efficient than gilts.

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