JOURNAL OF ANIMAL SCIENCE
The Premier Journal and Leading Source of New Knowledge and Perspective in Animal Science

**Feed preference in pigs: Relationship between cereal preference and nutrient composition and digestibility**

D. Solà-Oriol, E. Roura and D. Torrallardona

*J ANIM SCI* 2014, 92:220-228.
doi: 10.2527/jas.2013-6791 originally published online December 18, 2013

# Feed preference in pigs: Relationship between cereal preference and nutrient composition and digestibility[1]

D. Solà-Oriol,*[2] E. Roura,†[3] and D. Torrallardona*[4]

*Animal Nutrition, Institut de Recerca i Tecnologia Agroalimentàries (IRTA), E-43120 Constantí, Tarragona, Spain; and †Lucta SA, E-08170 Montornés del Vallès, Barcelona, Spain

**ABSTRACT:** The present work aimed to identify the nutritional characteristics that best explain cereal feed preference in pigs. A total of 25 cereals of known preference (at 60% of inclusion in complete feed) from a previous study were evaluated. The cereals were analyzed for DM, OM, crude fiber, ether extract, CP, GE, digestible starch, and glycemic index. Additionally, for 12 of the cereals, complete feeds (the same composition as those previously used to measure preference) were prepared, analyzed for DM, OM, CP, and starch, and fed to pigs (33 ± 5.1 kg BW) fitted with ileal T-cannulae to assess the apparent ileal (AID) and total tract digestibility (ATTD) of these nutrients using titanium dioxide as an indigestible marker. The relationships among the different energy and nutrient contents were studied by principal component (PC) analysis, and the correlations between the generated PC scores and cereal preference were analyzed. A correlation between preference and the second PC obtained with data of the 25 cereals was observed ($P < 0.01$), which indicated that crude fiber (negatively) and digestible starch, OM, and glycemic index (positively) were correlated with feed preference. Statistically significant linear relationships with preference were confirmed for crude fiber, digestible starch, and glycemic index ($R^2 = 0.38$, 0.36, and 0.23, respectively; $P < 0.02$). Similarly, the first PC obtained with data of the 12 feeds also correlated with preference ($P < 0.01$), indicating that the digestible nutrients (positively) and the nondigestible nutrients (negatively) were correlated with preference. Statistically significant relationships with preference were observed for the contents of starch (total, digestible AID, and digestible ATTD: $R^2 = 0.62$, 0.66, and 0.63, respectively; $P < 0.01$), AID DM (digestible and nondigestible: $R^2 = 0.41$ and 0.44, respectively; $P < 0.05$), ATTD DM (digestible and nondigestible: $R^2 = 0.67$ and 0.70, respectively; $P < 0.01$), AID OM (digestible and nondigestible: $R^2 = 0.45$ and 0.43, respectively; $P < 0.05$), and ATTD OM (digestible and nondigestible: $R^2 = 0.64$ and 0.66, respectively; $P < 0.01$). It is concluded that cereal preference in pigs is positively related with their content in digestible nutrients, such as starch, and negatively related with their nondigestible nutrients, such as crude fiber.

**Key words:** cereal, digestibility, nutrient availability, preference, pigs



J. Anim. Sci. 2014.92:220–228
doi:10.2527/jas2013-6791

## INTRODUCTION

Feed preference (i.e., relative intake of a given feed when offered as double choice with a reference feed) may be an important factor to facilitate the initiation to dry feeding in weanling pigs (Solà-Oriol et al., 2009a). Taste and olfaction have evolved to associate the nutritional values of feeds with pleasant or unpleasant sensations, thus affecting feed choice. In pigs, sweet and umami tastes are evoked by simple carbohydrates and several L-AA, respectively, while toxic and antinutritional compounds elicit a bitter taste (Roura, 2011). Feed's physical

[1]This study was supported by CICYT (Project AGL2005-07438-C02-02/GAN; Ministry of Science and Education, Madrid, Spain) and CDTI (Project 050369; Spanish Innovation Agency, Ministry of Industry Tourism and Trade, Madrid, Spain). The authors acknowledge the support received from S. Pujol and T. van Kempen for the glycemic index determination and IRTA's laboratory and farm staff.

[2]Current address: Servei de Nutrició i Benestar Animal (SNiBA), Departament de Ciència Animal i dels Aliments, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Barcelona, Spain.

[3]Current address: Centre for Nutrition and Food Sciences, Queensland Alliance for Agriculture and Food Innovation, University of Queensland, Brisbane, QLD 4072, Australia.

[4]Corresponding author: david.torrallardona@irta.es

Received June 11, 2013.
Accepted November 5, 2013.

properties affecting texture or gut wall distention may also affect feed intake and preference (Lepionka et al., 1997; Solà-Oriol et al., 2009b). Finally, dietary nutrients generate feedback signals that regulate feed intake; therefore, starch digestibility and glucose release may play an important role.

Our group has evaluated the pig's preference for 25 cereals (as part of a complete feed) with double choice comparisons using a reference feed with rice (Solà-Oriol et al., 2009c). As no correction for nutrient composition was made when preparing the test feed by replacing rice in the reference feed for the cereal being evaluated, preference may be attributed to the cereal's sensorial, nutritional, or physical properties. Sensorial and physical effects on feed preference have been described (Solà-Oriol et al., 2009b; Roura, 2011), but the relevance of different nutrients on feed preference remains unclear.

The aim of this work was to study the effect of the nutrient composition and digestibility of the cereals on the previously observed preferences. The nutrient composition of the same 25 cereals used previously was analyzed and its correlation with preference was studied. In addition, the nutrient's apparent ileal (**AID**) and total tract digestibility (**ATTD**) in 12 of these cereals were measured, and the correlations between their digested and nondigested nutrient contents and preference were also evaluated.

## MATERIALS AND METHODS

Animal trials were conducted at the Animal Nutrition Unit of Institut de Recerca i Tecnologia Agroalimentàries (**IRTA**, Constantí, Spain) after approval by IRTA's Ethical Committee on Animal Experimentation.

### *Cereals and Feeds*

The purpose of study was to evaluate 25 cereals previously tested for preference (as part of complete feeds) in pigs (Solà-Oriol et al., 2009c). Nutrient composition of the 25 cereal sources was analyzed and its relationship with the reported preference at 60% inclusion in feed was studied. In addition, for 12 of the cereals (those with the exact same batch used to measure preference still available at the start of the study), experimental complete feeds were formulated to contain test cereal (60%), soybean meal (20%), wheat bran (13%), sunflower oil (3%), and AA, vitamins, and minerals (4%), as for the previous preference study. Titanium dioxide was added on top of the feeds (5 g/kg) as an indigestible marker. Experimental feeds were offered to pigs in mash form. Details on the preparation of the diets and the processing of the cereals have been described in Solà-Oriol et al. (2009c). The apparent ileal and total tract energy and nutrient digestibilities for these 12 feeds were evaluated and their relationship with preference was also studied.

### *Analysis of Cereals*

The cereals' DM, ash, crude fiber (**CF**), ether extract (**EE**), and CP contents were analyzed previously (Solà-Oriol et al., 2009c). Cereals were further analyzed for GE with an adiabatic bomb calorimeter C-400 (IKA, Staufen, Germany; DIN 51900).

For each cereal, in vitro release of glucose over time was estimated using a digestibility model consisting of an initial incubation at 39°C of a sample of 1 g of cereal with pepsin (reference P-7000; Sigma, St. Louis, MO) for 30 min followed by 240 min of incubation with pancreatin (reference P-7545; Sigma). Aliquots from the pancreatin incubation were obtained at 0.5, 20, 60, 120, and 240 min, added into absolute ethanol, and centrifuged for 5 min at 500 × *g* at room temperature. Glucose content in the supernatant was then quantified according to the glucose hexokinase/glucose-6-phosphate dehydrogenase colorimetric assay (996.11; AOAC Int., 2000). Glycemic index was calculated as the maximal glucose release rate per minute, and digestible starch was obtained from the plateau value of the predicted data obtained after fitting the glucose release values to the Chapman Richards model (van Kempen et al., 2010).

### *Digestibility of Feeds*

Thirty-six pigs (Landrace × Pietrain; approximately 25 kg BW) were subjected to surgery after 15 h of feed deprivation. Pigs were anesthetized with a mixture of 5% isofluorane (Isoba vet; Schering-Plough, S.A, Madrid, Spain) and oxygen using a mask, and they were intubated and anesthesia was maintained with 2 to 3% isofluorane in a closed-circuit system. The pigs were fitted with a simple T-cannula at the terminal ileum following an adaptation of previously reported procedures (Walker et al., 1986; Stein et al., 1998). After surgery, pigs were supervised until they were fully awake, and they were moved to fully slatted individual pens in a room provided with automatic heating and forced ventilation. As a prevention measure, pigs were treated with 2 mL of an antibiotic solution (Shotapen L. A.; 0.1 MUI/mL procaine penicillin, 0.1 MUI/mL benzathine penicillin, and 0.2 g/mL dihydrostreptomycin sulfate; Virbac España, S.A., Barcelona, Spain) for 5 d and with 0.3 mg buprenorphine (Buprex; Schering-Plough, S.A, Madrid, Spain) for 3 d after surgery. After a recovery period of at least 2 wk, the pigs were used to conduct the digestibility measurements at an initial BW of 33 ± 5.1 kg. The AID and ATTD of the 12 experimental feeds were measured. Pigs were meal-fed twice daily (0800 and 2000 h) to meet 2.4 times the maintenance energy requirement (106 kcal ME/kg of $BW^{0.75}$; NRC, 1998). Feeds were offered according to a crossover design with 4 experimental periods, providing 12 observations for each feed, as each feed was offered to

3 pigs during each period. Each period consisted of 7 d:4 d of adaptation followed by 1 d of feces collection and 2 d of ileal digesta collection (fresh feces and ileal digesta continuously sampled between 0800 and 2000 h) and frozen (–20°C) as soon as possible during collection. The whole amount of feces and digesta obtained from each pig was pooled, freeze-dried, and homogenized before sampling and analysis. Pigs were weighed at the start of each experimental period to adjust feed intake.

Feed, ileal digesta, and feces were analyzed according to AOAC Int. (2000) for DM, ash, CP (only feed and ileal digesta), total starch, and titanium dioxide. The DM content was analyzed by drying the samples for 4 h at 103°C (925.09; AOAC Int., 2000), ash in a muffle oven at 525°C for 3 h (923.03; AOAC Int., 2000), and CP (N × 6.25) by the Dumas method with a nitrogen analyzer (FP528; Leco, St. Joseph, MI; 968.06; AOAC Int., 2000). Total starch was measured as glucose released after 1 h incubation with thermostable α-amylase (reference A-4551; Sigma) at 100°C and 6 h incubation with amyloglucosidase (reference A-9913; Sigma) at 60°C. Glucose in the soluble fraction was measured by the glucose exokynase/glucose-6-phosphate dehydrogenase colorimetric assay (996.11; AOAC Int., 2000). The starch content was calculated using a 0.9 conversion factor (Englyst et al., 1999). Titanium dioxide was determined following the methodology described by Short et al. (1996).

### *Calculations and Statistical Analysis*

Apparent ileal digestibility and ATTD were calculated based on the nutrient and titanium dioxide contents of ileal digesta or feces relative to dietary contents using the index method (Adeola, 2001). Digestibility values for each cereal diet were compared by ANOVA using the GLM procedure of SAS (9.2; SAS Inst. Inc., Cary, NC). The following mathematical model was used:

$$Y_i = \mu + \alpha_i + \varepsilon_i,$$

in which $Y_i$ is the ileal or total tract digestibility for the observations of cereal source $i$, μ is the general mean of all observations, $\alpha_i$ is the effect of the feed cereal source, and $\varepsilon_i \sim N(0,\sigma^2_\varepsilon)$ is the unexplained random error. The α level used for the determination of significance was set at 0.05. Differences between means were compared using the Tukey's studentized range test. The contents of digestible and nondigestible nutrients of the cereal based diets (values not shown) were calculated from the corresponding analyzed nutrient content and ileal and total tract digestibility values.

Because many of the variables studied are not independent, the relationships among nutrient contents in cereals or in feeds were investigated with principal components (**PC**) analysis using the PRINCOMP procedure of SAS. The relationship between the newly generated independent variables (scores for PC with an eigenvalue larger than 1.0) and the previously reported feed preference values were studied by Spearman correlation analyses using the CORR procedure of SAS. The linear relationships between selected nutrients (representative of the main variability of principal components showing significant correlations with preference) and feed preference were also analyzed using the REG procedure of SAS.

One of the feeds, containing 1 of the sources of raw oats (source 2), resulted in persistent blockage problems of the T-cannula. It was considered that the samples of ileal digesta obtained were not representative and, therefore, this cereal was not included in the calculations of ileal digestibility and PC analysis.

## RESULTS

### *Nutrient Composition of Cereals*

The analyzed nutrient composition of the cereals studied and their previously reported in vivo preference values as part of complete feed in pigs (expressed as percent contribution of feeds with 60% cereal to total intake when offered as double choice vs. a common reference feed with 60% white rice) is shown in Table 1. The PC analysis of these data resulted in a negative correlation between starch and CF and a strong covariation among DM, EE, and GE (Fig. 1). This graph also shows different characteristics for rice sources, oats, and dehulled oats (i.e., naked oats or dehulled thick rolled oats) despite a considerable variability within each group. The first 3 PC had eigenvalues above 1 (3.80, 1.63 and 1.08, respectively) and explained 47.5, 20.3, and 13.5% of total variability, respectively. The correlations of their scores with the previously reported in vivo preference values as part of complete feeds are presented in Table 2. Only PC2 scores showed a correlation ($P < 0.01$); therefore, CF (negatively) and digestible starch, OM, and glycemic index (positively) are the main nutrients correlated with feed preference (Fig. 1). Among these, CF, digestible starch, and glycemic index showed a linear relationship with feed preference (Fig. 2; $R^2 = 0.38$, 0.36, and 0.23, respectively; $P < 0.02$).

### *Nutrient Composition and Digestibility of Feeds*

The analyzed nutrient composition of the feeds studied is shown in Table 3 and their corresponding AID and ATTD are shown in Table 4. Dry matter and OM AID were greatest for the feeds with long-grain rice whereas CP AID was greatest for the feed with

**Table 1.** Analyzed energy and nutrient contents and glycemic index of the cereals studied and their correlation with in vivo preference values in pigs fed complete diets containing 60% of the corresponding cereal, as-fed basis

| Cereal | Description | DM,[1] % | OM,[1] % | Crude fiber,[1] % | Fat,[1] % | CP,[1] % | GE,[1] MJ/kg | Digestible starch,[2] % | Glycemic index,[3] % Glu/min | Preference,[4] % of total feed intake |
|---|---|---|---|---|---|---|---|---|---|---|
| Rice (short-grain) | White raw (reference) | 86.1 | 85.6 | 0.3 | 0.6 | 7.1 | 15.6 | 74.7 | 1.16 | 50.0 |
| Rice (short-grain) | Unhulled raw | 87.5 | 83.9 | 8.2 | 2.3 | 6.6 | 16.0 | 54.8 | 1.11 | 10.8 |
| | Brown raw | 86.7 | 85.2 | 0.8 | 2.6 | 7.6 | 16.1 | 68.5 | 1.18 | 45.6 |
| | White extruded | 88.9 | 88.1 | 0.2 | 0.3 | 7.2 | 16.3 | 74.7 | 1.70 | 52.3 |
| Rice (long-grain) | White raw | 87.7 | 86.8 | 0.4 | 1.2 | 8.9 | 15.9 | 70.8 | 1.11 | 43.5 |
| | White cooked | 87.7 | 86.2 | 0.6 | 1.3 | 7.4 | 16.1 | 70.8 | 1.40 | 27.9 |
| Barley | Raw | 90.9 | 88.3 | 4.6 | 1.8 | 11.9 | 16.7 | 51.3 | 0.76 | 22.8 |
| | Extruded | 89.7 | 87.6 | 3.8 | 2.0 | 10.0 | 16.8 | 51.4 | 1.46 | 25.8 |
| Corn | Raw (source 1) | 88.7 | 87.5 | 1.3 | 3.9 | 8.2 | 16.6 | 61.0 | 0.76 | 11.3 |
| | Raw (source 2) | 87.5 | 86.3 | 1.5 | 4.1 | 7.3 | 16.8 | 55.9 | 0.71 | 8.4 |
| | Extruded | 89.0 | 87.3 | 1.4 | 2.8 | 9.6 | 16.7 | 60.4 | 1.54 | 33.6 |
| Wheat | Raw | 89.8 | 88.2 | 2.8 | 1.5 | 13.1 | 15.5 | 57.0 | 0.90 | 21.7 |
| | Extruded | 88.5 | 86.8 | 1.7 | 1.5 | 11.4 | 16.4 | 57.5 | 1.55 | 23.5 |
| Cassava | Pellets | 88.0 | 81.0 | 5.9 | 0.7 | 2.4 | 14.6 | 58.3 | 1.50 | 21.8 |
| Biscuit meal | Bakery by product | 90.5 | 84.3 | 1.3 | 8.6 | 9.5 | 17.4 | 46.6 | 1.38 | 18.4 |
| Rye | Raw | 88.6 | 87.3 | 1.9 | 1.5 | 9.7 | 16.5 | 51.0 | 1.14 | 29.1 |
| Sorghum | Raw | 86.7 | 85.3 | 1.2 | 2.9 | 7.7 | 16.4 | 60.5 | 0.72 | 11.2 |
| Oats | Raw (source 1) | 89.5 | 87.5 | 12.6 | 5.2 | 10.2 | 17.8 | 34.3 | 0.94 | 3.0 |
| | Raw (source 2) | 87.2 | 84.6 | 8.5 | 2.7 | 9.7 | 16.8 | 45.2 | 1.20 | 6.6 |
| | Raw (source 3) | 90.0 | 88.1 | 9.1 | 3.8 | 11.9 | 17.9 | 43.5 | 0.90 | 8.3 |
| | Thick rolled (source 2) | 88.9 | 87.1 | 1.0 | 5.3 | 12.5 | 17.4 | 54.8 | 1.63 | 34.2 |
| | Cooked (source 3) | 90.0 | 87.2 | 9.2 | 5.9 | 11.8 | 18.2 | 38.1 | 1.47 | 6.9 |
| Naked oats | Raw | 87.8 | 86.3 | 1.9 | 6.7 | 13.7 | 17.9 | 53.8 | 1.26 | 42.2 |
| | Extruded | 89.8 | 88.1 | 1.2 | 7.9 | 11.2 | 17.8 | 57.8 | 1.55 | 81.8 |
| | Micronized | 90.7 | 88.9 | 2.2 | 7.7 | 13.3 | 18.4 | 50.8 | 1.48 | 25.0 |

[1]Data obtained from a previous trial (Solà-Oriol et al., 2009c).

[2]Calculated from glucose release plateau in an in vitro digestibility system (van Kempen et al., 2010).

[3]Calculated as the maximal glucose release rate per minute using an in vitro digestibility system (van Kempen et al., 2010).

[4]Previously reported in vivo preference values expressed as percentage of total intake accounted by a diet with 60% cereal when offered to pigs in a double choice experiment against a common reference diet containing 60% raw white rice (Solà-Oriol et al., 2009c).

dehulled thick rolled oats. The feed containing barley presented the lowest AID for DM, OM, and CP. The barley and the sorghum feeds had the lowest starch AID ($P < 0.05$) followed by the short-grain white rice feed ($P < 0.05$, except 1 source of raw oats). The remaining feeds had starch AID above 98% that did not differ among them. Total tract apparent digestibilities for DM and OM were greatest for the diets containing rice and dehulled oats (i.e., naked and thick rolled oats) and lowest for the feed with cooked hulled oats. Starch ATTD was close to 100% for all feeds, and only the feeds containing barley, sorghum, and 1 source of raw hulled oats had slightly lower values (98.9, 98.8, and 99.3%, respectively).

**Table 2.** Correlation between the principal component scores obtained from the analysis of the nutrient composition of cereals and the corresponding in vivo preference values of feeds containing 60% cereal[1]

| Principal component | *r* | *P*-value |
|---|---|---|
| 1 | –0.28 | 0.18 |
| 2 | 0.82 | <0.01 |
| 3 | 0.22 | 0.30 |

[1]Spearman correlation coefficients between the scores of principal components with an eigenvalue larger than 1.0 and previously reported feed preference values; $n = 25$.

The PC analysis of the total nutrient contents of the feeds as well as the corresponding calculated contents of digestible and nondigestible nutrients showed negative correlations between the content of digestible and nondigestible nutrients and a strong covariation between OM and DM values for digestible and nondigestible at the ileal and the fecal levels as well as for total and digestible starch (Fig. 3). This figure also confirms the observations for the cereal analyses showing different characteristics for rice, oats, and dehulled oats (i.e., naked oats or dehulled thick rolled oats) based feeds. The first 4 PC had eigenvalues above 1 (10.76, 3.92, 1.48, and 1.25, respectively) and explained 59.8, 21.8, 8.2, and 6.9% of total variability, respectively. The correlation of their scores with the previously reported in vivo preference values as part of complete feed are

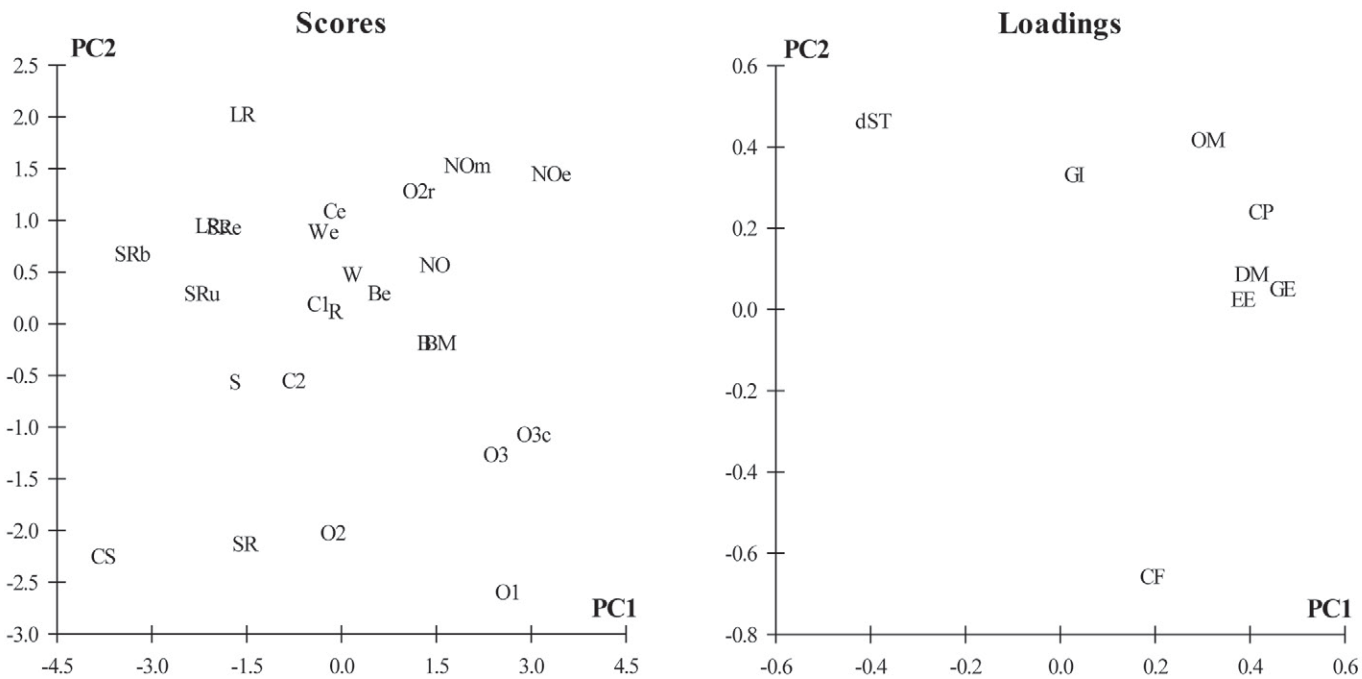


**Figure 1.** Principal component (PC) analysis of the nutrient composition (DM; OM, CF = crude fiber, EE = fat, CP, GE = gross energy, dST = digestible starch, and GI = glycemic index) of the 25 cereals (SR = short rice, LR = long rice; B = barley, C = corn, W = wheat, CS = cassava, BM = biscuit meal, R = rye, S = sorghum, O = oats; NO = naked oats, 1 = source 1, 2 = source 2, 3 = source 3, b = brown, e = extruded, c = cooked, r = thick rolled, and m = micronized). The PC1 explained 47.5% of the total variation, and PC2 explained 20.3% of the variation. Scores: orientation of the cereals relative to the PC. Loadings: orientation of the nutrient concentrations relative to the PC.

presented in Table 5. Only PC1 showed a correlation; therefore, the digestible nutrients (positively) and the nondigestible nutrients (negatively) are the main nutrients correlated with feed preference (Fig. 3). Among these, statistically significant relationship with feed preference were observed for the total and the digestible (AID and ATTD) starch contents ($R^2$ = 0.62, 0.66, and 0.63, respectively; $P < 0.01$) and the digestible and nondigestible (AID and ATTD) contents of DM ($R^2$ = 0.41 and 0.44, respectively, for AID, $P < 0.05$; and $R^2$ = 0.67 and 0.70, respectively, for ATTD, $P < 0.01$) and OM ($R^2$ = 0.45 and 0.43, respectively, for AID, $P < 0.05$; and $R^2$ = 0.64 and 0.66, respectively, for ATTD, $P < 0.01$). Data for digestible starch and DM and nondigestible DM are presented in Fig. 4 as examples for these relationships.

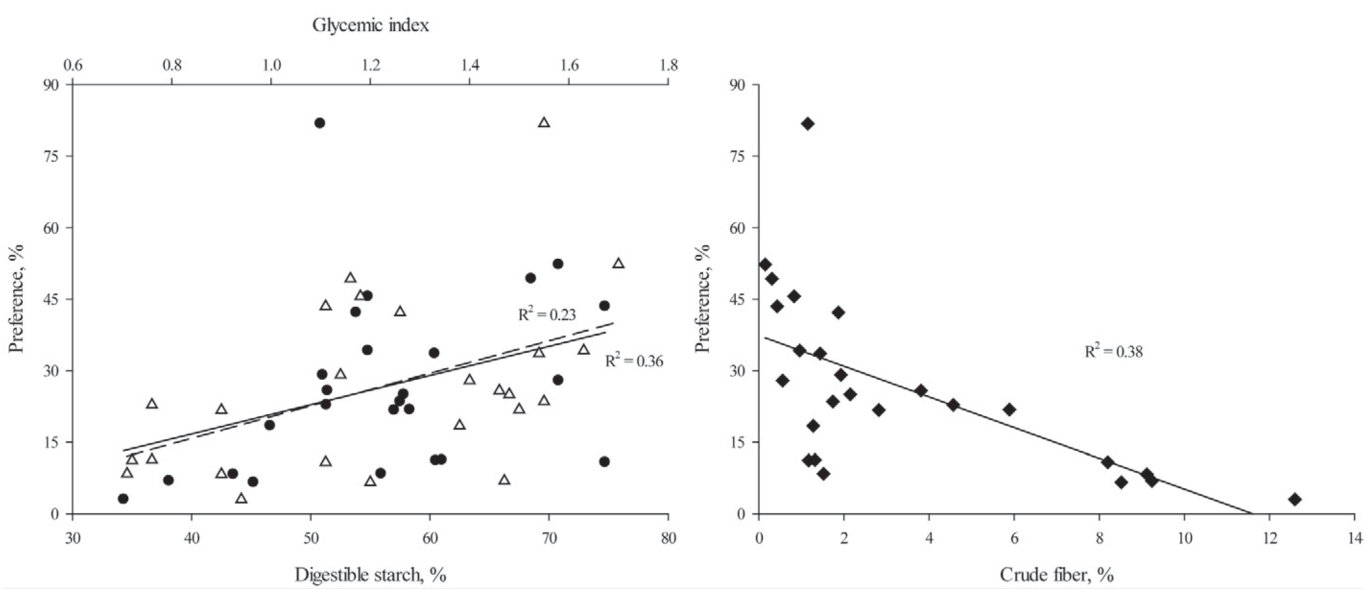


**Figure 2.** Regression between contents of digestible starch (circles), glycemic index (triangles) and crude fiber (diamonds) in cereals, and their previously reported feed preference values.

**Table 3.** Nutrient composition of feeds (%) containing 60% of the different cereals studied, as-fed basis

| Cereal | Description | DM | OM | CP | Total starch |
|---|---|---|---|---|---|
| Rice (short-grain) | White raw (reference) | 90.1 | 84.7 | 18.5 | 46.8 |
| Rice (long-grain) | White raw | 89.3 | 83.0 | 16.6 | 46.6 |
| | White cooked | 89.9 | 82.5 | 19.9 | 39.5 |
| Barley | Raw | 91.2 | 84.6 | 19.4 | 32.5 |
| Sorghum | Raw | 90.1 | 83.9 | 18.3 | 37.2 |
| Oats | Raw (source 1) | 91.6 | 85.4 | 19.9 | 23.5 |
| | Raw (source 2) | 89.8 | 82.4 | 19.7 | 27.9 |
| | Raw (source 3) | 91.0 | 83.7 | 22.0 | 27.5 |
| | Thick rolled (source 2) | 90.3 | 83.2 | 19.2 | 39.2 |
| | Cooked (source 3) | 90.7 | 83.3 | 20.5 | 27.3 |
| Naked oats | Raw | 90.2 | 83.0 | 24.0 | 31.0 |
| | Micronized | 91.7 | 84.5 | 19.4 | 33.9 |

## DISCUSSION

The present work aimed to study the effect of cereal nutrient composition and digestibility on feed preference in pigs. The study of the nutrient composition of the 25 cereals revealed positive correlations of feed preference with the digestible starch content and the glycemic index of the cereals. On the other hand, a clear negative correlation was also observed between preference and the cereal's CF content. The study of digestible and nondigestible nutrient contents in the 12 feeds considered showed positive correlations of preference with the digestible contents of starch, DM, and OM and negative correlations with the nondigestible contents of DM and OM. Similar observations were obtained with the 25 cereals and with the 12 feeds because the content of digestible starch in the feeds is highly dependent on the starch content in the cereals. Similarly, the feeds content of digestible and nondigestible DM and OM are highly dependent on the CF content of the cereal.

Although digestible starch appears to be the most important nutrient driving a positive preference response among the nutrients tested, further studies are required to ascertain whether this response is mediated by the metabolism of the absorbed glucose or by associated sensorial perception. It is well accepted that chemical senses (e.g., taste and smell) have evolved to identify nutritive and antinutritive components in feeds and are linked to pleasant and unpleasant sensations, respectively (Goff and Klee, 2006). For example, flavor preferences and aversions have been linked to the nutritional value associated with the feeds (Gilbertson et al., 1997; Myers et al., 2005). It has been suggested that mammalian species may have a unique taste type triggered by complex carbohydrates (Sclafani, 2004; Bonacchi et al., 2008). Unpublished results from our group show that pigs have a high preference for 2% or greater maltodextrin solutions (E. Roura, unpublished data). A positive relationship with preference has also been observed for glycemic index, which is an indicator of fast glucose release (Brennan, 2005). The sweet taste receptor (the heterodimer T1R2/T1R3) present in the oral cavity senses glucose and sugars and drives short-term preferences for simple carbohydrates in pigs (Danilova et al., 1999; Glaser et al., 2000; Roura, 2011). Consequently, it is tempting to speculate that cereal preference is partially explained through peripheral chemosensing mechanisms.

However, the cereal preference values used in this study were obtained after 4 d of double choice feeding.

**Table 4.** Apparent ileal and total tract digestibility of nutrients in feeds containing 60% of different cereals measured in grower pigs fitted with a T-cannula at the terminal ileum

| | | Ileal digestibility, % | | | | Total tract digestibility, % | | |
|---|---|---|---|---|---|---|---|---|
| Cereal | Description | DM | OM | CP | Starch | DM | OM | Starch |
| Rice (short-grain) | White raw (reference) | 65.2[bc] | 68.3[bc] | 69.3[bcd] | 94.0[b] | 86.7[a] | 88.4[a] | 99.5[ab] |
| Rice (long-grain) | White raw | 75.2[a] | 78.7[a] | 72.2[ab] | 98.1[a] | 86.9[a] | 90.2[a] | 99.9[a] |
| | White cooked | 74.2[a] | 77.9[a] | 76.7[ab] | 98.7[a] | 87.2[a] | 90.7[a] | 99.9[a] |
| Barley | Raw | 49.3[e] | 53.5[e] | 63.0[d] | 88.3[c] | 74.7[b] | 76.6[b] | 98.9[cd] |
| Sorghum | Raw | 57.7[cde] | 60.4[cde] | 66.7[cd] | 88.1[c] | 76.8[b] | 78.8[b] | 98.8[d] |
| Oats | Raw (source 1) | 54.6[de] | 59.1[de] | 64.9[cd] | 97.4[ab] | 73.4[b] | 76.1[b] | 99.3[bc] |
| | Raw (source 2)[1] | – | – | – | – | 75.2[b] | 78.5[b] | 99.7[ab] |
| | Raw (source 3) | 61.6[cd] | 64.5[cd] | 77.2[ab] | 98.6[a] | 74.1[b] | 77.5[b] | 99.7[ab] |
| | Thick rolled (source 2) | 72.7[ab] | 76.3[ab] | 77.5[a] | 99.0[a] | 83.9[a] | 88.0[a] | 99.9[a] |
| | Cooked (source 3) | 57.3[cde] | 61.1[cde] | 72.7[abc] | 98.3[a] | 64.4[c] | 65.6[c] | 99.6[ab] |
| Naked oats | Raw | 70.3[ab] | 73.9[ab] | 76.9[ab] | 98.2[a] | 84.5[a] | 87.8[a] | 99.4[ab] |
| | Micronized | 70.3[ab] | 74.0[ab] | 75.9[ab] | 98.7[a] | 84.1[a] | 87.5[a] | 99.8[a] |
| Pooled SE | | 2.0 | 1.9 | 1.8 | 0.7 | 1.0 | 1.0 | 0.1 |
| *P*-value | | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |

[a–e]Within a column, means without a common superscript differ ($P < 0.05$); $n = 12$.

[1]The feed containing raw oats (source 2) had problems of cannula blockage and the corresponding ileal digestibility measurements were not considered representative.

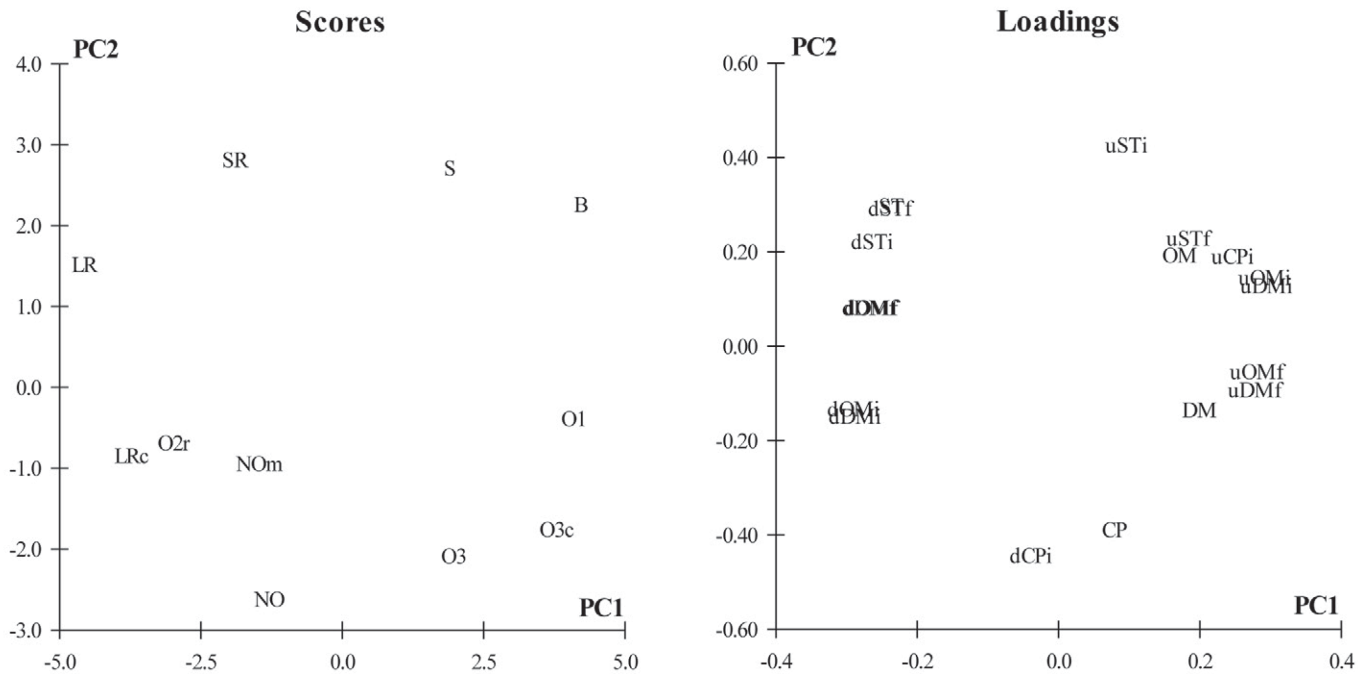


**Figure 3.** Principal component (PC) analysis of the nutrient composition(DM, OM, CP, ST = starch, d = digested content, u = nondigested content, i = at the ileal level, and f = at the fecal level) of the 12 feeds containing 60% cereal (SR = short rice, LR = long rice, B = barley, S = sorghum, O = oats, NO = naked oats, 1 = source 1, 2 = source 2, 3 = source 3, c = cooked, r = thick rolled, and m = micronized). The PC1 explained 59.8% of the total variation, and PC2 explained 21.8% of the variation. Scores: orientation of the feeds relative to the PC. Loadings: orientation of the nutrient concentrations relative to the PC.

Therefore, it is also possible that the preference responses observed were mediated by feedback signals from postabsorptive effects and intermediary metabolism (Forbes, 2007, 2010). The glucostatic theory of control of feed intake was initially postulated by Mayer (1953) and states that meal size and frequency aim at maintaining a constant level of glucose in blood. Glucose sensing receptors are ubiquitous. Among many other tissues, glucose sensors have been described along the gastrointestinal tract in pigs and are claimed to play a direct role in regulating feed intake by initiating a cascade of events intimately related to the enteroendocrine system and the hunger–satiety cycle (Stephens, 1980, 1985; Shirazi-Beechey et al., 2011). It has recently been shown that specific taste receptors (such as the sweet taste receptor heterodimer T1R2 + T1R3 among many others) are expressed on the luminal membrane of enteroendocrine cells in pigs (Roura, 2011). The sweet taste receptor seems to sense luminal glucose concentration and to regulate the externalization of the intestinal $Na^+$/glucose co-transporter, SGLT1 (a major route to increase glucose transport from the lumen of the intestine into the enterocyte), essential for an efficient absorption of glucose and avoidance of malabsorption (Moran et al., 2010a,b). In addition, consistent with our findings, starch digestibility and glucose release have been shown to influence nutrient sensor gene expression in the gut, which in turn may affect the response of the enteroendocrine system orchestrating voluntary feed intake (Menoyo et al., 2011; Regmi et al., 2011).

The cereals' content in digestible starch was negatively correlated with CF content (Fig. 1), and as a result there was also a negative correlation between preference and CF (and the related nondigested fraction in the feed). It is, therefore, possible that preference is also driven (negatively) by properties associated with CF. Additional studies are required to ascertain whether this response is mediated by the physical properties of CF or by indirect metabolism related effects such as reduced levels of absorbed glucose. Bulky fibrous feeds have a lower energy density, poorer digestibility, and longer digestive process that may result in greater gut fill sensations (Kyriazakis and Emmans, 1995; Whittemore et al., 2003) because of the stimulation of stretch receptors causing satiety (Johansen et al., 1996; Lepionka et al.,

**Table 5.** Correlation between the principal component scores obtained from the analysis of the total, digestible, and nondigestible nutrient content in feeds containing 60% cereal and the corresponding in vivo preference values[1]

| Principal component | *r* | *P*-value |
|---|---|---|
| 1 | –0.77 | <0.01 |
| 2 | 0.23 | 0.50 |
| 3 | 0.04 | 0.92 |
| 4 | 0.15 | 0.67 |

[1]Spearman correlation coefficients between the scores of principal components with an eigenvalue larger than 1.0 and previously reported feed preference values; $n$ = 11. The feed containing raw oats (source 2) had problems of cannula blockage and the corresponding ileal digestibility measurements were not considered as representative.

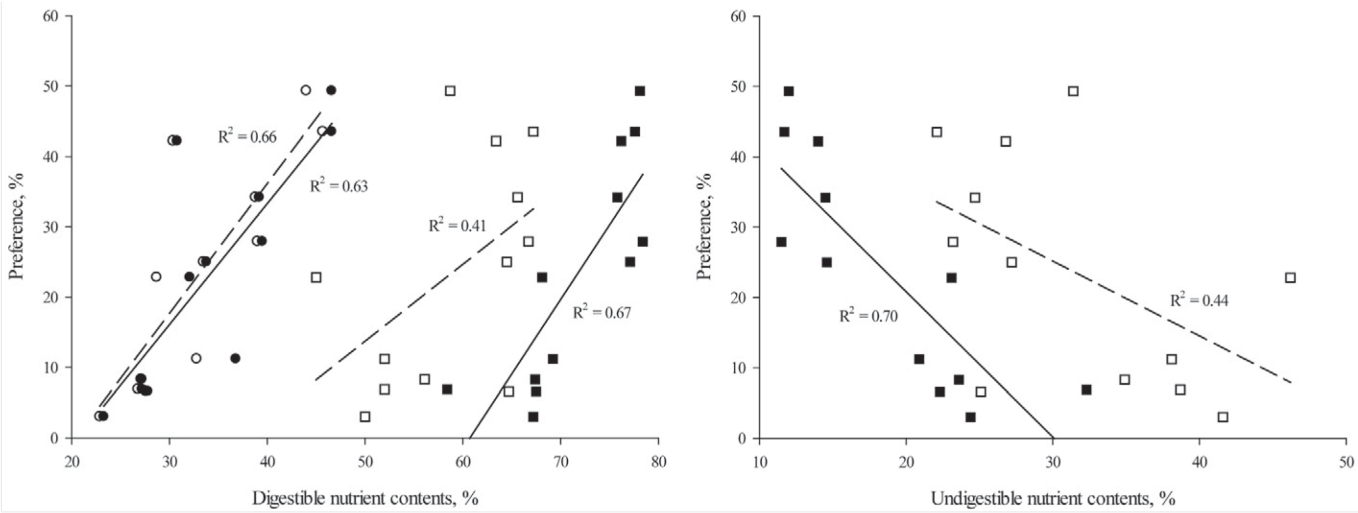


**Figure 4.** Regression between ileal (empty symbols and dashed lines) and fecal (filled symbols and solid lines) digestible and nondigestible contents of starch (circles) and DM (squares) in cereal based feeds, and their previously reported feed preference values.

1997). It has been suggested that pigs may adjust feed intake to achieve a required digestible energy intake, and low caloric densities typical of high fiber diets may result in greater feed intake (Cole and Chadd, 1989). However, gut capacity and maturity in young pigs limits their ability to compensate for energy density (Owen and Ridgman, 1967), which may explain the negative correlation between preference and CF or nondigestible DM and OM. In addition, CF may also influence the texture characteristics of the feed, and they have been shown to also affect feed preference (Solà-Oriol et al., 2009b). Crude fiber is mostly found in the hull and outer layers of the cereal grains, and our data indicates that these particular parts of the cereals may negatively affect cereal palatability in pigs. For example, dehulled or naked oats have been shown to have greater preferences than whole oats (Solà-Oriol et al., 2009c). The nutrient regulation of digesta passage rate may also play a role in gut fill sensation and indirectly on feed preference. Fiber has been shown to contribute to gut distension by delaying the gastric emptying (Johansen et al., 1996), and on the contrary, glycemic index has been shown to be positively correlated with digesta flow rate, indicating that a faster digesta passage is related with cereals easily digested and nutrients rapidly absorbed (Solà-Oriol et al., 2010).

In summary, we have studied the relationship between feed preference and some nutritional characteristics of cereals, and our results indicate that nutrient composition can explain more than 60% of the observed variation in cereal feed preference. Digestible starch (positively) and CF (negatively) have been shown to play an important role, which may be driven by nutritional, physical, or sensorial properties associated with these nutrients. However, in addition to cereals, other ingredients such as protein, fat, and fiber sources have also been shown to play an important role in feed preference (Solà-Oriol et al., 2011). It is likely that for these ingredients, the nutrients driving feed preference are different from those observed in cereals. It is concluded that cereal preference in pigs is positively related with digestible nutrients (mainly starch) and negatively related with nondigestible nutrients (mainly CF).

## LITERATURE CITED


Adeola, O. 2001. Digestion and balance technique in pigs. In: A. J. Lewis and L. L. Southern, editors, Swine nutrition. 2nd ed. CRC Press, Boca Raton. p. 903–916.

AOAC. 2000. Official methods of analysis. Assoc. Off. Anal. Chem., Washington, DC.

Bonacchi, K. B., K. Ackroff, and A. Sclafani. 2008. Sucrose taste but not Polycose taste conditions flavor preferences in rats. Physiol. Behav. 95:235–244.

Brennan, C. S. 2005. Dietary fibre, glycaemic response, and diabetes. Mol. Nutr. Food Res. 49:560–570.

Cole, D. J. A., and S. A. Chadd. 1989. Voluntary food intake of growing pigs. In: J. M. Forbes, M. A. Varley, and T. L. J. Lawrence, editors, The voluntary food intake of pigs. Br. Soc. Anim. Prod, Midlothian, UK. p. 61–70.

Danilova, V., T. Roberts, and G. Hellekant. 1999. Responses of single taste fibers and whole chorda tympani and glossopharyngeal nerve in the domestic pig, *Sus scrofa*. Chem. Senses 24:301–316.

Englyst, K. N., H. N. Englyst, G. J. Hudson, T. J. Cole, and J. H. Cummings. 1999. Rapidly available glucose in foods: An in vitro measurement that reflects the glycemic response. Am. J. Clin. Nutr. 69:448–454.

Forbes, J. M. 2007. Voluntary food intake and diet selection in farm animals. 2nd ed. CAB Int., Wallingford, UK.

Forbes, J. M. 2010. Palatability: Principles, methodology and practice for farm animals. CAB Rev. 5:1–15.

Gilbertson, T. A., D. T. Fontenot, L. D. Liu, H. Zhang, and W. T. Monroe. 1997. Fatty acid modulation of $K^+$ channels in taste receptor cells: Gustatory cues for dietary fat. Am. J. Physiol. Cell Physiol. 41:C1203–C1210.

Glaser, D., M. Wanner, J. M. Tinti, and C. Nofre. 2000. Gustatory responses of pigs to various natural and artificial compounds known to be sweet in man. Food Chem. 68:375–385.

Goff, S. A., and H. J. Klee. 2006. Plant volatile compounds: Sensory cues for health and nutritional value? Science 311:815–819.

Johansen, H. N., K. E. B. Knudsen, B. Sandstrom, and F. Skjoth. 1996. Effects of varying content of soluble dietary fibre from wheat flour and oat milling fractions on gastric emptying in pigs. Br. J. Nutr. 75:339–351.

Kyriazakis, I., and G. C. Emmans. 1995. The voluntary feed intake of pigs given feeds based on wheat bran, dried citrus pulp and grass meal, in relation to measurements of feed bulk. Br. J. Nutr. 73:191–207.

Lepionka, L., C. H. Malbert, and J. P. Laplace. 1997. Proximal gastric distension modifies ingestion rate in pigs. Reprod. Nutr. Dev. 37:449–457.

Mayer, J. 1953. Glucostatic mechanism of regulation of food intake. N. Engl. J. Med. 249:13–16.

Menoyo, D., M. P. Serrano, V. Barrios, D. G. Valencia, R. Lázaro, J. Argente, and G. G. Mateos. 2011. Cereal type and heat processing of the cereal affect nutrient digestibility and dynamics of serum insulin and ghrelin in weanling pigs. J. Anim. Sci. 89:2793–2800.

Moran, A. W., M. A. Al-Rammahi, D. K. Arora, D. J. Batchelor, A. Erin, E. A. Coulter, K. Daly, C. Ionescu, D. Bravo, and S. P. Shirazi-Beechey. 2010a. Expression of Na1/glucose co-transporter 1 (SGLT1) is enhanced by supplementation of the diet of weaning piglets with artificial sweeteners. Br. J. Nutr. 104:637–646.

Moran, A. W., M. A. Al-Rammahi, D. K. Arora, D. J. Batchelor, E. A. Coulter, C. Ionescu, D. Bravo, and S. P. Shirazi-Beechey. 2010b. Expression of Na1/glucose co-transporter 1 (SGLT1) in the intestine of piglets weaned to different concentrations of dietary carbohydrate. Br. J. Nutr. 104:647–655.

Myers, K. P., J. Ferris, and A. Sclafani. 2005. Flavor preferences conditioned by postingestive effects of nutrients in preweanling rats. Physiol. Behav. 84:407–419.

NRC. 1998. Nutrient requirements of swine. 10th ed. Natl. Acad. Press, Washington, DC.

Owen, J. B., and W. J. Ridgman. 1967. Effect of dietary energy content on voluntary intake of pigs. Anim. Prod. 9:107–113.

Regmi, P. R., T. A. T. G. van Kempen, J. J. Matte, and R. T. Zijlstra. 2011. Starch with high amylose and low in vitro digestibility increases short-chain fatty acid absorption, reduces peak insulin secretion, and modulates incretin secretion in pigs. J. Nutr. 141:398–405.

Roura, E. 2011. Taste beyond taste. In: R. van Barneveld, editor, Manipulating pig production XIII. Australas. Pig Sci. Assoc., Adelaide, Australia. p. 106–117.

Sclafani, A. 2004. The sixth taste? Appetite 43:1–3.

Shirazi-Beechey, S. P., A. W. Moran, D. J. Batchelor, K. Daly, and M. Al-Rammahi. 2011. Glucose sensing and signalling; Regulation of intestinal glucose transport. Proc. Nutr. Soc. 70:185–193.

Short, F. J., P. Gorton, J. Wiseman, and K. N. Boorman. 1996. Determination of titanium dioxide added as an inert marker in chicken digestibility studies. Anim. Feed Sci. Technol. 59:215–221.

Solà-Oriol, D., E. Roura, and D. Torrallardona. 2009a. Use of double-choice feeding to quantify feed ingredient preferences in pigs. Livest. Sci. 123:129–137.

Solà-Oriol, D., E. Roura, and D. Torrallardona. 2009b. Feed preferences in pigs: Relationship with feed particle size and texture. J. Anim. Sci. 87:571–582.

Solà-Oriol, D., E. Roura, and D. Torrallardona. 2009c. Feed preference in pigs: Effect of cereal sources at different inclusion rates. J. Anim. Sci. 87:562–570.

Solà-Oriol, D., E. Roura, and D. Torrallardona. 2011. Feed preference in pigs: Effect of selected protein, fat, and fiber sources at different inclusion rates. J. Anim. Sci. 89:3219–3227.

Solà-Oriol, D., T. van Kempen, and D. Torrallardona. 2010. Relationships between glycaemic index and digesta passage of cereal-based diets in pigs. Livest. Sci. 134:41–43.

Stein, H. H., C. F. Shipley, and R. A. Easter. 1998. Technical note: A technique for inserting a T-cannula into the distal ileum of pregnant sows. J. Anim. Sci. 76:1433–1436.

Stephens, D. B. 1980. The effects of 2-deoxy-d-glucose given via the jugular or hepatic-portal vein on food-intake and plasma-glucose levels in pigs. Physiol. Behav. 25:691–697.

Stephens, D. B. 1985. Influence of intraduodenal glucose on meal size and its modification by 2-deoxy-d-glucose or vagotomy in hungry pigs. Q. J. Exp. Physiol. Cogn. Med. Sci. 70:129–135.

van Kempen, T. A. T. G., P. R. Regmi, J. J. Matte, and R. T. Zijlstra. 2010. In vitro starch digestion kinetics, corrected for estimated gastric emptying, predict portal glucose appearance in pigs. J. Nutr. 140:1227–1233.

Walker, W. R., G. L. Morgan, and C. V. Maxwell. 1986. Ileal cannulation in baby pigs with a simple T-cannula. J. Anim. Sci. 62:407–411.

Whittemore, E. C., G. C. Emmans, and I. Kyriazakis. 2003. The relationship between live weight and the intake of bulky foods in pigs. Anim. Sci. 76:89–100.