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Pea protein as a substitute of soya bean protein in diets for young pigs: Effects on productivity and digestive traits ☆

D.G. Valencia [a], M.P. Serrano [a], C. Centeno [b], R. Lázaro [a], G.G. Mateos [a,*]

[a] *Departamento de Producción Animal, Universidad Politécnica de Madrid, Ciudad Universitaria, 28040 Madrid, Spain*
[b] *Instituto del Frío, C.S.I.C., Ciudad Universitaria, 28040 Madrid, Spain*

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Abstract

Two trials were conducted to study pea protein concentrate (PPC) as a substitute of soya bean meal (SBM), soya protein concentrate (SPC) or fullfat soya bean (FFSB) in the diet on equivalent protein basis, on productive performance and digestive traits of piglets. The design was completely randomised with 4 treatments and 5 (six piglets; trial 1) or 6 (one piglet; trial 2) pens per treatment. In trial 1 growth traits from 26 to 48 days of age and the coefficient of total tract apparent digestibility (CTTAD) of dietary components at 36 and 48 days of age were assessed. In trial 2 the coefficient of ileal apparent digestibility (CIAD) of dietary components, the pH of the gastro intestinal tract (GIT) and the weight of digestive organs and spleen were measured at 48 days of age. From 26 to 36 days of age pigs fed SBM and SPC grew faster and were more efficient than pigs fed PPC ($P<0.01$) with pigs fed FFSB being intermediate. From 37 to 48 days of age pigs fed SPC or SBM ate more feed than pigs fed FFSB ($P<0.05$) with pigs fed PPC being intermediate. For the entire experiment (26 to 48 days of age) pigs fed SPC and SBM tended to have higher average daily gain and feed intake than pigs fed PPC or FFSB ($P<0.10$). Pigs fed SBM and SPC tended to have higher CTTAD of crude protein ($P<0.10$) and had higher CIAD of organic matter and gross energy ($P<0.01$) than pigs fed PPC and FFSB. The weight of the GIT was greater for pigs fed FFSB and PPC than for pigs fed SBM ($P<0.05$) with pigs fed SPC being intermediate. In summary, the inclusion of pea protein concentrate and fullfat soya bean in the diet reduces pig performance from 26 to 36 days of age. In addition, these two protein sources impair ileal digestibility of organic matter and gross energy at 48 days of age. On the other hand, growth performance was similar for pigs fed the soya bean meal and soya protein concentrate diets.

Keywords: Pea protein concentrate; Soya protein concentrate; Soya bean meal; Fullfat soya bean; Piglet feeding; Nutrient digestibility

1. Introduction

Peas (*Pisum sativum* L.) are a good source of energy and crude protein (CP) for pigs and contain more lysine but less sulphur amino acids and tryptophan per unit of protein than soya bean meal (Fundación Española Desarrollo Nutrición Animal, 2003). The inclusion of peas in pig diets is limited because of its negative effects on feed intake and nutrient digestibility. The trypsin inhibitors (TI) content of raw peas is believed to be responsible for the low digestibility of CP (Huisman and Le Guen, 1991). Also, peas have a high content in saponins (0.7–1.9 g/kg) that confers a bitter taste to the seed (Price et al., 1985; Heng et al., 2006) and might be responsible for the reduction in feed intake observed in

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* Corresponding author. Tel.: +34 91 4524851; fax: +34 91 5430071.
E-mail address: gonzalo.gmateos@upm.es (G.G. Mateos).

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young pigs. Dehulling of the peas followed by grinding and air classification allows the separation of the fine (mostly protein) and the coarse (mostly starch) particles of peas. The protein fraction contains 400 to 605 g CP/kg and 78 to 276 g starch/kg (Vose et al., 1976) and can be used as an alternative to conventional protein sources in pig diets.

Heat processed soya bean (FFSB) is a good ingredient in pig diets provided that heat is applied under well controlled conditions. Under-heating of FFSB leaves intact part of the heat-labile anti-nutritive factors (ANF) contained in the bean, including the TI, whereas over-heating leads to Maillard reactions that reduce amino acid digestibility. Other ANF present in soya beans such as the antigenic proteins and the oligosaccharides, are not destroyed by heat but can be deactivated by alcohol extraction or fermentation. Soya protein concentrate (SPC) results from reducing the fibre, lectins, TI, oligosaccharides and allergenic proteins contained in the meal (Refstie et al., 1998). Zhu et al. (1998) observed an improvement in growth and digestibility in pigs when SPC was used in the diet in substitution of soya bean meal (SBM) or FFSB. However, Friesen et al. (1993) indicated that moist extrusion of less-refined soya bean products, such as regular SBM, allows pig growth and nutrient digestibilities comparable to those obtained with more complex products such as SPC. Similarly, Dilger et al. (2004) did not find any benefit on true ileal digestibility of nitrogen (N) and of most limiting amino acids when SBM was substituted by SPC. The aim of this trial was to compare pea protein concentrate, soya protein concentrate, regular soya bean meal and fullfat soya bean as a source of dietary protein on performance, faecal and ileal digestibility and digestive traits of young pigs.

2. Materials and methods

All the experimental procedures described in these experiments were approved by the Animal Ethics Committee of the Universidad Politécnica de Madrid and were in compliance with the Spanish guidelines for the care and use of animals in research (Boletín Oficial del Estado, 2005).

2.1. Protein sources and diets

A batch of yellow peas (*P. sativum*, L.) was obtained from a local supplier (Esteve-Santiago, S.A., Valladolid, Spain), cleaned, dehulled and micronized (very fine grinding) to a mean particle size (MPS) of 15.9 μm by using an air classifying mill (Circoplex mill 200 ZPS, Hosokawa-Alpine, Augsburg, Germany). Subsequently, micronized peas were passed through an air classifier equipment (Turboplex ATP 200, Hosokawa-Alpine, Augsburg, Germany) to separate the fine and the coarse fractions. The fine fraction (28% of the original peas) corresponded to the pea protein concentrate (PPC) and was the fraction used in this trial. The SPC used was obtained from a conventional trader and was produced via an enzymatic and microbial process from defatted and decorticated soya flakes. The SBM used was obtained from soya beans of North American origin and were crushed and processed locally (Bunge, La Coruña, Spain). The FFSB was also provided by a local supplier from soya beans of Brazilian origin. The beans were cracked, cooked (Amandus Kahl, Reinbek, Germany) for 1 h (105±5 °C and 300 g moisture/kg), expanded at 117 °C (Amandus Kahl, Reinbek, Germany), cooled, dried (130 °C for 10 min) and passed through a hammer mill (2.5-mm screen, Bühler AG, Uzwil, Switzerland). The determined analysis of the experimental protein sources used is shown in Table 1.

Table 1
Chemical analysis and mean particle size of the protein sources tested (g/kg, as-fed basis unless stated otherwise)[a]

Item	Peas[b]	PPC[c]	SPC[d]	SBM[e]	FFSB[f]
Dry matter	880	912	910	921	901
Gross energy, MJ/kg	16.7	17.8	18.7	18	21.8
Total ash	25	49	67	63	51
Ether extract	9	17	9	21	178
Crude fibre	60	15	44	57	88
Neutral detergent fibre	149	49	85	133	176
Crude protein	235	525	546	452	349
Calcium	1.0	1.1	3.8	6.0	3.9
Phosphorus	3.8	8.2	7.5	7.4	5.0
Potassium	7.7	16.4	21.1	20.2	16.3
Arginine	20.7	50.6	39.6	31.3	25.9
Histidine	5.8	12.1	13.6	11.1	9.3
Isoleucine	9.3	20.6	24.4	19.6	16.5
Leucine	16.3	35.1	40.7	33.3	26.6
Lysine	15.9	30.5	29.5	26.6	21.6
Methionine	2.0	4.7	7.1	5.9	4.8
Methionine+cystine	5.2	10.8	14.5	12.3	10.3
Phenylalanine	10.7	23.0	26.0	21.3	14.9
Threonine	8.2	17.3	21.7	17.0	14.4
Valine	10.4	26.1	25.2	21.1	17.4
PDI, %[g]	54.1	62.8	9.1	9.7	8.2
KOH solubility, %	93.3	98.0	49.8	80.5	85.8
Urease activity, mg N/g	0.015	0.023	0.023	0.044	0.032
Trypsin inhibitor	3.2	4.9	1.6	2.7	4.7
Particle size MPS, μm[h]	15.9	8.4	216	881	778
S.D.[i]	2.42	2.63	1.91	1.69	2.82

[a] Analysed in duplicate samples.
[b] Batch of field peas processed to obtain the pea protein concentrate.
[c] Pea protein concentrate.
[d] Soya protein concentrate.
[e] Soya bean meal.
[f] Fullfat soya bean.
[g] Protein dispersibility index.
[h] Mean particle size. The method used was by Heuer and Lechonski (1985) for peas and PPC and American Society of Agricultural Engineers (1995) for SPC, SBM and FFSB.
[i] Log S.D.

Table 2
Composition of the experimental diets (g/kg, as-fed basis)

Item	PPC [a]	SPC [b]	SBM [c]	FFSB [d]
Pea protein concentrate, 525 g CP [e]/kg	105	–	–	–
Soya protein concentrate, 546 g CP/kg	–	100.8	–	–
Soya bean meal, 452 g CP/kg	–	–	121.7	–
Fullfat soya bean, 349 g CP/kg	–	–	–	157.6
Cooked maize	400	400	400	400
Barley	143.4	144.1	115.3	101.8
Dried whey	200	200	200	200
Fish meal, 700 g CP/kg	104	104	109	109
Soya bean oil	16.5	20.7	24.6	1.6
Calcium carbonate	5.8	5.6	5.0	5.1
Dicalcium phosphate	1.2	1.3	1.2	1.0
Salt	2.0	2.0	2.0	2.0
Methionine-OH, 880 g/kg	2.1	1.8	1.6	1.8
L-lysine HCl, 780 g/kg	1.9	2.2	2.1	2.4
L-threonine, 980 g/kg	1.5	1.1	1.1	1.3
L-tryptophan, 990 g/kg	0.6	0.4	0.4	0.4
Celite [f]	10.0	10.0	10.0	10.0
Vitamin and mineral premix [g]	6.0	6.0	6.0	6.0

[a] Pea protein concentrate.
[b] Soya protein concentrate.
[c] Soya bean meal.
[d] Fullfat soya bean.
[e] Crude protein.
[f] Acid-washed diatomaceous earth (Ceca, Saint-Bautizile, France).
[g] Supplied per kg of diet: vitamin A (*trans*-retinyl acetate), 15,000 IU; vitamin D3 (cholecalciferol), 2000 UI; vitamin E (all-*rac*-tocopherol acetate), 25,000 mg; vitamin K (menadione sodium bisulphite), 2.5 mg; riboflavin, 5 mg; pantothenic acid (Ca-D-pantothenate), 15 mg; nicotinic acid, 30 mg; pyridoxine (pyridoxine·HCl), 5 mg; thiamin (thiamin-mononitrate), 2 mg; vitamin B_{12} (cyanocobalamin), 30 µg; D-biotin, 150 µg; choline (choline chloride), 100 mg; folic acid, 1 mg; Se (Na_2SeO_3), 0.2 mg; I (KI), 1 mg; Cu ($CuSO_4 \cdot 5H_2O$), 160 mg; Fe ($FeCO_3$), 225 mg; Zn ($ZnSO_4 \cdot H_2O$), 150 mg; Mn (MnO), 50 mg.

From 22 to 25 days of age all pigs received a common commercial pelleted diet based on cereals, milk by-products and fish meal that contained by analysis 197 g CP and 14.4 g total lysine/kg. Afterwards, four isonutritive experimental diets were produced and fed in pellet form (2.5 mm diameter) from 26 to 48 days of age. Diets were formulated according to Fundación Española Desarrollo Nutrición Animal (2003) to meet or exceed the nutrient requirements for pigs of this age (Fundación Española Desarrollo Nutrición Animal, 2006). The experimental diets were formulated to include 5.5% of the dietary protein from either PPC (525 g CP/kg), SPC (546 g CP/kg), SBM (452 g CP/kg) or FFSB (349 g CP/kg). The remainder of the dietary protein was provided by fish meal, dried whey and cereals in all cases. No growth promoters were included in these diets. To increase the concentration of acid insoluble ash (AIA), 10 g acid-washed diatomaceous earth (Celite, Ceca, Saint-Bautizile, France)/kg diet was added. The ingredient composition and nutrient content of the experimental diets are shown in Tables 2 and 3, respectively.

2.2. Husbandry and experimental design

Both experiments were conducted using the same husbandry, diets and experimental design. The piglets (Pietrain × Large White) × (Landrace × Large White) were obtained at weaning from a commercial farm (Proinserga, Segovia, Spain) and males and females at the same proportion were used. On arrival at the experimental station, pigs were ear-tagged, weighed and allotted to the experimental units according to sex and body weight (BW). The environmental conditions were controlled automatically according to the age of the pigs. Room temperature was kept at 32 °C for the first week of the trial and then reduced by 2 °C per week until reaching 26 °C. Pigs that showed signs of diarrhoea, as assessed by veterinarian inspection, were treated by intramuscular injection with Excenel® (Ceftiofur clorhidrate

Table 3
Chemical analysis and mean particle size of the experimental diets (g/kg, as-fed basis unless stated otherwise)

Item	PPC [a]	SPC [b]	SBM [c]	FFSB [d]
Calculated analysis [e]				
Net energy, MJ/kg	10.4	10.4	10.4	10.4
Neutral detergent fibre	67	67	69	70
Calcium	7.0	7.0	7.0	7.0
Available phosphorus	4.0	4.0	4.0	4.0
Sodium	3.2	3.2	3.3	3.3
Chloride	5.9	6.0	6.0	5.9
Potassium	9.3	9.7	9.8	9.9
Digestible lysine	12.8	12.8	12.8	12.8
Digestible tryptophan	2.3	2.3	2.3	2.3
Trypsin inhibitors	0.5	0.2	0.3	0.7
Determined analysis [f]				
Dry matter	920	931	924	919
Gross energy, MJ/kg	17.1	17.3	17.3	17.3
Total ash	67	75	71	73
Ether extract	47	62	64	62
Crude protein	210	214	213	216
Arginine	11.7	12.9	12.0	11.4
Histidine	5.3	5.5	5.5	5.8
Isoleucine	8.6	8.9	8.9	8.8
Leucine	16.6	17.5	18.5	17.8
Lysine	14.9	15.1	14.8	15.0
Methionine	6.2	6.0	5.9	6.1
Methionine + cystine	9.3	9.0	8.8	9.3
Phenylalanine	9.9	10.0	10.3	10.2
Threonine	10.1	10.0	9.7	10.1
Valine	10.2	10.4	10.5	10.3
Particle size MPS, µm [g]	272	307	361	342
S.D. [h]	2.76	2.45	2.42	2.56

[a] Pea protein concentrate.
[b] Soya protein concentrate.
[c] Soya bean meal.
[d] Fullfat soya bean.
[e] Fundación Española Desarrollo Nutrición Animal (2003).
[f] Analysed in duplicate samples.
[g] Mean particle size.
[h] Log S.D.

0.4 mL/10 kg BW every 24 h; Pharmacia N.V., S.A., Belgium) for 3 consecutive days.

2.2.1. Productive performance and coefficient of total tract apparent digestibility of dietary components (Experiment 1)

A total of 120 piglets, 22±4 days of age (mean±S.D.) and 6.2±1.38 kg BW, were selected the day of weaning. There were 4 treatments and 5 replicates of 6 piglets per treatment. Pigs were housed in flat-deck pens (1.60×1.10 m) provided with individual feeders (3 places) and nipple drinkers. The pigs were kept on a 24-h/d light program and had free access to feed and water throughout the trial. Pigs were weighed individually at 26, 36 and 48 days of age. Average daily gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (FCR) were calculated by period and for the entire experiment. Diarrhoea incidence (DI) was recorded for each piglet by an observer who was blind to treatment modality. The DI was estimated by pen as the proportion of days in which pigs showed clinical signs of diarrhoea with respect to the total number of days on trial (Mateos et al., 2006). At 36 and 48 days of age, pooled samples of faeces from at least four pigs per replicate, were taken by rectal massage and frozen until chemical analysis to determine the coefficient of total tract apparent digestibility (CTTAD) of organic matter (OM), gross energy (GE), ether extract (EE) and CP.

2.2.2. Coefficient of ileal apparent digestibility of dietary components and digestive traits (Experiment 2)

A total of 24 piglets, 27±3 days of age and 7.2±1.19 kg BW were used. There were 4 treatments and 6 replicates of one pig per treatment. At 30 days of age pigs were individually allotted to flat-deck digestibility cages (1.00×1.00 m) provided with individual feeders and nipple water drinkers with all treatments having similar BW. Pigs had free access to their experimental feeds and water until 47 days of age and were then maintained without feed for 12 h to achieve feed intake as homogeneous as possible. Afterwards, they were re-fed *ad libitum* during 6 h. Subsequently, pigs were administered a single intramuscular injection of Imalgène 500 (20 mg Ketamine clorhidrate/kg BW; Merial Laboratories S.A., Lyon, France) plus Xilalgesic (2.2 mg Xylazil-20/kg BW; Calier Laboratories S.A., Barcelona, España) to induce general anaesthesia. The pigs were satisfactorily anaesthetised within 9 to 11 min post-induction and were then weighed and slaughtered by exsanguination to reduce blood contamination during sample collection procedures.

The stomach, intestines, pancreas, liver and spleen were excised, cleaned, dried with desiccant paper and weighed. The weight of the empty organs was expressed relative to live BW (g/kg). In addition, the small intestine was separated into three sections: duodenum (first section; about 1.5 m), jejunum (second section; about 2.0 m) and ileum (remaining section). Next, 20 mL of digesta from each section of the gastro intestinal tract (GIT) was obtained and homogenized in a 50-mL beaker, and pH was measured in duplicate using a temperature-corrected, digital pH-meter (Crison GLP 21, Crison Instruments S.A., Barcelona, Spain). To determine the coefficient of ileal apparent digestibility (CIAD) of OM, GE, CP and amino acids, 20 g of digesta from the last 20 to 40 cm of ileum was taken from each pig and frozen at −20 °C until chemical analysis.

2.3. Laboratory analysis

Samples of faeces were heat-dried (60 °C, 48 h) and samples of the ileal digesta were freeze-dried. All the samples, including protein sources and feeds, were ground (1-mm screen, Retsch Model Z-I, Stuttgart, Germany) and analysed for moisture by the oven-drying method (930.15), total ash by a muffle furnace (942.05) and N by combustion (990.03) using a Leco equipment (model FP-528, Leco corporation, St. Joseph, MI, USA). In addition, EE of protein sources feeds and faeces were analysed by Soxhlet fat analysis after 3 N HCl acid hydrolysis (920.39). The amino acids of protein sources, feeds and ileal digesta were determined using a Beckman 6300 (Beckman Instruments, Inc., Palo Alto, CA, USA) amino acid analyser as described (994.12) by the Association of Official Analytical Chemists International (2000). The GE of all samples was determined using an adiabatic bomb calorimeter (model 1356, Parr Instrument Company, Moline, IL, USA) and the AIA using the technique described by Vogtmann et al. (1975).

Protein dispersibility index (PDI) of the protein sources was determined by method Ba 10-65 (American Oil Chemists Society, 1980), KOH protein solubility index by the method of Araba and Dale (1990), urease activity according to Boletín Oficial Estado (1995) and trypsin inhibitors by method 71-10 (American Association of Cereal Chemists, 1995). The MPS of the soya bean products tested and the experimental feeds was determined according to the method outlined by the American Society of Agricultural Engineers (1995) using a filtra 200 (Filtra, S.A., Barcelona, Spain) with 7 sieves ranging in mesh from 2500 to 40 µm. For PPC, the MPS (8.4±2.63 µm) was measured using a Sympatec Helos compact KA laser diffraction equipment (Sympatec GmbH, Clausthal-Zellerfeld, Germany), using a Rodos dry powder dispenser at 2 bar (Heuer and Leschonski, 1985). This methodology was used for PPC because method recommended by the American Society of Agricultural Engineers (1995) is not valid when the particle size of the sample is less than 40 µm.

2.4. Statistical analysis

Performance, CIAD, pH of the GIT and organ weights data from this study were analysed as a completely randomised design with type of diet as main effect, using the General Linear Model Procedure of Statistical Analysis System Institute (1990). Individual pens represented the experimental unit. Initial live weight was used as the covariant for adjustment performance data. Significant values ($P<0.05$) were examined with a LSD-test to make pairwise comparisons. The results in tables are presented as least-square means. The DI data were analysed by the CATMOD procedure because the variance was not normal. For CTTAD, the data were analysed by a repeated measures analysis using the Proc Mix procedure of Statistical Analysis Systems Institute (1992) and the model included diet, age and the interaction between diet and age as main effects. All differences were considered significant at $P<0.05$ and P values between 0.05 and 0.10 were considered a trend.

3. Results

3.1. Analytical evaluation of protein sources and diets

The determined values of major nutrients in the protein sources tested (Table 1) were close to expected values except for FFSB that contained less CP (349 vs. 363 g/kg) and EE (178 vs. 198 g/kg) and more NDF (176 vs. 120 g/kg) than indicated by Fundación Española Desarrollo Nutrición Animal (2003). The PDI was highest for PPC (62.8%) and similar for SBM (9.7%), SPC (9.1%) and FFSB (8.2%). Protein solubility in KOH was highest for PPC (98.0%) and lowest for SPC (49.8 %) with SBM and FFSB being intermediate (80.5 and 85.8%, respectively). Urease activity was low for all samples (<0.045 mg N/g) and within the range accepted by the feed compound industry. The TI content was highest for PPC (4.9 g/kg) and FFSB (4.7 g/kg) and lowest for SPC (1.6 g/kg) and SBM (2.7 g/kg). Also, the determined analysis of the diets (Table 3) was similar to expected values. The total lysine content varied from 14.8 g/kg (SBM diet) to 15.1 g/kg (SPC diet) and the total methionine+cystine values varied from 8.8 g/kg (SBM diet) to 9.3 g/kg (PPC and FFSB diets). The MPS was higher for the SBM and FFSB diets (361 and 342 μm, respectively) than for the SPC and PPC diets (307 and 272 μm, respectively).

3.2. Productive performance (Experiment 1)

From 26 to 36 days of age pigs fed SPC and SBM grew faster and had better FCR than pigs fed PPC ($P<0.01$) with pigs fed FFSB being intermediate (271 and 286 vs. 212 and 244 g/day for ADG and 0.87 and 0.81 vs. 0.98 and 0.94 g/g for FCR, respectively; Table 4). However, from 37 to 48 days of age pigs fed PPC and SPC grew faster than pigs fed FFSB with pigs fed SBM being intermediate (530 and 546 vs. 477 and 517 g/day, respectively; $P<0.05$). Also, in this period pigs fed SPC and SBM ate more feed than pigs fed FFSB with pigs fed PPC being intermediate (613 and 614 vs. 551 and 580 g/day, respectively; $P<0.05$). Moreover, pigs fed PPC had better FCR than pigs fed SBM with pigs fed SPC and FFSB being intermediate (1.09 vs. 1.19, 1.13 and 1.16 g/g, respectively; $P<0.01$). For the overall experiment (26 to 48 days of age) pigs

Table 4
Influence of diet on growth performance of pigs weaned at 22 days of age

Diet	PPC[1]	SPC[2]	SBM[3]	FFSB[4]	S.E.M.[5]	Probability
26 to 36 days						
ADG, g[6]	212[c]	271[ab]	286[a]	244[bc]	13.5	**
ADFI, g[7]	207	234	232	230	10.1	NS
FCR[8]	0.98[a]	0.87[bc]	0.81[c]	0.94[ab]	0.0281	**
DI[9]	0.67	2.00	2.33	3.00	–	NS
37 to 48 days						
ADG, g	530[a]	546[a]	517[ab]	477[b]	17.7	*
ADFI, g	580[ab]	613[a]	614[a]	551[b]	15.9	*
FCR	1.09[b]	1.13[ab]	1.19[a]	1.16[ab]	0.0219	**
DI	0.83	1.07	0.28	2.50	–	NS
Overall (26 to 48 days)						
ADG, g	386	418	412	376	12.6	+
ADFI, g	411	441	441	405	11.6	+
FCR	1.06	1.06	1.07	1.08	0.0192	NS
DI	0.76	1.49	1.21	2.73	–	NS

[1]Pea protein concentrate.
[2]Soya protein concentrate.
[3]Soya bean meal.
[4]Fullfat soya bean.
[5]Standard error mean ($n=5$).
[6]Average daily gain.
[7]Average daily feed intake.
[8]Feed conversion ratio.
[9]Diarrhoea incidence (proportion of days in which pigs showed clinical signs of diarrhoea with respect to the total number of days on trial).
NS = Not significant; +$P<0.10$; *$P<0.05$; **$P<0.01$.
[a,b,c]Mean values within a row with different superscripts are significantly different.

Table 5
Influence of age (A) and diet (D) on coefficient of total tract apparent digestibility of dietary components at 36 and 48 days of age

Item	A	PPC[a]	SPC[b]	SBM[c]	FFSB[d]	S.E.M.[e]	S.E.M.[f]	Probability		
								A	D	A×D
Organic matter										
36 days	0.900	0.893	0.903	0.908	0.898	0.002081				
48 days	0.905	0.907	0.909	0.906	0.899	0.002166				
Average	0.903	0.900	0.906	0.907	0.899		0.003747	*	NS	+
Gross energy										
36 days	0.884	0.873	0.887	0.893	0.883	0.002745				
48 days	0.888	0.885	0.891	0.890	0.884	0.002704				
Average	0.886	0.879	0.889	0.892	0.884		0.005006	NS	NS	NS
Ether extract										
36 days	0.859	0.866	0.862	0.859	0.850	0.006229				
48 days	0.872	0.887	0.871	0.879	0.851	0.004145				
Average	0.866	0.877	0.867	0.869	0.851		0.009510	*	NS	NS
Crude protein										
36 days	0.837	0.813	0.847	0.856	0.830	0.005175				
48 days	0.864	0.862	0.872	0.868	0.855	0.003880				
Average	0.851	0.838	0.860	0.862	0.843		0.007632	***	+	NS

[a] Pea protein concentrate.
[b] Soya protein concentrate.
[c] Soya bean meal.
[d] Fullfat soya bean.
[e] Standard error mean for age (n=20).
[f] Standard error mean for protein source (n=5).
NS = Not significant; +P<0.10; *P<0.05; ***P<0.001.

fed SPC and SBM tended (P<0.10) to have higher ADG (418 and 412 vs. 386 and 376 g/day, respectively) and ADFI (441 and 441 vs. 411 and 405 g/day, respectively) than pigs fed PPC and FFSB. However, FCR was not affected by dietary treatment. The DI during the experiment was low (1.55%) and not affected by dietary treatment (Table 4). No mortality occurred during the trial.

Table 6
Influence of diet on coefficient of ileal apparent digestibility of dietary components and amino acids at 48 days of age

Diet	PPC[1]	SPC[2]	SBM[3]	FFSB[4]	S.E.M.[5]	Probability
Organic matter	0.789[b]	0.813[a]	0.813[a]	0.768[b]	0.008177	**
Gross energy	0.789[b]	0.810[a]	0.816[a]	0.768[b]	0.007188	**
Crude protein	0.737	0.761	0.760	0.749	0.009283	NS
Arginine	0.835	0.839	0.836	0.816	0.01264	NS
Histidine	0.780	0.790	0.792	0.800	0.01602	NS
Isoleucine	0.786	0.814	0.809	0.818	0.01486	NS
Leucine	0.804	0.828	0.819	0.820	0.01610	NS
Lysine	0.803	0.796	0.808	0.787	0.01540	NS
Methionine	0.829	0.819	0.825	0.809	0.01056	NS
Cystine	0.649	0.688	0.686	0.693	0.01581	NS
Phenylalanine	0.806	0.810	0.813	0.807	0.01346	NS
Threonine	0.753	0.784	0.762	0.762	0.01146	NS
Valine	0.790	0.800	0.797	0.784	0.01670	NS

[1]Pea protein concentrate.
[2]Soya protein concentrate.
[3]Soya bean meal.
[4]Fullfat soya bean.
[5]Standard error mean (n=6).
NS = Not significant; **P<0.01.
[a,b]Mean values within a row with different superscripts are significantly different.

3.3. Coefficient of total tract apparent digestibility of dietary components (Experiment 1)

In general, CTTAD of dietary components was higher at 48 than at 36 days of age (0.905 vs. 0.900 for OM; and 0.872 vs. 0.859 for EE; $P<0.05$ and 0.864 vs. 0.837 for CP; $P<0.001$) (Table 5). Protein source had little influence on CTTAD of dietary components, except for CP that tended to be higher for SPC and SBM than for PPC and FFSB (0.860 and 862 vs. 0.838 and 0.843, respectively; $P<0.10$). An interaction between age and dietary treatment was detected for OM; the CTTAD tended to increase more with age in pigs fed PPC than in pigs fed the protein sources based on soya ($P<0.10$).

3.4. Coefficient of ileal apparent digestibility of dietary components (Experiment 2)

Protein source had no effect on CIAD of CP or amino acids (Table 6). However, the CIAD of OM (0.813 and 0.813 vs. 0.789 and 0.768 g/kg) and GE (0.810 and 0.816 vs. 0.789 and 0.768) was greater for pigs fed SPC and SBM than for pigs fed PPC and FFSB ($P<0.01$).

3.5. Digestive traits (Experiment 2)

The pH of the different segments of the GIT was not affected by dietary treatment (Table 7). Organ weights were similar for all diets, except for the GIT that was heavier for pigs fed PPC and FFSB than for pigs fed SBM with pigs fed SPC being intermediate (60.3, 61.0, 52.8 and 55.9 g/kg BW, respectively; $P<0.05$).

Table 7
Influence of diet on pH of the gastro intestinal tract and on relative weights of digestive organs and spleen (g/kg body weight) at 48 days of age

Diet	PPC[1]	SPC[2]	SBM[3]	FFSB[4]	S.E.M.[5]	Probability
pH						
Stomach	3.88	4.29	4.08	3.91	0.260	NS
Duodenum	5.22	5.50	5.58	5.38	0.225	NS
Jejunum	6.00	6.01	6.02	6.16	0.114	NS
Ileum	6.47	6.54	6.50	6.43	0.183	NS
Organ weight						
GIT[6]	60.3[a]	55.9[ab]	52.8[b]	61.0[a]	2.04	*
Pancreas	1.8	2.1	1.9	1.8	0.090	NS
Liver	32.3	33.6	31.0	29.4	1.54	NS
Spleen	1.9	2.2	2.0	2.1	0.18	NS

[1]Pea protein concentrate.
[2]Soya protein concentrate.
[3]Soya bean meal.
[4]Fullfat soya bean.
[5]Standard error mean ($n=6$).
[6]Gastro intestinal tract (empty stomach and intestines).
NS = Not significant; *$P<0.05$.
[a,b]Mean values within a row with different superscripts are significantly different.

4. Discussion

4.1. Productive performance

From 26 to 36 days of age pigs fed SPC and SBM containing diets grew faster and had better FCR than pigs fed PPC and FFSB. The poor growth observed in pigs fed the PPC diet was related to the lower ADFI and poorer digestibility found for this diet. This information agrees with Christison and Parra de Solano (1982) who observed a 13% reduction in ADFI in pigs from 21 to 42 days of age when 10% PPC was included in the diet. In the current trial the negative effect of feeding PPC on productive performance disappeared with age which also agrees with Christison and Parra de Solano (1982). Raw peas contain several ANF, namely TI and lectins (Gatel and Grosjean, 1990), saponins (Heng et al., 2006), antigenic proteins (Crevieu-Gabriel, 1999) and oligosaccharides (Abrahamsson et al., 1993) that are known to affect negatively nutrient digestibility, palatability and feed intake. The air classification process used to separate the fine and the coarse fractions of the peas concentrates the protein in the light portion, but also the saponins (Price et al., 1985), the TI (Owusu-Ansah and McCurdy, 1991) and the oligosaccharides (Vose et al., 1976), increasing the negative effect of PPC on voluntary feed intake and nutrient digestibility. In fact, it was noticed that the PPC used in the current trial had a strong bitter aftertaste which indicates the presence of saponins. Besides, the analysed TI content for PPC was 4.9 g/kg. Probably, the bitter taste imparted by PPC inclusion caused an initial rejection of the feed, reducing growth performance. However, normal intakes were resumed within a few days which agree with the data of Forbes and Kyriazakis (1995).

The reason for the poor growth performance and digestibility of pigs fed FFSB as compared to pigs fed SPC and SBM is not known but might be related to differences in TI content, the procedence of the beans or to the thermal process used as has been observed by Qin et al. (1996, 1998). Zarkadas and Wiseman (2005) observed that in piglets, a reduction in the TI content of the diet from 4.8 to 0.60 g/kg increased ADFI by 12% and ADG by 29% and improved FCR by 15.6%. Similarly, Cook et al. (1988) observed an improvement in ADG and FCR in weanling pigs when 32% raw soya beans (4.4 g TI/kg diet) were replaced by extruded soya beans (0.44 g TI/kg diet).

Also, Schulze et al. (1993a) observed that when 2.4 or 7.2 g TI/kg isolated from soya beans were added to a basal diet containing 0.21 g TI/kg, the ADG was impaired by 13 and 32%, respectively.

4.2. Coefficient of total tract and ileal apparent digestibility of dietary components

Age increased CTTAD of dietary components which agrees with most published reports (Medel et al., 2002; Vicente et al., 2008). The observed increase in digestibility with age was more pronounced for PPC than for the soya bean protein sources, which agrees with the impairment observed in FCR for the first 10 days of trial in pigs fed PPC. However, a reverse trend was observed for the last 12 days of trial, a period in which piglets fed the PPC diet had better FCR than piglets fed SBM, indicating that piglets adapted quickly with age to PPC inclusion in the diet.

At 48 days of age pigs fed SPC and SBM tended to have higher CTTAD of CP and had higher CIAD of OM and GE than pigs fed PPC and FFSB. The lower digestibility of CP observed for PPC in the current research agrees with Christison and Parra de Solano (1982) comparing PPC and SBM in 42 days old pigs. Also, the lower CIAD of OM and GE observed for the PPC diet agrees with Grala et al. (1999) who observed lower values for pigs fed peas than for pigs fed various types of soya bean products.

In the current trial, the peas used to obtain the PPC contained 3.2 g TI/kg, a value that is within the range (2.1 to 10.6 g TI/kg pea) found in peas by other authors (Crevieu-Gabriel, 1999; Grosjean et al., 2000). Le Guen et al. (1995) observed that pigs fed pea diets with 1.1 g TI/kg had poorer growth and lower CIAD of CP than pigs fed pea diets with 0.4 g TI/kg. Similarly, Grosjean et al. (2000) compared diets containing peas from 69.3 to 93.5% of different varieties varying in TI content from 2.1 to 10.6 g/kg diet in growing pigs and observed a linear reduction in CIAD of CP as the level of TI increased.

In the current trial, the CIAD of OM and GE was lower in pigs fed FFSB than in pigs fed SPC and SBM. Diets based on SPC or SBM had most of the EE as free oil (added as soya bean oil) whereas in the diets based on FFSB the oil was encapsulated within the spherosomes. Therefore, the availability of the EE was expected to be higher in the diets based on SPC and SBM than in the diets based on FFSB (Adams and Jensen, 1984; Mateos et al., 2007). Also, in the current research, pigs fed SBM tended to have higher CTTAD of CP than pigs fed FFSB, data that agrees with Kaankuka et al. (1996).

The source of protein used had little effect on the CIAD of the amino acids. This information disagree with Grala et al. (1999) who found higher CIAD of sulphur amino acids and threonine in 70 days old pigs fed SBM or SPC than in pigs fed peas. In the current trial the peas were finely ground (15.9 μm of MPS) prior to obtaining PPC, a process that might have improved amino acid digestibility as has been demonstrated for SBM by Fastinger and Mahan (2003). Also, Nyachoti et al. (2006) found that the CIAD of amino acids was improved when raw peas were replaced by heat processed peas in diets for young pigs suggesting that heat processing reduces the deleterious effects of heat-labile anti-nutritive factors of raw peas on nutrient digestibility. In respect to CIAD of soya products, Knabe et al. (1989) and Fan et al. (1995) observed higher CIAD of amino acids in pigs fed SBM than in pigs fed FFSB which disagree with the results of the current trial. In contrast, Dilger et al. (2004) have not found any improvement in amino acid digestibility when SPC substituted SBM in diets of 35 kg BW pigs.

In the current research, TI content was higher in FFSB than in SPC and SBM (4.7, 1.6 and 2.7 g TI/kg, respectively). Protease inhibitors reduce trypsin and chymotrypsin activity and increase endogenous losses of N and amino acids (Boisen and Moughan, 1996). Schulze et al. (1993b) observed that when 2.4 or 7.2 g TI/kg isolated from soya beans was added to a basal diet containing 0.21 g TI/kg, the endogenous losses of N and the true ileal digestibility of CP increased by 42 and 51% and by 14.8 and 35%, respectively. Also, Cook et al. (1988) observed an increase in CIAD of CP (15%) and GE (7%) when raw soya beans (4.4 g TI/kg) were replaced by extruded soya beans (4.4 vs. 0.44 g TI/kg diet, respectively).

The beneficial effect on growth performance and nutrient digestibility of including SPC in substitution of SBM in diets for young pigs is the subject of debate. In general, when SPC replaces SBM in equivalent protein bases, piglet performance and nutrient digestibility are improved (Sohn et al., 1994a,b; Zhu et al., 1998). However, Friesen et al. (1993) did not observe any improvement in piglet growth and Dilger et al. (2004) did not find any increase in CIAD of N, when SBM was replaced by SPC, which agrees with the current trial. In the current trial, pig performance and nutrient digestibility were similar for pigs fed SPC or SBM. Probably the heating process applied to the soya bean used to produce SBM was adequate, an observation that was corroborated by the KOH solubility (80.5%), urease (0.044 mg N/g) and TI content (2.7 g/kg) data.

4.3. Digestive traits

We have not found any research comparing the effects of feeding peas and soya bean products on pH of the GIT of pigs. In the current trial, no effect of the protein source on pH was observed which agrees with Makkink et al. (1994) who did not find any effect on pH when SBM was replaced by SPC. On the other hand, pigs fed FFSB and PPC diets had heavier GIT than pigs fed SBM diets with pigs fed SPC being intermediate. We do not have any explanation for this finding although Huisman et al. (1990) attributed the increase in the weight of the small intestine of 49-day old piglets to the ANF content of the raw *Phaseolus vulgaris* (200 g beans with 4.7 g TI and 40 g haemaglutinins/kg bean) used in substitution of the same amount of toasted beans (0.3 g TI and 0.8 g haemaglutinins/kg bean).

5. Conclusion

The inclusion of 10.5% raw pea protein concentrate (4.9 g TI/kg) in the diet reduces growth performance in pigs from 26 to 36 days of age and nutrient digestibility at 48 days of age. The inclusion of 15.8% fullfat soya bean (4.7 g TI/kg) also reduces performance and nutrient digestibility as compared to soya protein concentrate (1.6 g TI/kg) or regular soya bean meal (2.7 g TI/kg). The inclusion of soya protein concentrate at the expenses of soya bean meal did not elicit a clear positive response on piglet growth or nutrient digestibility. Therefore, the use of raw pea protein concentrate and fullfat soya bean high in trypsin inhibitors should be restricted in diets for young pigs.

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