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The environmental consequences of using home-grown legumes as a protein source in pig diets (Green Pig)

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Jos Houdijk, SRUC

Green Pig project manager

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Academic partners: SRUC, University of Nottingham, NIAB

Industrial partners: BOCM Pauls, BPEX, Evonik-Degussa GmbH, Harbro, MPP, PGRO, Premier Nutrition, QMS, Soil Association and UNIP

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The environmental consequences of using home-grown legumes as a protein source in pig diets

In order to remain globally competitive and comply with government policy that promotes sustainable pig farming and reduce environmental impact, the British Pig Industry must seek viable and sustainable alternatives to sourcing high quality protein feedstuffs whilst maintaining desirable levels of output. Green Pig investigated the potential of using UK grown peas and faba beans in growing and finishing pig diets, to reduce reliance on soya bean meal (SBM) and its associated environmental concerns.

The specific objectives were: (1) to develop a life cycle assessment (LCA) model to assess environmental impact of pig production using existing industry guidelines; (2) to quantify constraints in pea and bean usage in pig feeds; (3) to identify varietal difference in crude protein (CP) level, amino acid (AA) composition and digestibility, and anti-nutritional factor (ANF) content, (4) to review literature on peas and beans for protein composition, ANF and threshold dietary inclusion levels, (5) to test impact of exchanging SBM for peas or beans on N-balance, growth performance and carcass characteristics, (6) to undertake large scale demonstration trials; (7) to re-run LCA based on the outcome of Objectives 2-6, and (8) to disseminate findings to relevant audiences. Figure 1 shows the structure of Green Pig.

This report has been written by many partners of Green pig and describes the approach taken and the results found. All together, they have led to the overall conclusion of Green Pig, which brought together pulse growers on the one hand, with pig feed manufacturers and producers on the other hand, that **UK grown peas and beans are viable home-grown alternatives to SBM in nutritionally balanced grower and finisher pig diets,** as higher than traditionally considered upper inclusion limits can completely replace SBM without detrimentally affecting growth performance, digestibility and N-balance, and carcass quality whilst reducing environmental impact, especially if SBM replaced is associated with land use change.

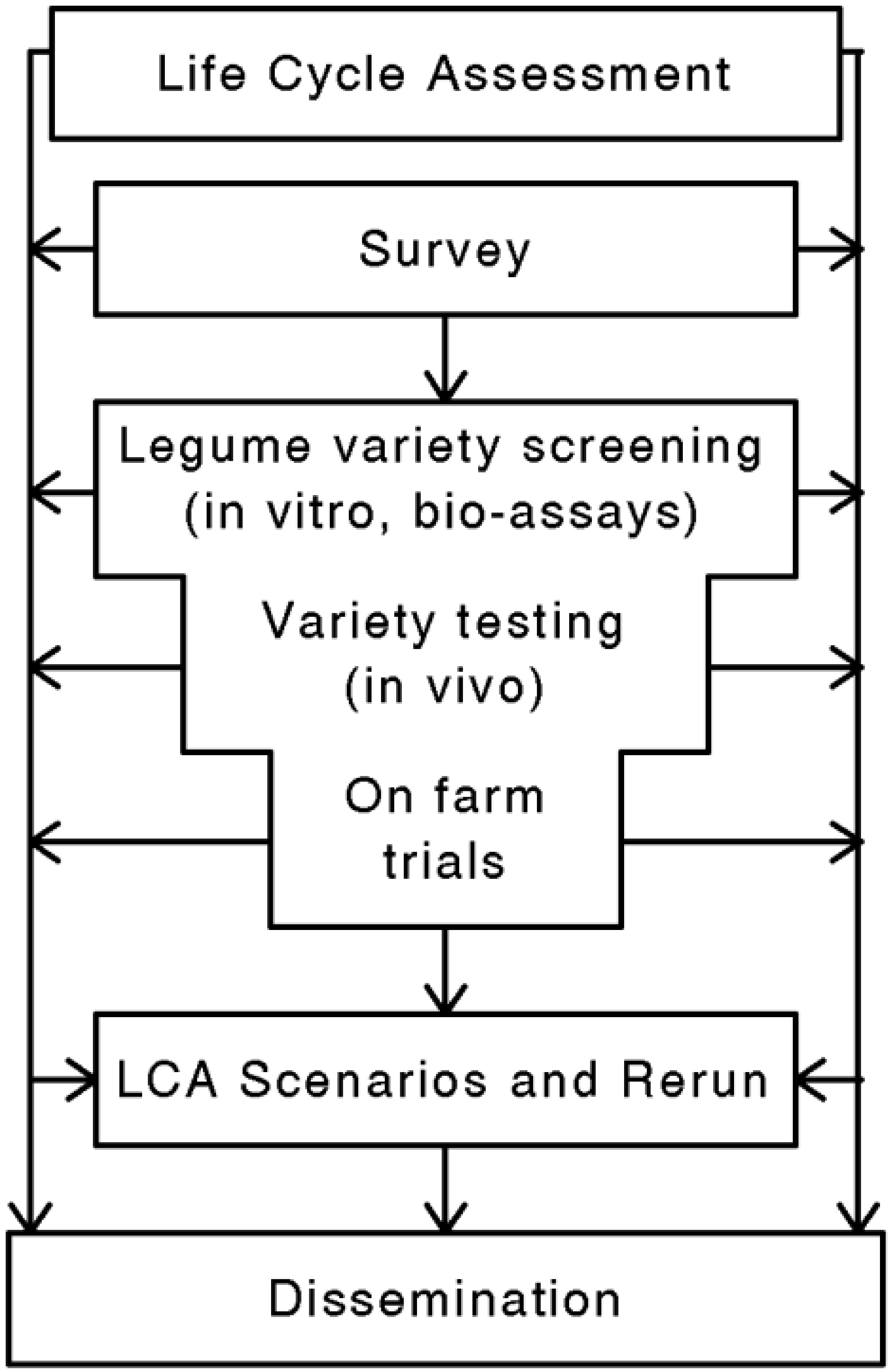

Figure 1. The structure of Green Pig

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Contents

Full report Objective 1: Development of a life cycle assessment tool to assess environmental impact of replacing soya bean meal with peas and beans in pig diets

Lead authors: Davide Tarsitano, Kairsty Topp and Bert Tolkamp (SRUC).

Executive Summary

- A Life Cycle Assessment (LCA) from cradle to grave has been implemented to assess the environmental impact, i.e. global warming potential, eutrophication potential and acidification potential, of replacing soya bean meal (SBM) with home grown peas and beans in pig diets.
- Three diets have been design: Peas, Beans and Soya diet, where the primary source of proteins is associated to each of the crop considered.
- The farmer is a home mixer and most of the animal feeds are produced *in situ*, with SBM is imported from outside the UK.
- The farm size and rotations management are assumed to be able to fulfil the dietary needs, using three rotations to supply all the crop related ingredients.
- The manure produced by the pigs is stored in a slurry tank within the farm area and is subsequently used as organic fertiliser for crop production.
- The LCA has been design using the IPCC 2007 Tier I, II and III methodologies, which accounts for several N_2O and CH_4 emission sources and establishes their global warming potential (GWP), measured in CO_2eq per functional unit. Eutrophication potential (PO_4eq) and acidification potential (SO_2eq) have been determined using standard methodology.
- Where the production of SBM and palm oil, used as fat supplement in the pig diets, are associated with land use change, this factor has been accounted for, considering a GWP of 3.57 kgCO_2eq/kg and 1.36 kgCO_2eq/kg respectively.
- The LCA results show from the environmental point of view the use of home grown beans and peas in grower and finisher pig diets is associated with similar emissions to the traditional SBM based diets if the soya is derived from sources that are not associated with deforestation or other forms of land use change, with an estimated GWP of 1.59 kgCO_2eq/kg pig, 1.63 kgCO_2eq/kg pig and 1.69 kgCO_2eq/kg pig, for the peas, beans and SBM based diet respectively.

- However, if soya is cultivated on land that has been converted from natural to crop land, then the SBM used in the diet is associated with land use change, and this significantly increases its GWP per kg pig, 2.02 kgCO_2eq/kg pig, 1.99 kgCO_2eq/kg pig and 2.85 kgCO_2eq/kg pig for the peas, beans and SBM based diet respectively.

Introduction

A Life Cycle Assessment (LCA) from cradle to grave is a methodology to assess the environmental impacts through e.g. greenhouse gas (GHG) emissions, eutrophication and acidification, associated with a production system. In this study the production of pigs for food consumption has been investigated.

The level of detail included varies greatly between LCAs, depending on the available information describing the system under investigation and the main goal of the study. This variability makes it difficult to directly compare the outputs from different LCA. The system has been divided into processes and sub-models have been implemented to estimate their environmental impact and global warming potential (Figure 1).

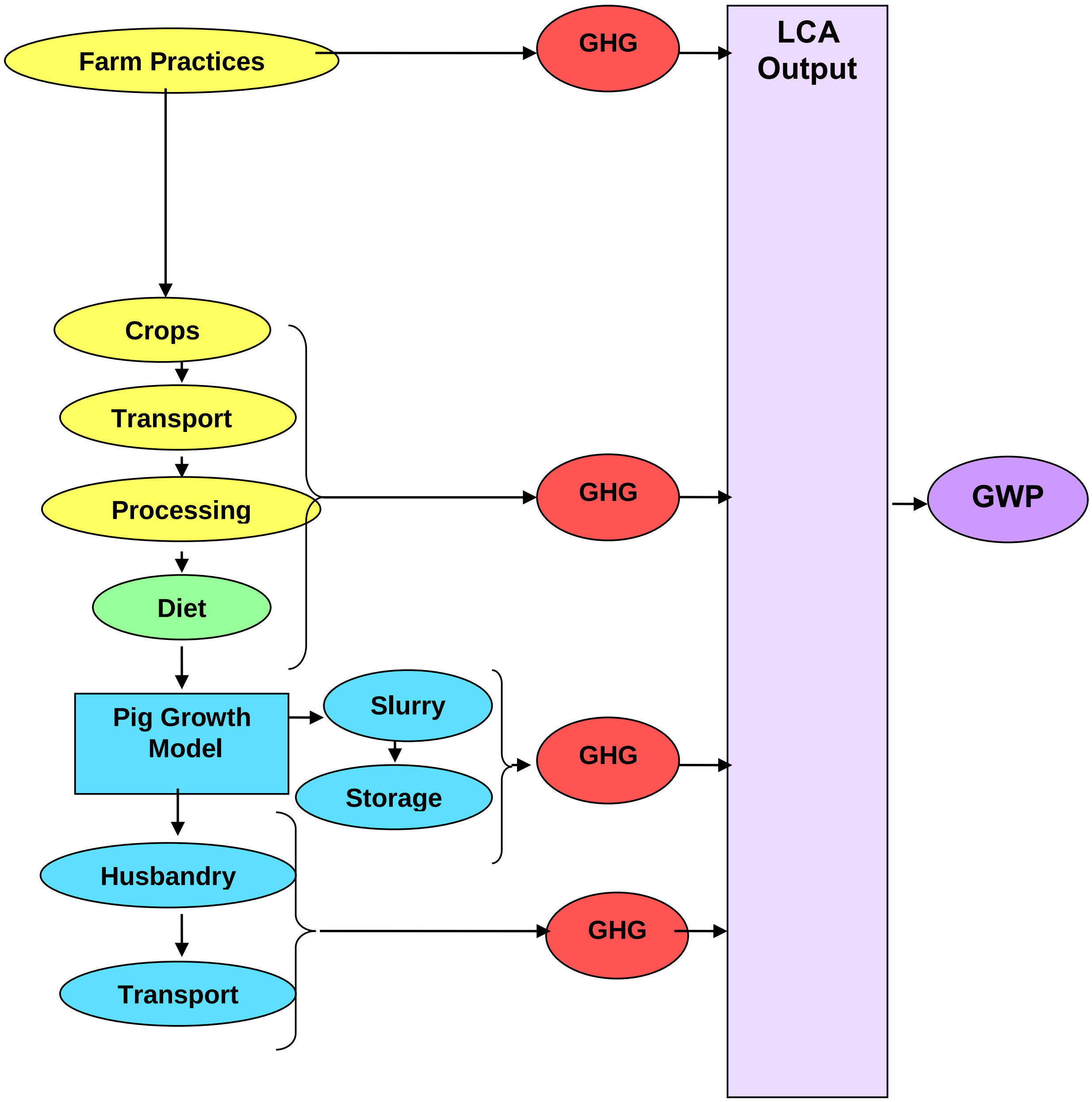

Figure 1. The processes that contribute to the global warming potential (GWP) that are considered in the LCA. Similar processes inform on eutrophication and acidification potential.

Global warming potential

Global warming arises from the use of fuels and electricity, and also from pig enteric methane (CH_4) production, CH_4 and nitrous oxide (N_2O) production from slurry storage and N_2O production from soils. The processes that result in N_2O emissions from soils are illustrated in Figure 2.

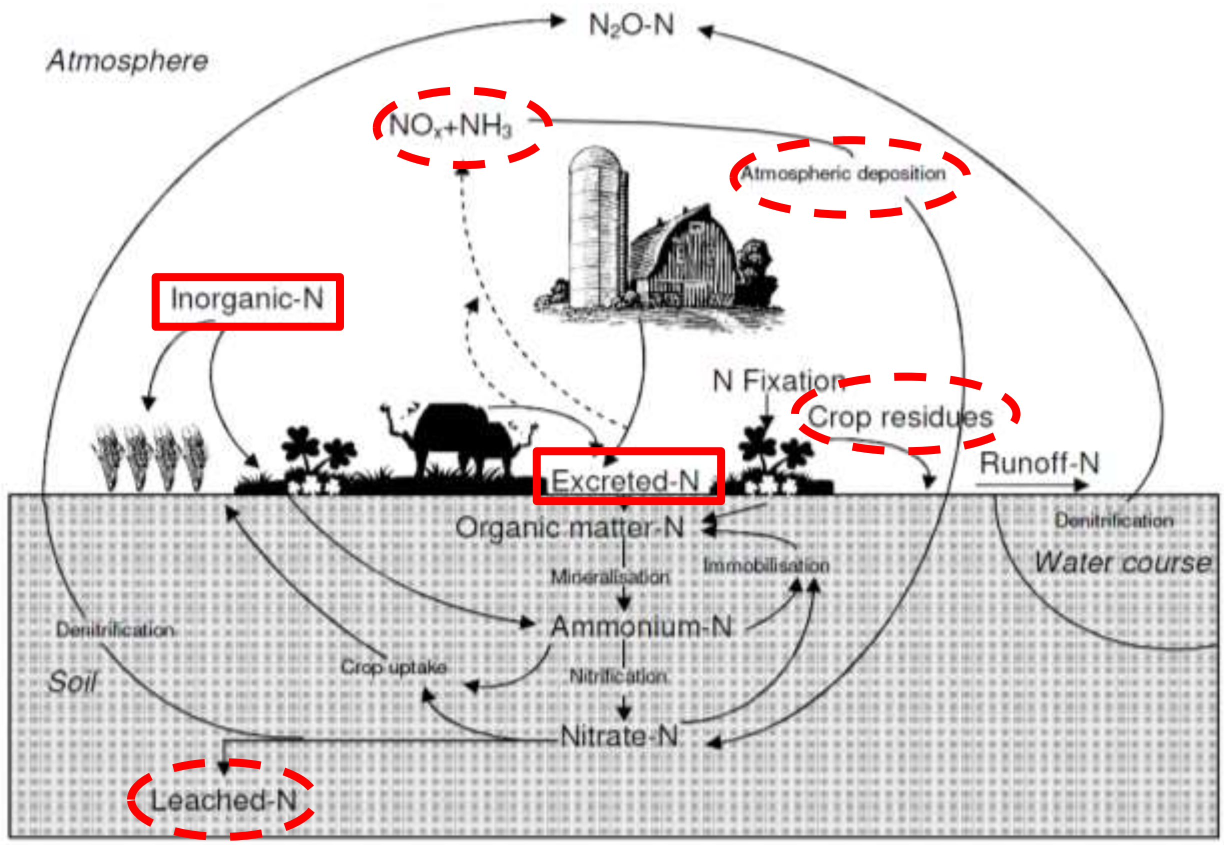

Figure 2. The on-farm processes that result in the production of N_2O.

The GWP of any process is expressed as CO_2eq per functional unit. The term CO_2eq is used to sum the contribution of CO_2, CH_4 and N_2O, where one unit of CH_4 is equivalent to 25 units of CO_2eq and one unit of N_2O is the equivalent of 298 units of CO_2eq (BSI, 2011). The used functional unit is 1 kg of pig growth. Values expressed this way can be converted to values expressed per kg of carcass weight or lean weight growth by division with 0.75 or 0.62, respectively.

Eutrophication and Acidification potential

Pig production also results in eutrophication and acidification. Acidification is primarily caused by the deposition of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3) onto the land or water bodies. While the SO_2 and NO_x are mostly products of combustion (i.e.

oil, coal and vehicles fuel), NH_3 is predominantly originated from livestock production. A second source of these compounds is crop production, specifically the use of organic and mineral fertiliser as they can produce significant NH_3 and NO_x emissions due to the volatilisation of urea and ammonium. The SO_2, NH_3 and NO_x deposition affects the soil and water acidity level, resulting in a negative effect on the environment. The acidification potential (AP), measured in SO_2eq per functional unit, is used to assess and compare the acidification effects of different systems. Eutrophication can result in the increase of biomass in a terrestrial and aquatic ecosystem due to the input of nutrients by anthropogenic activities. This process may cause ecosystem changes due to shift in species composition. The most dramatic example may be the algal blooms in water bodies, where the considerable increase in algal total biomass depletes the oxygen water content which may result in the complete death of the aquatic ecosystem. Eutrophication potential (EP, in PO_4^{3-}equivalents) is the standard unit of measurement.

Land Use Change

Soya bean meal (SBM) used in the UK as livestock feed is primarily derived from soya beans grown in Brazil and Argentina. It has been shown that the production of soya in these two countries is associated with deforestation or, in more general terms, land use change due to the increased use of land for agricultural purposes (Dalgaard et al 2008, Mattsson et al 2008, Soystats). A second ingredient in a pig diet that is associated to LUC is the fat supplement as it is palm oil primarily from Indonesia and Malaysia (Defra, 2011). Land use change (LUC) is a general terminology to describe a change in the management of the considered land. Within a LCA framework, it mostly refers to the conversion of an area from natural ecosystem, such as a forest, to grassland/cropland or from improved grassland to cropland. There are several environmental implications which make LUC an important factor in a carbon footprint assessment, such as losses in biodiversity, soil erosion and greenhouse gas emissions (Eriksson et al 2005), with the latter is arguably the most relevant aspect for our study.

A natural ecosystem, such as a forest, is considered a carbon sink due to the process of absorbing and storing carbon dioxide from the atmosphere into soil organic matter. In addition, trees with their high biomass and longevity are able to store carbon for a long period of time. However, this type of ecosystem may change from carbon sink to carbon source, if it is converted into agricultural land. Estimates of world emissions associated to LUC give as much as 5.9±2.9 Gt CO_2eq/y solely for the 1990s (Flynn et al 2012), with emissions from Brazilian rainforest converted to soya bean cultivation being estimated to 41.6 t CO_2eq/ha/y (Fargione et al, 2008).

The processes causing the large release of greenhouse gases, such as CO_2 and N_2O, following LUC is primarily associated with the alteration of the carbon-nitrogen cycle equilibrium. Generally they can be identified with the mineralisation of soil organic matter (SOM) and changes in plant biomass stock. The greenhouse gases emissions following land conversion are generally associated with two different release rates. In the short term, a considerable quantity of CO_2 is emitted due to the practice of burning the not economically valuable plant material. In the long term, the establishment of new carbon - nitrogen cycle equilibrium emits considerable amount of N_2O, CO_2 and CH_4. Cultivated soils are characterised by a lower level of SOM than natural systems. The amount of plant material that returns to the soil litter pool is reduced, resulting in a progressive decline of the soil humus (Stevenson 1999). In addition, the decomposition rate of soil organic matter increases following the higher oxygenation of the soil caused by management practices as ploughing. In an aerobic environment ammonifying bacteria are able to convert more rapidly the nitrogen present in the organic matter into ammonium (NH_4^+). This in turn affects the nitrification and denitrification process and therefore increases the N_2O production and release.

LCA of Pig production – Methodology

The LCA methodology has been implemented to establish and compare the environmental impact of conventional pig production to an alternative management, where the main sources of proteins are home grown peas and beans as SBM alternatives. The two most important pig-producing regions in the UK are Yorkshire and East Anglia. The functional unit used in this study is defined as 1 kg pig growth, considering an average live weight gain of 90 kg from 20 kg live weight to 120 kg live weight). With respect to GWP, the approach implemented is based on the IPCC 2007 Tier I, II and III methodologies, which account for several N_2O and CH_4 emission sources and establishes their global warming potential (GWP), measured in CO_2eq per functional unit. Eutrophication potential (PO_4eq) and acidification potential (SO_2eq) have been determined using standard methodology (Williams et al. 2006).

The LCA focused on five areas: (1) Crop production (CO_2eq), Tier II, (2) Manure management (CO_2eq), Tier I, (3) Pig growth and management (CO_2eq), Tier III, (4) Eutrophication (PO_4eq) and (5) Acidification (SO_2eq).

System Description

The system considered is a conventional arable-livestock farm, where the farmer is a home mixer and most of the animal feeds are produced *in situ*, with SBM the only ingredient imported from outside the UK. The farm size and rotations management are assumed to be able to fulfil the dietary needs. The manure produced by the pigs is stored in a slurry tank within the farm area and is subsequently used as organic fertiliser for crop production.

The crop rotations (Table 1), used to grown the animal feeds, have been compiled with the support of Green Pig project members in order to have a realistic representation of UK rotations, which combine legumes, cereals and oilseed rape.

Table 1. The rotations that have been used in the study

Year	Rotation 1	Rotation 2	Rotation 3
I	Spring pea	Spring bean	Winter bean
II	Winter wheat	Winter wheat	Winter wheat
III	Winter oilseed rape	Winter oilseed rape	Winter wheat
IV	Winter wheat	Winter wheat	Winter oilseed rape
V	Winter barley	Winter barley	Winter wheat
VI	-	-	Winter wheat

The fertilisers (N-P-K) required to meet the crop needs have been derived using the RB209 methodology (Table 2), which takes account of the climatic conditions, rotations and soil type (Defra, 2008). The crop nutrient needs have been fulfilled primarily by organic fertiliser. However, synthetic fertiliser has been applied when the Defra limit for manure application (i.e. 170 kg/ha per year or 60% of the crop N requirement) has been reached (Defra, 2008).

Table 2. The N (kg/ha) requirements of each crop for two soils type for each of Yorkshire and East Anglia. The terms 'sp' and 'w' in the table indicate whether it is a spring or winter crop, while CL, SaCL, SCL refer to the soil type, Clay loam, Sandy Clay Loam and Silty Clay Loam respectively

		Yorkshire						East Anglia					
		CL			SaCL			SCL			SaCL		
		N	P	K	N	P	K	N	P	K	N	P	K
Rotation 1	sp pea	0	40	40	0	40	40	0	40	40	0	40	40
	w wheat	190	70	70	130	70	70	130	70	70	130	70	70
	w OSR	220	40	40	190	40	40	220	40	40	190	40	40
	w wheat	190	70	70	160	70	70	160	70	70	160	70	70
	w barley	170	70	70	150	70	70	140	70	70	150	70	70
Rotation 2	sp bean	0	40	50	0	40	50	0	40	50	0	40	50
	w wheat	190	70	70	130	70	70	130	70	70	130	70	70
	w OSR	220	40	40	190	40	40	220	40	40	190	40	40
	w wheat	190	70	70	160	70	70	160	70	70	160	70	70
	w barley	170	70	70	150	70	70	140	70	70	150	70	70
Rotation 3	w bean	0	40	50	0	40	50	0	40	50	0	40	50
	w wheat	190	70	70	130	70	70	130	70	70	130	70	70
	w wheat	220	70	70	160	70	70	190	70	70	160	70	70
	w OSR	220	40	40	190	40	40	220	40	40	190	40	40
	w wheat	190	70	70	130	70	70	160	70	70	130	70	70
	w wheat	220	70	70	160	70	70	190	70	70	160	70	70

Crop Production

The crop production has been modelled using a tier I approach. Representative crop yields have been based on expert knowledge (Table 3). Therefore, the crops have been assumed to be produced under normal temperature, nitrogen or water stress.

Table 3. Assumed yields for the considered crops; the average (B_{mid}), maximum and minimum yield, B_{high} and B_{low} respectively are reported in tDW/ha assuming 85% dry weight.

	Crop biomass		
	B_{low} (tDW/ha)	B_{mid} (tDW/ha)	B_{high} (tDW/ha)
Spring Barley	4	5.5	7.5
Winter Barley	6	7.5	9
Winter Wheat	6	8	10
Spring Oat	4	5	6
Winter Oilseed Rape	3	4	5
Spring Peas	2.5	4.5	5.5
Spring Beans	2.5	5	6
Winter Beans	2.5	5	6
Soya bean	2.2	2.6	3

Conventional farming

The N_2O emissions from managed land are the results of direct or indirect losses. The former are due to the increase of available N in the soil, caused by the application of synthetic and organic fertiliser, which leads to an enhancement of the nitrification and denitrification rate producing further N_2O emissions. Using a Tier I approach (eq 1) such emissions have been established assuming a 1% emission (EF1) from the nitrogen applied. This includes synthetic and organic fertiliser, and crop residues. The IPCC (2006) default values required for the calculations of the global warming potential from resulting from N_2O emissions from soils are reported in Table 4.

$$N_2O = CF * \left(F_{SN} + F_{ON} + F_{CR}\right) * EF_1 \qquad \text{Eq 1}$$

Where

EF_1 is the emission factor developed for N_2Oemissions from synthetic and organic N fertiliser.
F_{SN} is the annual amount of synthetic fertiliser that it is applied on the considered field (kgN/y)
F_{ON} is the amount of organic N that has been applied to the field (kgN/y)
F_{CR} is the N in the crop resides that are left in the field and therefore return to the soil (kgN/y)
CF is the conversion factor from N_2O-N to N_2O, and it is the ratio of the atomic weight of the two molecules, i.e. 44/28.

Organic source of N entering the system is mostly due to the application of manure (F_{ON}); nevertheless, a second component that has to be included is the N content of the crop residues that are annually returned to the soil, (F_{CR}, eq 2), which are incorporated into the soil organic matter after ploughing. The yield value (B_{AG}) has been used to estimate the above and below ground biomass using a linear regression model (eq 3) using the parameters from Table 5, which is part of the tier I IPCC guidelines. The crop biomass has been used to calculate the N content in the above-ground residues and therefore the total N in the below-ground residues, Eq 2 and 3. Table 5 reports the factors used to determine the N content.

$$F_{CR} = B_{AG} * \left[R_{AG} * N_{AG} * \left(1 - Frac_{remove}\right) + R_{BG} * N_{BG}\right] \qquad \text{Eq 2}$$

Where
B_{AG} is the annual above ground dry weight biomass, eq. 3 (kg/ha)
N_{AG} is the N content in the above ground plant residue (kg N/kg)
$Frac_{remove}$ is defined as the fraction of above ground residue removed annually, a value of 90% have assumed for this work.
R_{BG} is the ratio between the below ground residue and the crop yield.

Table 4. The IPCC (2006) default values required for the calculations of the global warming potential from resulting from N_2O emissions from soils.

Emissions factors		Default value	Uncertainty range
EF_1	Gas emissions for N addition to the field, for mineral and organic fertiliser. (KgN_2O-N/kg N)	0.01	0.003 – 0.03
EF_4	Fraction of N volatised and deposited. kgN_2O-N/($kgNH_3$-N + NO_x-N)	0.01	0.002 – 0.05
EF_5	Leaching and runoff Kg N_2O-N/KgN leaching and runoff.	0.0075	0.0005 – 0.025
$Frac_{gasm}$	Volatilisation from organic fertiliser. Kg(NH_3-N + NO_x-N)/kg N applied	0.2	0.05 – 0.5
$Frac_{gasf}$	Volatilisation from synthetic fertiliser. Kg(NH_3-N + NO_x-N)/kg N applied	0.1	0.03 – 0.3
$Frac_{leach}$	N losses by leaching and runoff Kg N/kg N added	0.3	0.1 – 0.8
GWP	N_2O Global Warming Potential (CO_2eq)	298	–
EF_3	Direct N_2O emission from a Slurry tank (kg N_2O-N/Kg N manure)	0.005	Factor of 2
EF_4	Emission factor for N_2O from atmospheric deposition of nitrogen on soil, kg N_2O-N/($kgNH_3$-N+NO_x)	0.01	-
$Frac_{gasMS}$	Percentage of organic N lost as NH_3 and NO_x when stored in slurry tank, %	48	15 – 60
$Frac_{leachMS}$	Percentage of organic N lost through leaching and runoff when stored in slurry tank, %	1	1 – 20

Table 5. The IPCC (2006) values for calculating the N content of the crop residues. The parameters m and c are used in Eq. 3, while N_{bg} are the N content in below ground plant

biomass respectively. $R_{bg\text{-}bio}$ is the ratio of below ground residue to above ground biomass, used in Eq. 4.

	m	c	$R_{bg\text{-}bio}$	N_{bg}
S barley	0.98	0.59	0.22	0.014
W barley	0.98	0.59	0.22	0.014
W oilseed rape	1.5	0	0.19	0.017
W wheat	1.61	0.4	0.23	0.009
S peas	1.13	0.85	0.19	0.008
S beans	1.13	0.85	0.19	0.008
W beans	1.13	0.85	0.19	0.008
S Oats	0.91	0.89	0.25	0.008
Nfixing forage	0.3	0	0.4	0.022
Soya beans	0.93	1.35	0.19	0.008

$$B_{AG} = Yield * m * c \qquad \text{Eq 3}$$

Where

Yield is the crop dry weight yield (kg/ha)

m and c are parameters, Table 5

$$N_{BG\_res} = B_{AG} * R_{bg-bio} * N_{bg} \qquad \text{Eq 4}$$

Where

Yield is the crop dry weight yield (kg/ha)

m and c are parameters, Table 5

In addition to the pathways previously described, N_2O enters the environment through indirect pathways. The first of these sources is the volatilisation of the N applied as fertiliser, in the form of NH_3 and NO_x. It is assumed that 10% ($Frac_{gasf}$) of the synthetic fertiliser volatilises in the form of NH_3 and NO_x, while the percentage of N volatilisation from organic fertiliser sources is 20% ($Frac_{gasm}$). A fraction ($Frac_{gasm}$, 1%) of the volatilised N is assumed to deposit onto soil and water bodies, Eq. 5. (IPCC, 2006)

$$N_2O_{ATD} = CF * [(F_{SN} * Frac_{GASF}) + (F_{ON} * Frac_{GASM})] * EF_4 \qquad \text{Eq 5}$$

Where

F_{SN} is the annual amount of synthetic fertiliser that it is used (kgN/ha)

$Frac_{GASF}$ is the fraction of mineral N fertiliser that it is lost through volatilisation as NH3 and NO_x (kgN)

F_{ON} is the annual amount of organic N added to the field (kgN).

$Frac_{GASM}$ is the fraction of organic N fertiliser materials (e.g. manure) that volatilised as NH3 and NOx

EF_4 is the emission factor for N_2O emissions from atmospheric deposition of N on soils and water bodies (kgN-N_2O (kgNH_3-N + NO_x-N volatilised)

A second indirect pathway is the leaching and runoff of N (N_2O_L), Eq 6, which is function of the N content in crop residues (F_{CR}), synthetic (F_{SN}) and organic fertilisers (F_{ON}). It is assumed that a 30 % ($Frac_{LEACH}$) of the N applied will be lost through this process. However, there is a large uncertainty associated with this parameter as leaching is strongly affected by soil texture, hydrology and weather conditions. In general terms a factor of 30% losses is assumed for humid regions, such as the UK, or for dry regions where irrigation is implemented.

$$N_2O_L = CF*\left(F_{SN}+F_{ON}+F_{CR}\right)*Frac_{LEACH}*EF_5 \qquad \text{Eq 6}$$

Where

F_{SN} is the annual amount of synthetic fertiliser that it is used (kg N/ha)

F_{ON} is the annual amount of organic N added to the field (kg N/ha).

F_{CR} is the annual amount of organic N added to the field (kg N/ha).

$Frac_{LEACH}$ is the fraction of synthetic/organic N fertiliser that is lost due leaching and run-off, (kgN/kgN added).

EF_5 is the emission factor for N_2O emissions from N leaching and runoff (kgN_2O-N (kgN lost)

Allocation

An essential aspect that has to be taken into consideration when assessing the carbon footprint of animal feed is that several dietary ingredients are co-products. A relevant example is SBM that is a meal residue of soya bean oil production. Therefore a question arises on how to determine the impact of a co-product without overestimating its contribution on the overall carbon footprint. The ISO (2006) recommends avoiding allocation factor whenever possible by either subdividing certain processes or expanding the system limits to include the additional functions. Nonetheless, this disaggregation is not achievable with crop production systems. Therefore, in processes where it is not is not possible to avoid allocation, the ISO series (2006) recommend to use allocation factors that are based on the mass fraction of the co-product and/or on its economic value. These two methodologies have been discussed in the recent literature (e.g. Blonk et al, 2009, Williams 2006, Cederberg and Mattsson, 2000).

The method that has been adopted in this work is the economic allocation as described by M. Macleod (personal communication), where the emission per kg crop is multiplied by the ratio between the economic and mass allocation to assign a value per kg co-product. A summary of economic and mass allocation for concentrated components is shown in Table 6 (Eriksson et al 2005, Cederberg and Mattsson, 2000).

Table 6. The mass and economic allocations factors for the co-products.

Crop	Mass allocation		Economic allocation	
	Oil/flour	Meal	Oil/flour	Meal
Soya bean	0.2	0.8	0.3	0.7
Rape seed	0.45	0.55	0.7	0.3
Sunflower	0.4	0.6	0.75	0.25
Wheatfeed	0.8	0.2	0.9	0.1
Palm Oil	0.77	0.13	0.83	0.03

Land Use Change

Land conversion from forest to agriculture generates greenhouse gas emissions and this is of international concern due to the ever increasing globalised market, where trends in the EU may affect land use practices in the other side of the globe. However, a detail estimation of changes in carbon and nitrogen stocks within a LCA framework has seldom been performed due to the lack of an established methodology (Mattsson et al 2000). Methodological problems are primarily related to the level of details required to address such a task. Factors such as knowledge of previous land use, carbon stocked above ground as well as below ground and the time required for the carbon-nitrogen cycle to establish a new level of equilibrium, which is strongly dependent on soil type, climate and hydrology, are difficult to establish particularly if the area of interest is large, e.g. Brazil.

The guidelines from the PAS2050 (BSI, 2011) are that if the previous land use is not known, the LUC emissions can be established using an average emissions value from the country under investigation. In addition, it is suggested that when the timing of the land use change cannot be established the worst case scenario should be considered. The LUC impact, related to SBM imported in the UK is derived from FAO data referring to SBM used in the UK (Gerber et al 2010). The assumption is that UK used SBM from Argentina is partially associated with LUC while Brazilian soya beans are considered to be completely associated with LUC. The UK imports soya / SBM directly from Brazil and Argentina (Table 7).

Table 7. The sources of the imports of soya bean to the UK in 2007, (Gerber et al 2010)

Source	Imports in the UK (t)	Share (by mass)	LUC emissions ($kgCO_2eq/kg$)	Production emissions ($kgCO_2eq/kg$)	Total emissions ($kgCO_2eq/kg$)	Total emissions ($kgCO_2eq/kgDM$)
Argentina	9.99E+05	53%	0.93	0.21	1.14	1.27
Brazil	7.38E+05	40%	7.69	0.22	7.91	8.79
Others	1.33E+05	6%	0	0.26	0.26	0.29

With regards to the imports from Brazil, it is reasonable to assume that there is an overestimation of the LUC associated with soya bean. The literature suggests that soya bean from the South of Brazil is not cultivated on recently converted land, as opposed to the products from the Centre West of Brazil (Da Silva et al, 2010). Nonetheless, the information regarding the UK imports are not detailed enough to be able to tell the exact origin of SBM used in pig industry. Therefore the worst case scenario has been adopted considering an emission of 3.6 $kgCO_2eq/kgDM$, which has been estimated as a weighted average of the UK imports (Table 7).

A second ingredient that is associated to LUC is palm oil, which is imported in the UK primarily from Indonesia 66% and Malaysia 20% (DEFRA, 2011). The carbon footprint of the deforestation for these two countries has been derived using the PAS205 values (BSI, 2011), which give 31 tCO2eq/ha and 26 tCO2/ha for the transition from forest to perennial cropland.

Manure management

Manure is a considerable source of CH_4 and N_2O. Its production is due to the decomposition of animal excretion under anaerobic conditions. Consequently, the two main factors that control the rate of production are the storage system temperature, which is an important driver of the decomposition process, and the length of the storage process. Different storage facilities are characterised by different emission rates due to their specifications and type of manure stored. Ponds, tanks, or pits store manure in liquid form, which decomposes anaerobically therefore emitting a significant volume of CH_4. If dung and urine are directly deposited on pasture, as for organic systems or handled as a solid (e.g. in stacks or piles) they decompose under more aerobic conditions and therefore a lower volumes of CH_4 are produced.

As for the soil nitrogen, manure emits N_2O through two pathways: direct and indirect. The direct emissions occur via the combined process of nitrification and denitrification of the manure N (eq 7). The former is the oxidation of ammonia to nitrate, through the activity of denitrifier microbes, and occurs in aerobic conditions. In the latter, the nitrites and nitrates are transformed into N_2O in anaerobic conditions. The manure management system that has been considered for this work is a slurry tank, which is characterised by direct N_2O losses of 0.5% of the manure N.

Volatilisation of ammonia-NO_x ($N_2O_{G(mm)}$) and nitrogen leaching and runoff ($N_2O_{L(mm)}$) are the two processes that are considered for the indirect N_2O emissions. Volatilisation is the result of mineralisation of organic nitrogen occurring through the manure collection and storage and therefore is mostly dependent on time (eq 8). On the other hand, leaching and run off are strongly dependent on the type of storage facility (eq. 9).

$$N_2O_{D(mm)} = CF * \left(N_{ex} * MS\right) * EF_3 \qquad \text{Eq 7}$$

Where

N_{ex} is the annual average N excretion per head, kgN/animal y

MS is the fraction of the total annual nitrogen excretion managed in the manure management system under consideration, dimensionless

EF_3 is the emission factor for the direct N_2O emissions, kg N_2O-N / kg N

CF is the conversion factor from N_2O-N to N_2O, and it is the ratio of the atomic weight of the two molecules, i.e. 44/28.

$$N_2O_{G(mm)} = CF * \left(N_{ex} * MS\right) * \left(\frac{Frac_{GasMS}}{100}\right) * EF_4 \qquad \text{Eq 8}$$

Where

N_{ex} is the annual average N excretion per head, kgN/animal y

MS is the fraction of the total annual nitrogen excretion managed in the manure management system under consideration, dimensionless

$Frac_{GasMs}$ is the percent of manure Nitrogen that volatilises as NH_3 and NO_x, %

EF_4 is the emission factor for the direct N_2O emissions from atmospheric deposition on soil and water bodies, kg N_2O-N / kg (NH_3-N + NO_x-N)

CF is the conversion factor from N_2O-N to N_2O, and it is the ratio of the atomic weight of the two molecules, i.e. 44/28.

$$N_2O_{L(mm)} = CF * \left(N_{ex} * MS\right) * \left(\frac{Frac_{LeachMS}}{100}\right) * EF_5 \qquad \text{Eq 9}$$

Where

N_{ex} is the annual average N excretion per head, kgN/animal y

MS is the fraction of the total annual nitrogen excretion managed in the manure management system under consideration, dimensionless

$Frac_{LeachMs}$ is the percent of manure Nitrogen lost due to leaching and runoff, %

EF_5 is the emission factor for the direct N_2O emissions from atmospheric deposition on soil and water bodies, kg N_2O-N / kg (NH3-N + NOx-N)

CF is the conversion factor from N_2O-N to N_2O, and it is the ratio of the atomic weight of the two molecules, i.e. 44/28.

CH_4 from enteric fermentation

The second important source of methane is produced by the enteric fermentation. It is highly variable as it is dependent on several animal specific characteristics as the age, weight and type (i.e. ruminant or non-ruminant). In this study it is assumed that the enteric fermentation emission is 0.56 kgCH_4/pig during the entire growth period (IPCC, 2006)

Additional Processes

All the addition processes that are present in a pig production system have been included in the LCA.

Synthetic Fertilizer and production

The GWP associated in producing and transporting synthetic fertilizers were derived from the Defra ISO2050 LCA (Williams et al. 2006). It is assumed that 6.8 kg CO_2eq/kg N, 1.2 kg CO_2eq/kg P and 5.7 kg CO_2eq/kg K respectively are required for the production of N-P-K fertilizer.

Transport

The LCA scenario considered for this study is of a home-mixer, therefore the ingredients for the pigs diets are grown in the farm. This scenario design reduces considerably the impact of crops transport. It is assumed that all the crops, with the exception of SBM, are transported only for the processing and grain storage unit. The GWP associated is $1.68*10^{-4}$ kg CO_2eq/kg per km for road transport and $1.06*10^{-4}$ kg CO_2eq/kg per sea km (Dalgaard et al. 2007). It is assumed that soya beans are produced in Brazil and Argentina; therefore soya beans or SBM are transported for 9,980 km on sea, with an emission of $1.06*10^{-5}$ kg CO_2eq/km and 850 km on road at $1.68*10^{-4}$ kg CO_2eq/km (Dalgaard et al. 2007).

Grain processing

The grain processing is assumed to take place in the farm and energy requirements for grain drying is calculated assuming 26 MJ/kg for cereals, 0.31 MJ/kg for rapeseed and 0.47 MJ/kg for soya (Eriksson et al. 2004), considering that 1 MJ electricity is equal to 0.261 kgCO_{2eq} (Yan 2009).

SAA and additional ingredients

The environmental cost for the production of synthetic amino acids (SAA) has been assumed to be equal to 3.6 kg CO_2eq/kg. The proportion of the diet classified as rest consists of molasses, vitamins and minerals (Meth) which have a GWP of 0.4 kg CO_2eq/kg (Eriksson, 2004). Finally the carbon footprint of palm oil, used as fat supplement in the pig diet, has been considered equal to 0.36 kg CO_2eq/kg. This value is based on the weighted average of the estimated emissions for palm oil imported from Indonesia and Malaysia (Blonk et al, 2009).

Pig Model

Growth and body composition model

The used animal growth model was largely developed at SAC (e.g. Emmans, 1997; Wellock et al. 2003, 2004; Whittemore and Kyriazakis, 2006; Whittemore, 2006) and predicts potential growth and voluntary food intake of an animal. The body composition of the pig is modelled as consisting of protein, lipid, ash and water plus a correction for gut fill (Emmans 1997; Wellock, 2003). The basis of the model is a Gompertz equation that describes protein content of the pig body as a function of age since conception (t):

$$P = P_m e^{-e(-G_0 - B.t)} \quad \text{Eq 10}$$

Where

P = protein weight (kg) on day t,

Pm = the asymptotic (mature) protein weigh (kg),

G0 = the Gompertz variable -2.586 (a measure of the relative protein content of the animal at conception),

B = the rate parameter of protein growth.

Different genotypes can be modelled by adjusting the input parameters B and Pm and initial values for average modern pig genotypes of Pm = 40 kg and B = 0.01 (Whittemore and Kyriazakis 2006) were selected as starting values for the initial LCA.

Lipid growth is calculated assuming that the animal is not constrained in any way, i.e. the animal is assumed to be free from infection and not restricted in feed intake or constrained as a result of social stressors and can achieve its ‘desired’ level of fatness (Wellock et al., 2003). Q is the desired degree of fatness for the mature animal and is defined as:

$$Q = \frac{L_m}{P_m}$$ Eq 11

Where

Lm is defined as the asymptotic (mature) lipid mass (kg) of an animal that is achieving its genetic potential for growth.

The selected starting value for Q was 2 (Whittemore and Kyriazakis, 2006), which corresponds with an asymptotic fat mass of 80 kg at Pm = 40 kg. The actual lipid weight at a given protein weight is calculated using the allometric model:

$$L = L_m * \left(\frac{P}{P_m} \right)^b$$ Eq 12

Where

L = the lipid mass (kg) for an animal with protein weight P,

P = current protein weight (kg)

b is defined (Wellock, 2003) as in eq 13:

$$b = 1.46 * Q^{0.27} = 1.71$$ Eq 13

The quantity of ash (minerals) has been shown to be relatively constant in relation to the quantity of protein so that for every kg of protein there is 0.19 kg of ash (Wellock, 2003). Body water (BWat) is again related to the actual protein weight via an allometric relation (based on Wellock, 2003):

$$BWat = 5.19 * P^{0.855}$$ Eq 14

The empty body weight can then be calculated from the sum of the protein, lipid, ash and water weight. Gut fill is assumed to be constant at 5% of the empty body weight (Wellock, 2003); the empty body weight is, therefore, divided by 0.95 to estimate full body weight.

The parameter values for the pig model were selected depending on the simulation that was run. For the original LCA, the mentioned starter values were used because these seem representative of currently used pig genotypes and they resulted in weight gains that can be expected for growing pigs within the industry under reasonably good management conditions (gains of 682 g/d in the starter/grower phase and 900 g/d in the finisher phase).

Feed requirement model

To calculate the daily energy requirements for achieving the potential growth of protein and lipid, the rates of protein and lipid deposition are determined for each relevant day of the growth period. To calculate this, the protein growth equation was differentiated to find the rate of protein growth with respect to time:

$$\frac{dP}{dt} = P * B * \ln\left(\frac{P_m}{P}\right) \qquad \text{Eq 15}$$

Where
dP/dt = protein retention (kg/d),
P = the current protein mass (kg),
B = the aforementioned growth rate parameter
Pm = mature protein weight (kg).

For daily lipid retention the differential equation is:

$$\frac{dL}{dt} = L * B * \ln\left(\frac{L_m}{L}\right) \qquad \text{Eq 16}$$

Where
dL/dt = lipid retention (kg/d),
L = the current lipid mass (kg),
B = the growth rate parameter
Lm = the mature lipid mass (kg).

Energy required to meet the cost of protein and fat synthesis was estimated at 55 and 53 MJ ME per kg retained (Whittemore and Kyriazakis 2006).

The model estimated the daily maintenance energy costs from the actual protein weight of the pig. Maintenance energy costs are expressed as MJ ME per day:

$$\frac{dM}{dt} = M_e * 1.1 * P^{0.75} \qquad \text{Eq 17}$$

Where
dM/dt = daily maintenance energy requirements (MJ/d),
P = current protein weight (kg)
Me = a constant energy requirement within a genotype estimated at 1.63 MJ per kg P per day.

The factor 1.1 is a correction applied to take account of the use of ME instead of effective energy (Wellock, 2003; Whittemore, 2006). Total daily energy requirements were calculated as the sum of the daily energy requirements for protein and lipid growth and for maintenance. From these, daily feed intake (kg) was predicted by dividing total daily ME requirements with the ME concentration in the feed. From the feed intake predictions, combined with the diet compositions, the requirements for each diet ingredient were calculated.

Animal N output

Animal N excretions were calculated from feed composition and the predictions of daily intake and N-retention. The amount of N excreted (kg/d) is estimated as:

$$N_{excreted} = \frac{\left(CP_{in} - \frac{dP}{dt}\right)}{6.25} \qquad \text{Eq 18}$$

Where
CPin = the intake of feed crude protein (CP, kg/d)
dP/dt = protein retention (kg/d).

CPin is calculated from feed intake (kg/d) and crude protein concentration (kg/kg) in the feed. The initial parameters values used in modelling are given in Table 8 (based on Emmans 1997; Wellock, 2003; Wellock et al., 2003; Whittemore and Kyriazakis, 2006, Whittemore, 2006).

Table 8. Initial parameters and their values used in the LCA pig model

Parameter	Initial value
Protein mass of the mature pig (kg), Pm	40
Gompertz variable in protein growth equation, Go	-2.586
Rate parameter in Gompertz equation, B	0.01
Mature lipid mass (kg); Lm	80
Constant in allometric lipid equation	1.46
Exponent in allometric lipid equation	1.71
Constant in allometric water equation	5.19
Exponent in allometric water equation	0.855
Ash, as fraction of protein weight P	0.19
Empty body weight as fraction of full body weight	0.95
Total energy cost of protein retention (MJ ME/kg)	55
Total energy cost of protein retention (MJ ME/kg)	53
Constant in allometric maintenance energy equation	1.63
Exponent in allometric maintenance energy equation	0.75

Pigs diets

The initial LCA was based on diets as informed by the industry prior to the start of Green Pig (Alison Johnson, BQP, personal communications, Autumn 2007). The starting point for this LCA was a soya based diet that was considered typical for diets used in the UK; subsequently, soya was replaced (as far as possible) by either peas or beans. Substitution was subject to a number of rules:

1) The proportion of peas in the diet could not be greater than 300 g/kg.
2) The proportion of beans in the diet could not be greater than 200 g/kg.
3) The proportion of rapeseed meal could not be greater than 50, 100 or 150 g/kg in starter, grower and finisher diets, respectively.
4) The content of CP and NDF and the yield of ME in the diets that included peas or beans should be similar to the content in the original industry-based soya-based diet.
5) Synthetic amino acids (SAA) were added to achieve similar (minimum) essential AA contents in the diets.

The result of the strict application of these rules was that some soya was still required in the pea- and bean-based starter and grower (but not in the finisher) diets. The nutritional composition of each diet was estimated from feed ingredient compositions, using average data from feeding tables (Premier Nutrition Products 2005). The resulting diet composition and nutritional values are given in Tables 9 and 10. In the LCA's, the 'rest' term refers to small additional ingredients in the diets such as such as mineral and vitamins, fat, and molasses.

The diets and model settings used in the various LCAs

During the project, the LCAs associated with three series of diets were calculated. Initial diets (based on received industry information) in which soya was (largely) replaced with either peas or beans, were investigated first. These diets (as in appendix) were slightly simplified to facilitate correct calculations of environmental burdens. In these analyses, the starter values for modelling as given above were used. Pig growth was modelled for each diet type with specific diet compositions for the starter (20 – 40 kg), grower (40 – 65 kg) and finisher (65-120 kg) phase.

Table 9. The ingredient composition (g/kg) of the starter, grower and finisher diets used in the initial LCA that compared diets with main protein sources SBM, peas or beans.

Period	Starter			Grower			Finisher		
	SBM	Peas	Beans	SBM	Peas	Beans	SBM	Peas	Beans
SBM	230.0	145.0	140.0	140.0	75.0	52.6	70.0	0.0	0.0
Peas	0.0	300.0	0.0	0.0	300.0	0.0	0.0	300.0	0.0
Beans	0.0	0.0	200.0	0.0	0.0	200.0	0.0	0.0	200.0
Barley	140.5	0.3	0.0	122.8	418.1	72.1	284.1	154.3	123.1
Wheat	513.0	424.0	536.0	442.7	0.0	391.8	158.0	60.0	190.0
Rapeseed meal	25.0	50.0	50.0	70.0	71.2	100.0	140.0	140.0	140.0
Wheat feed	39.0	30.0	20.0	150.0	63.6	109.1	275.0	275.0	275.0
Fat	18.0	18.0	18.0	11.0	11.0	11.0	10.0	10.0	10.0
Min-Vit	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2
Molasses	0.0	0.0	0.0	30.0	30.0	30.0	30.0	30.0	30.0
Lysine	5.1	3.2	5.0	4.1	1.6	3.4	3.8	1.9	2.9
Methionine	0.9	1.3	1.8	0.8	1.2	1.3	0.8	1.4	1.4
Threonine	1.3	1.1	1.9	1.4	1.0	1.5	1.1	0.3	0.4

Table 10. The nutritional characteristics of the starter, grower and finisher diets used in the initial LCA, expressed in MJ/kg (for ME) or in g/kg (for the remainder).

Period	Starter			Grower			Finisher		
	Soya	Peas	Beans	Soya	Peas	Beans	Soya	Peas	Beans
ME	13.3	13.3	13.3	12.6	12.5	12.6	11.8	11.9	11.9
NDF	114	110	114	150	146	150	206	202	207
CP	207	206	207	185	183	185	179	178	180
Lysine	13.7	13.6	14.0	11.4	11.3	11.4	10.9	10.9	10.8
Meth	7.6	7.6	8.0	7.2	7.0	7.2	7.4	7.4	7.4
Thr	8.3	8.3	8.7	7.6	7.5	7.6	7.3	6.6	6.5
Tryp	2.6	2.4	2.3	2.3	2.1	2.0	2.3	2.1	2.0

Eutrophication

The eutrophication potential associated with pig production is calculated for each diet accounting for the effect of ammonia (NH_3), nitrate and nitrite (NO_x) and phosphorus (P). The eutrophication potential per kg pure N was considered equivalent to 0.42 kg PO_4 with corresponding values for NH_3 and NO_x of 0.35 and 0.13 kg PO_{4eq} respectively (Misselbrook, 2000, Huijbregts and Seppala, 2001). The PO_4 equivalent of 1 kg pure P is derived directly from the atomic weights, 3.06 kg PO_4. The cost to produce 1 kg of synthetic N fertilizer (ammonium nitrate) was assumed to be equivalent to $5*10^{-4}$ kg PO_4eq, 1 kg P (triple super phosphate) fertilizer resulting in $7.4*10^{-5}$ kg PO_4eq and finally 1 kg K (K_2O) fertilizer to $3*10^{-5}$ kg PO_{4eq} (Williams *et al*, 2006). Pesticide production was also quantified as 0.015 kg PO_4 per dose (Williams *et al*, 2006).

The main cause of eutrophication is the leaching from cultivated soils. This process has been included in the LCA assuming a loss of 3% of the applied N fertilizer (IPCC, 2006) and 2.6% for the P (Dalgaard et al, 2008) and 1% for K inputs (Chen et al. 2006). Similarly the leaching from slurry storage tank has been assumed to be 1% of the N-P-K present in the store slurry.

The production of NO_x from diesel combustion used in farm operations and transport is also included. The Freight Transportation Services (2008) reports an emission per litre of diesel consumed of 0.026 kg NO_x/l. Finally, the release of NO_x from diesel combustion during the transportation of crops assumed to be $3.2*10^{-5}$ kg NO_x kg/km (Freight Transportation Services, 2008).

The eutrophication potential for SAA has been assumed to be 0.013 kg PO_4eq/kg (Erikson, 2004), while for the remaining additives it has not been accounted for due to lack of information in the literature. The soya production is not simulated in this project therefore the EP has been estimated considering similar farm management adopted for the peas and beans. However the transport from South America has been accounted. However, these assumptions do not affect the diets comparison.

Acidification

Acidification is caused by the deposition of SO_x, NH_3 and NO_x and it is expressed in terms of SO_{4eq}. The conversion factors considered in this study are 1.88 kg SO_{4eq}/kg NH_3 and 0.7 kg SO_{4eq}/kg NO_x (Cabaraban et al. 2008; Thomassen 2008; Basset-Mens et al. 2009). The emissions of NH_3 and NO_x associated with fertilizer volatilization have been assumed to be 10% for inorganic N and 20% for the manure (IPCC, 2007). On the other hand the losses for the slurry storage tank have been assumed to be 0.65 kg NH_3/m^3 (Lopez-Ridaura et al. 2009)

The contribution of diesel combustion for farm operations has been considered as 0.026 kg NO_x/l and $6.8*10^{-4}$ kg SO_x/l (Freight Transportation Services, 2008). Transport of crops into and around the farm has been calculated as $3.2*10^{-5}$ kg NO_x/km per kg of crop and $1.3*10^{-6}$ kg SO_x/km per kg of crop. The production of pesticides and fertilizers also contribute to the acidification potential as summarized in the Table 11. In addition the acidification potential for the SAA has been assumed to be 0.041 kg SO_{4eq}/kg (Eriksson 2004) and for the remaining additives the acidification potential has not been considered due to limited information in the literature.

Table 11. The contribution of pesticides and fertilizers to acidification.

	SO_{4eq}/kg
Pesticide	0.096
Ammonium nitrate fertilizer	0.0047
Triple super phosphate fertilizer	0.008
Potassium fertilizer	0.0047

Results and discussion

The global warming, eutrophication and acidification potential have been evaluated for the conventional management practices. The analysis of the LCA results has focused in each case on the comparison between the three diets and therefore on the possible benefit of replacing SBM as a main source of protein in pig diets.

The first objective of this study was to evaluate the environmental impact of replacing SBM with home grown peas and beans as the main source of protein in growing and finishing pig diets. Three factors were considered: global warming potential per kilogram pig grown, measured in $kgCO_{2eq}$/kg pig, eutrophication potential ($kgPO_{4eq}$/kg pig) and acidification potential ($kgPO_{4eq}$/kg pig).

The environmental impact of pig production in terms of GWP was estimated for the three diets. In the scenario where LUC is included in the calculation, pea or bean based diets do not show a significant difference in GHG emissions as the GWP is 2.02 and 1.99 $kgCO_{2eq}$ /kg pig respectively. On the other hand, the SBM based diet is characterised by a 42% higher GHG emission, 2.85 $kgCO_{2eq}$ /kg pig (Figure 3). If it is assumed, however, that SBM is derived from sources not associated with deforestation, the emissions for the three diets are not different, i.e. 1.59, 1.63 and 1.69 $kgCO_{2eq}$ /kg pig for the pea, bean and soya based diets respectively (Figure 1). It is important to note that there is a small amount of SBM included in the pea and bean diets (3%), which has an associated LUC value (Figure 3).

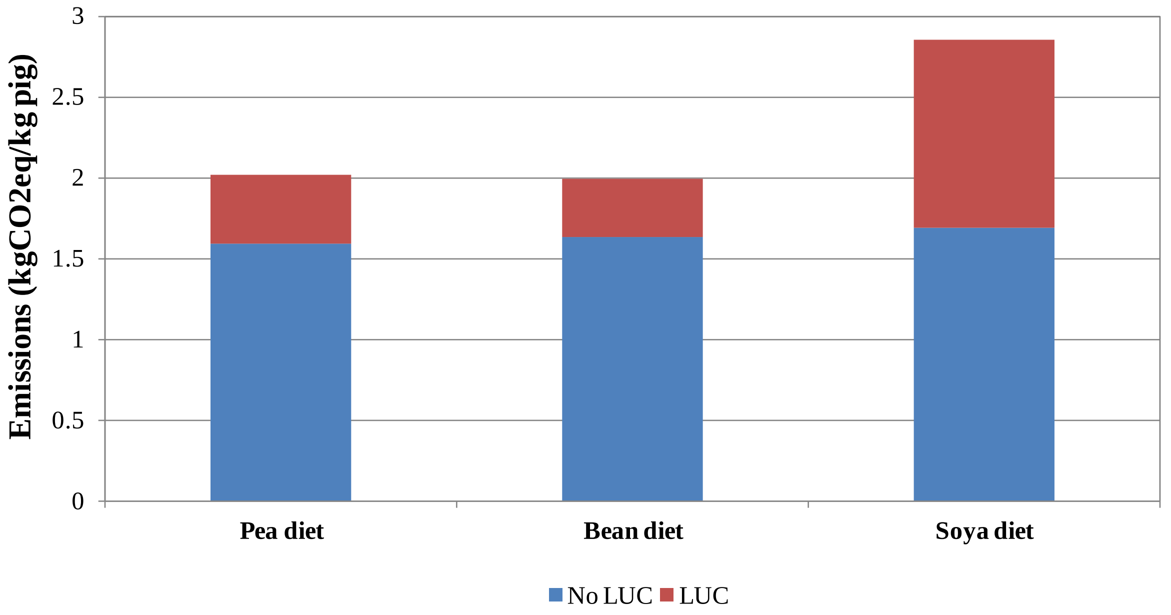

Figure 3. Greenhouse gas emissions associated with diets based on peas, beans or SBM as main protein sources when taking account of land use change for soya production (LUC) and excluding LUC from the calculations (No LUC).

In order to establish and compare the contribution of each process considered in the LCA, the total GWP can be disaggregated. The contribution of each process is comparable across the three diets, if the SBM source is not associated with LUC (Table 12). The highest contributor is the crop production of pig diet ingredients, accounting for nearly 45% of the total emissions. Volatilisations from the slurry storage tank accounts for between 15% and 20% of the total emissions of GHG, with the remaining 25% divided between animal enteric fermentation, buildings, transport and the various additives.

The relative contribution of each of these processes is reduced if the effects of LUC are considered (Table 12). In the pea and bean diet the LUC contribution to the total emissions is 50%, while in the SBM diet it is the main contributor with 65% of the emissions.

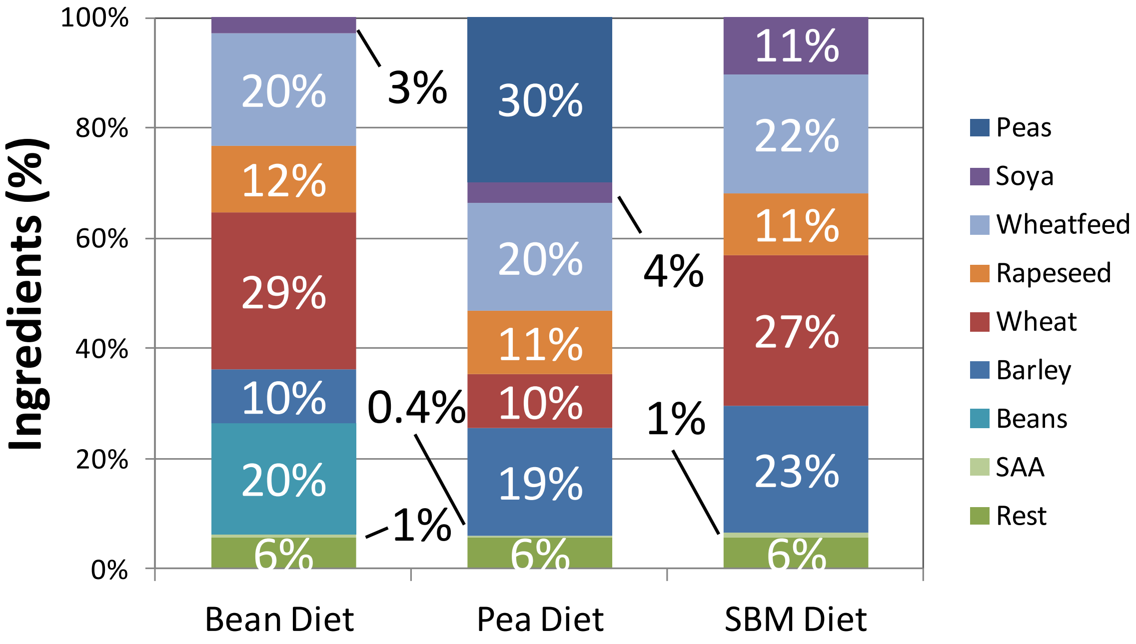

Figure 4. Average composition of the starter, grower and finisher diets used in the Objective 1 LCA modelling. Rest refers to small amounts of additives such as minerals and vitamins, fat supplements, while SAA refers to synthetic amino acids.

The LCA results clearly show that the three diets are comparable in terms of GWP when it is assumed that SBM is derived from soya sources that are not associated with land use change. However, when LUC is accounted for, the SBM based diet is characterised by a higher GWP impact than the pea or bean based diets due to the land conversion burden.

The analysis of the eutrophication and acidification potential associated with the three diets shows a similar trend to the GWP (Table 13). There is no appreciable difference between the environmental impact of peas and beans based diets. The SBM based diet is, however, characterised by a higher eutrophication and acidification potential, mostly due to the transport from south Brazil and Argentina (more details are given in the Appendix).

In the present LCA only the costs associated with growing pigs were included as the costs associated with the production of weaned piglets and rearing until start weights were assumed to be the same for the different diet types.

Table 12. The proportions of total greenhouse gas emissions associated with pig production systems based on mainly peas, beans or SBM as protein source for the pig diets that can be attributed to the different underlying processes when land use change (LUC) is not accounted for in the production of SBM and included in the total evaluation.

	No LUC			Plus LUC		
	Pea Diets (%)	Bean Diets (%)	SBM Diets (%)	Pea Diets (%)	Bean Diets (%)	SBM Diets (%)
Crop production	45.7	44.7	44.0	54.9	52.6	65.1
Slurry/CH4	26.1	25.6	24.6	20.6	20.9	14.6
Enteric CH4	8.3	8.1	7.8	6.5	6.6	4.6
Buildings, etc.	8.7	8.5	8.2	6.9	6.9	4.9
SAA additives	2.5	4.9	3.7	2.0	4.0	2.2
Rest additives	4.6	4.5	4.3	5.8	5.9	4.1
Transport	4.1	3.8	7.5	3.3	3.1	4.5

Table 13. Eutrophication and acidification associated with the three diet scenarios.

	Pea diet	Bean diet	SBM diet
Eutrophication ($kg PO_4eq/kg$ pig)	0.014	0.013	0.024
Acidification ($kg SO_4eq/kg$ pig)	0.046	0.050	0.111

The outcomes from different LCA are difficult to compare due to the different assumptions and system boundaries considered, nonetheless it is important to compare the environmental impacts estimated in this project for the SBM based diet with the literature values (Table 14). There a considerable variability associated with the GWP, ranging between 6.4 kg CO_2eq/kg pig and 1.47 kg CO_2eq/kg pig and the value of 2.85 kg CO_2eq/kg pig calculated in this project is within the considered range. On the other hand the EP ranges between 0.2 kg PO_4eq/kg pig and 0.02 kg PO_4eq/kg pig with the this project estimation comparable to the lower end of the range and finally the AP ranging between 0.34 kg SO_4eq/kg pig and 0.02 kg SO_4eq/kg pig with our prediction of 0.1 kg SO_4eq/kg pig being within the literature estimations.

Table 14. The LCA results from literature for pig production, expressed per 1 kg of pig.

	GWP (kg CO_2eq)	Eutrophication (kg PO_4 eq)	Acidification (kg SO_2eq)
Canada[1]:			
1981	2.98	—	—
2001	2.31		
Denmark[2]	3.6	0.15	0.045
Delivered:			
UK	3.6	0.20	0.064
Netherlands	3.6	0.14	0.042
UK[3]	6.4	0.1	0.34
Sweden[4]:			
Soya	1.47	0.185	0.024
Pea	1.31	0.185	0.025
Rapeseed & SAA	1.38	0.185	0.019
France[5]:			
GAP	2.3	0.02	0.04
RL	3.46	0.02	0.02
OA	3.97	0.02	0.04

[1] Verge et al, 2009,
[2] Dalgaard et al, 2007
[3] Williams et al, 2006
[4] Eriksson, 2004
[5] Basset-Mens and van der Werf, 2005

Conclusions

The LCA results from the considered scenario demonstrate that from an environmental point of view the use of home grown beans and peas in grower and finisher pig diets is associated with similar emissions to the traditional SBM based diets if the soya is derived from sources that are not associated with deforestation or other forms of land use change. However, if soya is cultivated on land that has been converted from natural to crop land in the last 20 years, then the SBM used in the diet is associated with a large carbon footprint, and this significantly increases its GWP per kg pig. The emissions associated with LUC have a high degree of uncertainty due to the complexity of the system. However, it is important to note that if any GWP is associated with LUC, the SBM diets will always have a higher impact than diets based on other protein sources such as beans and peas. Mainly as a result of transport-based emissions, the acidification and eutrophication potential associated with diets based on soya are considerably and systematically higher than those associated with diets based on peas and/or beans.

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Appendix LCA Objective 1

Table A1. Total ingredient requirements (in kg) for the whole of the growing period for each of the three LCA diets.

Diet	SBM Diet (kg)	Peas Diet (kg)	Beans Diet (kg)
Barley	65.477	54.894	27.115
Wheat	77.872	28.113	81.41
Peas	0	86.136	0
Soya	31.03	10.647	9.014
Beans	0	0	57.424
Rapeseedmeal	31.084	32.171	34.008
Wheatfeed	61.446	55.574	58.071
Min-Vit	7.81	7.81	7.81
Molasses	7.401	7.401	7.401
Lysine	1.161	0.583	0.955
Methionine	0.232	0.379	0.824
Threonine	0.349	0.153	0.413
Fat supplement	3.258	3.258	3.258
Total	287.12	287.119	287.703

Table A2. Proportions of total greenhouse gas emissions associated with each diet ingredients and system processes.

	No LUC			LUC		
	Bean Diet (%)	Pea Diet (%)	SBM Diet (%)	Bean Diet (%)	Pea Diet (%)	SBM Diet (%)
Barley	6.60	3.20	7.40	5.21	2.61	4.40
Wheat	3.15	8.94	8.20	2.49	7.29	4.88
Peas	10.58	0.00	0.00	8.35	0.00	0.00
SBM	1.41	1.17	3.87	19.98	17.14	41.25
Beans	0.00	6.84	0.00	0.00	5.58	0.00
Rapeseed	2.54	2.63	2.91	2.00	2.14	1.73
Wheat feed	3.11	3.19	3.24	2.46	2.60	1.92
S AA	2.52	4.86	3.70	1.99	3.96	2.20
Rest	4.57	4.48	4.30	5.81	5.89	4.12
Field op	8.11	7.52	6.59	6.40	6.14	3.92
Fertiliser	5.21	5.80	6.60	4.12	4.73	3.92
Pesticides	0.28	0.33	0.31	0.22	0.27	0.19
Transport	4.15	3.77	7.53	3.28	3.07	4.48
Grain drying	4.70	5.07	4.88	3.71	4.14	2.90
Slurry storage	26.12	25.61	24.56	20.62	20.90	14.61
Building energy	8.68	8.51	8.16	6.85	6.94	4.86
Enteric CH4	8.25	8.09	7.76	6.51	6.60	4.62

Table A3. Eutrophication and acidification potential associated with the three diet scenarios modelled. "Field Op" refers to the field operations activities, their contributions are reported in Table A4.

	Pea diet		Bean diet		SBM diet	
	Eutrophicaton ($kgPO_4$/kgLWG)	Acidification ($kgSO_x$/kgLWG)	Eutrophicaton ($kgPO_4$/kgLWG)	Acidification ($kgSO_x$/kgLWG)	Eutrophicaton ($kgPO_4$/kgLWG)	Acidification ($kgSO_x$/kgLWG)
Barley	0.00240	0.00637	0.00119	0.00315	0.00248	0.00760
Wheat	0.00114	0.00296	0.00280	0.00857	0.00315	0.00819
Pea	0.00296	0.00014	-	-	-	-
SBM	-	-	-	-	-	-
Bean	-	-	0.00151	0.00008	-	-
Rapeseed	0.00074	0.00241	0.00067	0.00255	0.00143	0.00467
Wheatfeed	0.00057	0.00264	0.00140	0.00765	0.00157	0.00731
SAA	0.00015	0.00046	0.00459	0.02620	0.00023	0.00071
FarmOp	0.00538	0.03080	0.00029	0.00090	0.01440	0.08270
Total	0.01360	0.04590	0.01330	0.04920	0.02410	0.11100

Table A4. Eutrophication and acidification potential for the field operations associated with the three diet scenarios modelled.

		Pea diet		Bean diet		SBM diet	
		Eutrophication	Acidification	Eutrophication	Acidification	Eutrophication	Acidification
		($kgPO_4$/kgLWG)	($kgSO_x$/kgLWG)	($kgPO_4$/kgLWG)	($kgSO_x$/kgLWG)	($kgPO_4$/kgLWG)	($kgSO_x$/kgLWG)
FarmOp	NO_x	0.00017	0.00091	0.00011	0.00060	0.00015	0.00078
	SO_x	-	0.00003	-	0.00002	-	0.00003
Transport	NOx from fuel per diet (kg/kg LWG)	0.00521	0.02800	0.00450	0.02400	0.01400	0.07700
	SOx from fuel per diet (kg/kg LWG)	-	0.00162	-	0.00139	-	0.00448
Pesticide production	Pesticide production per diet	-	0.00005	-	0.00005	-	0.00006
Fertiliser Prod N	Acidification per diet	-	0.00004	-	0.00005	-	0.00007
Fertiliser Prod P	Acidification per diet	-	0.00009	-	0.00004	-	0.00006
Fertiliser Prod K	Acidification per diet	-	0.00004	-	0.00000	-	0.00000
Total		0.00538	0.03080	0.00459	0.02630	0.01450	0.08270

Full report Objective 2: The Green Pig survey: constraints of using peas and faba beans in growing and finishing pig diets

Lead author: Lesley Smith (SRUC).

Executive Summary

- Europe is deficient in the protein sources for livestock nutrition and imports over 70% of the protein used in animal feed. The most commonly imported protein source is soya bean meal (SBM) from North and South America.
- The UK pig industry uses ~300,000 tonnes of SBM in grower and finisher pig diets per year. There are increasing environmental and economical concerns about this reliance on SBM, and thus the sustainability of the UK pig industry. As a consequence there a need to find viable home-grown protein sources for pig diets.
- Grain legumes (peas and faba beans) are home-grown protein sources that could potentially be considered for pig feed.
- The Green Pig Survey aims to investigate the use (inclusion levels) of peas and faba beans in the feeds of UK growing and finisher pigs, and the constraints (real or perceived) associated with them.
- The two parts of the survey are 1) a quantitative survey of compound producers and home mixers, and 2) a qualitative survey of pig nutritionists that give advice to both compounder feed companies and home mixers.
- Current use of peas and faba beans by UK compounders and home-mixers is low relative to use of SBM or rapeseed meal. The survey of pig nutritionists supports this finding, as they sometimes, rarely or never recommended their use.
- Both current and perceived maximum inclusion levels of peas and faba beans in the UK are lower that reported elsewhere. This indicates that knowledge of acceptable inclusion levels in pig diets may be limited and promotion of acceptable inclusion levels of modern varieties of peas and faba beans may increase confidence in pea and faba bean use in growing and finisher pig diets.
- Compounders and nutritionists do not use or recommend a specific variety of peas of faba beans, although white flowered faba bean varieties may be prefered. Home-mixers were more aware of the specific variety used in their pig diets, which likely arises from growing pulses on their own farm.

- Availability of peas and faba beans was identified as a potential constraint for increased use in pig feed, as volumes of pulses produced in the UK are limited and grown for human consumption mainly. This real constraint may be overcome by increasing UK pulse production. However, the finite availability of arable land suggest sourcing pulses from "close to home" regions could also be considered.
- The second constraint identified in the survey was the cost of peas and faba beans relative to the cost of SBM. Although SBM has recently been subject to volatile price fluctuations, the price per unit of pulse protein still has not been economically competitive. However, with world-wide consumption of soya rapidly increasing (e.g. Asian markets), future security of SBM for UK animal feed is uncertain, which may benefit the economics of using pulses in animal feed.
- There was inconsistency (both in the compounder/home-mixer survey and the nutritionist survey) in the perception of the environmental benefits of using peas or faba beans over SBM, indicating that there is a lack of information and knowledge on this topic. Thus, promotion of results from the Green Pig life cycle assessment (LCA) would be beneficial to those in the pig industry to allow informed decisions when considering the environmental impact of different diets.
- Both compounders and home-mixers felt that peas and faba beans provided adequate nutritional value, indicating that the latter is not a major constraint for increasing their use in the future. In contrast, nutritionists had less confidence in their nutritional value. The difference in perception between compounders and home-mixers on the one hand and nutritionists on the other hand highlights the requirement for the Green Pig large scale demonstration trials.
- All participants showed a positive response to increasing future use of peas and faba beans in grower and finisher pig diets, provided that there are no negative effects on pig performance.
- Overall, the outcome of the Green Pig survey strongly suggests that promotion of positive outcomes from the Green Pig project to the pig industry as a whole should increase the confidence in using home-grown peas and faba beans in grower and finisher pig diets.

Introduction

Europe is deficient in the protein sources required for livestock nutrition and imports over 70% of the protein used in animal feed (Crepon, 2006; Baumgartner *et al.,* 2008). The most commonly imported protein source for animal feed is soya bean meal (SBM) from North and South America (Gatel and Grosjean, 1990). The UK pig industry relies heavily on SBM; using national pig performance data (Fowler, 2008) and typical diet formulations, we have estimated that out of the >2 million tonnes used in the UK in general, ~300,000 tonnes of SBM were used for grower and finisher diets in 2007. The cost and continuing availability of SBM is influenced by the global market and are therefore subject to rapid fluctuations (Jezierny *et al.,* 2010). Thus, due to the pig industry's reliance on SBM there are increasing concerns about the sustainability and security of UK pig production, if this raw material continues to be used at the current rate. There are also increasing environmental concerns with SBM as the rapid increase in demand for soya is associated with increasing demands of land use, including deforestation (Fearnside, 2001). Furthermore, the use of soya bean meal in organic farming is limited due to the ban on both oilseed products processed by solvent extraction, and the use of genetically modified feed ingredients (European Communities, 2007).

In order to remain competitive in the global market, promote sustainable pig farming, provide alternatives for organic farming, and reduce the environmental impact of the UK pig industry, there is a need to increase the use of viable home-grown protein sources in pig diets. In temperate environments, grain legumes (peas, faba beans and lupins) are potential home-grown protein sources that could be considered for pig feed. In addition to the reduced transport and the issues of food security associated with these home-grown crops, legumes have natural nitrogen-fixing abilities (Crepon, 2006; Zijlstra *et al.,* 2008). This makes them an attractive rotation crop, and gives further environmental benefits by reducing the need for importing and using nitrogen fertilisers. However, data on current practice relating to dietary inclusion levels of peas and faba beans in UK pig feed are scarce. The Green Pig Survey aims to investigate the use (inclusion levels) of home-grown protein sources in the feeds of UK growing and finisher pigs, and the constraints (real or perceived) associated with them. The 'real' constraints being a problem that may require something to be overcome, and 'perceived' constraint may be something that required tackling negative attitudes towards the use of peas and faba beans in pig diets.

The survey is divided into two parts. The first part is a quantitative survey of compounder feed companies that make grower and finisher phase pig feed (compound producers) and pig producers that prepare their rations on farm (home mixers). The aims of this survey were: (1) quantify the use (and inclusion levels) of home-grown protein sources in the feeds of UK growing and finisher pigs, and (2) quantify the constraints (real or perceived) in the use of home-grown protein sources for UK pig feed. The second part of the survey is a qualitative survey of pig nutritionists that give advice to both compounder feed companies and pig producers. The aim of the qualitative survey was to document the expert opinion of pig nutritionists on using peas and faba beans in UK grower and finisher pig diets.

Materials and Methods

Quantitative survey of Compounders and Home mixers

Data were collected from compound producers and home-mixers via postal survey, email survey or telephone interviews between April 2009 and December 2009. In order to ensure the data collected from different respondents at different times of the year were comparable, respondents were asked to answer questions for pig diets sold/used in the year 2008. The compounder responses covered 181101 tonnes of grower feed sold, and 438737 tonnes of finisher feed sold. Approximately 348000 tonnes of grower diet and 584800 tonnes of finisher diet was sold in 2008 (Defra, 2009), thus the sample covered approximately 52% and 75% of the grower and finisher feeds sold in the UK in 2008, respectively. As compounders sell a number of different diets, respondents were asked to answer questions on their two highest selling diets. Consequently, there were no organic diets included in the sample. The home-mixer sample covered 36 home-mixer holdings with a total of 30464 sows. With home mixers representing approximately 51% of the UK herd (approximately 423000 breeding sows in 2008) (BPEX, 2009), the home-mixers sample covered 14.1% of the 2008 UK home-mixer herd. Conventional holdings and organic holdings made up 99.91% and 0.09% of the home-mixer sample respectively.

The questionnaire was developed and tested with the project steering group. There were 21 questions, taking approximately 10 minutes to complete. The questionnaire gathered information on current protein sources used in pig feeds, current inclusion levels used, and the participants' attitudes to using alternative protein sources in pig feed. The majority of the questions were in a 'closed' question format with tick box choices, followed by an 'open' question giving the respondent the opportunity to give further information. Attitudes were measured on either a categorical scale ("yes", "no" or "don't know"), or on a 5-point interval rating scale (ranging from "strongly agree" to "strongly disagree"). Since individual participants varied in feed sold and farm size, a weighted analysis was performed on data returns to ensure appropriate representativeness of the data. To this effect, compounder weights were calculated using tonnes of grower and finisher compound feed sold, whilst home-mixer weights were calculated using sow numbers.

Qualitative survey of Pig Nutritionists

Data were collected from pig nutritionists via postal survey, email survey or telephone interviews between November 2009 and April 2010. In order to ensure the data collected from different respondents at different times of the year were comparable, respondents were asked to answer questions on pig nutritional advice given in the year 2008. The pig nutritionist response covered 11 UK based independent and feed company pig nutritionists.

As with the compounder and home-mixer survey, the pig nutritionist questionnaire was developed and tested with the project steering group. There were 19 questions, again taking approximately 10 minutes to complete. The questionnaire gathered information on recommended current protein sources for pig feed, recommended inclusion levels used, and the participants' attitudes to using alternative protein sources in pig feed. There were 4 question formats used in the questionnaire. Questions on current protein sources recommended were measured on a 5-point interval scale (ranging from "always" to "never"). The majority of the other questions were in a 'closed' question format with tick box choices, followed by an 'open' question giving the respondent the opportunity to give further information. Attitudes were measured on either a categorical scale ("yes", "no" or "don't know"), or on a 5-point interval rating scale (ranging from "strongly agree" to "strongly disagree"). As there is no data available to determine the number of pig nutritionists giving advice to home-mixers or compound feed companies in the UK, we were unable to calculate the sample size of the pig nutritionist respondents. As a result the data from the nutritionist survey was treated as *expert opinion* rather than being representative to all UK pig nutritionists and data has been presented as the number of responses for each question.

Results

Quantitative survey of compounders and home-mixers

Protein sources used in compounder and home-mixer pig feed

The use of peas and beans in pig feed in the UK is largely unknown. Thus, in order to determine the current use of peas and beans, respondents were asked a series of questions on the types of protein sources they used in their grower and finisher pig feed; inclusion levels used; origin of the protein sources used; and for peas and beans only, the variety used. Compounders were also asked about any processing technologies used for peas and beans being included in grower and finisher pig diets.

Q. Which of the following did you use in your grower and finisher pig diets in 2008?

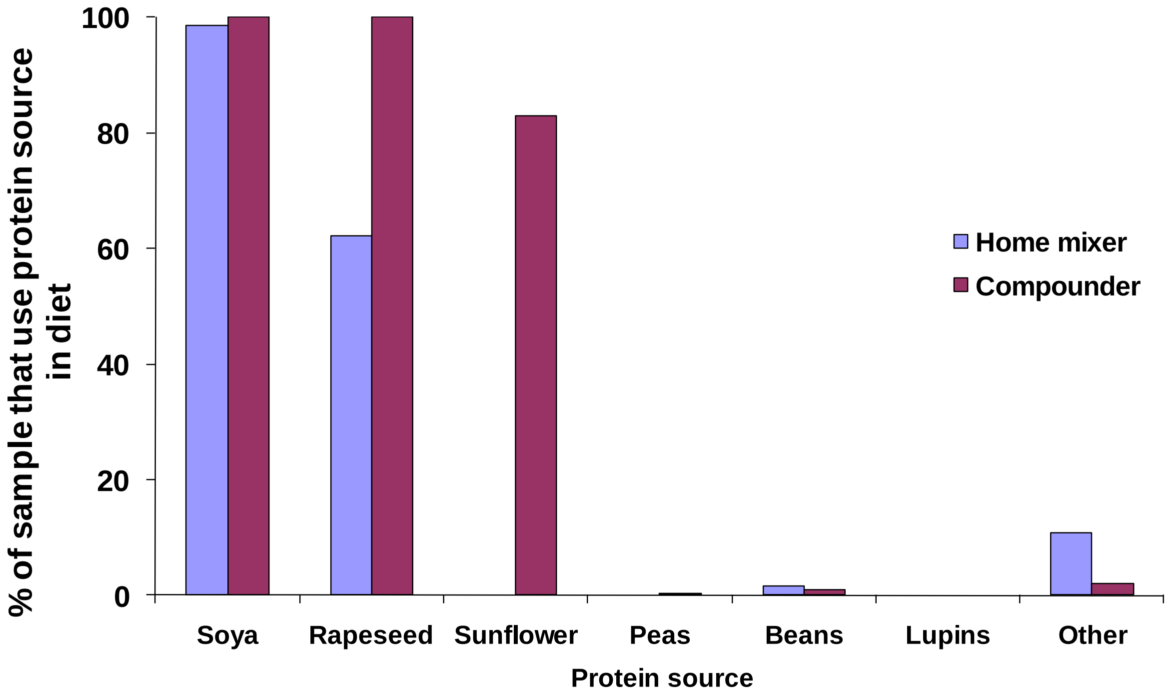

Figure 1. Percentage home mixers and compounders that use the above protein sources in their diets in 2008.

As expected, the most common protein used in pig diets was SBM with over 98% of both the compounder and home-mixer samples including SBM in their diets (Fig 1). In contrast less than 1% of the compounder sample used peas and faba beans in their diets. None of the home-mixer responders used peas, whilst less than 2% of the home-mixer sample used faba beans in their pig diets (Figure 1). The “other” protein sources included in the diets for both compounder and home-mixer respondents was fishmeal.

Q. For the following protein sources used in 2008, what is the total weight (tonnes) used in your grower and finisher pig diets?

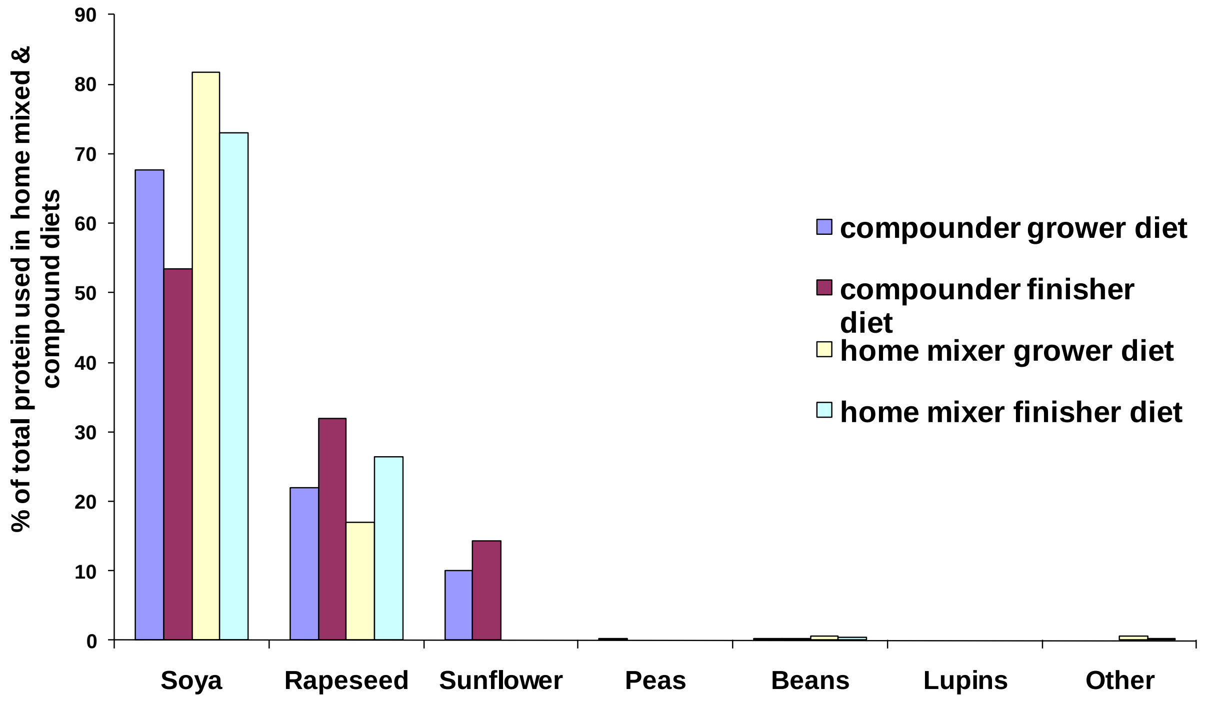

Figure 2. Total weight of each protein used, Figures are the percentage of total protein used in home mixed and compound diets in 2008.

SBM was also used in greater volumes, with SBM contributing to 68% and 54% of the total protein used in the compounder grower and finisher diets respectively (Figure 2). Similarly, for home-mixer diets, over 73% of the total protein used in the grower and finisher diets was SBM (Figure 2). However, less than 0.3% of the total protein used in both compounder grower and finisher diets was faba beans, and less than 0.02% of the total grower protein used was peas. For home-mixers, less than 0.7% of the total protein used in home-mixer grower and finisher diets was faba beans (Figure 2).

Q. For the following protein sources used in 2008, what was inclusion levels (% of diet) used in your grower and finisher pig diets?

AND

Q. What do you think are the maximum inclusion levels (% of diet) of peas and faba beans in grower and finisher diets, that won't negatively affect pig production and health?

Table 1. The weighted maximum inclusion levels (% of diet) of soya bean meal (SBM), rapeseed, sunflower, lupins, peas and faba beans currently used by compounders and home-mixers in grower and finisher pig feed, and the perceived absolute maximum inclusion levels of peas and faba beans for pig feed.

	Weighted mean maximum inclusion level (%) with range			
	Compounder Grower	Compounder Finisher	Home-mixer grower	Home-mixer finisher
SBM	20.1 (15-25)	19.4 (12-25)	19.3 (15-25)	16.3 (9.5-25)
Rapeseed	7.4 (5-8.5)	10.6 (5-12.5)	7.6 (2.5-10)	14.2 (5-18)
Sunflower	5.0 (5-7.5)	6.8 (3-10)	-	-
Lupins	-	-	-	-
Peas (current)	8 (-)	-	-	-
Peas (perceived max)	15.0 (5-20)	19.5 (5-25)	12.7 (5-30)	13.2 (5-30)
Faba beans (current)	5.8 (3.8-6)	9.5 (5-10)	11.0 (8-30)	10.0 (8-15)
Faba beans (perceived max)	11.4 (2.5-15)	13.1 (5-20)	9.3 (5-40)	14.9 (5-40)

Q. For the following protein sources used in 2008, if known, where are they produced?

Table 2. Origins of protein sources used in UK compounder and home-mixer pig feeds. Figures are the percentage of the sample that source the protein used in their pig diets from non-local world regions, local Europe regions, local UK regions or home grown on their own farm. Respondents sourcing protein from more than 1 region are included in both categories. SBM = soya bean meal.

	Compounder (% of sample)			Home-mixer (% of sample)			
	Non-local world	Local Europe	Local UK	Non-local world	Local Europe	Local UK	Home grown
SBM	100			97.9			
Rapeseed	3.5	31.2	34.7	-	48.3	41.6	10.1
Sunflower	100	26	-	-	-	-	-
Peas	-	-	100	-	-	-	-
Faba beans	-	-	100	-	-	-	100

The inclusion level (% of diet) of SBM used in pig feed was greater than all other alternative protein sources for both compounder and home-mixer grower and finisher diets (Table 1). In contrast, the inclusion level of peas and beans currently being used by compounders and home-mixers is relatively low with inclusion levels of approximately 5-11%. The perceived maximum inclusion level of peas and beans (which includes responses from participants not currently using peas and beans in their pig diets) is greater than the current inclusion level being used for peas and beans in most compounder and home mixer pig diets. However, for the home-mixer grower diet, the perceived maximum inclusion level is lower than the inclusion levels currently being used by home-mixer responders (Table 1). Thus, those home-mixers not currently using beans in their grower diets perceive the acceptable inclusion levels of beans to be lower than what is currently being used by other home-mixer pig producers. Additionally, the range associated with perceived maximum inclusion levels for peas and beans suggests there is a large variation in the perceived maximum inclusion levels (Table 1).

SBM in compounder diets was exclusively imported from non-local world regions. Similarly, 97.9% of home-mixers sourced their SBM from non-local regions (Table 2). The remaining 2.1% of home-mixers (not shown in the table) did not know the origin of the SBM used in their pig diets. 100% of compounders that used sunflower sourced this from non-local world regions, with 26% of compounders also sourcing sunflower from local Europe regions (Table 2). Rapeseed was mainly sourced from local Europe and UK regions for both compounders and home-mixers (Table 2). Peas and faba beans were the only protein that was sourced exclusively from local UK regions for compounders. Similarly for home-mixers that used beans in their diets 100% used faba beans home grown on their own farm.

Q For peas and faba beans only, if known, please list varieties/cultivars used in 2008 for your grower and finisher diets.

For all compounders using peas and faba beans the specific variety of the pulse was unknown. In contrast for home-mixers, 89% that included faba beans in their pig diets used the variety ‘Wizard’ which is a winter bean variety currently on the PGRO recommended list for 2011.

Q (For compounders only): In 2008, which if any of the following processing technologies have you used for peas and faba beans that are included in your grower and finisher pig diets?

Table 3. Percentage of compounders that uses peas and beans that used the following processing technologies when including peas or faba beans in pig diets.

	Peas	Faba beans
No Processing	-	-
Milling	100	11
Grinding	100	100
Dehulling	-	-
Soaking and cooking	-	-
Atmospheric steaming	-	-
Pressurized steaming	-	-
Micronisation	100	-
Dry Roasting	-	-
Extrusion cooking	-	-
Pelleting	100	100

For those compounders that used peas and faba beans in their pig diets, 100% used some form of processing technology (Table 3). For peas, the processing used was milling, grinding, micronisation and pelleting. For faba beans, all compounders used grinding and pelleting, while only 11% of compounders that used faba beans used milling (Table 3).

Attitudes to using alternative protein sources in pig feed

In order to investigate the constraints ('real' or 'perceived') of using alternative protein sources such as peas or faba beans in UK pig diets, respondents were asked questions on their attitudes of using peas and faba beans in pig diets. These questions covered topics such as availability, nutritional value, negative effects, environmental impact, and future use of peas and faba beans.

Availability of alternative protein sources for pig feed.

Compounders perceived pulses in general (lupins, peas and faba beans) to be less available than the other alternative proteins rapeseed and sunflower (Table 4). Home-mixers also perceived peas and lupins to be unavailable for regular use in their pig diets (Table 4). While 41.6% of home-mixer respondents perceived faba beans to be a sufficiently available protein source, 38.7% of the home-mixer sample still felt that faba beans were not available to be included in their pig diets (Table 4).

Compounders considered the two main limiting factors that limit availability of peas and faba beans were i) the seasonal nature of their production and ii) that they are by-products which are not normally produced for the animal feed (Table 5). In contrast, 32% of home-mixers did not consider the availability of faba beans to be limited. However, for the remaining home-mixer participants the two main limiting factors of faba beans were also seasonality and that they are by-products which are not normally produced for the animal feed (Table 5). For peas, home-mixers considered cultivation and harvesting as the main limiting factors that affect availability (Table 5).

Q. Are the following available in sufficient quantities all year to be regularly included in your grower and finisher pig diets?

Table 4. Perceived availability of alternative protein sources used in pig feed. Figures are the percentage of the sample that responded "yes", "no" or "don't know".

	Compounder (% of sample)			Home-mixer (% of sample)		
	Yes	No	Don't know	Yes	No	Don't know
Rapeseed	100	0	0	90.5	2.9	6.5
Sunflower	74.4	23.3	2.4	56.7	23	20.2
Lupins	0	99.4	0.6	4.9	42.6	52.5
Peas	3.6	95.8	0.6	10.5	69.7	19.8
Faba beans	3.6	96.4	0	41.6	38.7	18.8

Q. For peas and faba beans only, what factors do you think may limit their availability in the UK pig feed industry?

Table 5. Perceived factors that limit the availability of peas and faba beans to be used in UK pig diets. Figures are the percentage of sample that ticked the following categories. By-Product = not produced for animal feed.

	Compounder (% of sample)		Home-mixer (% of sample)	
	Peas	Faba beans	Peas	Faba beans
Not limited	0.02	0	2.4	32
Seasonality	89.8	90.4	29.4	29.1
By Product	88.3	65.5	29.3	32.9
Quality	23.4	23.4	10.9	3.8
Storage	0	0.6	2.8	4.3
Processing	2.4	2.4	12.8	11.9
Cultivation	22.8	0	36.2	0.8
Harvesting	23.2	0.4	42.8	2.4
Marketing	1.3	1.3	6.8	1.5
Other	4.7	4.7	2.6	2.6

Nutritional value of peas and beans for pig feed

Q. Do peas/faba beans provide adequate nutritional value to be used in grower and finisher pig diets?

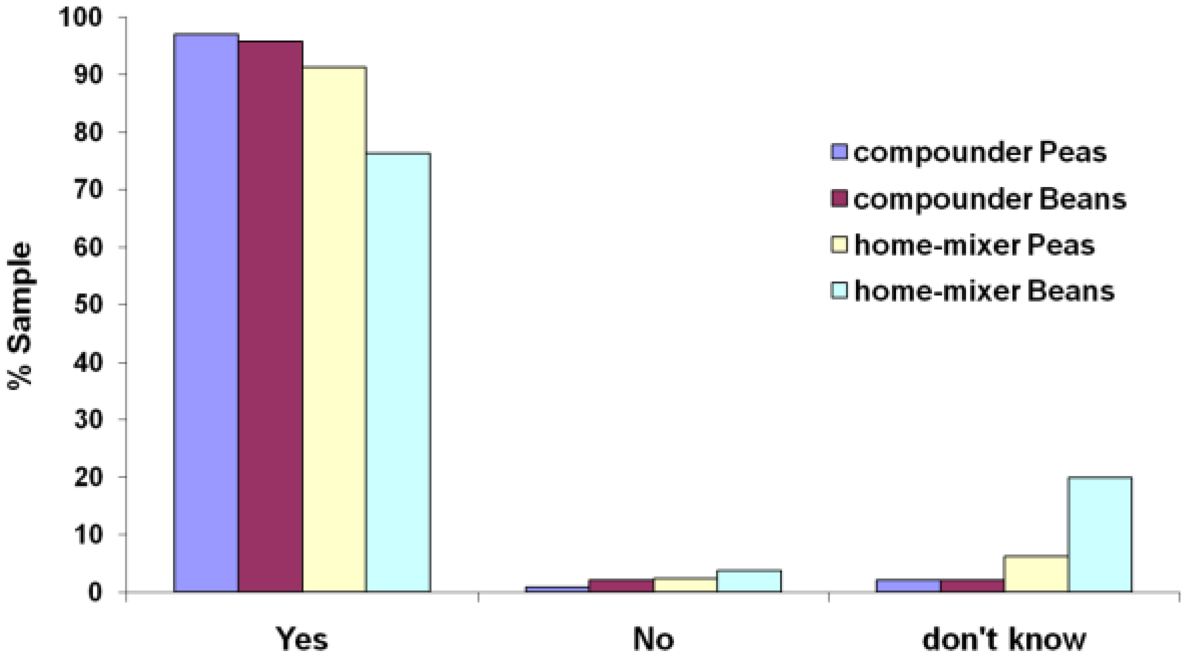

Figure 3. Perceived nutritional value of peas and faba beans for use in pig feed. Figures are the percentage of the sample that responded "yes", "no" or "don't know".

Over 90% of compounder respondents thought that both peas and beans had adequate nutritional value to be included in pig diets (Figure 3). Similarly, 91% and 76% of home-mixer respondents felt that peas and beans respectively, had adequate nutritional value to be included in pig diets (Figure 3).

Q If peas/faba beans do not provide adequate nutritional value, why?

Table 6. Perceived factors that affect the nutritional value of peas and faba beans for pig diets. Figures are the percentage of sample that ticked the following categories. AA= amino acids. ANFs = anti-nutritional factors.

	Compounder (% of sample)		Home-mixer (% of sample)	
	Peas	Faba beans	Peas	Faba beans
Crude protein	3	3	1.8	0
Digestibility	25.8	27.1	0.4	1.5
Fibre	2.4	2.4	0	0
AA profile	3	3.3	0.4	27.6
ANFs			1.5	13.4
Trypsin inhibitor	64.3	0.6		
Condensed tannins	0	88.8		
Other	0	65.3	0	0

Although the previous question indicates that both compounders and home-mixers appear to have good confidence in the nutritional value of peas and faba beans, many respondents that felt that peas and faba beans did have adequate nutritional value, still went on to answer the current question regarding factors that affect the nutritional value of peas and beans. The tick categories for this question were different for the compounder and home-mixer surveys. As it was expected that compounders would have more knowledge of anti-nutritional factors than home-mixers, when asked about factors that might affect the nutritional value of peas and faba beans, compounders were provided with specific tick categories for ANFs (Trypsin inhibitors and Condensed tannins), while home-mixers were provided with a more general ANFs category. Compounders felt that the main factor affecting the nutritional value of pulses was trypsin inhibitors for peas, and condensed tannins for faba beans. Additionally compounders perceived that ‘other’ factors affected the nutritional value of faba beans (Table 6). The other factors that compounders felt affected the nutritional value of faba beans included haemagglutinin or other lectins and palatability. In contrast, home-mixers felt that the main factor affecting beans was the amino acid profile (Table 6).

Negative effects of peas and beans in pig feed

Q Are you aware of any negative affects of using peas and beans in grower and finisher pig diets

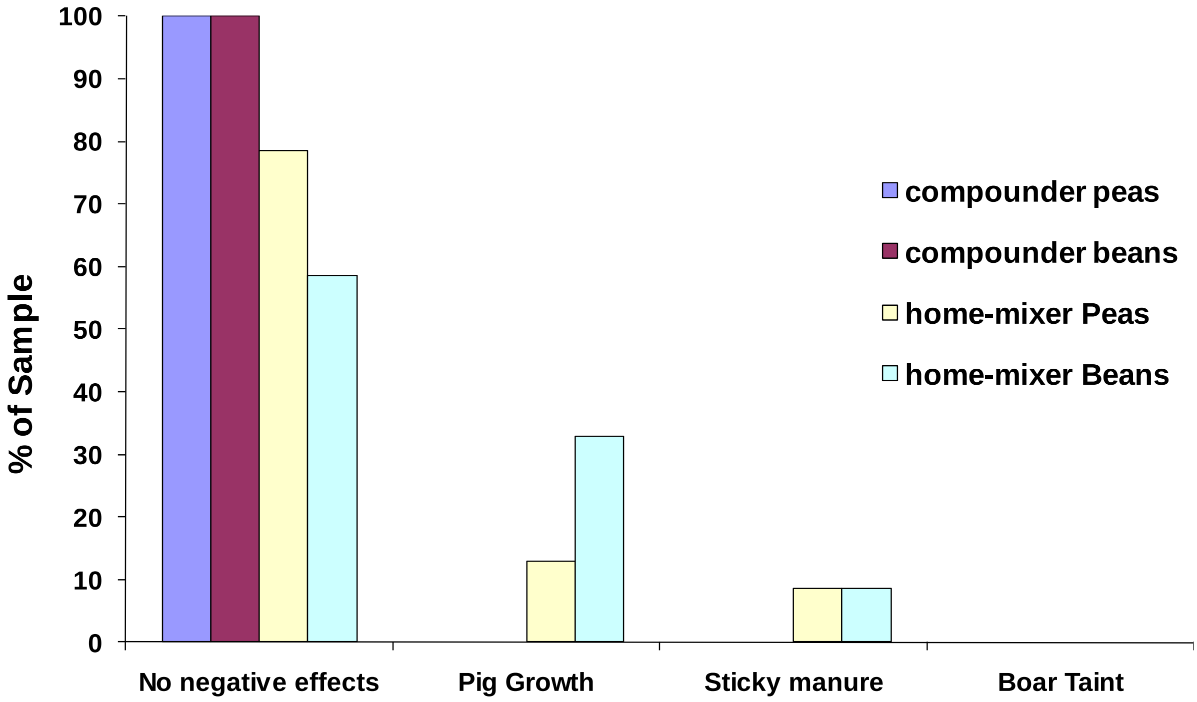

Figure 4. Perceived negative affects of peas and faba beans for use in pig feed. Figures are the percentage of the sample that ticked the above categories.

All compounder respondents thought there were no negative effects of using peas or faba beans in pig diets. Similarly the majority of home-mixers perceived no negative effects of using peas and faba beans (Figure 4). However 12.9% and 8.6% of home-mixer respondents felt that peas may affect pig growth and sticky manure respectively. Additionally, 32.9 % and 8.5% of home-mixer respondents felt that faba beans may affect pig growth and sticky manure respectively (Figure 4).

Economics of using peas and beans in pig feed

Q. How much do you agree or disagree with the statement *Peas/beans are an economically competitive alternative to soya*.

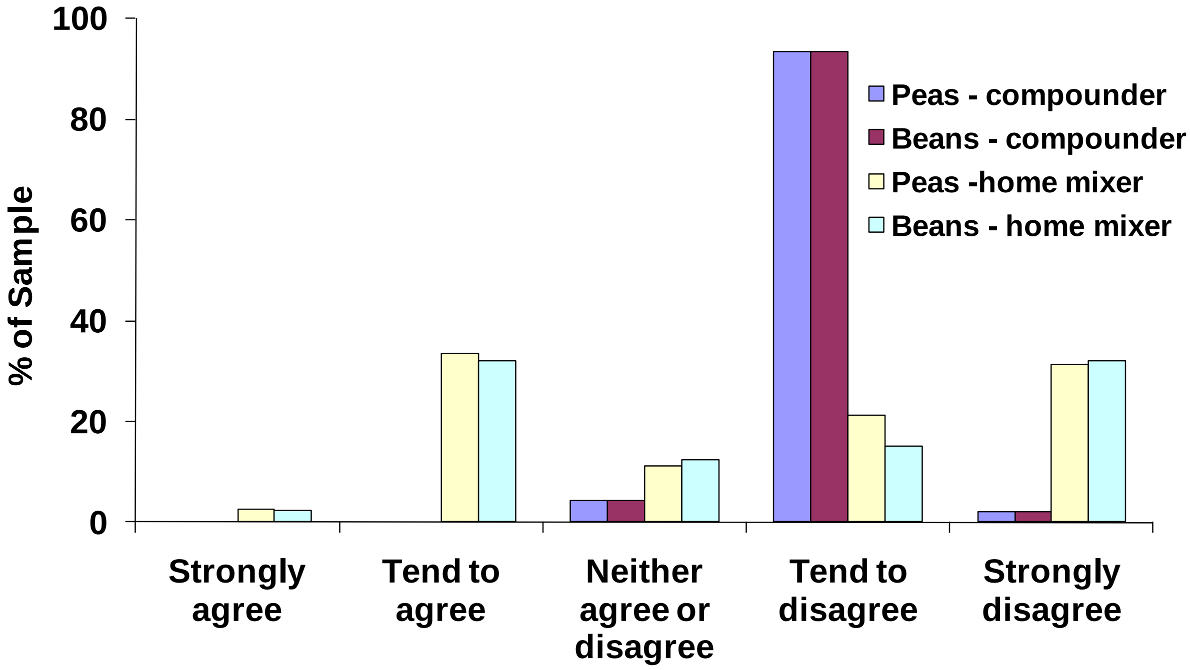

Figure 5. Perceived economics of using peas and faba beans in pig feed. Figures are the percentage of the sample that ticked the above categories in a 5-point interval scale.

Almost 100% of compounders "tend to disagree" with the statement "Peas/beans are an economically competitive alternative to soya" (Figure 5). Whilst around 35% of home-mixers "tended to agree" with this statement for peas and faba beans, approximately 50% of the home-mixers responses either "tended to disagree" or "strongly disagreed" with this statement for both peas and faba beans (Fig 5).

Environmental Impact of using peas and beans in pig feed

Q. How much do you agree or disagree with the statement "using peas or faba beans in pig diets instead of soya is better for the environment."

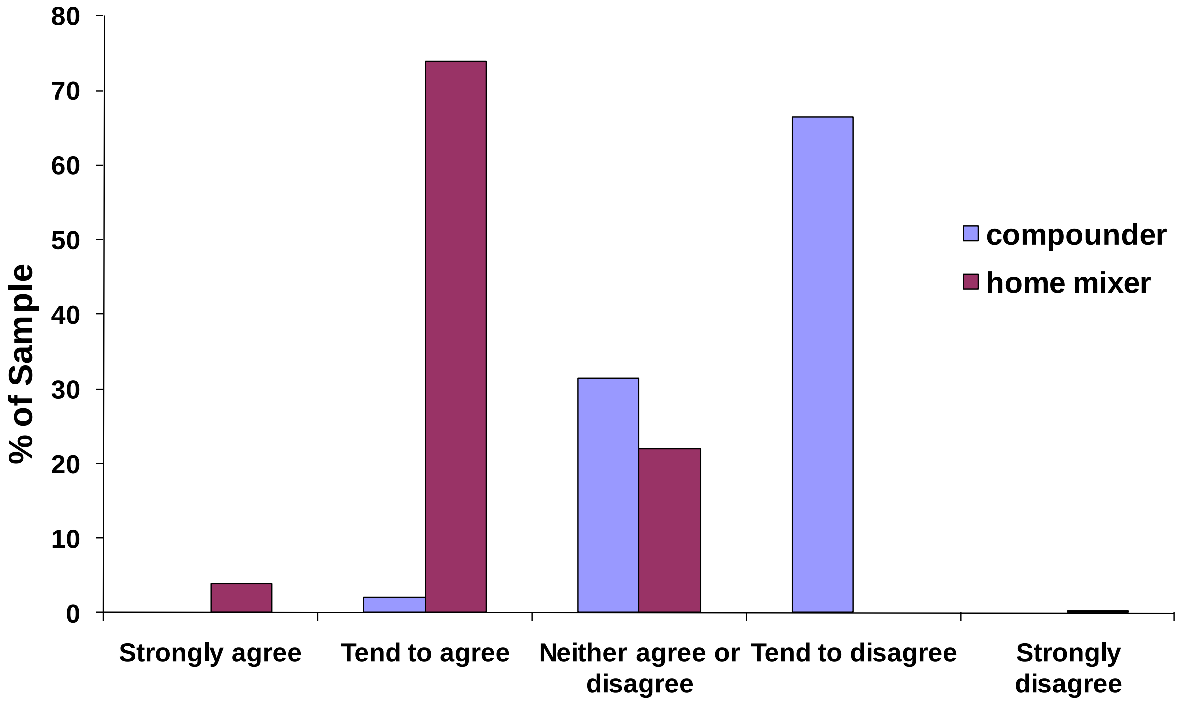

Figure 6. Perceived environmental impact of using peas and faba beans in pig feed. Figures are the percentage of the sample that ticked the above categories in a 5-point interval scale.

66% of compounders "tend to disagree" with the statement that "using peas or faba beans in pig diets instead of soya is better for the environment". In contrast, 73% of home-mixers "tend to agree" with the statement.

Future use of peas and beans in pig feed

Q. How much do you agree or disagree with the statement "If pig production and costs were unaffected, I would increase the use of peas and beans in future diets."

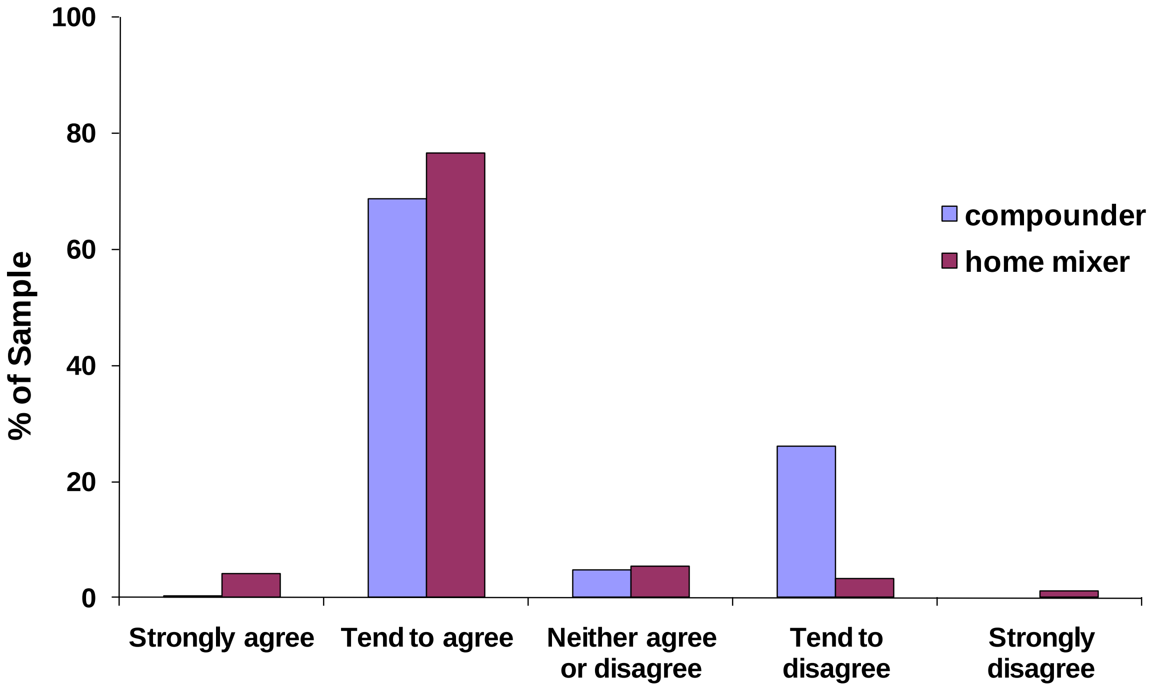

Figure 7. Perceived future use of peas and faba beans in grower and finisher pig diets. Figures are the percentage of the sample that ticked the above categories. in a 5-point interval scale.

68% and 76% of compounders and home-mixers, respectively "tend to agree" with the statement "If pig production and costs were unaffected, I would increase the use of peas and beans in future diets".

Qualitative survey of Pig Nutritionists

Protein sources recommended by nutritionists for pig feed

Pig Nutritionists that give advice to both compounder feed companies and home-mixers pig nutritionists have a significant impact on the formulations used in the UK pig industry. In order to determine the types of proteins and inclusion levels being recommended by pig nutritionists, respondents were asked a series of questions on the proteins recommended in their grower and finisher pig feed formulations; inclusion levels recommended; origin of the protein sources used; and for peas and beans only, the processing technologies recommended and the variety recommended.

Q. In 2008, how often did you include the following protein sources in your grower diet formulations?

Table 7. The frequency that nutritionist's (n=11) recommended the following protein sources in their grower diet formulations

	Frequency recommended				
	Always	**Often**	**Sometimes**	**Rarely**	**Never**
Soya	11	-	-	-	-
Rapeseed	2	3	1	4	1
Sunflower	-	2	1	3	5
Peas	-	-	2	4	5
Faba beans	-	-	5	3	3
Lupins	-	-	-	1	10
DDGS	-	-	1	-	10

DDGS (dried distiller grains with solubles) was included as an additional protein source in the qualitative survey as this survey was conducted at a later date than the quantitative survey, when DDGS had become a new protein source available for use in animal feed. Thus, although the results here indicate that currently very few nutritionist respondents recommend DDGS for use in pig diets, as it was a relatively new product at the time this survey was conducted, the frequency of recommendation may change over time. The main protein source for grower diets recommended by nutritionists in our survey was soya, with all 11 nutritionists respondents always recommended soya in their grower diet formulations (Table 7). In contrast, the protein sources that were recommended the least for grower diets were lupins and distillers dried grain, which were never recommended by 10 of the respondents. Similarly, 9 respondents either rarely or never recommended peas. Beans were sometimes recommended by 5 respondents, but either rarely or never by 6 respondents (Table 7).

Q. In 2008, how often did you include the following protein sources in your finisher diet formulations?

Table 8. The frequency that nutritionist's (n=11) recommended the following protein sources in their **finisher diet formulations**

	Frequency recommended				
	Always	**Often**	**Sometimes**	**Rarely**	**Never**
Soya	9	2	-	-	-
Rapeseed	2	4	4	1	-
Sunflower	-	3	1	3	4
Peas	-	-	3	3	5
Faba beans	-	1	5	2	3
Lupins	-	-	-	1	10
Distillers Dried Grain (DDG)	-	-	1	-	10

As with the grower diets formulations, the main protein recommended by nutritionists in our survey for finisher diets was soya, with 9 out of 11 nutritionist respondents always recommended soya in their finisher diet formulations (Table 8). The protein sources that were recommended the least for finisher diets were lupins and distillers dried grain, with 10 out of the 11 respondents never recommended these proteins for finisher pig diets. Peas were sometimes recommended by 3 respondents, but either rarely or never recommended by 8 out of 11 respondents. Beans were sometimes recommended by 5 respondents, but either rarely or never by 6 respondents. However, alternative protein sources such as peas and faba beans were recommended more often in finisher diets relative to grower diets (Table 8).

Q. In 2008, for the following protein sources, what range of inclusion levels (% of diet) did you recommend in grower pig diets

AND

Q. What do you think are the maximum inclusion levels (% of diet) of peas and faba beans in grower pig diets, that won't negatively affect pig production and health?

Table 9. The number of nutritionists that recommended the following maximum inclusion levels of soya bean meal (SBM), sunflower, rapeseed, lupins, distillers' dried grain (DDG), peas and faba beans in grower pig diets in 2008 (n=11), and the number of nutritionist that perceived the following maximum inclusion levels of peas and faba beans for grower pig diets (n=9)

	Maximum inclusion level (%)							
	0	5	10	15	20	25	30	No max
SBM	0	0	0	0	4	6	0	1
Sunflower	0	5	6	0	0	0	0	0
Rapeseed	4	2	5	0	0	0	0	0
Lupins	10	1	0	0	0	0	0	0
DDG	11	0	0	0	0	0	0	0
Peas (current)	3	1	5	1	0	0	0	0
Peas (perceived max)	1	0	3	4	0	1	0	0
Faba beans (current)	4	4	3	0	0	0	0	0
Faba beans (perceived max)	3	3	2	1	0	0	0	0

Q. In 2008, for the following protein sources, what range of inclusion levels (% of diet) did you recommend in finisher pig diets

AND

Q. What do you think are the maximum inclusion levels (% of diet) of peas and faba beans in finisher pig diets, that won't negatively affect pig production and health?

Table 10. The number of nutritionists that recommended the following maximum inclusion levels of soya bean meal (SBM), sunflower, rapeseed, lupins, distillers' dried grain (DDG), peas and faba beans in finisher pig diets in 2008 (n=11), and the number of nutritionist that perceived the following maximum inclusion levels of peas and faba beans for finisher pig diets (n=11).

	Maximum inclusion level (%)							
	0	5	10	15	20	25	30	No max
SBM	0	0	1	1	3	5	0	1
Sunflower	0	2	4	0	1	0	0	0
Rapeseed	0	3	3	5	0	0	0	0
Lupins	10	0	1	0	0	0	0	0
DDG	9	0	2	0	0	0	0	0
Peas (current)	4	1	1	2	2	0	1	0
Peas (perceived max)	2	0	0	1	4	1	1	2
Faba beans (current)	3	1	4	2	1	0	0	0
Faba beans (perceived max)	2	0	3	3	1	0	0	2

Q For the following protein sources recommended in 2008, if known, where are they produced?

Table 11. Origins of protein sources recommended by UK pig nutritionists. Figures are the number of respondents that source the protein recommended in their pig diet formulations from non-local world regions, local Europe regions, or local UK regions (n=11). Respondents sourcing protein from more than 1 region are included in both categories. SBM = soya bean meal, DDGS = distillers dried grain with solubles.

	Where protein source used in pig diets was produced					
	Not recommended in 2008	Home grown on pig farm	Local UK	Local Europe	Imported – rest of the world	Don't know
SBM	-			-	11	-
Sunflower	4	-	-	4	2	1
Rapeseed	-	2	6	4	0	3
Lupins	8	3	-	-	-	-
DDGS	9	1	1	-	-	-
Peas	3	3	7	-	-	-
Faba beans	3	3	7	-	-	-

The maximum inclusion level of SBM recommended in grower pig by respondents in 2008 was 20-25% inclusion, with 10 out of 11 respondents recommending this inclusion level (Table 9). Furthermore 1 respondent recommended that there was no maximum inclusion level. In contrast, for those nutritionists that recommended peas, an inclusion level of less than 15% inclusion was recommended. Similarly for respondents that recommended sunflower, rapeseed and faba beans in grower pig diets an inclusion level of less than 10% was recommended. Only 1 respondent had recommended lupins for grower diets and this was recommended at the 5% inclusion level. No respondents recommended the use of distillers dried grain for grower diets (Table 9). The perceived maximum inclusion level for peas (which includes responses from nutritionists that did not recommend peas in 2008) was similar the inclusion level currently recommended with all respondents perceiving a maximum inclusion level of less than 15% inclusion in grower diets. However, 1 out of the 11 respondents felt that peas should not be included in grower diets (i.e. 0% maximum inclusion level) (Table 9). The perceived maximum inclusion level for beans was also similar to the inclusion level currently recommended with 5 out of 11 respondents perceiving a maximum inclusion level of less than 10%. However, 1 respondent felt that the maximum inclusion level could be increased to 15%, while 3 out of 11 respondents felt that faba beans should not be included in grower diets (Table 9).

The maximum inclusion level of SBM recommended in finisher pig by respondents in 2008 was 10-25% inclusion, with 10 out of 11 respondents recommending this inclusion level (Table 10). However, as with the grower diets 1 respondent recommended that there was no maximum inclusion level. In contrast, for most alternative protein sources there was an increase in the recommended inclusion levels for finisher pigs relative to the levels recommended for growing pigs. For those nutritionists that recommended peas in finisher pig diets, most nutritionists recommended an inclusion level of 20% or less. Furthermore, 1 respondent recommended an inclusion level of 30%. Similarly for respondents that recommended rapeseed and faba beans in finisher pig diets, the recommended inclusion level increased to less than 15%. However, 1 respondent recommended a greater inclusion of up to 20% inclusion of faba beans in their finisher diet formulations. For respondents that recommended the inclusion of lupins and DDG in their diets, inclusions of up to 10% were recommended. (Table 10). The perceived maximum inclusion level for peas for finisher diets (which includes responses from nutritionists that did not recommend peas in 2008) was similar the inclusion level currently recommended with 5 out of 11 respondents perceiving a maximum inclusion level of less than 20%. However, 2 out of the 11 respondents felt that peas could be included at 20-25% inclusion, while 2 out of 11 respondents felt that there was no maximum inclusion level for peas in finisher diets (Table 10). The perceived maximum inclusion level for beans was also similar to the inclusion level currently recommended with 8 out of 11 respondents perceiving a maximum inclusion level of less than 15%, and 1 out of 11 respondents perceiving a maximum inclusion level of 20%. However, 2 respondents felt that peas could be included at 20-25% inclusion, while 2 out of 11 respondents felt that there was no maximum inclusion level for peas in finisher diets (Table 10).

All respondents that recommended SBM in their diets felt that the SBM used was imported from non-local world regions. Sunflower was sourced from either non-local world regions or local Europe regions. Rapeseed was sourced from local Europe regions as well as local UK regions and home-grown on the pig farm. For alternative protein sources such as lupins, DDG, peas and beans that were recommended for inclusion on pig diets, they were exclusively sourced from either local UK regions or home-grown on the pig farm. (Table 11).

Q For peas and beans only, in 2008 did you recommend a variety/cultivar to be used in grower and finisher pig formulations?

Table 12. The variety/cultivar of peas and beans recommended by nutritionists for use in grower and finisher pig diets (n=11).

	Did not recommend peas/beans	Did not recommend a particular variety	White-flowered (no specific variety)	Specific Variety recommended	
				Coloured-flowered	White-flowered
Peas	3	7	1	-	-
Faba beans	3	3	3	1 *	1 **

* Variety recommended was Victor, Compass or Quattro.
** Variety recommended was Grace

For those nutritionists that recommended peas in their formulations, most did not recommend a particular variety, with only 1 out of 8 nutritionists recommending a white-flowered type Table 12). For faba bean recommendations, 3 out of 8 nutritionists did not recommend any specific variety, however 3 nutritionists did recommend any white flowered variety. Specific variety recommendations were made by 2 out of the 8 nutritionists, with 1 nutritionist recommending the coloured varieties Victor, Compass or Quattro (currently outdated spring varieties, however farmers may keep their own seed), while another nutritionist recommended the white flowered faba bean Grace (Table 12).

Q Which, if any of the following processing technologies would you recommend for peas and faba beans to be included in grower and finisher pig diets?

Table 13. The number of nutritionists that recommend the following processing technologies when including peas or faba beans in pig diets (n=11). Respondents recommending more than 1 processing technology are included in all categories chosen.

	Peas	Faba beans
No Processing	3	2
Milling	5	5
Grinding	7	8
Dehulling	-	-
Soaking and cooking	2	2
Atmospheric steaming	-	-
Pressurized steaming	-	-
Micronisation	-	-
Dry Roasting	-	-
Extrusion cooking	-	-
Rolling	1	1
Pelleting	2	2

The main processing technologies that nutritionists recommend for peas and faba beans to be included in grower and finisher pig diets was grinding and miling. However, other processing technologies such as soaking and cooking, rolling, and pelleting were also recommended for both peas and faba beans.

Attitudes to using alternative protein sources in pig feed

As with the quantitative survey of compounders and home mixers, respondents of the nutritional survey were asked attitudinal questions on using peas and beans in pig diets. These questions covered topics such as availability, nutritional value, negative effects, environmental impact, and future use of peas and faba beans in pig diets.

Availability of alternative protein sources for pig feed

Q. Are the following protein sources available in sufficient quantities all year to be regularly included in your grower and finisher pig diet formulations?

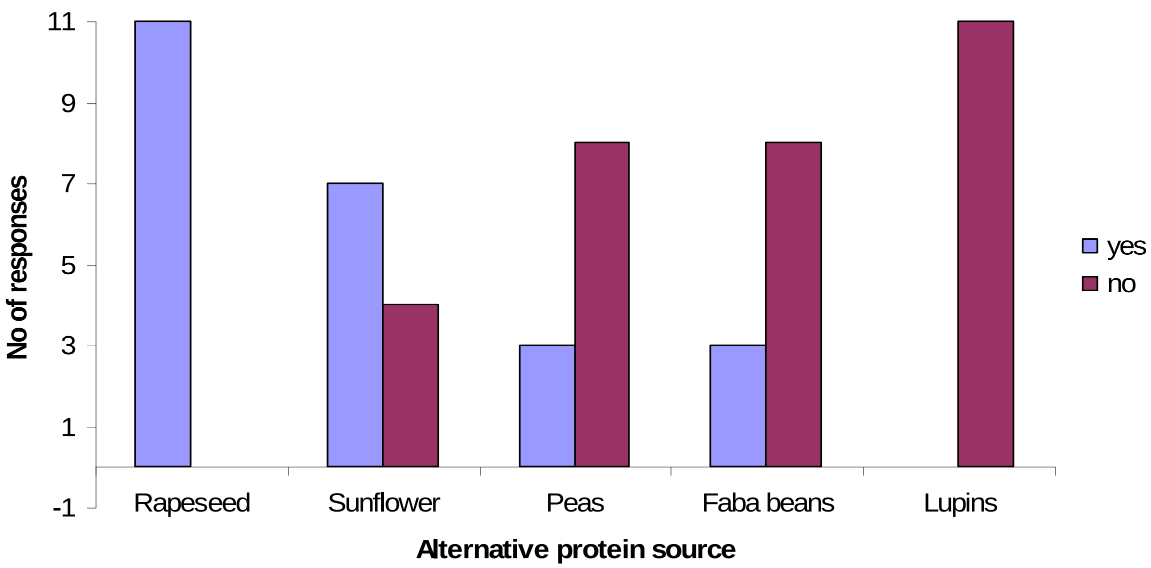

Figure 8. Perceived availability of alternative protein sources used in pig feed. Figures are the number of respondents that responded “yes” or “no”.

Rapeseed and sunflower were perceived to be more readily available to be included regularly in grower and finisher pig diet formulations relative to pulses in general (Fig 8). 8 out of 11 nutritionists believed peas and faba beans were not readily available to be included in formulations, while all 11 nutritionists felt that lupins were not available to be included in pig feed formulations (Figure 8).

Q. For peas and faba beans only, what factors do you think may limit their availability for the UK pig feed industry?

Table 14. Percieved factors that limit availability of peas and faba beans to be used in UK pig diets. Figures are the number of nutritionists that felt the following factors limited the availability of peas and faba beans for inclusion in UK pig diets (n=11). By-Product = not produced for animal feed.

	Peas	Faba beans
Not limited	1	0
Seasonality	5	7
By-Product	6	2
Quality	3	2
Storage	1	2
Processing	4	4
Cultivation	1	1
Harvesting	3	2
Marketing	1	1
Others	2	3

The two main factors affecting availability of peas that were previously identified in the compounder and home-mixer survey were also identified by nutritionists (e.g. seasonality and being a by-product not normally produced for animal feed) (Table 14). However, although seasonality was also identified as a factor limiting faba beans, only 2 out of the 11 nutritionists identified being a by-product as a factor limiting faba beans to be used in pig feed (Table 14).

Nutritional value of peas and beans for pig feed

Q Do peas/faba beans provide adequate nutritional value to be used in grower and finisher pig diets?

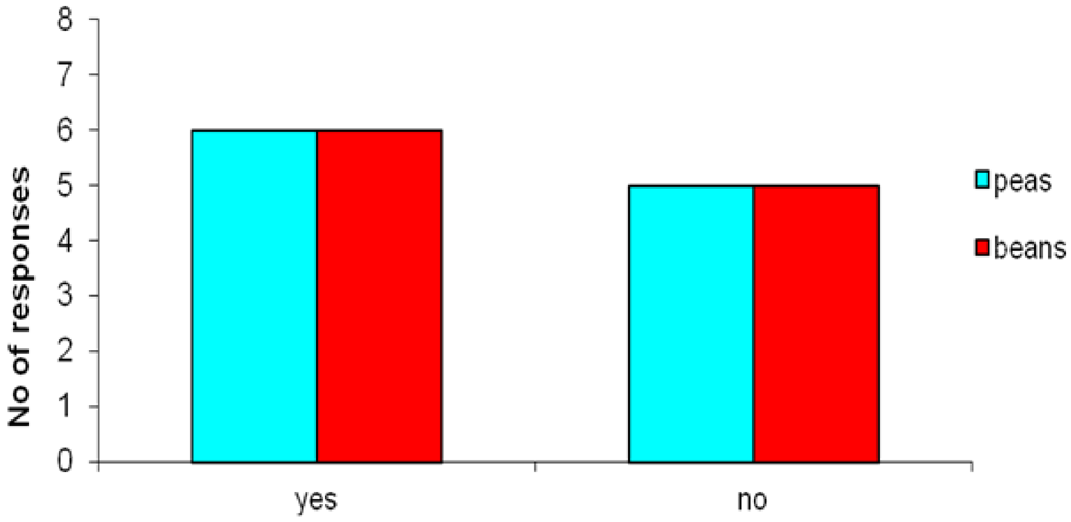

Figure 9. Perceived nutritional value of peas and faba beans for use in pig feed by nutritionists. Figures are the number of nutritionists that responded “yes” or “no”.

In contrast to the compounder and home-mixer survey, the nutritionist’s response to the question of adequate nutritional value is more divided. Although just over half of the nutritionists feeling that both peas and beans had adequate nutritional value, 5 out of 11 nutritionists felt that peas and beans did not have adequate nutritional value to be used in grower and finisher pig feed (Figure 9).

Q If peas/faba beans do not provide adequate nutritional value, why?

Table 15. Perceived factors that affect the nutritional value of peas and faba beans for pig diets. Figures are the number of nutritionists that felt the categories (n=11). AA = Amino acid.

	Peas	Faba beans
Crude Protein content	2	2
Digestibility	0	3
Fibre content	1	3
AA profile	2	3
Trypsin inibitors	2	3
Condensed tannins	0	4
Other	4*	4**

* ↓ feed intake, economics, flatulence, ↑ mineral supplementation required

** ↓ feed intake, economics, poor palatability, degradation of raw material during storage

Although 5 out of the 11 nutritionists that participated in survey felt that peas did not have adequate nutritional value to be included in pig feed, there was no consensus on the factors that affect the nutritional value of peas, with nutritionists selecting a number of different factors that affect the nutritional value of the pea (Table 15). There was a similar response to this question for faba beans, however 4 out of the 5 nutritionists that considered faba beans to not have adequate nutritional value, felt that condensed tannins affected the nutritional value of the faba bean (Table 15).

Negative effects of peas and beans in pig feed

Q Are you aware of any negative effects associated with using peas/faba beans in grower and finisher pig diets?

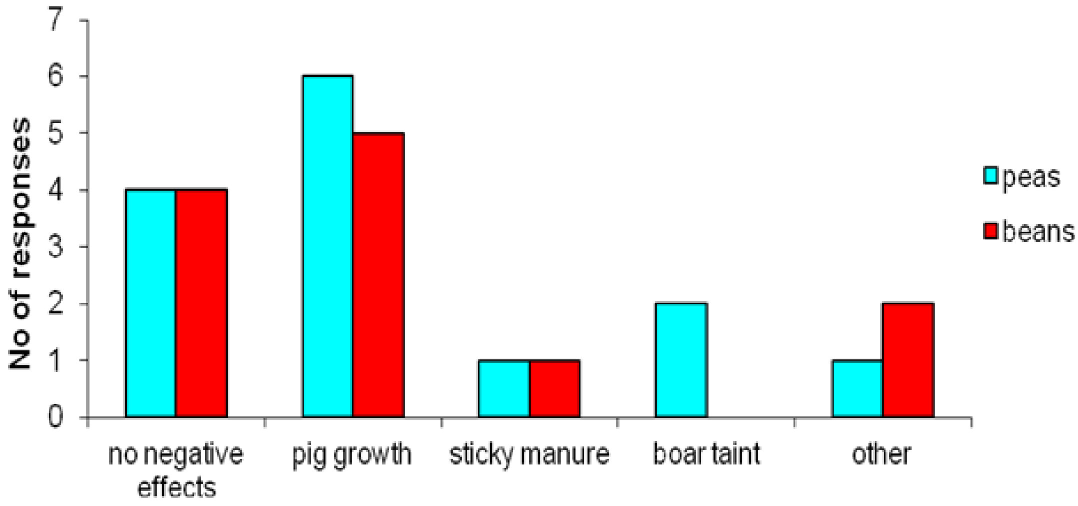

Figure 10. Perceived negative affects of peas and faba beans for use in pig feed by nutritionists. Figures are the number of nutritionists that ticked the above categories (n=11). Respondents ticking more than 1 category are included in all categories ticked.

Although 4 out of 11 nutritionists felt there were no negative effects of using peas and faba beans in grower and finisher pig feed, the remaining 7 nutritionists reported negative effects. The main negative effect was pig growth reported from using both pea and faba bean diets (Figure 10).

Economics of using peas and beans in pig feed

Q How much do you agree or disagree with the statement "Peas/faba beans are an economically competitive alternative to soya."

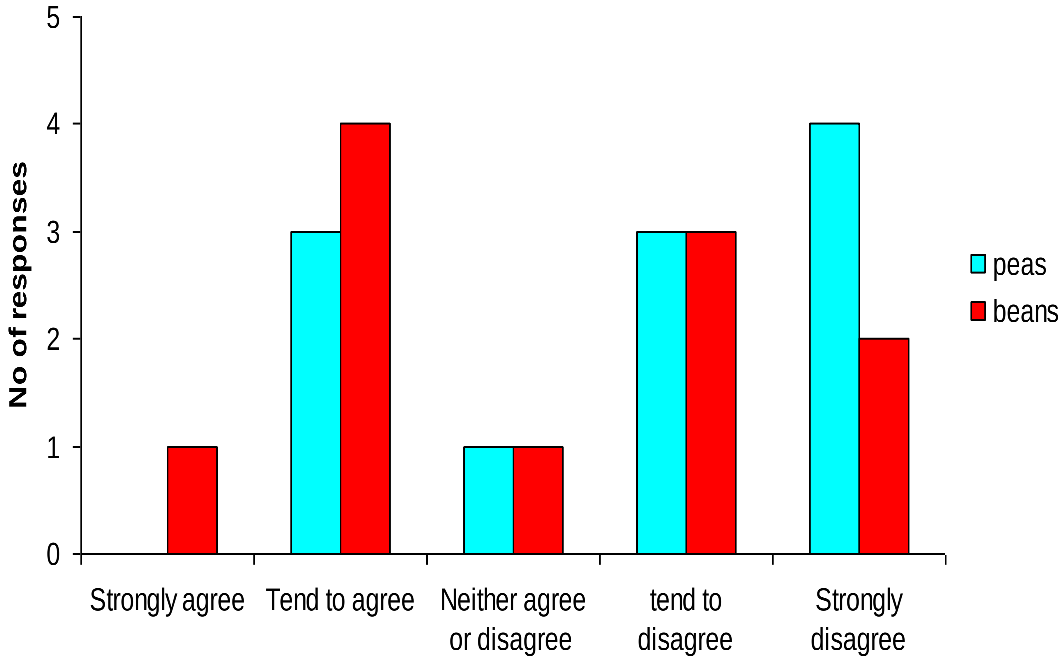

Figure 11. Perceived economics of using peas and faba beans in pig feed by nutritionists. Figures are the number of nutritionists that ticked the above categories.

There was a divided response from nutritionists regarding how economically competitive peas and faba beans are relative to soya. However, for peas the majority of responses from nutritionists were distributed across the "tend to disagree" or "strongly disagree categories". For faba beans, 5 out of 11 nutritionist's responses were distributed across the "tend to disagree" or "strongly disagree categories". However, 5 out of 11 nutritionists responses were also distributed across the "strongly agree" and "tend to agree" category.

Environmental impact of using peas and beans in pig feed

Q How much do you agree or disagree with the statement *using peas or faba beans in pig diets instead of soya is better for the environment.*

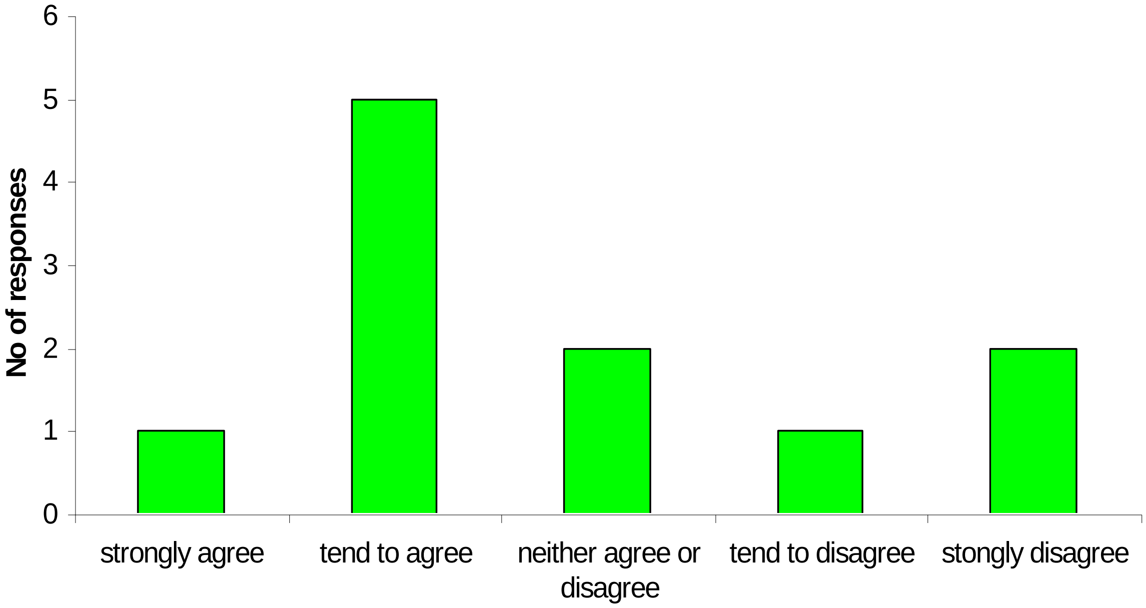

Figure 12. Perceived environmental impact of using peas and faba beans in pig feed by nutritionists. Figures are the number of nutritionists that ticked the above categories.

There is a mixed response to the statement of environmental impact, with 5 out of 11 nutritionists either "tend to agree" or "strongly agree" with the statement; 3 out of the 11 nutritionists either "tend to disagree" or "strongly disagree" with this statement; and a further 3 nutritionists "neither agree or disagree" with this statement.

Future use of peas and beans in pig feed

Q How much do you agree or disagree with the statement "I would recommend increasing the use of peas and faba beans in grower and finisher pig diets if my clients were satisfied with these diets."

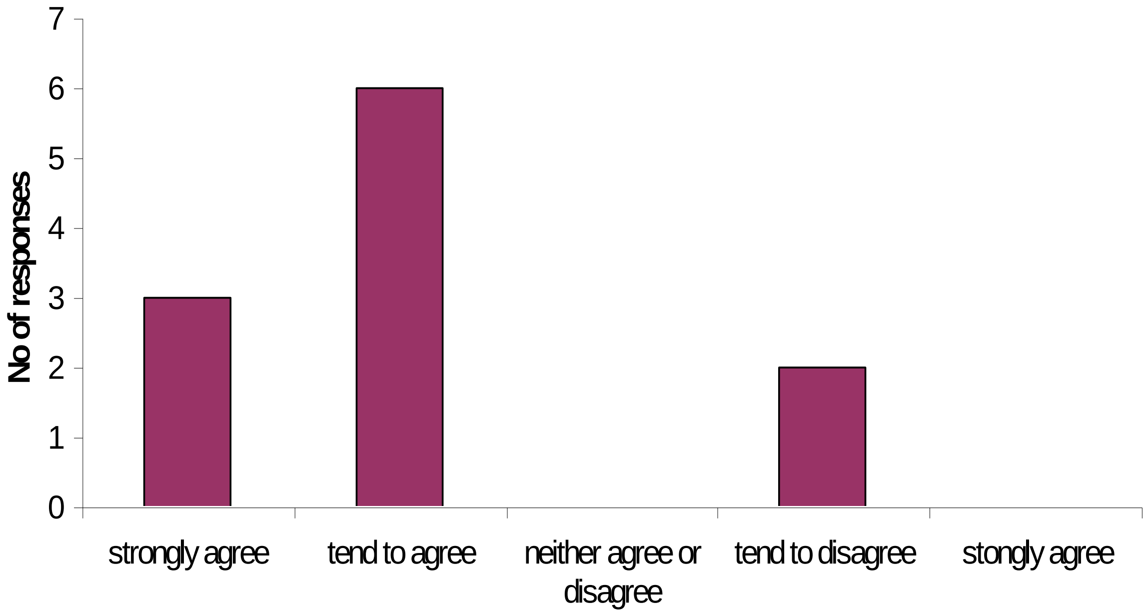

Figure 13. Perceived future use of peas and faba beans in grower and finisher pig diets by nutritionists. Figures are the number of nutritionists that ticked the above categories.

The majority of nutritionists responded positively to this statement, with 9 out of 11 nutritionists either "strongly agree" or "tend to agree" with this statement.

Discussion

The first aim of this survey was to quantify the use and inclusion levels of home grown protein sources in the feeds of UK growing and finisher pigs. The data from the quantitative survey of compounders and home-mixers indicates that current use home-grown protein sources such as peas and faba beans in the UK is low relative to traditional protein sources such as SBM or rapeseed meal. This is further supported by the qualitative survey of pig nutritionists who only recommended their inclusion in grower and finisher diets either sometimes, rarely or never. Additionally, when peas and faba beans are included or recommended in pig diets, the inclusion levels used are low relative to the 30% inclusion level reported in other countries (Jezierny et al., 2010). Furthermore, the perceived maximum inclusion levels by nutritionists are similar to their current recommendations, suggesting that nutritionists would be unhappy to recommend increasing these inclusion levels. The low current inclusion levels used and the large variation in perceived maximum inclusion levels of peas and faba beans (in the compounder and home-mixer survey), indicates that knowledge of acceptable inclusion levels in pig diets may be limited, or based on previous research using older varieties/cultivars of legumes which have been associated with negative effects on pig production (Jansman and Longstaff, 1993; Le Guen and Birk, 1993; Lallès and Jansman, 1998). However, recent advances in plant breeding have resulted in the development of new varieties of pulses with reduced ANFs (Monti and Grillo, 1983; Makkar et al., 1997; Duc et al. 1999; Wiseman et al. 2003). Thus, promotion of acceptable inclusion levels of modern varieties of peas and faba beans may be advantageous in increasing confidence in the use of these pulses for growing and finisher pig diets.

Questions asking respondents about the origins of the protein sources used in UK pig diets confirmed that it is widely known that SBM used in the UK pig diets is sourced from non-local world regions. Thus, with almost all participants using or recommending SBM in their pig diets, the reliance of the pig industry on imported SBM is highlighted. In contrast, all the peas and beans used or recommended were sourced from the UK or home-grown on farm. The survey data also indicates that for compounders and nutritionists no specific variety of peas of faba beans are used or recommended, however for faba beans a general white flowered variety may be a more important consideration. Home-mixers in general were more aware of the specific variety that they used in their pig diets and this may be due to many home-mixers growing their protein source on their own farm. However compounders will have to purchase peas and faba beans on the market when they are available and therefore using a specific variety may be more unrealistic. Whether this is desired in the first place is part of Green Pig.

The second aim of this survey was to investigate the constraints (real or perceived) associated with using the home-grown protein sources peas and faba beans. Availability of peas and faba beans was highlighted as a potential constraint for increasing their use in pig feed, with both the compounder/home-mixer survey and the nutritionists survey indicating that peas and faba beans are not available in sufficient quantities to be regularly used in grower and finisher pig feed. However, home-mixers did appear to perceive that faba beans were more available for use in pig feed relative to the perception of compounders and nutritionists. This difference in perception of availability is likely to be influenced by the method of sourcing the faba beans. All the home-mixers that used faba beans in their pig feed used home-grown faba beans in their diet, suggesting that the faba beans were grown specifically for use in their pig diets. In contrast, compounders must source and compete in an open market where peas and faba beans are mainly produced for human consumption and export markets. From the volumes of pulses produced in Harvest 2010, estimated volumes of peas and faba beans available for animal feed (both ruminant and monogastric) are approximately 48,000 tonnes and 151,666 tonnes, respectively (Salvador Potter, *pers. Comms*., April 2011). In order to supply enough protein for UK grower and finisher pig feed alone, we have estimated that ~500.000 tonnes of peas or beans would be required. Therefore, the constraint of availability of peas and faba beans is a real constraint. Increasing the production of UK grown pulses through policy implementation such as subsidies may aid in reducing this constraint. However, given that in the UK there is a finite availability of arable land, there is also the possibility to source pulses from "close to home" regions such as North-Western Europe. The second constraint identified in the survey was the cost of peas and faba beans relative to the cost of SBM. The survey results indicate that almost all of the compounders felt that the cost of peas and faba beans was not economical for use in pig diets. Although SBM has recently been subject to volatile price fluctuations, with prices in 2010 and 2011 of approximately £300 per tonne, the quoted market price per unit of protein of peas and faba beans still has not been economically competitive in conventional diet formulae (Kev Stickney, *pers. Comms.*, August 2011). However, with world-wide consumption of soya rapidly increasing, especially for Asian markets, the future security of SBM for UK animal feed is uncertain, which may in turn affect the economics of using pulses in animal feed. There was a greater difference in perception of the cost of peas and faba beans relative to soya across the home-mixer and nutritionist respondents. Whilst cost was still perceived to be a constraint among home-mixers and nutritionists, there was an increase in respondents perceiving the use of peas and faba beans as an economically competitive alternative to soya. This may be due to increased awareness of the economics of growing pulses on farm rather than purchasing them on the open market, and potential economic benefits gained from using pulses as a rotation crop.

Food production is considered to have a major impact on climate change, and thus there is increasing pressure on the agricultural industry to seek ways to mitigate its effect on climate change (Foresight, 2011). However, the inconsistency between participants in this survey (both in the compounder/home-mixer survey and the nutritionist survey) in the perception of the environmental impact of both legume crops and soya use in pig diets indicates that there is a lack of information and knowledge on this topic. Thus, the life cycle assessment (LCA) of the Green Pig project is an essential component of the project. Increased promotion of research outcomes from the Green Pig LCA would be beneficial to those in the pig industry to allow informed decisions when considering the environmental impact of different diets.

Both compounders and home-mixers had a positive response to questions about the nutritional value of peas and beans indicating that there is good confidence in using these pulses as a protein source in pig feed. This suggests that the perception of the nutritional value of peas and beans is not a major constraint in increasing the use of peas and beans in the future. However, despite this confidence in the nutritional value of many home-mixer and compounder respondents still felt that factors such as crude protein, AA profile and ANFs affected the nutritional value of peas and faba beans. This indicates that compounders and home-mixers consider the nutritional value of peas and beans to be good enough to be used in their pig diets, but they are aware of some of the negative factors associated with them. Nutritionists had less confidence in the nutritional value of these pulses. The difference in perception between compounders/home-mixers and nutritionists highlights the requirement for the research currently being carried out in the Green Pig project on modern varieties of peas and faba beans. Furthermore, there is a need for promotion of project outcomes, particularly the large scale demonstration trials, in order to increase confidence in peas and beans. Participants (both in the compounder/home-mixer and nutritionist surveys) also showed a positive response to increasing their use/recommendations of peas and faba beans in grower and finisher pig diets in the future. This suggests that people in the pig industry are open to increasing the use of peas and faba beans in pig feed.

Conclusions

This survey indicates that there is the opportunity to increase the confidence in home-grown peas and faba beans as a protein source for grower and finisher pig feed if we can overcome the constraints of cost and availability. The survey has also identified several areas where perceptions of peas and faba beans are inconsistent indicating a gap in knowledge of acceptable use of current varieties of peas and faba beans in pig feed. Thus, promotion of the Green Pig project outcomes to the pig industry would be expected to increase the confidence of peas and faba beans in pig industry and allow the increase of their use in pig feed alongside other home-grown proteins sources, provided that results demonstrate that higher than currently acceptable inclusion levels can be used without detrimental impact on pig performance.

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Full report Objective 3a: Overcoming constraints. Analysis of variation in amino acid composition of pea and bean varieties harvested dry for animal consumption

Lead authors: Simon Kightley (NIAB) and Meike Rademacher (Evonik-Degussa), with a contribution of Bert Tolkamp (SRUC).

Executive Summary

- To assess the potential value of UK produced crops of peas and faba beans for pig feeding, a sampling and analysis program was devised, drawing on the resources of the Recommended List variety testing scheme.
- The objectives were to investigate the range and variability of crude protein content and its constituent amino acids, with respect to the effects of variety, season, and location and to identify genotypes that might provide a breeding platform for improving the nutritional status of the pea and faba bean crops.
- As reported in previous literature, peas exhibited lower protein content than either winter or spring faba beans with average values of 20.32, 24.37 and 24.51% CP respectively, when adjusted to standardised dry matter content of 88%. The range between varieties within the three crops was small (2.48, 1.93 and 1.58% respectively). Annual variation for protein content was in the order of 1.0% for peas. 2% for winter beans and 1.5% for spring beans. Site to site variation was comparatively large for peas, depending on year and variety, with a variation of over 4% recorded for peas in 2010 but smaller for beans with a variation of less than 1.5%. Variation in the order of 2% was also observed between plot replicates.
- The amino acid composition of the protein was very consistent within all three crop groups. Expressed as % standardised dry matter, the individual amino acid levels rose or fell in proportion to the crude protein content of samples but the ratios of the amino acids to each other showed little or no variation.
- Levels of the nutritionally important amino acids, Cystine, Methionine, Threonine and Tryptophan, in proportion to Lysine were sup-optimal and would require balancing with other feedstuffs, high in those amino acids, or synthetic amino acids.
- While a range of protein content between varieties was observed, no indications of sufficient genetic variation in amino acid composition were seen that might guide any

development of breeding programs designed to further improve the nutritional status of peas or faba beans.

- Pig producers should have a high level of confidence in the predictability of nutritional quality of peas and faba beans, irrespective of variety or crop origin, within the range of UK environmental conditions.

Introduction

The purpose of this investigation was to screen a wide range of varieties of peas (*Pisum sativum* L.) and faba beans (*Vicia faba* L.) to identify those with superior nutritional traits in order to advise the animal feed supply chain and breeders wishing to target further feed value improvement in their breeding programs.

In the United Kingdom pea and bean crops, harvested dry, are grown for a number animal feed and human consumption markets. These markets are largely interchangeable, depending on supply and demand. An attractive grain appearance at harvest is crucial for human consumption markets, for which premium prices, compared to feed, are usually offered. In recent years, until the start of the Green Pig Project, little attention has been given to nutritional variation within pulse crops, or between varieties.

Within the European Union varieties of peas and beans are obliged to undergo testing for their yield, field characters and disease resistance before they can be marketed to growers for commercial crop production. Chemical analysis for nutritional traits is not obligatory. Tests are carried out in one or more member states and successful varieties are then added to the National Lists (NL) of these states before subsequent addition to the EU Common Catalogue and commercialisation EU-wide. The UK also have a Recommended List (RL) system for peas and beans, introduced by the National institute of Agricultural Botany (NIAB) in 1960 for field beans and 1984 for peas, and now run and funded by the Processors and Growers Research Organisation (PGRO). This continues trials on the most promising NL varieties with the intention of promoting the use of the best varieties and driving crop improvement. Very little emphasis has been placed on nutritional quality. Crude protein for Recommended varieties has been published since 1969 but, with human consumption markets dominating, this was discontinued after harvest 2007. Composition of the protein itself has never been investigated as part of the NL/RL system although the morphological variation within each crop is considerable and might suggest an equivalent diversity of grain composition.

The most comprehensive recently published listings for variety protein content, obtained from NL/RL trials, were in the form of NIAB Classified Lists (2010) and based on 20-year data sets. Table 1 summarises the mean values and ranges observed for peas and for winter and spring faba beans. Values for peas were about 4% lower in crude protein content than either winter of spring beans and, of the cultivars tested, showed a greater range of values than beans.

Table 1. Crude protein maximum, mean and minimum values obtained for peas and beans in Recommended List trials. (% dry matter) Source: *NIAB Classified Lists, 2010/11*

	Peas	Winter beans	Spring beans
Maximum	27.1	28.7	30.9
Mean	23.9	27.7	28.3
Minimum	21.9	26.6	26.8
Range	5.2	2.1	4.1
Number of varieties	39	8	18

Three classifications of beans are recognised: coloured-flower types, generally regarded as having high tannin content, low-tannin, white-flowered types and tic beans, marked by their small size and dark seed coats, grown specifically for pigeon food. Good samples of the high tannin types are sold into the export market in the Middle-East, for human consumption, for which the preferred specification is for pale, smooth-skinned beans with a pale hilum (the structure attaching the seed within the pod). This is most commonly met by spring bean varieties. Winter beans tend to be darker and less attractive and, until recently, varieties have been characterised by black hilums. The low tannin types, bred specifically for feeding to non-ruminants, typically have a rather unattractive grey appearance and are not acceptable for human consumption markets. To-date the low tannin varieties have been relatively low yielding and, in the absence of any price premium inducement from the feed compounders, have not been widely grown.

The principal types of white-flowered peas are all regarded as low in tannins. These include: white grained peas (also known as yellow), traditionally grown for feed but with a number of human consumption outlets; large blue (green) peas, used in the pet food industry after micronising; marrowfat and small blue peas, both grown specifically for human consumption, mainly as canned peas. Crops of any of these varieties failing to meet the specifications of the premium outlets will be sold as lower-value, animal feed. A further classification is the coloured flower ‘maple’ pea. Maple peas are high in tannins, with a brown seed coat and the grain is produced specifically for inclusion in pigeon feed mixtures.

The current balance of pea and bean production in the UK is heavily in favour of beans (Figure 1). The combined area of pulse crops is approximately 200,000 hectares *per annum,* with considerable variation resulting from the fluctuating popularity of other arable crops. The annual contribution of the pea crop has declined to about 25,000ha since the early 90s having previously varied between 60 and 100,000ha mainly been due to the relative difficulty of harvesting peas, compared with beans.

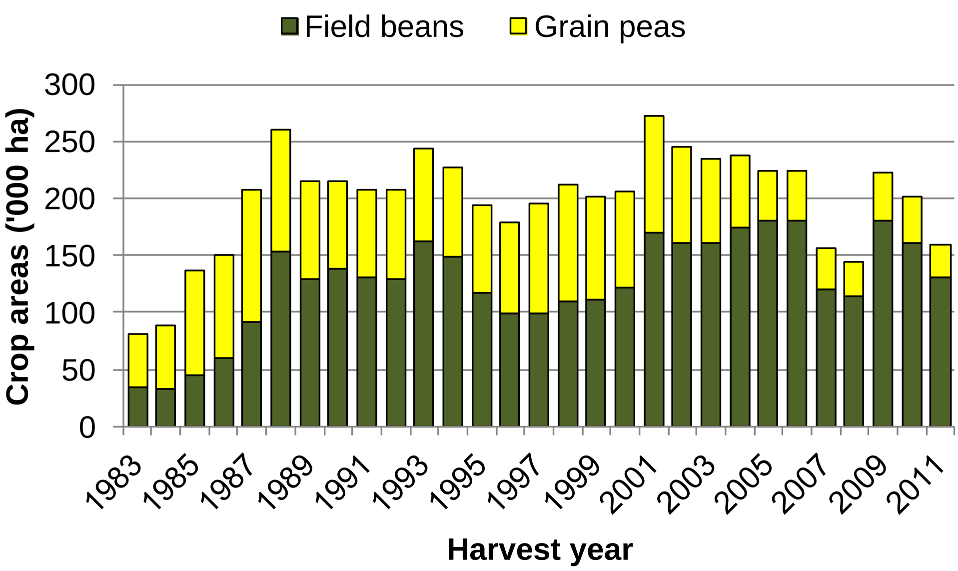

Figure 1. Annual combined crop areas of peas and faba beans for the last 25 years (*Source:* Defra).

Feed compounders use generic values for peas and beans. Table 2 presents values provided by Premier Nutrition (2008). In comparison with soya bean meal (SBM) the composition of both crop species is regarded as sub-optimal, particularly with respect to the ratios of methionine, threonine, tryptophan and methionine + cystine relative to lysine (Wiseman, *pers com*), as set out in Table 2 and based the digestible amino acid contents in the on the Premier Nutrition analyses.

Table 2. Grain composition of field peas and beans expressed at standardised dry matter (86% DM). *Source:* Premier Nutrition

Grain composition	Beans, coloured	Beans, white	Peas
Crude protein	24.0	25.5	20.5
Amino acids			
Lysine	1.51	1.61	1.45
Methionine	0.17	0.18	0.19
Cystine	0.30	0.32	0.29
Methonine + Cystine	0.47	0.49	0.48
Threonine	0.82	0.87	0.75
Tryptophan	0.19	0.20	0.19
Isoleucine	0.99	1.06	0.85
Valine	1.10	1.17	0.96
Leucine	1.78	1.89	1.43
Phenylalinine + Tyrosine	1.73	1.84	1.60
Histidine	0.60	0.63	0.51
Arginine	2.16	2.30	1.76

Table 3. Comparison of key amino acid ratios with "ideal" composition for nutrition.

	"Ideal" composition	SBM	Beans	Peas
Methionine:Lysine	0.30	0.22	0.10	0.13
Threonine:Lysine	0.65	0.62	0.51	0.48
Tryptophan:Lysine	0.19	0.21	0.10	0.11
Methionine + Cystine:Lysine	0.59	0.45	0.28	0.29

As can be seen, in both comparisons the composition, peas and beans are deficient, suggesting that their inclusion in pig diets need to be supplemented by cystine, methionine, threonine and tryptophan from other crop-based feedstuffs, or with pure amino acids.

There have been few detailed studies of amino acid profile variation between cultivars. Grosjean *et al* (2000) reported on the analysis of 12 commercial; varieties of peas from different breeding companies and including winter- and spring-sown types. Examination of the amino acid analysis in this study reveals little variation between varieties and average values close to those given in Table 1. (See also the Green Pig Literature Review, Report on Objective 4).

In order to gain further understanding of variation in amino acid composition of pulse protein, variety samples from common origins, were required for analysis, rather than relying on analysis of samples submitted by breeders from a range of seed production environments. Accessing the Recommended List trials program provided the opportunity to source common origin samples, from multiple locations, to investigate variability of protein content and quality of peas and faba beans and to determine the effects of variety, year and site.

Materials and Methods

Sampling

The sampling program was conducted by NIAB, in collaboration with PGRO. At the project inception meeting it was agreed that samples of all pea and bean varieties represented in RL trials would be collected for analysis over a minimum of a two year period. The samples would be taken from each of five trial locations in order to observe the impact of environmental influences, by drawing on a wide geographical range of sites. It was hoped that the combination of varieties, years and sites would provide a sound indication of variation and reliability of protein quality, especially in terms of amino acid contents. Sampling and analysis continued into a third harvest year to address specific questions that arose during the course of the project, particularly with respect to repeatability of analysis between in-site replicates and some elements of amino acid analysis for peas.

Recommended List variety trials are conducted at multiple sites to reflect the geographical distribution of the different crops, the numbers of varieties passing through the test program, and the relative variability in harvest data within different crop species. Within the pulse crop group there are currently 9 trials for peas, 9 for spring beans and 6 for winter beans. Trials are sown as either 3- or 4-replicate randomisations, with typical harvest plot dimensions of 10m x 2m. At maturity the whole plots are harvested, using plot combines, and samples are collected for further analysis, including moisture content, estimation of 1000 grain weight and visual suitability for different niche markets. For the purposes of the Green Pig project additional samples were collected for amino acid analysis (100g) and selected varieties were also sampled for inclusion in poultry chick feeding studies (10kg). Samples were stored in cloth bags and air dried to prevent deterioration. In addition to varieties being tested within the RL system breeders were contacted and invited to submit additional lines if they thought that this might introduce additional genetic diversity. As a consequence a number of such lines were sown in un-replicated plots, at selected sites in the second harvest year.

In the first year single bulked samples of each variety were collected from each site, rather than from individual plot replicates. This has become established practice within the RL system as a cost saving measure. As a result of concerns within the project steering group over lack of replication, an element of separate replicate sampling was introduced in the second harvest year, to address any lack of precision and to satisfy industry concern on relying on non-replicate data to inform decisions on potential nutritional value.

A third year of sampling was agreed upon, with reduced variety sets, with the objectives of further investigating environmental influences, variation of amino acid composition between replicates and as to validate the analytical methodology used for peas.

The full sampling program is tabulated in Appendix 1. During the course of the three years 35 varieties of peas, 8 winter beans and 13 spring beans were sampled, providing material for a total of 477 analyses.

Sample analysis: amino acid and nitrogen analysis

The N content in beans was determined with a Leco FP-2000 nitrogen determinator (Leco Corporation, St. Joseph, MI). Amino acid composition in faba beans were determined by ion exchange chromatography with postcolumn derivatization with ninhydrin. Amino acids were oxidized with performic acid, which was neutralized with sodium metabisulfite

(Llames and Fontaine, 1994; Commission Directive, 1998). Amino acids were liberated from the protein by hydrolysis with 6N HCL for 24 h at 1108C and were quantified with the internal standard method by measuring the absorption of reaction products with ninhydrin at 570 nm. Tryptophan was determined by HPLC with fluorescence detection (extinction 280 nm, emission 356 nm) after alkaline hydrolysis with barium hydroxide octahydrate for 20 h at 1108C (Commission Directive, 2000).

Amino acid composition and N content in peas was determined with near Infrared Reflectance Spectroscopy (NIRS). NIRS is a standard application in the feed industry. Samples are radiated with NIR-light and the reflectance is analyzed as compared to a ceramic plate. The resulting spectrum, caused by specific absorbences due to initiated vibrations or rotations of molecule parts, contains information about the sample ingredients. With the MPLS (modified partial least square) algorithm the correlations between spectral data points and the amino acid reference data (wet chemistry) are analyzed and a prediction model (NIR calibration) is developed.

NIRS is able to process huge numbers of samples which opens a lot of new opportunities in raw material evaluation and selection compared with the limited capacities of wet chemistry analyses. The prediction equations for the various raw materials are based on specific calibrations developed by Evonik using wet chemistry methods on a wide range of qualities and number of samples (> 100) for each raw material. AminoNIR® has several advantages including: Excellent precision due to being based on very accurate wet chemistry analysis as well as fast and reliable identification of variable feed ingredients and data error detection. Evonik has developed single calibrations for more than 20 raw materials.

Due to the low frequency of beans compared with peas used by the feed industry, Evonik has been able to develop an NIRS equation for peas but not for beans and, consequently, the bean samples were analysed by wet chemistry.

Analysis of sample data

Raw data for sample analysis, received from Evonik-Degussa, was compiled by NIAB and subjected to statistical tests (analysis of variance) using Genstat. For over-years analysis on incomplete variety matrices, variety means were adjusted using Fitted Constant Analysis.

Review of historic data for protein content from Recommended List trials

As a separate exercise an investigation of historic data for protein content, grain size and yield was conducted to explore the practical significance of the crude protein variation observed in the Green Pig analyses. As a first step the entire National List/Recommended List database was trawled to identify samples for which all three parameters were recorded. This gave results for 2,322 pea samples, 416 winter beans and 1,125 spring bean samples. For each crop dry matter yield and crude protein were compared with grain size, expressed as thousand seed weight. It should be noted that for Recommended List purposes crude protein has traditionally been reported as percent dry matter rather than as percent standardised dry matter (88%DM). This explains the higher protein values discussed in this section.

Results

It should be noted that amino acid data presented here are expressed as percentage of grain weight, standardised to 88% moisture content (SDM). Discussion within the project group concluded that this, rather than expressing amino acids as percent of crude protein, reflected the industry standard and that the data expressed in this form would have the greatest relevance.

Because of the turnover of varieties the data collected do not comprise a complete matrix. The summary tables present mean over-years data, adjusted by fitted constant analysis. Full annual data sets are available for inspection via the Green Pig SharePoint.

Peas

Mean data for peas (Table 4) indicate that the principle source of variation is in crude protein content. Values range from 21.46 for Bilbo down to 18.88%SDM for Rocket, both in the white pea classification. The difference of 2.59% exceeds the least significant difference (1.5%). The marrowfat peas, bred for human consumption, had the highest mean percent crude protein content (21.00%), followed by the white peas (20.21%) and the large blue peas

(20.03%). The single example of a small blue pea variety was of intermediate protein content (20.43%).

Amino acid content showed very little variation between varieties and what variation was observed can be related to differences in crude protein content, as evidenced by the examples given for lysine, methionine + cystine , threonine and tryptophan in Figure 2. This implies a very great level of genetic homogeneity with respect to amino acid composition. This is further corroborated by the ratios of Lysine to methionine + cystine, threonine and tryptophan given in Table 4 which show almost no variation between varieties and for which the overall mean values conform almost exactly to the figures derived from the Premier Nutrition guide values in Table 2.

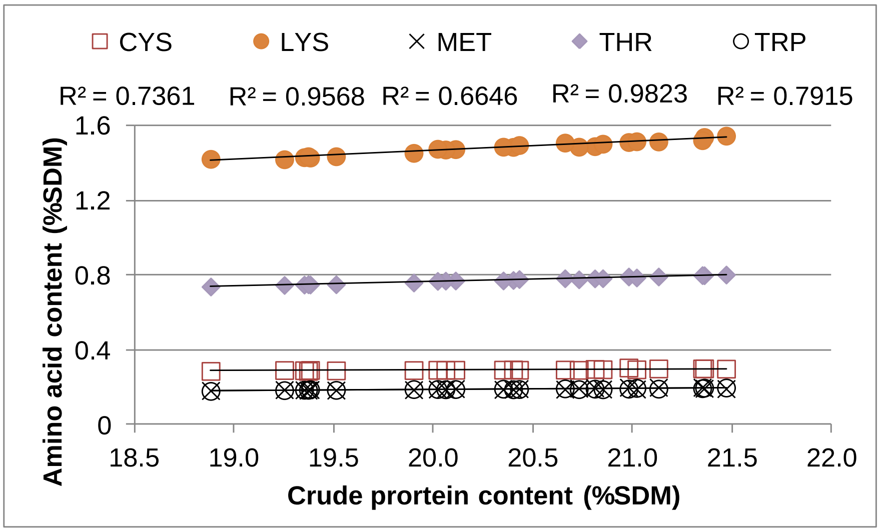

Figure 2. Relationship of crude protein content to content of selected amino acids (Cystine, Lysine, Methionine, Threonine and Tryptophan) for 23 grain pea varieties.

Table 4. Summary of crude protein and amino acid analysis for pea varieties, averaged over sites and years (88% DM). Varieties grouped by market classification. **Types:** LB = Large blue; MF = Marrowfat; SB = Small blue; W = White

Variety	Type	Samples	CP	Arg	Cys	His	Ile	Leu	Lys	M+C	Met	Phe	Thr	Trp	Val	Lys:M+C	Lys:Thr	Lys:Trp
Nitouche	LB	10	21.36	1.76	0.30	0.53	0.88	1.53	1.54	0.50	0.20	1.03	0.80	0.20	0.99	0.32	0.52	0.13
Crackerjack	LB	15	20.40	1.70	0.30	0.49	0.85	1.47	1.49	0.48	0.19	0.99	0.77	0.19	0.95	0.33	0.52	0.13
Bluemoon	LB	10	20.35	1.69	0.30	0.50	0.85	1.47	1.49	0.48	0.19	0.99	0.77	0.19	0.95	0.32	0.52	0.13
Raptor	LB	5	20.11	1.59	0.29	0.50	0.84	1.45	1.48	0.49	0.19	0.97	0.77	0.19	0.94	0.33	0.52	0.13
Bluestar	LB	10	20.06	1.61	0.29	0.50	0.84	1.46	1.47	0.49	0.19	0.98	0.77	0.19	0.94	0.33	0.52	0.13
Venture	LB	5	20.02	1.55	0.29	0.49	0.85	1.45	1.48	0.48	0.19	0.98	0.77	0.19	0.95	0.33	0.52	0.13
Prophet	LB	31	19.38	1.51	0.29	0.47	0.82	1.40	1.43	0.48	0.19	0.95	0.75	0.19	0.92	0.34	0.52	0.13
Daytona	LB	10	19.35	1.58	0.29	0.48	0.82	1.41	1.43	0.47	0.19	0.95	0.75	0.19	0.91	0.33	0.52	0.13
Madras	LB	10	19.25	1.56	0.29	0.47	0.81	1.40	1.42	0.47	0.19	0.94	0.75	0.19	0.91	0.33	0.53	0.13
Kahuna	MF	5	21.35	1.73	0.30	0.52	0.88	1.51	1.52	0.50	0.20	1.02	0.80	0.20	0.99	0.33	0.53	0.13
Falstaff	MF	5	21.13	1.68	0.30	0.51	0.87	1.49	1.52	0.50	0.20	1.01	0.79	0.19	0.98	0.33	0.52	0.13
Genki	MF	5	20.98	1.60	0.31	0.50	0.88	1.49	1.51	0.51	0.20	1.01	0.79	0.19	0.98	0.33	0.52	0.13
Samson	MF	5	20.81	1.65	0.30	0.51	0.86	1.47	1.49	0.50	0.20	0.99	0.78	0.19	0.96	0.33	0.53	0.13
Sakura	MF	5	20.73	1.67	0.29	0.50	0.86	1.47	1.49	0.49	0.20	0.99	0.78	0.19	0.96	0.33	0.52	0.13
Paris	SB	5	20.43	1.65	0.29	0.50	0.86	1.47	1.50	0.49	0.19	0.99	0.78	0.19	0.96	0.32	0.52	0.13
Bilbo	W	5	21.47	1.84	0.30	0.52	0.89	1.53	1.55	0.49	0.19	1.03	0.80	0.20	0.99	0.32	0.52	0.13
Gregor	W	15	21.02	1.79	0.30	0.52	0.87	1.51	1.52	0.48	0.19	1.01	0.79	0.20	0.97	0.32	0.52	0.13
Aviso	W	10	20.85	1.73	0.30	0.51	0.86	1.49	1.50	0.49	0.19	1.00	0.78	0.19	0.97	0.33	0.52	0.13
Ragtime	W	15	20.66	1.64	0.30	0.51	0.86	1.50	1.51	0.49	0.19	1.01	0.78	0.19	0.97	0.32	0.52	0.13
Respect	W	15	19.90	1.63	0.29	0.49	0.83	1.43	1.46	0.48	0.19	0.96	0.76	0.19	0.93	0.33	0.52	0.13
Mascara	W	31	19.51	1.54	0.29	0.48	0.82	1.41	1.44	0.47	0.19	0.95	0.75	0.19	0.92	0.33	0.52	0.13
Tonga	W	5	19.37	1.53	0.29	0.48	0.82	1.41	1.44	0.47	0.19	0.96	0.75	0.19	0.92	0.33	0.52	0.13
Rocket	W	5	18.88	1.41	0.29	0.46	0.81	1.39	1.42	0.47	0.18	0.94	0.74	0.18	0.91	0.33	0.52	0.13
Mean			20.32	1.64	0.30	0.50	0.85	1.46	1.48	0.49	0.19	0.99	0.77	0.19	0.95	0.33	0.52	0.13
STD Error			0.36	0.053	0.001	0.006	0.015	0.026	0.026	0.002	0.002	0.016	0.012	0.003	0.014			
LSD (Average)			1.11	0.079	0.006	0.018	0.020	0.033	0.031	0.010	0.005	0.022	0.014	0.009	0.023			
LSD (Largest)			1.45	0.104	0.007	0.023	0.026	0.044	0.041	0.012	0.006	0.029	0.019	0.011	0.030			

Abbreviations: *CP* crude protein; *Arg* Arginine; *Cys* Cystine; *His* Histidine; *Ile* Isoleucine; *Leu* Leucine; *Lys* Lysine; *M+C* Methionine + Cystine; *Met* Methionine; *Phe* Phenlylalinine + Tyrosine; *Thr* Theonine; *Trp* Tryptophan; *Val* Valine

Table 5 presents a full matrix of correlation coefficients for crude protein and individual amino acids for the data given in Table 4. All correlations between crude protein and individual amino acids are highly significant at the 0.1% level of probability. The weakest relationship was between methionine and arginine but even this is significant at the 5.0% level.

Table 5. Correlation coefficients for crude protein and amino acids analysed in 23 pea varieties over 5 sites and 3 years. (Significance levels: 5.0% = 0.4227; 1.0% = 0.5368; 0.1% = 0.6524).

	ARG	*CYS*	*HIS*	*ILE*	*LEU*	*LYS*	*M+C*	*MET*	*PHE*	*THR*	*TRP*	*VAL*	*CP*
CP	0.8820	0.8579	0.9691	0.9809	0.9790	0.9782	0.8790	0.8152	0.9698	0.9911	0.8897	0.9912	1.0000
ARG	1.0000												
CYS	0.6494	1.0000											
HIS	0.8935	0.7661	1.0000										
ILE	0.8223	0.8728	0.9418	1.0000									
LEU	0.8903	0.8020	0.9721	0.9778	1.0000								
LYS	0.8647	0.8217	0.9615	0.9873	0.9944	1.0000							
M+C	0.6177	0.9418	0.7946	0.8965	0.8197	0.8395	1.0000						
MET	0.5283	0.8767	0.7207	0.8143	0.7229	0.7428	0.9263	1.0000					
PHE	0.8651	0.8149	0.9504	0.9832	0.9939	0.9946	0.8215	0.7167	1.0000				
THR	0.8510	0.8747	0.9618	0.9924	0.9825	0.9860	0.8976	0.8276	0.9781	1.0000			
TRP	0.8522	0.7538	0.9117	0.8806	0.8996	0.8968	0.7092	0.6474	0.8915	0.8921	1.0000		
VAL	0.8410	0.8584	0.9619	0.9927	0.9819	0.9874	0.8898	0.8170	0.9798	0.9932	0.8805	1.0000	

Annual and site-to-site variation in amino acid content can also be explained by variation in protein content. Six varieties were present in all three years and detailed variety analyses are given in Appendix 3. Table 6 summarises this information.

Analysis of samples from each of the three individual replicates was performed for two varieties, Mascara and Prophet, for four sites in 2009 and three sites in 2010. The results are fully listed in Appendix 4. Results for crude protein are given in Table 7, with an average range of 0.94% variation between highest and lowest replicates and a maximum of 2.21% for the variety, Prophet, at site 1 in 2009.

Table 6. Annual variation in crude protein and amino acid composition of 6 pea varieties, averaged over 5 sites.

	2008	**2009**	**2010**
Crude protein	20.39	20.56	19.44
Argenine	1.71	1.68	1.53
Cystine	0.29	0.29	0.29
Histidine	0.51	0.50	0.48
Isoleucine	0.85	0.86	0.81
Leucine	1.47	1.49	1.40
Lysine	1.49	1.51	1.42
Methionine	0.19	0.19	0.19
Methionine + Cystine	0.48	0.48	0.48
Phelylalinine + Tyrosine	0.99	1.00	0.95
Threonine	0.78	0.78	0.74
Tryptophan	0.19	0.19	0.18
Valine	0.96	0.96	0.92
Totals	9.91	9.94	9.41

Table 7. Crude protein analysis of individual replicate samples, for two pea varieties, from seven trials over a two-year period.

Year	Site	Mascara					Prophet				
		Rep1	Rep 2	Rep 3	Mean	Range	Rep1	Rep 2	Rep 3	Mean	Range
2009	1	21.10	20.57	19.87	20.51	1.23	18.14	20.62	19.79	19.52	2.21
2009	2	19.44	20.18	19.35	19.66	0.83	20.63	21.08	20.18	20.63	0.9
2009	3	19.90	19.73	18.48	19.37	1.42	19.36	20.08	19.13	19.52	0.95
2009	5	20.82	20.64	20.95	20.80	0.31	19.23	20.14	20.04	19.80	0.91
2010	1	19.90	18.87	19.08	19.28	1.03	19.01	19.40	19.67	19.36	0.66
2010	2	20.17	20.49	20.00	20.22	0.49	19.05	20.18	20.01	19.75	1.14
2010	3	17.35	16.68	16.90	16.98	0.67	17.24	17.07	16.88	17.06	0.36

In 2010 the concern over the use of NIRS analysis for peas was addressed with the analysis of a subset of 10 samples by both NIRS and wet chemistry (Table 8). Inspection of the data suggests that NIRS generally underestimates the values obtained by wet chemistry. Here, in the case of crude protein, the average underestimate is -0.53% and ranges from -1.1% for Prophet, at Site 2, to an overestimate of +0.12% for Ragtime at Site 2. It is important to note that for crude protein and for the majority of the amino acids the correlations between the two methods were highly significant at the 0.1% level of probability.

For methionine and cystine and the combined methionine + cystine the correlations were not significant.

Table 8. Comparison of NIRS *vs*. wet chemistry for analysis of crude protein and amino acid analysis of 10 pea samples. Data expressed as % SDM and ranked in descending order of crude protein content from the NIRS analysis.

Sample	NIR Analysis											
	CP	ARG	CYS	HIS	ILE	LEU	LYS	M+C	MET	PHE	THR	VAL
Gregor: Site2	22.71	1.98	0.31	0.56	0.92	1.61	1.60	0.51	0.20	1.07	0.82	1.03
Ragtime: Site 2	21.82	1.75	0.30	0.54	0.90	1.57	1.57	0.50	0.20	1.06	0.80	1.00
Respect: Site 2	20.81	1.74	0.30	0.51	0.86	1.49	1.50	0.49	0.19	1.00	0.77	0.97
Bluestar: Site 1	20.27	1.68	0.31	0.49	0.83	1.44	1.45	0.51	0.20	0.96	0.77	0.94
Mascara: Site 2	20.17	1.61	0.29	0.49	0.83	1.45	1.46	0.48	0.19	0.98	0.76	0.94
Prophet: Site 2	19.05	1.44	0.30	0.45	0.81	1.39	1.42	0.49	0.19	0.94	0.73	0.91
Prophet: Site 1	19.01	1.45	0.30	0.46	0.80	1.37	1.41	0.49	0.19	0.92	0.73	0.90
Green Pig Peas	18.74	1.47	0.31	0.47	0.79	1.36	1.38	0.49	0.19	0.92	0.75	0.89
Prophet: Site 4	18.40	1.37	0.29	0.46	0.80	1.36	1.38	0.48	0.19	0.92	0.73	0.89
Crackerjack: Site 3	17.94	1.35	0.29	0.43	0.75	1.29	1.32	0.48	0.19	0.88	0.70	0.85
Sample	Wet chemistry											
	CP	ARG	CYS	HIS	ILE	LEU	LYS	M+C	MET	PHE	THR	VAL
Gregor: Site2	22.94	2.19	0.33	0.58	0.94	1.61	1.60	0.53	0.21	1.09	0.82	1.07
Ragtime: Site 2	21.70	1.84	0.31	0.56	0.92	1.60	1.59	0.50	0.19	1.14	0.81	1.01
Respect: Site 2	21.22	1.91	0.31	0.54	0.86	1.51	1.50	0.50	0.19	1.01	0.76	0.97
Bluestar: Site 1	21.01	1.77	0.30	0.53	0.90	1.53	1.55	0.50	0.19	1.04	0.78	1.01
Mascara: Site 2	20.39	1.70	0.33	0.54	0.86	1.47	1.50	0.52	0.20	1.01	0.77	0.98
Prophet: Site 2	20.15	1.69	0.31	0.52	0.83	1.43	1.45	0.51	0.20	0.99	0.77	0.95
Prophet: Site 1	19.58	1.66	0.30	0.51	0.83	1.43	1.45	0.50	0.20	0.98	0.77	0.95
Green Pig Peas	19.21	1.55	0.32	0.51	0.83	1.40	1.43	0.52	0.20	0.97	0.76	0.94
Prophet: Site 4	19.29	1.57	0.30	0.52	0.84	1.42	1.44	0.49	0.19	0.97	0.75	0.95
Crackerjack: Site 3	18.69	1.52	0.27	0.48	0.82	1.39	1.39	0.45	0.18	0.94	0.72	0.92
Correlation coefficient	0.982	0.951	0.467	0.956	0.894	0.963	0.944	0.533	0.534	0.932	0.898	0.914
Significance level (%)	0.1	0.1	NS	0.1	0.1	0.1	0.1	NS	NS	0.1	0.1	0.1

Bert Tolkamp (SRUC) assessed several ways proposed to try to establish the usefulness of NIR to predict AA composition as determined by wet chemistry (Table 8a). If R-square is used as estimator of the accuracy of the use of NIR to predict AA concentrations as determined by wet chemistry, LEU and ARG are amongst the AA with the best ranking (R-squares higher than 90%) and MET and CYS amongst the worst (R-squares lower than 30%). This is, however, not the best comparison because there are considerable differences between AA in the variation in concentration, which have a large effect on R-square.

The prediction error, as estimated by S, is likely more relevant to compare accuracy across AA. In that case, the situation has almost reversed because ARG is then predicted least accurately and MET best (with an almost 10-fold range in S). There are, however, also considerable differences between AA in the average concentration and it might be better to use as a measure of accuracy the prediction error as a percentage of the mean concentration.

Table 8a. The accuracy of NIR predictions for amino acid concentrations as determined by wet chemistry and judged from (i) the R-square (Rsq) of regression of WET on NIR values and their ranking, (ii) the prediction error S (i.e. the square root of the residual error MS) and their ranking, (iii) S as a percentage of the mean AA concentration and their ranking, (iv) the mean difference between NIR and WET and their ranking and (v) the mean difference between NIR and WET as a proportion of their mean and their ranking.

AA	Rsq	Rank	S	Rank	S, % of mean	Rank	Mean diff. NIR-WET	Ra nk	Diff, % of mean	Rank
LEU	92.7	1	0.023	8	1.6	1	-0.046	9	-3.2	5
HIS	91.4	2	0.009	2	1.8	4	-0.044	8	-8.7	10
ARG	90.5	3	0.066	11	4.0	9	-0.156	11	-9.4	11
LYS	89.1	4	0.025	10	1.7	3	-0.041	6	-2.8	4
PHE	86.9	5	0.024	9	2.4	7	-0.048	10	-4.8	9
VAL	83.4	6	0.019	5	2.0	5	-0.043	7	-4.6	8
THR	80.7	7	0.013	3	1.7	2	-0.017	4	-2.3	3
ILE	79.9	8	0.021	7	2.2	6	-0.031	5	-3.3	7
MET	28.5	9	0.007	1	3.6	8	-0.001	1	-0.6	1
M+C	28.4	10	0.021	6	4.1	10	-0.009	2	-1.9	2
CYS	21.8	11	0.015	4	5.0	11	-0.010	3	-3.3	6

In that case, MET, CYS and ARG are all ranked at the same side of the ranking scale, while the previous comparisons placed them at (different) opposite ends. Please note, however, that the range used for the last ranking is very limited: the prediction error as a percentage of the mean varies only between 1.6 and 5.0%, which suggests a similar accuracy for all AA.

Evaluation of S informs about the magnitude of differences between the two methods for the different AA, not about the direction(s) of these differences. Therefore, another way is ranking the AA for the smallest average difference between predictions by NIR and wet chemistry. The data show that, on average, NIR underestimates concentrations as determined by WET for all AA (all values are negative) and that direct ranking is, therefore, possible.

MET and CYS are again amongst the best and LEU and ARG amongst the worst in rank, again in stark contrast to the ranking according to R-square. For reasons mentioned above, accuracy can perhaps better be judged from the average difference as a percentage of the mean level of AA. ARG is then again ranked the worst and MET the best. However, if judged this way, most AA are very similar with differences that are on average a few percent negative (most between -0.5 and -5%, i.e. similar to the suggestion from the evaluation of S/Mean). Exceptions are HIS and ARG, where the differences are larger, which turns out to be pretty systematic and not a result of one or two outliers.

Figure 3 shows a plot of all differences as a proportion of means for each AA. It shows that the differences between the two methods as a percentage of the mean is not affected much by the mean level but that the differences are larger than average for HIS and ARG.

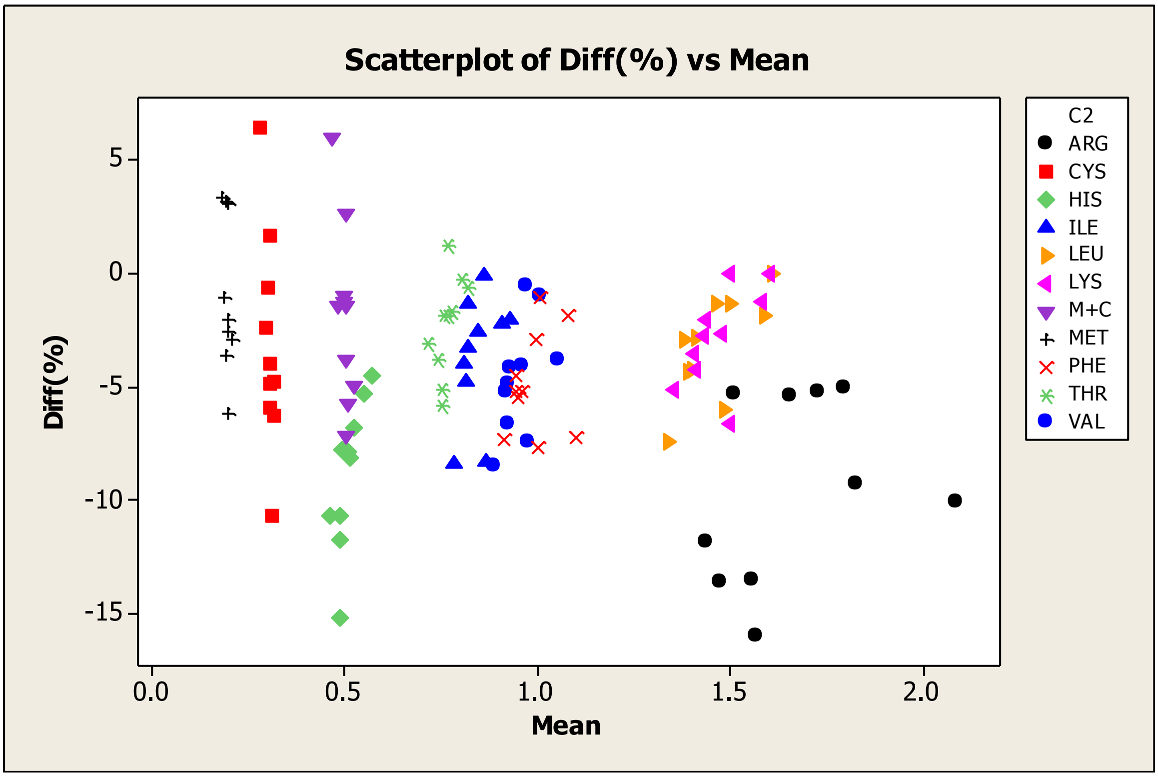

Figure 3. All differences as a proportion of means for each AA.

In conclusion, using the prediction error as the basis for method comparisons, NIR underestimates concentrations as determined by wet chemistry. For most AA the concentrations as predicted by NIR are, on average a few % lower than those determined by wet chemistry, which would allow for applying a sensible correction factor across AA, though the differences tend to be larger for ARG and HIS.

Additional pea varieties

As a result of our request for varieties from a wider genetic base than those received into the Recommended list trials program, nine varieties – one from Serasem, France and nine from the University of Saskatoon, Canada – were submitted and grown in un-replicated plots at two sites to produce grain samples for analysis in 2009. Of the two locations, satisfactory growth was achieved only at the Herefordshire site and the analytical results of the samples from this trial are presented in Table 9. The mean protein content of the additional pea lines was slightly lower than that of the Recommended varieties, with consequential depression of the amino acid levels in the analyses. This effect was strongly influenced by the high protein contents recorded for the recommended varieties Nitouche and Aviso at this site and the general comparison and examination of individual cultivar analyses reveals no evidence of increased genetic diversity in protein content or composition within the additional varieties submitted.

Faba beans

Variety mean data for crude protein and amino acid content for beans are given in Table 10. Because of changes to the program in the third year of the project, with resources diverted to wet chemistry on selected pea varieties, only five varieties of both winter and spring beans are available for this summary. Data on other varieties are available in the full annual analyses listed in at the Green Pig SharePoint.

As with peas, both winter and bean varieties exhibited significant differences in crude protein content ranging from 25.57 to 23.64% in winter beans and from 25.01 to 23.43% in spring beans, with LSDs of 0.726% and 0.555% respectively. Clear relationships between crude protein and amino acid levels are observed and examples of this are given in Figures 4 and 5. The proportions of the key amino acids, cystine, lycine, methionine, threonine and tryptophan show very good consistency in relation to crude protein content and the mean figures, in Table 10, are almost identical to those derived from the Premier Nutrition guide values.

Table 9. Comparison of protein content and amino acid composition of pea varieties tested within the Recommended List program and additional varieties submitted for analytical purposes from a wider range of breeding programs. Data expressed as % SDM)

	CP_NIR	ARG	CYS	HIS	ILE	LEU	LYS	M+C	MET	PHE	THR	TRP	VAL
UK RL varieties													
Nitouche	23.2	1.95	0.31	0.57	0.93	1.64	1.63	0.51	0.20	1.10	0.85	0.21	1.05
Aviso	22.7	1.92	0.31	0.56	0.91	1.60	1.60	0.51	0.20	1.07	0.83	0.21	1.03
Ragtime	21.8	1.78	0.30	0.53	0.89	1.56	1.57	0.50	0.20	1.04	0.82	0.20	1.00
Gregor	21.8	1.86	0.30	0.53	0.89	1.56	1.56	0.49	0.20	1.05	0.81	0.20	1.00
Respect	21.4	1.78	0.30	0.53	0.89	1.54	1.56	0.50	0.20	1.03	0.81	0.20	0.99
Bluemoon	21.0	1.73	0.30	0.51	0.87	1.50	1.52	0.49	0.20	1.01	0.79	0.20	0.97
Daytona	21.0	1.73	0.30	0.51	0.88	1.52	1.53	0.49	0.20	1.02	0.79	0.20	0.97
Bluestar	20.9	1.63	0.30	0.52	0.88	1.51	1.52	0.49	0.20	1.02	0.80	0.20	0.98
Crackerjack	20.9	1.75	0.30	0.50	0.88	1.52	1.53	0.49	0.19	1.02	0.79	0.20	0.98
Prophet	20.6	1.63	0.30	0.51	0.86	1.48	1.49	0.50	0.20	1.00	0.78	0.19	0.97
Mascara	19.4	1.50	0.29	0.48	0.81	1.41	1.44	0.47	0.19	0.95	0.76	0.19	0.91
Madras	19.3	1.54	0.29	0.47	0.83	1.42	1.44	0.48	0.19	0.95	0.75	0.18	0.92
Mean	**21.2**	**1.73**	**0.30**	**0.52**	**0.88**	**1.52**	**1.53**	**0.49**	**0.20**	**1.02**	**0.80**	**0.20**	**0.98**
Additional varieties													
CDCHandel	21.8	1.76	0.30	0.55	0.89	1.52	1.54	0.50	0.20	1.02	0.80	-	1.00
Cutlass	21.5	1.81	0.30	0.54	0.88	1.53	1.52	0.49	0.20	1.03	0.80	0.20	0.99
CDCBronco	21.0	1.70	0.30	0.52	0.89	1.53	1.55	0.49	0.20	1.03	0.80	0.20	0.99
CDCMinuet	20.9	1.73	0.30	0.52	0.86	1.51	1.52	0.49	0.19	1.02	0.79	0.19	0.97
CDCGolden	20.0	1.61	0.29	0.52	0.83	1.45	1.45	0.48	0.19	0.98	0.76	0.19	0.94
CDCMozart	19.9	1.62	0.29	0.51	0.84	1.45	1.44	0.49	0.19	0.98	0.76	0.18	0.95
CDCCentennial	19.3	1.47	0.29	0.48	0.81	1.41	1.43	0.47	0.19	0.95	0.75	0.19	0.91
S04H088	19.1	1.51	0.29	0.48	0.81	1.40	1.42	0.46	0.18	0.95	0.74	0.18	0.90
CDCMeadow	19.0	1.50	0.30	0.46	0.82	1.40	1.43	0.48	0.19	0.94	0.75	0.18	0.90
Mean	**20.3**	**1.63**	**0.30**	**0.51**	**0.85**	**1.47**	**1.48**	**0.48**	**0.19**	**0.99**	**0.77**	**0.19**	**0.95**

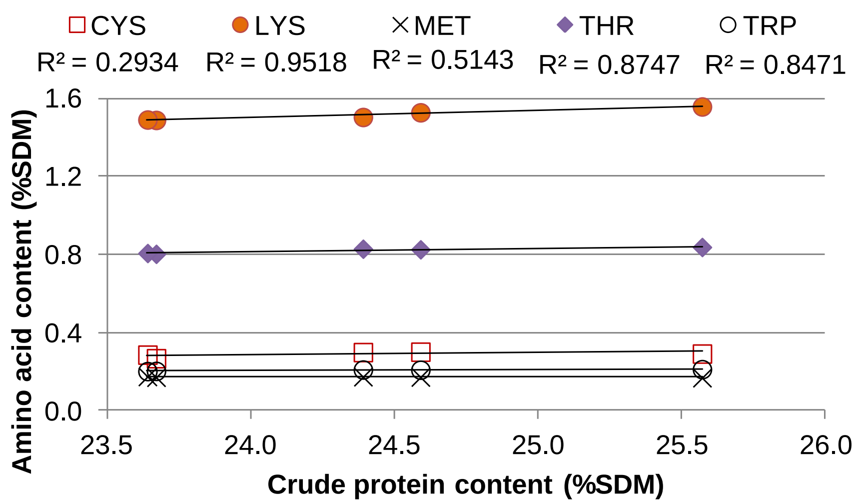

Figure 4. Relationship of crude protein content to content of selected amino acids (Cystine, Lysine, Methionine, Threonine and Tryptophan) for 5 winter bean varieties.

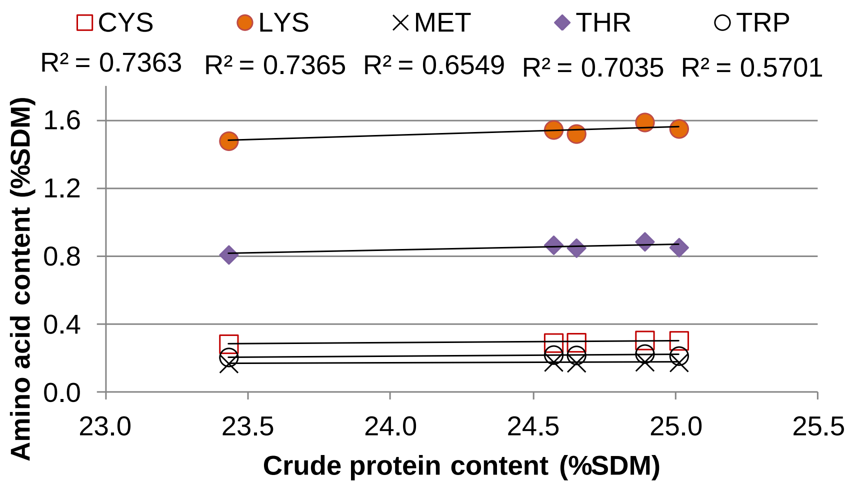

Figure 5. Relationship of crude protein content to content of selected amino acids (Cystine, Lysine, Methionine, Threonine and Tryptophan) for 5 spring bean varieties.

Table 10. Summary of crude protein and amino acid analysis for winter and spring bean varieties averaged over sites and years and expressed as percent total dry matter. **Types:** WF = white flower; CF = coloured flower; PH = pale hilum; BH = black hilum; LT = low tannin

Winter faba beans

Variety	Type	CP	Arg	Cys	His	Ile	Leu	Lys	M+C	Met	Phe	Thr	Trp	Val	Lys:M+C	Lys:Thr	Lys:Trp
Husky	CF/PH	25.57	2.23	0.29	0.64	1.00	1.81	1.56	0.46	0.17	1.04	0.84	0.21	1.11	0.30	0.54	0.14
Wizard	CF/PH	24.59	2.09	0.30	0.63	0.98	1.74	1.53	0.48	0.17	1.01	0.83	0.21	1.08	0.31	0.54	0.14
Arthur	CF/BH	24.39	2.03	0.30	0.62	0.96	1.72	1.51	0.47	0.17	1.00	0.83	0.21	1.07	0.31	0.55	0.14
Clipper	CF/BH	23.67	1.99	0.27	0.60	0.94	1.69	1.49	0.44	0.17	0.98	0.80	0.20	1.06	0.30	0.54	0.14
Sultan	CF/PH	23.64	1.95	0.29	0.61	0.93	1.66	1.49	0.46	0.18	0.97	0.81	0.20	1.06	0.31	0.54	0.14
Mean		24.37	2.06	0.29	0.62	0.96	1.72	1.52	0.46	0.17	1.00	0.82	0.21	1.08	0.31	0.54	0.14
STD Error		0.538	0.073	0.005	0.013	0.021	0.041	0.039	0.010	0.005	0.027	0.020	0.003	0.028			
LSD (Average)		0.685	0.100	0.010	0.019	0.033	0.057	0.041	0.012	0.005	0.029	0.023	0.016	0.037			
LSD (Largest)		0.726	0.106	0.011	0.021	0.035	0.061	0.043	0.013	0.005	0.031	0.024	0.231	0.039			

Spring faba beans

Variety	Type	CP	Arg	Cys	His	Ile	Leu	Lys	M+C	Met	Phe	Thr	Trp	Val	Lys:M+C	Lys:Thr	Lys:Trp
Tattoo	WF/LT	25.01	2.07	0.30	0.62	1.02	1.80	1.55	0.48	0.18	1.05	0.85	0.214	1.13	0.31	0.55	0.14
Betty	CF/PH	24.89	2.17	0.31	0.64	1.03	1.85	1.59	0.49	0.18	1.07	0.89	0.226	1.15	0.31	0.56	0.14
Fuego	CF/PH	24.65	2.04	0.29	0.62	0.97	1.75	1.52	0.46	0.17	1.01	0.85	0.218	1.09	0.31	0.56	0.14
Memphis	CF/PH	24.57	2.08	0.29	0.62	0.97	1.76	1.55	0.47	0.18	1.03	0.87	0.22	1.10	0.30	0.56	0.14
Ben	CF/PH	23.43	1.91	0.28	0.59	0.95	1.67	1.48	0.45	0.17	0.97	0.81	0.206	1.05	0.31	0.55	0.14
Mean		24.51	2.05	0.30	0.62	0.99	1.76	1.54	0.47	0.17	1.03	0.85	0.217	1.102	0.31	0.55	0.14
STD Error		0.464	0.036	0.004	0.019	0.015	0.035	0.037	0.006	0.003	0.025	0.016	0.003	0.018			
LSD (Average)		0.497	0.059	0.006	0.011	0.019	0.033	0.020	0.008	0.003	0.016	0.015	0.016	0.021			
LSD (Largest)		0.555	0.066	0.006	0.012	0.021	0.036	0.023	0.009	0.003	0.018	0.017	0.231	0.024			

Abbreviations: *CP* crude protein; *Arg* Argenine; *Cys* Cystine; *His* Histidine; *Ile* Isoleucine; *Leu* Leucine; *Lys* Lysine; *M+C* Methionine + Cystine; *Met* Methionine; *Phe* Phenlylalinine + Tyrosine; *Thr* Theonine; *Trp* Tryptophan; *Val* Valine

Annual variation in crude protein for selected bean varieties showed a range of 2.06% in the winter bean variety, Wizard (Table 11) and 1.51% and 1.74% for the spring bean varieties Fuego and Tattoo respectively (Table 12).

Table 11. Annual variation in the crude protein and amino acid content of the winter bean variety, Wizard.

Year	2008	2009	2010
Crude protein	25.52	23.46	25.11
Argenine	2.21	1.93	2.18
Cystine	0.32	0.30	0.30
Histidine	0.65	0.61	0.62
Isoleucine	1.02	0.94	0.97
Leucine	1.83	1.67	1.74
Lysine	1.62	1.48	1.49
Methionine	0.18	0.17	0.17
Methionine + Cystine	0.50	0.47	0.46
Phelylalininine + Tyrosine	1.07	0.97	1.01
Threonine	0.87	0.80	0.81
Tryptophan	0.22	0.20	*
Valine	1.14	1.05	1.07
Amino acid totals	11.64	10.58	10.81

* Not analysed

Table 12. Annual variation in crude protein and amino acid content of two spring bean varieties, Fuego and Tattoo.

Variety	Fuego			Tattoo		
Year	2008	2009	2010	2008	2009	2010
Crude protein	25.29	25.04	23.78	25.34	25.78	24.04
Argenine	2.10	2.07	1.97	2.09	2.12	2.00
Cystine	0.30	0.30	0.28	0.31	0.31	0.30
Histidine	0.64	0.63	0.58	0.63	0.64	0.59
Isoleucine	1.00	0.99	0.94	1.03	1.03	0.99
Leucine	1.81	1.76	1.68	1.83	1.84	1.72
Lysine	1.59	1.53	1.45	1.60	1.57	1.48
Methionine	0.47	0.47	0.45	0.48	0.48	0.47
Methionine + Cystine	0.18	0.17	0.17	0.18	0.17	0.17
Phelylalininine + Tyrosine	1.06	1.02	0.97	1.08	1.06	1.00
Threonine	0.88	0.86	0.82	0.86	0.88	0.82
Tryptophan	0.22	0.22	*	0.21	0.21	*
Valine	1.12	1.10	1.04	1.14	1.13	1.10
Amino acid totals	11.36	11.12	10.34	11.45	11.44	10.63

* Not analysed

Variation in protein content at the replicate level was recorded for the winter bean, Wizard and the spring bean, Fuego in 2009 and for Wizard, Fuego and a second spring bean, Tattoo, in 2010. For the winter bean, the average range of protein content between replicates was 0.88% SDM, with a maximum range of 1.87% at site 1 in 2009 (Table 13). For spring beans the average range between replicates was 1.03%, with a maximum range observed at site 1 in 2010, of 2.83%, for the variety Tattoo (Table 14).

Table 13. Replicate variation of crude protein content in the winter bean variety, Wizard

Year	Site	Wizard				
		Rep 1	Rep 2	Rep 3	Mean	Range
2009	1	23.91	22.04	22.74	22.90	1.87
2009	2	23.67	23.48	23.32	23.49	0.35
2009	4	24.57	23.43	24.76	24.25	1.33
2010	1	23.19	23.97	23.24	23.47	0.78
2010	2	27.08	26.63	27.27	26.99	0.19
2010	4	25.57	25.07	25.82	25.49	0.75

Table 14. Replicate variation in crude protein content in the spring bean varieties, Fuego and Tattoo.

Year	Site	Fuego					Tattoo				
		Rep 1	Rep 2	Rep 3	Mean	Range	Rep 1	Rep 2	Rep 3	Mean	Range
2009	1	25.85	26.35	26.56	26.25	0.71					
2009	4	24.72	25.32	24.21	24.75	1.11					
2009	5	25.71	25.03	25.21	25.32	0.68					
2010	1	26.02	23.58	23.39	24.33	2.63	25.72	22.89	24.33	24.31	2.83
2010	2	23.50	22.58	23.25	23.11	0.92	23.66	23.84	23.98	23.83	0.32
2010	3	25.06	25.12	23.56	24.58	1.56	24.71	24.25	24.45	24.47	0.46
2010	4	23.94	23.89	23.67	23.83	0.27	24.33	24.10	24.01	24.15	0.32
2010	5	22.70	22.75	23.76	23.07	1.06	23.62	23.05	23.61	23.43	0.57

Analysis of historic data sets

Figures 4 indicates the high degree of variability observed for yield, crude protein content and grain size in peas and beans harvested from variety trials. Variation observed for individual varieties, selected to represent different types within the different crop species are presented in Appendix 5.

For peas no indications of relationships between yield, seed size and protein content were observed were observed. In the case of both winter and spring beans the relationship between seed size and protein was very flat but both crops indicated trends towards larger grain size with higher yields which were significant at the 1.0% confidence level.

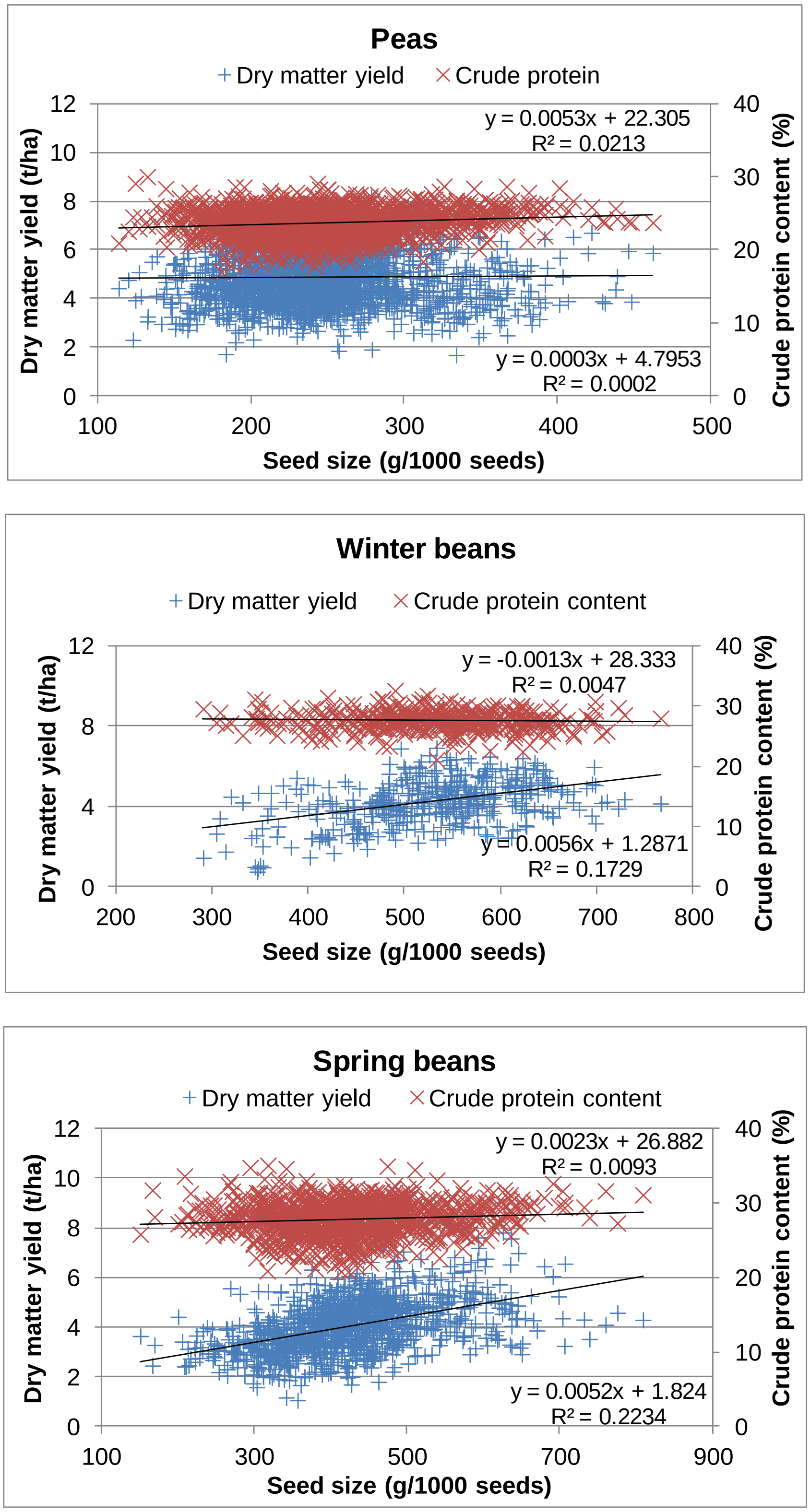

Figure 5. Variation in yield, crude protein content and seed size recorded for samples of peas, (2,322) winter beans (416) and spring beans (1,125) grown in Recommended List variety trials.

For peas the range of crude protein contents expressed by this set of varieties (5.2) was somewhat larger than the range observed for the Green Pig peas (4.2) but the smaller sets of faba beans were directly comparable with the Green Pig bean sets.

For peas no indications of relationships between yield, seed size and protein content were observed were observed. In the case of both winter and spring beans the relationship between seed size and protein was very flat but both crops indicated trends towards higher grain size with higher yields which were significant at the 1.0% confidence level.

Discussion

It has become evident that while crude protein content of both peas and beans shows a small but statistically significant variation between varieties, sites, replicates and years, the amino acid composition of the protein is very stable, as evidenced by Tables 4 and 10, for peas and faba beans respectively. The composition of the varieties investigated showed a high level of conformity with guide values published for compound feed mixtures, with both winter and spring beans having higher crude protein contents than peas. Both crop species had similar sub-optimal ratios of lysine to cystine, methionine, threonine and tryptophan, requiring the balancing of rations with other feedstuffs or by the use of synthetic amino acids. There was no evidence of significant genetic variation in amino acid composition of the crude protein and small observed differences could be related to differences in crude protein content of the samples.

Variation in protein content can be attributed to a number of sources which can now be quantified as a result of this study. Of the varieties properly replicated within the study and present for two or more harvest years, the differences between highest and lowest crude protein contents, for peas, winter beans and respectively, were 2.63%, 1.95% and 2.59%CP. These figures are likely to be the best overall guide to variability of protein content, as they include annual site-to-site variation (peas - 2.14%, winter beans – 2.17%, spring beans - 1.63%CP) and replicate variation (peas – 2.33%; winter beans – 2.44%; spring beans – 1.35%CP. Annual variation was in the order of 1% for peas, 2% for winter beans and 1.5% for spring beans.

The relatively large replicate-to-replicate variation in crude protein was surprising but there are two likely sources - variable crop growth across the trial site and carry-over of grain from one plot to another during harvest resulting in sample contamination.

Variable growth can affect grain size and the relative contribution of the seed coat to overall seed weight. However, analysis of the historic data sets for yield, grain size and crude protein content (Figure 5 and Appendix 5) showed that, while there is a relationship between high yield and large grain size (in beans but not in peas),there is evidence of a strong relationship between grain size and crude protein content. Protein content can be influenced by of nitrogen (Sosulski et al., 1974; Igbasan et al. 1996) and phosphate fertilisers (Sosulski et al., 1974). While nitrogen fertilisers are not applied to pulse crops in the UK, it is possible that residual N from preceding crops and patchy distribution of other nutrients might be influencing trials on some of the less uniform soil types. Similarly soil moisture availability can vary across trial sites and affect crop growth. It is likely that both variation in background soil fertility and local weather patterns contribute to both the site-to-site and annual variation in crude protein content that was observed during the course of the Green Pig study.

In-site, replicate-to-replicate variability may also be explained by localised variation in soil fertility across trial sites but a second cause of variation between replicated plot samples is contamination with grain from preceding plots during the harvest operation. Despite major improvements in the design of plot combine harvesters, plot-to-plot grain carry-over remains problematic in trials and is more conspicuous in pea trials than with other crop species because of different seed coat colours. This problem was minimised for the Green Pig project by using only trials which, after sample inspection, were deemed to show a high level of purity and by picking over the selected samples to remove obvious admixtures.

While it is beyond the scope of this study to explore the causes of the replicate variation observed in the Green Pig analyses, the work has highlighted the importance of using either replicated samples or well mixed bulked samples from different replicates, for future investigations.

In relation to the concerns raised over the accuracy of NIRS compared with wet chemistry analytical methods, some inconsistencies were identified, specifically with respect to the values for cystine and methionine, where correlations between the two methods were non-significant. Overall, the NIRS method was found to slightly underestimate the values obtained from wet chemistry. At project group meetings this discrepancy was discussed by representatives of feed companies and was generally acceptable for the needs of their formulations.

Conclusions

From the analysis of variety grain samples of dry peas and faba beans, conducted as part of the Green Pig Project, we conclude that the variation in amino acid protein composition of these crops is so small that variety choice should not impact on nutritional quality. Equally it was not possible to identify any varieties with sufficiently unique composition that might be useful in developing a breeding program targeted at further nutritional improvement.

However, crude protein content itself varied sufficiently over varieties, sites, seasons and replicates to suggest that routine testing of harvest loads received at feed mills is essential, to optimise feed mixes. The study has also highlighted the importance of testing well mixed, representative bulked samples from trial replicates or, preferable, testing of replicates separately.

Where crops are grown specifically for animal feed markets, protein production can be maximised through variety choice, assuming the availability of information on protein content from independent trials. The crude protein analysis obtained for varieties during the course of the project and the planned resumption of routine testing within the Recommended List program will help growers in this respect. This does not necessarily address the current reality, where the majority of growers are thought to target premium value, niche markets, for human consumption or pet food, for which grain appearance, rather than nutritional value, has an overriding importance. It is also necessary for growers to balance grain quality attributes of varieties against yield, field characters and disease resistance in order to optimise the opportunities for successful harvests and maximal gross margins.

Acknowledgements

We would like to thank PGRO for access to harvest samples from Recommended List trials for peas and beans and to local trial teams for supplying the samples requested.

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Appendices

Appendix 1. Annual sampling matrix 2008-2010

Variety identity		Crop	Type	Sample numbers			
AFP	Variety name			2008	2009	2010	**Totals**
84/330	Nitouche	Peas	Large blue	5	5		**10**
84/395	Samson	Peas	Marrowfat	5			**5**
84/402	Venture	Peas	Large blue	5			**5**
84/494	Kahuna	Peas	Marrowfat	5			**5**
84/529	Bilbo	Peas	White	5			**5**
84/549	Rocket	Peas	White	5			**5**
84/558	Paris	Peas	Large blue	5			**5**
84/562	Prophet	Peas	Large blue	5	15	11	**31**
84/569	Mascara	Peas	White	5	15	11	**31**
84/570	Ragtime	Peas	White	5	5	5	**15**
84/576	Genki	Peas	Marrowfat	5			**5**
84/584	Falstaff	Peas	Marrowfat	5			**5**
84/589	Crackerjack	Peas	Large blue	5	5	5	**15**
84/591	Sakura	Peas	Marrowfat	5			**5**
84/594	Bluemoon	Peas	Large blue	5	5		**10**
84/601	Raptor	Peas	Large blue	5			**5**
84/602	Respect	Peas	White	5	5	5	**15**
84/607	Gregor	Peas	White	5	5	5	**15**
84/610	Aviso	Peas	White	5	5		**10**
84/613	Tonga	Peas	White	5			**5**
84/619	Madras	Peas	Large blue		5	5	**10**
84/625	Bluestar	Peas	Large blue		5	5	**10**
84/626	Daytona	Peas	Large blue		5	5	**10**
84/629	Franklin	Peas	White			5	**5**
84/638	Salamanca	Peas	White			5	**5**
Extras	S04 H088	Peas	White		2		**2**
Extras	CDC Bronco	Peas	White		2		**2**
Extras	CDC Meadow	Peas	White		2		**2**
Extras	Cutlass	Peas	White		2		**2**
Extras	CDC Golden	Peas	White		2		**2**
Extras	CDC Centennial	Peas	White		2		**2**
Extras	CDC Handel	Peas	White		2		**2**
Extras	CDC Mozart	Peas	White		2		**2**
Extras	CDC Minuet	Peas	White		2		**2**
33/164	Clipper	Winter Beans	Black hilum	5	3	5	**13**
33/201	Wizard	Winter Beans	Pale hilum	5	12	9	**26**
33/211	Griffin	Winter Beans	Pale hilum	5			**5**
33/220	Arthur	Winter Beans	Black hilum	5	3	4	**12**
33/231	Husky	Winter Beans	Pale hilum	5	3	5	**13**
33/234	Sultan	Winter Beans	Pale hilum	5	3	5	**13**
Extras	Silver	Winter Beans	Low tannin		1		**1**
Extras	Gladys	Winter Beans	Low tannin		1		**1**
33/203	Syncro	Spring Beans	Pale hilum	5			**5**
33/213	Fuego	Spring Beans	Pale hilum	5	15	15	**35**
33/214	Ben	Spring Beans	Pale hilum	5	5		**10**
33/227	Memphis	Spring Beans	Pale hilum	5	5		**10**
33/229	Betty	Spring Beans	Pale hilum	5	5		**10**
33/235	Tattoo	Spring Beans	Pale hilum	5	5	15	**25**
33/236	Nemo	Spring Beans	?	5			**5**
33/241	Fury	Spring Beans	Pale hilum		4	4	**8**
33/243	Atlas	Spring Beans	?		5		**5**
33/244	Pyramid	Spring Beans	Pale hilum		5	4	**9**
33/247	Babylon	Spring Beans	Pale hilum			4	**4**
Extras	Lady	Spring Beans	Pale hilum		1		**1**
Extras	Mandolin	Spring Beans	Pale hilum		1		**1**
			Annual totals	**165**	**175**	**137**	**477**

Appendix 2. Sampling sites for peas and beans, 2008-2010

Peas			
Location	2008	2009	2010
NIAB, Hampshire	1	2	3
PGRO, Cambridegshire	2	5	5
Advanta, Norfolk	3	1	2
SACS, Essex	4	4	
NIAB, Kent	5		1
NIAB, Herefordshire		3	4
Winter beans			
NIAB, Cambridgeshire	1	4	2
NIAB, Yorkshire	2	3	3
PGRO, Cambridgeshire	3		
NIAB, Herefordshire	4	1	1
NIAB, Kent	5	2	4
PGRO Lincolnshire			5
Spring beans			
NIAB, Herefordshire	1	1	2
NIAB, Kent	2	2	3
PGRO, Cambridgeshire	3	4	
NIAB, Northumberland	4		
NIAB, Cambridgeshire	5	5	1
NIAB, Yorkshire		3	
PGRO, Norfolk			4
PGRO, Oxfordshire			5

Appendix 3. Annual variation in crude protein and amino acid composition of peas

Annual mean data for crude protein and amino acid analysis for 6 grain pea varieties, 2008-2010

	Crude protein			Argenine			Cystine		
Var.Year	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Crackerjack	20.67	20.79	19.74	1.78	1.74	1.59	0.30	0.29	0.30
Gregor	21.37	21.71	19.98	1.90	1.85	1.61	0.30	0.30	0.30
Mascara	19.83	19.80	18.76	1.61	1.57	1.44	0.29	0.29	0.29
Prophet	19.81	19.73	18.52	1.58	1.55	1.41	0.30	0.29	0.29
Ragtime	20.51	21.22	20.24	1.66	1.70	1.57	0.29	0.30	0.30
Respect	20.17	20.12	19.41	1.71	1.63	1.54	0.29	0.29	0.29
Mean	**20.39**	**20.56**	**19.44**	**1.71**	**1.68**	**1.53**	**0.29**	**0.29**	**0.29**
LSD	1.35			0.17			0.01		

	Histidine			Isoleucine			Leucine		
	2008	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Crackerjack	0.50	0.50	0.48	0.86	0.87	0.82	1.48	1.50	1.42
Gregor	0.53	0.53	0.49	0.89	0.89	0.83	1.53	1.55	1.44
Mascara	0.50	0.49	0.47	0.84	0.83	0.80	1.44	1.44	1.37
Prophet	0.49	0.47	0.46	0.84	0.84	0.79	1.43	1.44	1.34
Ragtime	0.51	0.51	0.50	0.86	0.88	0.84	1.50	1.54	1.46
Respect	0.50	0.49	0.49	0.84	0.85	0.81	1.44	1.46	1.39
Mean	**0.51**	**0.50**	**0.48**	**0.85**	**0.86**	**0.81**	**1.47**	**1.49**	**1.40**
LSD	0.03			0.04			0.08		

	Lysine			Methionine			Methionine + Cystine		
	2008	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Crackerjack	1.50	1.52	1.43	0.19	0.19	0.19	0.48	0.48	0.49
Gregor	1.54	1.56	1.45	0.19	0.20	0.19	0.48	0.49	0.49
Mascara	1.46	1.47	1.39	0.18	0.19	0.19	0.47	0.47	0.47
Prophet	1.46	1.47	1.38	0.19	0.19	0.19	0.48	0.48	0.48
Ragtime	1.51	1.55	1.47	0.19	0.20	0.19	0.48	0.49	0.49
Respect	1.46	1.49	1.41	0.18	0.19	0.19	0.47	0.48	0.48
Mean	**1.49**	**1.51**	**1.42**	**0.19**	**0.19**	**0.19**	**0.48**	**0.48**	**0.48**
LSD	0.07			0.01			0.01		

	Phenylalinine			Threonine			Tryptophan		
	2008	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Crackerjack	0.99	1.02	0.96	0.79	0.78	0.75	0.20	0.20	0.19
Gregor	1.03	1.05	0.96	0.81	0.80	0.75	0.20	0.20	0.19
Mascara	0.97	0.97	0.93	0.77	0.76	0.73	0.19	0.19	0.18
Prophet	0.97	0.97	0.92	0.77	0.76	0.72	0.19	0.19	0.18
Ragtime	1.00	1.03	0.98	0.79	0.80	0.77	0.20	0.20	0.19
Respect	0.97	0.98	0.94	0.77	0.77	0.74	0.19	0.19	0.19
Mean	**0.99**	**1.00**	**0.95**	**0.78**	**0.78**	**0.74**	**0.19**	**0.19**	**0.18**
LSD	0.05			0.03			0.01		

	Valine		
	2008	**2009**	**2010**
Crackerjack	0.97	0.97	0.92
Gregor	1.00	0.99	0.93
Mascara	0.94	0.93	0.90
Prophet	0.94	0.94	0.88
Ragtime	0.97	0.98	0.94
Respect	0.95	0.94	0.91
Mean	**0.96**	**0.96**	**0.92**
LSD	0.05		

Appendix 4: Replicate variation for crude protein and amino acid composition

4a. Variety: MASCARA 2009/2010 harvest years

Mascara 2009

Site	Rep	CP	ARG	CYS	HIS	ILE	LEU	LYS	M+C	MET	PHE	THR	TRP	VAL
1	1	21.1	1.76	0.29	0.51	0.86	1.50	1.51	0.48	0.19	1.01	0.78	0.20	0.97
1	2	20.6	1.72	0.29	0.50	0.85	1.48	1.50	0.47	0.19	1.00	0.78	0.19	0.95
1	3	19.9	1.60	0.29	0.48	0.83	1.44	1.46	0.47	0.19	0.97	0.76	0.19	0.93
3	1	19.4	1.50	0.29	0.48	0.81	1.41	1.44	0.47	0.19	0.95	0.76	0.19	0.91
3	2	20.2	1.62	0.30	0.50	0.84	1.46	1.48	0.48	0.19	0.99	0.77	0.19	0.94
3	3	19.4	1.53	0.29	0.48	0.83	1.42	1.45	0.47	0.19	0.96	0.76	0.19	0.92
4	1	19.9	1.58	0.29	0.51	0.83	1.44	1.46	0.48	0.19	0.97	0.77	0.19	0.93
4	2	19.7	1.51	0.30	0.49	0.84	1.45	1.49	0.48	0.19	0.97	0.77	0.19	0.93
4	3	18.5	1.43	0.29	0.46	0.80	1.37	1.41	0.46	0.18	0.92	0.74	0.18	0.89
5	1	20.8	1.63	0.30	0.50	0.88	1.53	1.55	0.48	0.20	1.03	0.79	0.20	0.97
5	2	20.6	1.68	0.29	0.50	0.86	1.50	1.52	0.47	0.19	1.02	0.78	0.19	0.96
5	3	21.0	1.70	0.30	0.50	0.87	1.51	1.54	0.48	0.20	1.02	0.79	0.20	0.97

Mascara 2010

Site	Rep	CP	ARG	CYS	HIS	ILE	LEU	LYS	M+C	MET	PHE	THR	TRP	VAL
1	1	19.9	1.58	0.30	0.50	0.83	1.43	1.44	0.48	0.19	0.97	0.76	0.19	0.93
1	2	18.9	1.47	0.29	0.47	0.80	1.38	1.40	0.48	0.19	0.93	0.74	0.18	0.90
1	3	19.1	1.44	0.29	0.47	0.81	1.39	1.42	0.48	0.19	0.94	0.74	0.18	0.91
2	1	20.2	1.61	0.29	0.49	0.83	1.45	1.46	0.48	0.19	0.98	0.76	0.19	0.94
2	2	20.5	1.64	0.30	0.50	0.84	1.47	1.48	0.49	0.19	0.99	0.76	0.19	0.95
2	3	20.0	1.61	0.30	0.48	0.84	1.45	1.47	0.49	0.19	0.97	0.75	0.19	0.94
3	1	17.4	1.23	0.28	0.43	0.74	1.27	1.30	0.46	0.18	0.86	0.69	0.17	0.84
3	2	16.7	1.24	0.28	0.44	0.73	1.21	1.28	0.46	0.18	0.84	0.67	*	0.83
3	3	16.9	1.28	0.28	0.44	0.74	1.24	1.30	0.46	0.18	0.86	0.68	*	0.85

4b. Variety: PROPHET 2009/2010 harvest years

Prophet 2009

Site	Rep	CP	ARG	CYS	HIS	ILE	LEU	LYS	M+C	MET	PHE	THR	TRP	VAL
1	1	18.1	1.36	0.28	0.42	0.77	1.32	1.35	0.47	0.19	0.90	0.71	0.17	0.86
1	2	20.6	1.63	0.30	0.49	0.88	1.50	1.54	0.49	0.20	1.01	0.79	0.20	0.97
1	3	19.8	1.59	0.30	0.47	0.85	1.44	1.47	0.49	0.20	0.97	0.76	0.19	0.94
3	1	20.6	1.63	0.30	0.51	0.86	1.48	1.49	0.50	0.20	1.00	0.78	0.19	0.97
3	2	21.1	1.74	0.28	0.55	0.90	1.54	1.51	0.47	0.19	1.01	0.80	*	1.02
3	3	20.2	1.59	0.30	0.49	0.87	1.48	1.49	0.50	0.20	1.00	0.77	0.19	0.96
4	1	19.4	1.51	0.30	0.47	0.84	1.43	1.47	0.49	0.19	0.96	0.77	0.19	0.93
4	2	20.1	1.59	0.30	0.48	0.84	1.45	1.48	0.48	0.19	0.98	0.78	0.19	0.94
4	3	19.1	1.47	0.30	0.46	0.83	1.41	1.45	0.48	0.19	0.95	0.76	0.18	0.92
5	1	19.2	1.54	0.30	0.45	0.83	1.41	1.45	0.48	0.20	0.96	0.75	0.18	0.92
5	2	20.1	1.56	0.29	0.48	0.87	1.48	1.52	0.48	0.19	1.01	0.78	0.19	0.95
5	3	20.0	1.58	0.29	0.47	0.85	1.45	1.49	0.48	0.20	0.99	0.76	0.19	0.94

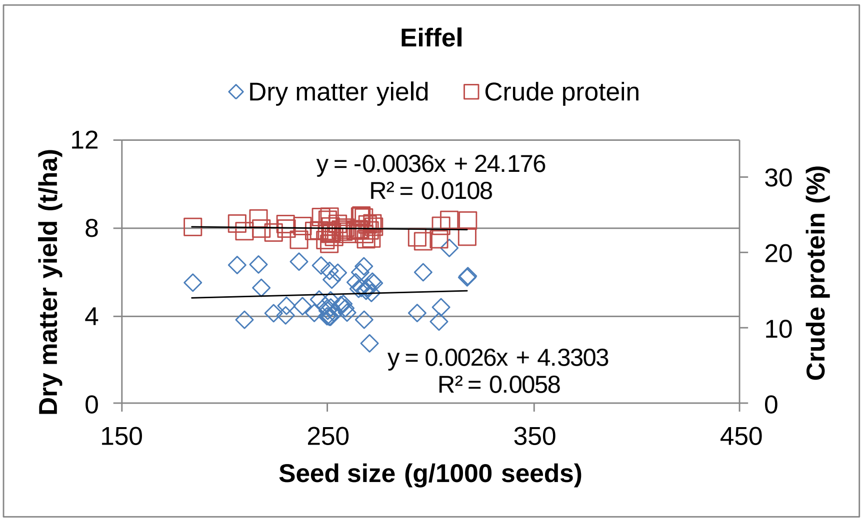
Prophet 2010

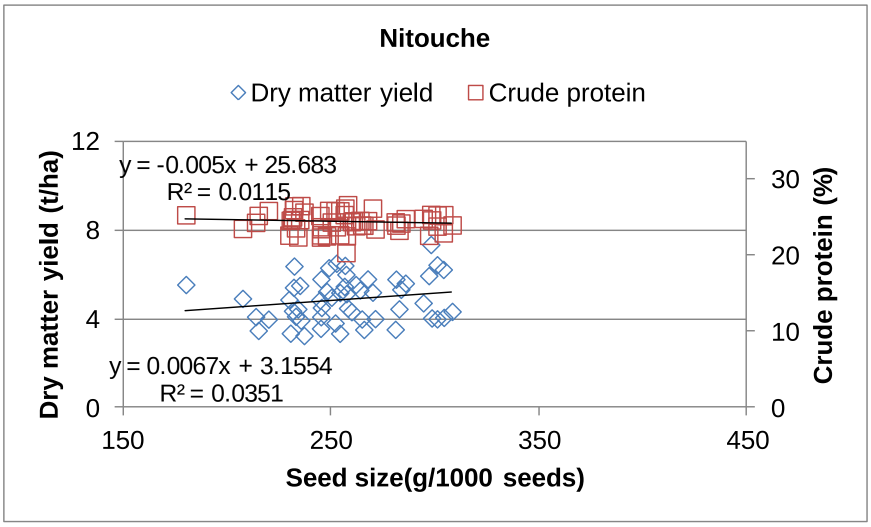
Site	Rep	CP	ARG	CYS	HIS	ILE	LEU	LYS	M+C	MET	PHE	THR	TRP	VAL
1	1	19.0	1.45	0.30	0.46	0.80	1.37	1.41	0.49	0.19	0.92	0.73	0.18	0.90
1	2	19.4	1.50	0.30	0.47	0.81	1.39	1.41	0.49	0.19	0.94	0.75	0.18	0.91
1	3	19.7	1.55	0.30	0.48	0.81	1.40	1.43	0.49	0.19	0.95	0.74	0.18	0.92
2	1	19.1	1.44	0.30	0.45	0.81	1.39	1.42	0.49	0.19	0.94	0.73	0.18	0.91
2	2	20.2	1.59	0.30	0.49	0.84	1.44	1.45	0.50	0.20	0.98	0.75	0.19	0.94
2	3	20.0	1.56	0.29	0.48	0.83	1.43	1.45	0.49	0.19	0.97	0.75	0.19	0.93
3	1	17.2	1.32	0.28	0.45	0.73	1.25	1.30	0.46	0.18	0.87	0.70	*	0.83
3	2	17.1	1.31	0.28	0.45	0.74	1.26	1.30	0.46	0.18	0.88	0.70	*	0.85
3	3	16.9	1.27	0.28	0.45	0.73	1.23	1.28	0.46	0.18	0.85	0.69	*	0.83

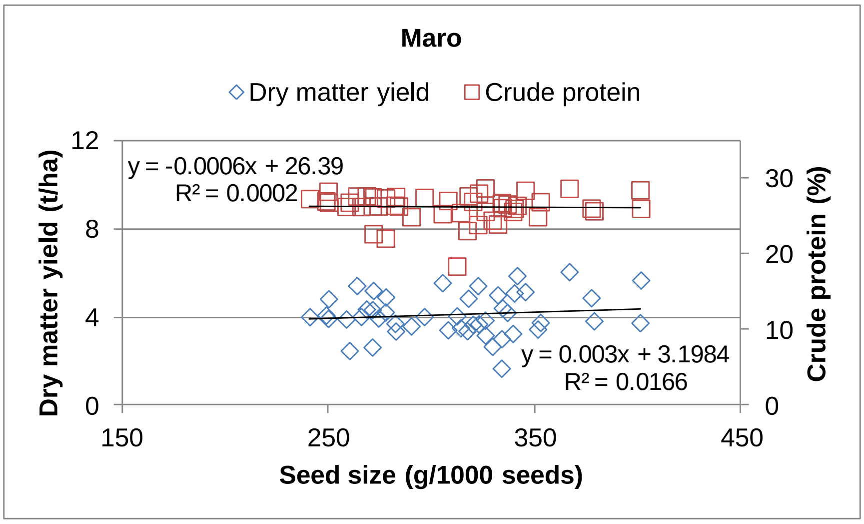
Appendix 5

Historic data illustrating variation in yield, seed size and crude protein content for example varieties of peas and faba beans

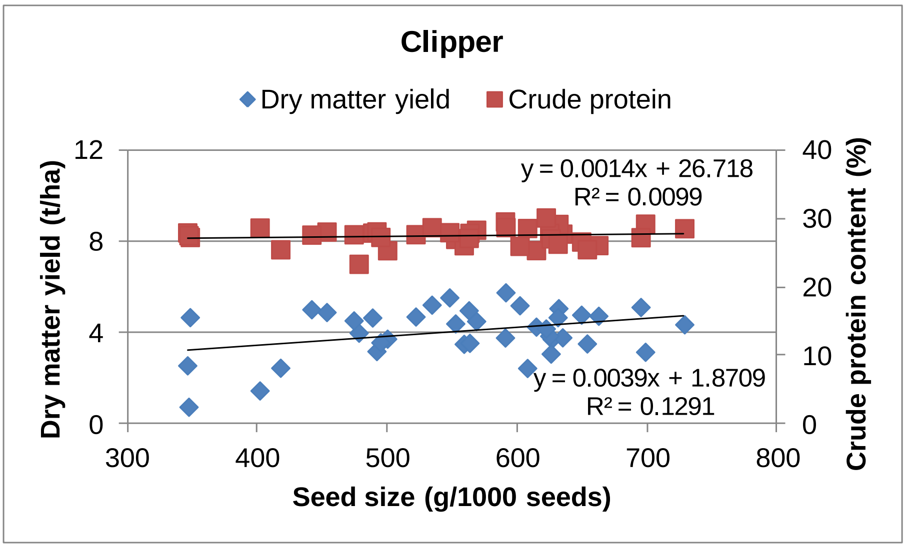
Appendix 5a. Analysis of historic data sets of three pea varieties for relationships between seed size, crude protein content and yield

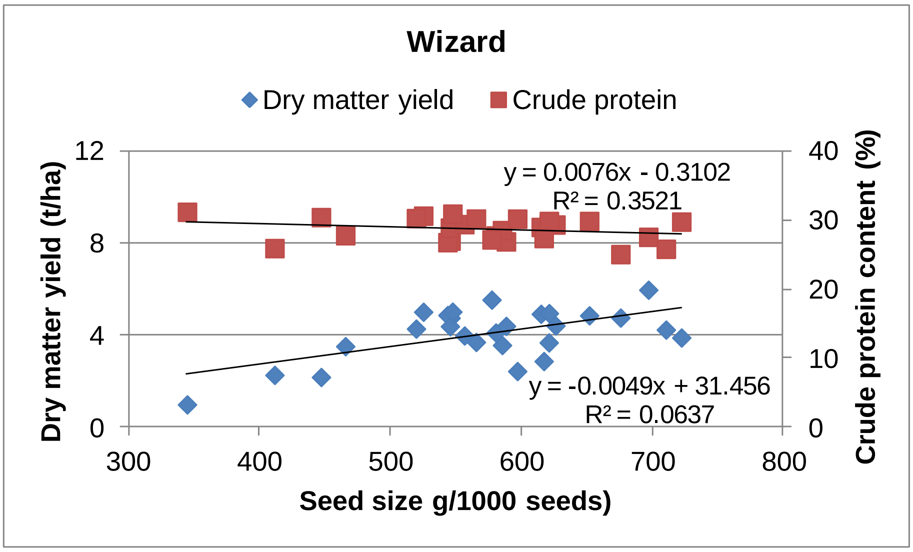


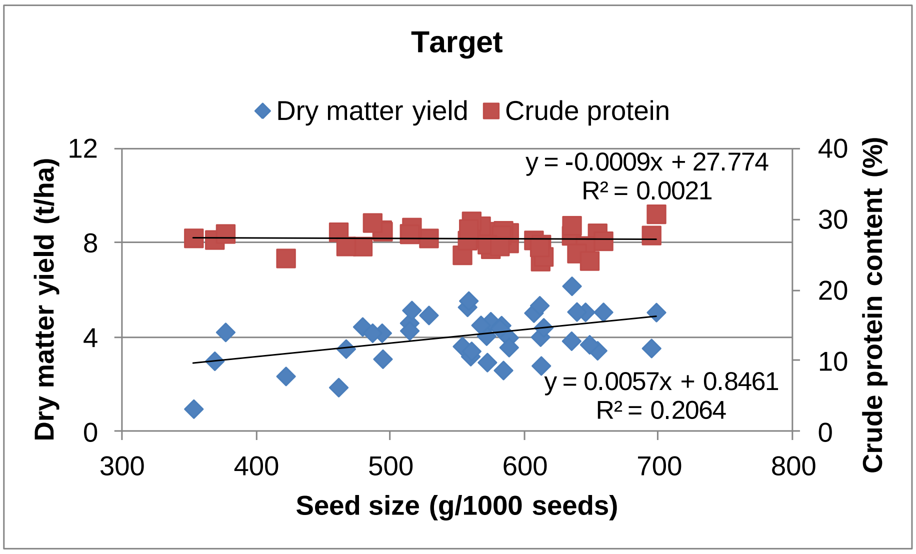



Maro
Dry matter yield
Crude protein
y = -0.0006x + 26.39
R² = 0.0002
y = 0.003x + 3.1984
R² = 0.0166
Dry matter yield (t/ha)
Crude protein (%)
Seed size (g/1000 seeds)
12
8
4
0
30
20
10
0
150
250
350
450

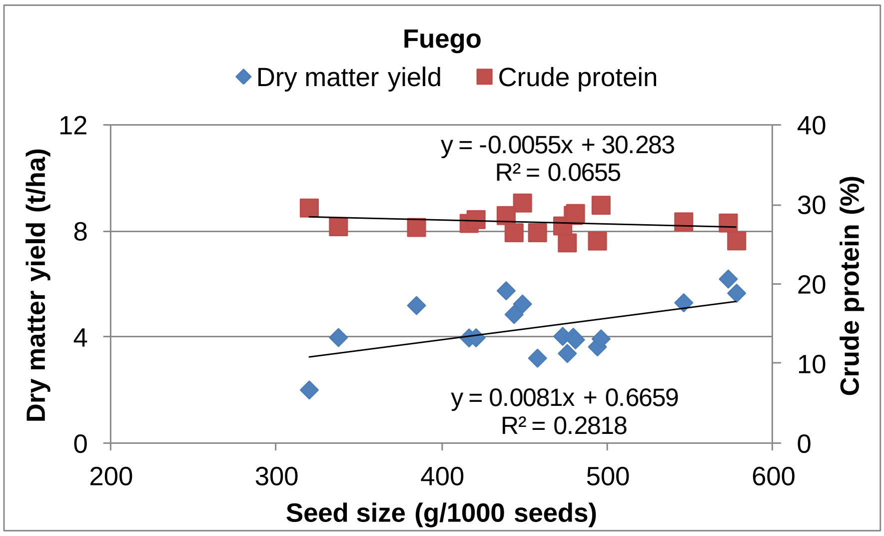
Appendix 5b. Analysis of historic data sets of three winter bean varieties for relationships between seed size, crude protein content and yield

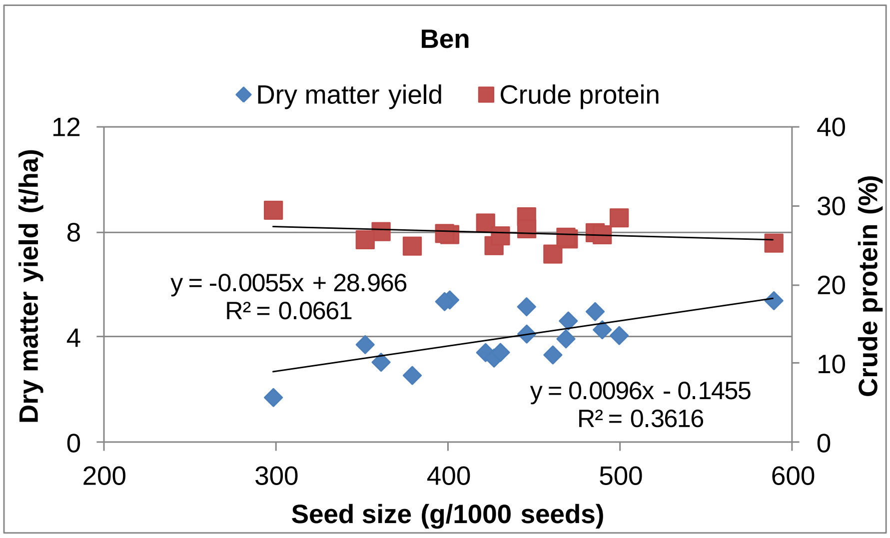


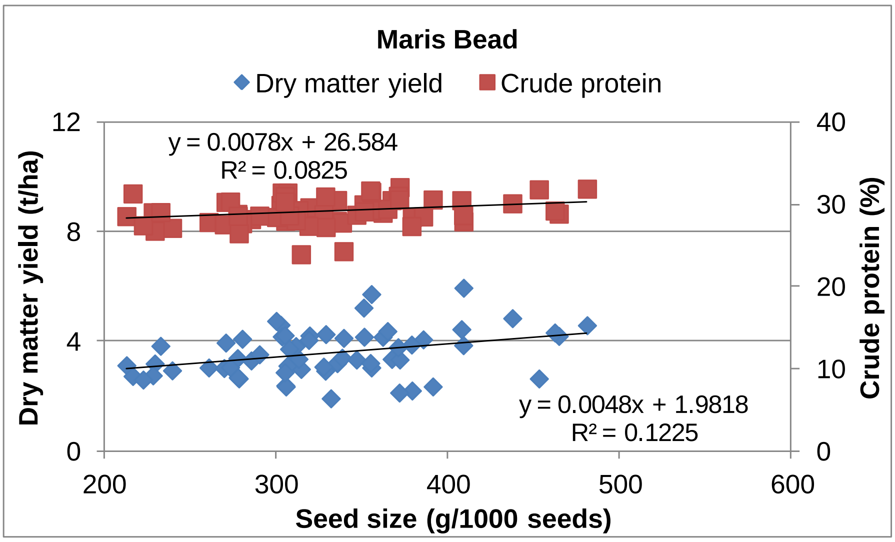




Appendix 5c. Analysis of historic data sets of three spring bean varieties for relationships between seed size, crude protein content and yield




Ben
Dry matter yield
Crude protein
12
8
4
0
40
30
20
10
0
Dry matter yield (t/ha)
Crude protein (%)
y = -0.0055x + 28.966
R² = 0.0661
y = 0.0096x - 0.1455
R² = 0.3616
200
300
400
500
600
Seed size (g/1000 seeds)


Maris Bead
Dry matter yield
Crude protein
12
8
4
0
40
30
20
10
0
Dry matter yield (t/ha)
Crude protein (%)
y = 0.0078x + 26.584
R² = 0.0825
y = 0.0048x + 1.9818
R² = 0.1225
200
300
400
500
600
Seed size (g/1000 seeds)

Appendix 6 Variety mean data for yield, thousand seed weight and crude protein content of peas and beans. Varieties ranked in descending order of crude protein content. Values expressed as percent dry matter *Source: NIAB Classified Lists, 2010*.

Peas

Variety	Yield	Type		Quality	
	(% mean of controls)	Flower colour / Leaf type	Type	1000 g wt @ 15% moisture (g)	Protein content (%)
Agilada	84	SL	LB	221	27.1
Maro	76	N	MF	310	26.6
Rhino	75	SL	MF	295	25.9
Pidgin	77	CF/SL	M	207	25.7
Kahuna	86	SL	MF	316	25.0
Crackerjack	105	SL	LB	256	24.9
Eagle	73	T	MF	271	24.9
Samson	83	SL	MF	352	24.9
Princess	83	SL	MF	294	24.8
Bilbo	100	SL	W	224	24.6
Flare	88	SL	SB	205	24.4
Nitouche	94	SL	LB	252	24.4
Genki	92	SL	MF	373	24.3
Falstaff	90	SL	M	311	24.2
Sakura	93	SL	MF	336	24.2
Rose	93	CF/SL	M	230	24.1
Bluemoon	102	SL	LB	250	23.9
Sunny	102	SL	LB	255	23.9
Swift	71	CF/SL	M	188	23.7
Ragtime	104	SL	W	265	23.6
Backgammon	97	SL	LB	238	23.5
Fiji	90	SL	M	197	23.5
Goblin	101	SL	W	235	23.5
Sioux	96	SL	W	259	23.5
Scuba	85	SL	LB	230	23.4
Orka	84	SL	MF	340	23.2
Paris	101	SL	LB	213	23.2
Eiffel	90	SL	W	257	23.1
Woody	96	SL	LB	262	23.1
Sully	97	SL	W	243	23.0
Mascara	107	SL	W	253	22.9
Venture	97	SL	LB	221	22.9
Cooper	98	SL	LB	248	22.8
Caddy	96	SL	W	253	22.7
Hardy	99	SL	W	245	22.7
Prophet	106	SL	LB	263	22.6
Soprano	95	SL	W	214	22.6
Hawaii	90	SL	SB	208	22.5
Rocket	103	SL	W	221	21.9
			Mean	256.7	23.9

Winter beans

Variety	Yield	Type		Quality	
	Seed yield (% mean of controls)	Flower colour (**C**oloured or **W**hite)	Hilum colour (**B**lack or **P**ale)	Thousand grain wt (g)	Protein content (%)
Wizard	102	C	P	594	28.7
Arthur	104	C	B	564	28.1
Griffin	98	C	B	588	28.1
Husky*	102	C	P	534	28.1
Clipper	98	C	B	559	27.5
Target	98	C	B	563	27.5
Sultan*	104	C	P	499	26.7
Striker	92	C	B	519	26.6
			Mean	552.7	27.7

Spring beans

Variety	Seed yield (% mean of controls)	Flower colour	Hilum colour	Thousand grain wt (g)	Protein content (%)
Paloma	84	W	B	450	30.9
Titch	75	C	B	310	29.5
Oena	96	C	B	398	29.4
Maris Bead	78	C	B	333	29.3
Alpine	82	W	B	452	28.9
Betty	98	C	P	442	28.9
Scirocco	89	C	B	420	28.2
Syncro	96	C	P	463	28.2
Memphis	98	C	P	488	28.1
Quattro	94	C	P	462	28.1
Fuego	105	C	P	483	27.9
Nile	92	C	P	445	27.8
Mars	92	C	B	437	27.6
Meli	97	C	B	481	27.6
Hobbit	97	C	B	523	27.5
Compass	92	C	P	468	27.3
Victor	87	C	P	442	27.1
Ben	97	C	P	454	26.8
			Mean	441.7	28.3

Full report Objective 3b: Overcoming constraints. Analysis of variation in anti-nutritional factor levels and amino acid digestibility in broilers.

Lead authors: Julian Wiseman, Nell Masey O'Neill, Gavin White (UoN), Meike Rademacher (Evonik-Degussa), Simon Kightley (NIAB)

(Note that data from 2008 and 2009 harvests have been published, see Appendix)

Executive summary

- Three experiments were conducted to evaluate samples of peas and faba beans for their standardised ileal digestibility (SID) of amino acids determined with young broiler chicks. Experiment One (2008 harvest) evaluated six faba bean and seven pea cultivars, Experiment Two (2009 harvest) evaluated two faba bean and three pea cultivars as well as a sample of soya bean meal provided as a reference material and Experiment Three (2010 harvest) evaluated three pea and two bean cultivars.
- Peas and beans were added at 750g/kg as the only source of protein / amino acids in a semi-synthetic diet containing the inert marker titanium dioxide; soya bean meal (SBM) was added, in a control diet, at 500g/kg.
- Each diet was fed to six replicates of a cage containing two Ross-type broilers for 96 hrs at which point birds were culled allowing removal of ileal digesta. Chemical analyses allowed the calculation of the coefficient of SID of amino acids.
- There were no differences between samples of the same pulse species but peas had higher values, similar to SBM, than beans. Data for crude protein digestibility and SID amino acids indicated that samples from 2010 were better.
- Trypsin inhibitor content (expressed as g trypsin inhibitor units /mg sample; TIU) of pea samples was low and in the range 0.83 – 2.50 mg/kg (below the feed industry accepted maximum of 4.00). There was relatively little variation in bean tannin content and composition amongst the coloured-flowered varieties in 2008 and 2009; however the white-flowered cultivar had no tannins. There was no correlation between tannin content and coefficient of SID.
- In conclusion, the cultivars of peas and field beans evaluated indicate that UK-grown legumes are valuable in poultry diets and should inform further work into their use as an alternative to other protein sources.

Introduction

A detailed introduction to the subject is presented in the attached published paper. The overall conclusions from the literature is that it is debateable whether or not digestibility of CP and AA from peas and faba beans are comparable to more commonly used protein sources, such as soya bean meal.

The aim of the current series of experiments was to investigate the variation in coefficient of SID of CP and AA in broilers of UK-grown legumes and compare the values to those of soya bean meal. The hypotheses tested were that variability within legume species was minimal and that data collected would allow greater confidence in their use.

Method and Materials

A number of home-grown legumes were obtained for evaluation as detailed in Table 1A. Composition is presented in Table 1B; crude protein was determined as N*6.25 and amino acid content by NIR.

Experimental diets were formulated using the ingredients described in Table 2 with legume as the only variable. All diets were manufactured on site at the University of Nottingham, Sutton Bonington Campus. Legumes were ground using a Pulverisette 15 cutting mill (Fritsch GmbH, Idar-Oberstein, Germany) fitted with a 4mm screen and then mixed using a commercial planetary dough mixer.

Day-old, male, Ross strain broilers were sourced and housed in pairs, within 10 g in weight (at 13-days) of each other. Each treatment was fed to 6 replicate cages of two birds per cage. Prior to the adaptation and trial period chicks were fed Chick Starter Crumb (Dodson and Horrell Ltd, Northamptonshire, UK). At day 19 the birds began a 4 day adaptation period, where they were fed the assigned trial diet. The trial period then took place between days 23 and 27, a total of 96 hours. During this time, feed intake was measured and excreta collected. At all times, feed and water were provided on an *ad libitum* basis. The birds were culled on day 28 of the bioassay by asphyxiation with carbon dioxide and cervical dislocation to confirm death. The ileal region of the gut was dissected out from the Meckel's diverticulum to the ileal-caecal junction.

The coefficient of apparent ileal digestibility (AID) of crude protein (CP) and amino acids (AA) in the assay diets were calculated according to equation (1):

$AID_I = 100\% - [((I_D \times A_F)/(A_D \times I_F)) \times 100\%]$; (1)

where AID_I=AID of CP or AA in the assay ingredient (%), I_D=marker concentration in the assay diet (g/kg DM), A_F=nutrient concentration in ileal digesta (g/kg DM), A_D=nutrient concentration in the assay diet (g/kg DM) and I_F=marker concentration in ileal digesta (g/kg DM).

The standard ileal digestibility (SID) of CP and AA in the assay diets were calculated by correcting AID of CP and AA for basal ileal endogenous CP and AA losses (IAALB), expressed as g/kg DM intake (DMI). The mean AA composition of basal endogenous protein (g/16 g N) was estimated as 3.9 for isoleucine, 3.8 for leucine, 2.6 for lysine, 0.8 for methionine, 1.7 for cystine, 2.5 for Met+Cys, 2.4 for phenylalanine, 5.7 for threonine, 0.8 for tryptophan, 4.5 for valine, 2.2 for arginine and 2.1 for histidine (Lemme et al., 2004)

The SID of CP and AA in the assay ingredients were obtained according to equation (2):

$SID_I = AID_I + [(IAALB/AA_I) \times 100\%]$; (2)

where SID_I=SID of CP or AA in the assay ingredients (%), AID_I=AID of CP or AA in the assay ingredients (%), IAALB=basal ileal endogenous CP or AA losses (g/kg DMI) and AA_I=CP or AA concentration in the assay ingredients (g/kg DM).

The ANOVA model was a simple factorial approach.

Results and Discussion

The data for CP confirm that beans have higher levels than peas, with the latter also being more variable. Trypsin inhibitor activity data for peas were all lower than the accepted feed industry maximum of 4.00 mgTIU/g.

SID data for CP and AA are presented in Table 3, 4 and 5 respectively for 2008, 2009 and 2010 harvests. For 2008, in all cases (except SID of leucine) peas had better SID of CP and AA than faba beans ($P<0.001$). Within species the only effect of cultivar on SID of CP was seen in beans, with Arthur and Wizard having increased SID compared to three of the four other cultivars ($P<0.05$). Within species, the only effect of cultivar on SID of AA was for leucine, in peas, where Venture and Kahuna had increased SID compared to three of the five other cultivars.

For 2009, in all cases (except SID of lysine and leucine) the mean SID of CP and AA was greater in peas than beans ($P<0.05$). Soya bean meal was intermediate, in all cases being greater ($P<0.05$) than or equivalent to the value for beans, and equivalent to or less than for peas. At no point was the SID for soya bean meal superior ($P>0.05$) to that of peas. Within species, the only effect of cultivar on SID of CP was seen in beans, with Tattoo having increased SID compared to Betty ($P<0.05$).

For 2010 in all cases (except threonine) mean SID for CP and AA was greater in peas than beans; there was no effect of variety.

All pea cultivars had very low levels of trypsin inhibitor activity and, accordingly, no correlations with SID were obtained. Tannin analyses (see attached paper) are very much more complex and it is difficult to identify one specific fraction that is of nutritional relevance. In any event, the white-flowered variety Tattoo was not superior to coloured-flowered cultivars confirming earlier work that flower colour may not be of nutritional significance.

Inter-year comparisons are presented in Figures 1, 2, 3 and 4 respectively for CP, lysine, methionine + cystine and threonine. There are no definite trends other than the suggestion that 2010 gave higher SID data than previous years.

Table 1A. Description of legume cultivars used in experiments one (2008 harvest), two (2009 harvest) and 3 (2010 harvest). A sample of hipro soya bean meal was obtained as a comparator for home grown legumes harvested in 2009

Species	Variety	Description	Flower	Experiment
Pea	Bilbo	White field pea	White	1
	Genki	Marrowfat field pea	White	1
	Gregor	White field pea	White	2, 3
	Kahuna	Marrowfat field pea	White	1
	Mascara	White field pea	White	1, 2, 3
	Nitouche	Blue field pea	White	1
	Prophet	Blue field pea	White	1, 2, 3
	Venture	Blue field pea	White	1
Bean	Arthur	Black hilum winter bean	Coloured	1
	Ben	Pale hilum spring bean	Coloured	1
	Betty	Pale hilum spring bean	Coloured	2
	Clipper	Black hilum winter bean	Coloured	1
	Fuego	Pale hilum spring bean	Coloured	1, 3
	Tattoo	Pale hilum spring bean, low tannin	White	1, 2, 3
	Wizard	Pale hilum winter bean	Coloured	1
SBM				2

Table 1B. Trypsin inhibitor activity (mg/g), crude protein and amino acid (g/kg DM) content of legumes evaluated in Experiment 3.

Species		TIU	CP	Met	Cys	M+C	Lys	Thr	Arg	Ile	Leu	Val	His	Phe	Gly	Ser	Pro	Ala	Asp	Glu
Pea	Gregor	1.99	234.3	2.1	3.2	5.3	16.0	8.8	20.6	9.1	16.4	10.2	5.8	10.9	10.1	11.2	9.3	9.9	26.5	37.9
	Mascara	2.50	214.3	2.0	3.0	5.0	15.2	8.2	17.6	8.7	15.4	9.8	5.5	10.3	9.6	10.3	8.9	9.4	24.3	35.4
	Prophet	2.23	217.0	2.0	3.1	5.1	14.9	8.4	17.6	8.6	15.3	9.7	5.4	10.2	9.6	10.4	8.9	9.6	24.5	34.8
Bean	Fuego		268.7	1.8	3.2	5.0	14.8	9.1	21.8	9.4	18.1	10.5	6.7	10.5	10.9	12.3	10.3	10.5	26.5	40.3
	Tattoo		268.9	1.8	3.3	5.1	15.7	9.2	22.3	10.1	19.0	11.1	6.7	11.0	11.1	12.7	10.6	10.6	28.2	42.3

Table 2. Diet formulation and calculated analysis.

Ingredient (g/kg)	Basal legume diet	Soya bean meal diet[a]
Test pea or bean	750	-
Soya bean meal[b]	-	500
Purified starch (maize)	70	195
Purified glucose	70	195
Soya oil	50	50
Vitamin and mineral premix[c]	50	50
Titanium dioxide	10	10
Crude Protein g/kg[d]	160	248
Apparent Metabolisable Energy MJ/kg[d]	11.4	11.4
Calcium g/kg[d]	8.2	9.0
Available Phosphorus g/kg[d]	6.1	6.0

[a] Experiment two (2009 harvest) only

[b] Harbro Limited, Aberdeenshire, UK; North American origin

[c] Target Feeds, Whitchurch, Shropshire, UK. Content per g of premix: 0.1g phosphorus, 0.017g magnesium, 0.152g calcium, 0.030g sodium, 150 IU vitamin A, 30 IU vitamin D_3, 0.2 IU vitamin E (as α-tocopherol acetate), 0.012mg copper (as copper sulphate), 3.2µg selenium (as selenium BCP).

[d] Estimated for the purposes of dietary design

Table 3. Experiment 1 (2008 harvest): Standardised Ileal Digestibility of Crude Protein and Amino acids

A. Peas

	Bilbo	Genki	Kahuna	Mascara	Nitouche	Prophet	Venture	sed[a]	P
Crude Protein	0.78	0.84	0.79	0.80	0.76	0.77	0.83	0.036	0.178
Lysine	0.85	0.91	0.87	0.87	0.84	0.85	0.89	0.027	0.097
Methionine + Cystine	0.77	0.84	0.79	0.87	0.76	0.77	0.84	0.053	0.263
Threonine	0.78	0.82	0.79	0.81	0.75	0.77	0.81	0.036	0.361
Tryptophan	0.77	0.83	0.76	0.79	0.76	0.76	0.81	0.035	0.208
Isoleucinecine	0.77	0.86	0.80	0.81	0.76	0.78	0.84	0.039	0.076
Leucine	0.78[z]	0.86[y]	0.80[y,z]	0.81[y,z]	0.77[z]	0.78[y]	0.85[y]	0.042	0.005
Valine	0.77	0.84	0.80	0.80	0.76	0.77	0.83	0.037	0.146
Histidine	0.83	0.88	0.85	0.85	0.82	0.83	0.87	0.031	0.242
Arginine	0.88	0.93	0.89	0.88	0.87	0.86	0.91	0.025	0.132
Phenylalanine	0.77	0.85	0.80	0.80	0.75	0.77	0.84	0.037	0.055

Table 3 continued

B. Beans, Species

	Arthur	Ben	Clipper	Fuego	Tattoo	Wizard			Species			
							sed[a]	P	Peas	Beans	sed[a]	P
Crude Protein	0.76[x]	0.71[x,z]	0.68[y,z]	0.69[y,z]	0.69[y,z]	0.76[x]	0.032	0.049	0.79[v]	0.72[w]	0.014	<0.001
Lysine	0.80	0.81	0.79	0.79	0.80	0.85	0.030	0.359	0.87[v]	0.78[w]	0.011	<0.001
Methionine + Cystine	0.56	0.59	0.58	0.57	0.62	0.62	0.041	0.538	0.77[v]	0.59[w]	0.015	<0.001
Threonine	0.70	0.71	0.68	0.70	0.69	0.75	0.036	0.462	0.79[v]	0.71[w]	0.014	<0.001
Tryptophan	0.63	0.62	0.63	0.65	0.66	0.71	0.041	0.337	0.78[v]	0.65[w]	0.015	<0.001
Isoleucinecine	0.71	0.70	0.69	0.70	0.69	0.76	0.041	0.448	0.80[v]	0.71[w]	0.016	<0.001
Leucine	0.73	0.72	0.70	0.71	0.71	0.79	0.040	0.333	0.74	0.73	0.017	<0.001
Valine	0.71	0.70	0.69	0.70	0.70	0.77	0.038	0.409	0.80[v]	0.71[w]	0.015	<0.001
Histidine	0.75	0.76	0.74	0.75	0.76	0.81	0.031	0.329	0.85[v]	0.76[w]	0.012	<0.001
Arginine	0.82	0.81	0.80	0.81	0.81	0.87	0.028	0.130	0.89[v]	0.82[w]	0.011	<0.001
Phenylalanine	0.73	0.71	0.70	0.71	0.70	0.78	0.037	0.257	0.80[v]	0.72[w]	0.015	<0.001

[a] sed = Standard error of the difference

[x,y,z] Means within a row, within species, with different superscripts vary

[v,w] Means within a row, between species, with different superscripts vary

Table 4. Experiment 2 (2009 harvest): Standardised Ileal Digestibility of Crude Protein and Amino acids

	Peas					Beans				Species				
	Gregor	Mascara	Prophet	Sed[a]	P	Betty	Tattoo	sed[a]	P	Peas	Beans	SBM	Sed[a]	P
CP	0.90	0.91	0.89	0.035	0.815	0.81^{y}	0.85^{z}	0.018	0.04	0.90^{w}	0.83^{x}	0.83^{x}	0.027	<0.001
Lysine	0.84	0.85	0.90	0.049	0.365	0.76	0.82	0.044	0.167	0.87	0.79	0.84	0.047	0.054
Methionine + Cystine	0.72	0.74	0.81	0.064	0.408	0.51	0.62	0.074	0.168	0.76^{x}	0.57^{w}	0.76^{x}	0.069	<0.001
Threonine	0.76	0.75	0.83	0.061	0.355	0.64	0.70	0.049	0.191	0.78^{w}	0.67^{x}	$0.78^{w,x}$	0.059	0.016
Isoleucinecine	0.75	0.77	0.85	0.068	0.274	0.65	0.74	0.059	0.132	0.80^{w}	0.69^{x}	$0.81^{w,x}$	0.063	0.034
Leucine	0.76	0.78	0.86	0.066	0.280	0.68	0.75	0.057	0.193	0.80	0.72	0.81	0.060	0.079
Valine	0.75	0.77	0.85	0.066	0.282	0.65	0.73	0.057	0.198	0.79^{w}	0.69^{x}	$0.80^{w,x}$	0.061	0.026
Histidine	0.83	0.85	0.90	0.048	0.260	0.74	0.81	0.051	0.202	0.86^{w}	0.78^{x}	$0.84^{w,x}$	0.048	0.029
Arginine	0.87	0.87	0.92	0.042	0.341	0.80	0.84	0.042	0.294	0.89^{w}	0.82^{x}	$0.86^{w,x}$	0.039	0.047
Phenylalanine	0.78	0.79	0.87	0.063	0.309	0.68	0.75	0.054	0.244	0.81^{w}	0.72^{x}	$0.82^{w,x}$	0.057	0.032

[a]sed = Standard error of the difference

[b]Soya Bean Meal

[y,z] Means within a row, within species, with different superscripts vary

[w,x] Means within a row, within **or** between species, with different superscripts vary ($P<0.05$)

Table 5. Experiment 3 (2010 harvest). Standardised Ileal Digestibility of Crude Protein and Amino acids

	Peas			Beans				
Item	Gregor	Mascara	Prophet	Tattoo	Fuego	SED	CV%	P
CP	0.91	0.89	0.88	0.75	0.82	0.025	5.1	<0.001
Arginine	0.90	0.91	0.92	0.88	0.88	0.010	2.0	0.002
Cystine	0.84	0.85	0.85	0.79	0.74	0.010	2.0	<0.001
Histidine	0.87	0.89	0.89	0.85	0.85	0.011	2.1	<0.001
Leucine	0.85	0.87	0.87	0.83	0.83	0.014	2.8	0.011
Lysine	0.90	0.91	0.92	0.88	0.89	0.011	2.1	0.019
Methionine	0.86	0.89	0.89	0.83	0.80	0.015	3.1	<0.001
Methionine + Cystine	0.82	0.85	0.83	0.77	0.73	0.010	2.2	<0.001
Phenylalanine	0.85	0.87	0.87	0.83	0.82	0.027	1.3	0.004
Threonine	0.81	0.83	0.83	0.81	0.79	0.010	2.2	0.006
Valine	0.83	0.85	0.85	0.82	0.81	0.013	2.7	0.024

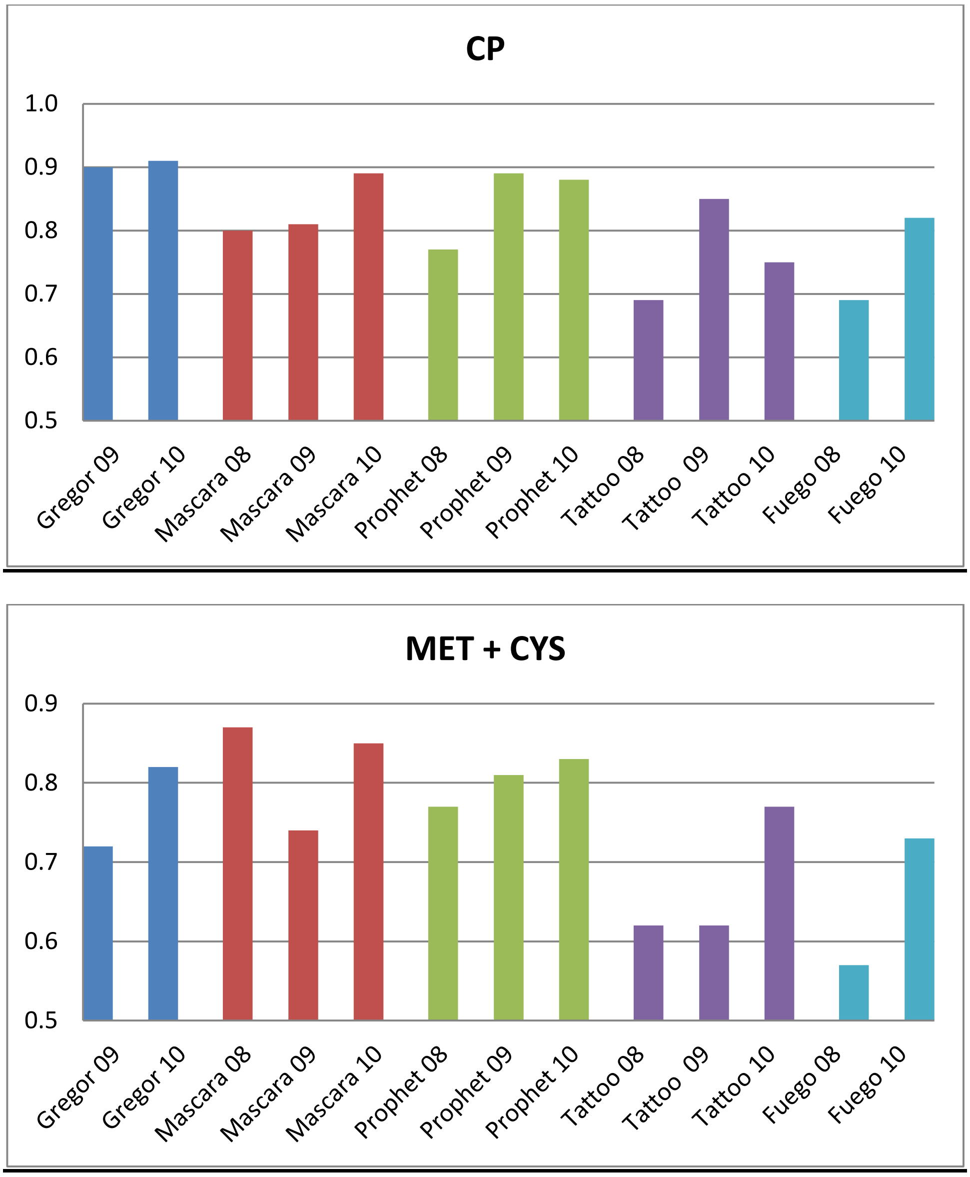
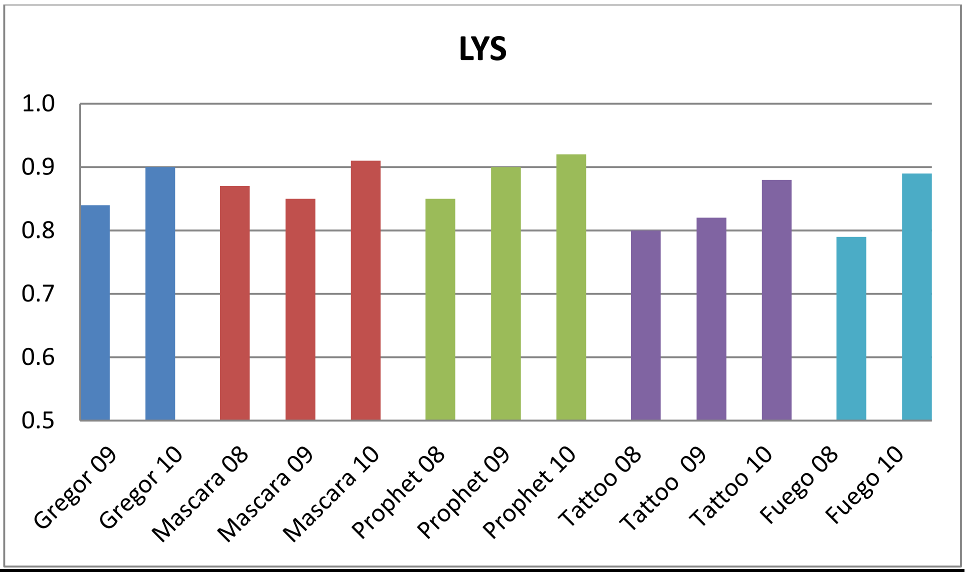


Figure 1. Standardised Ileal Digestibility of Crude Protein and sulphur-containing AA across years



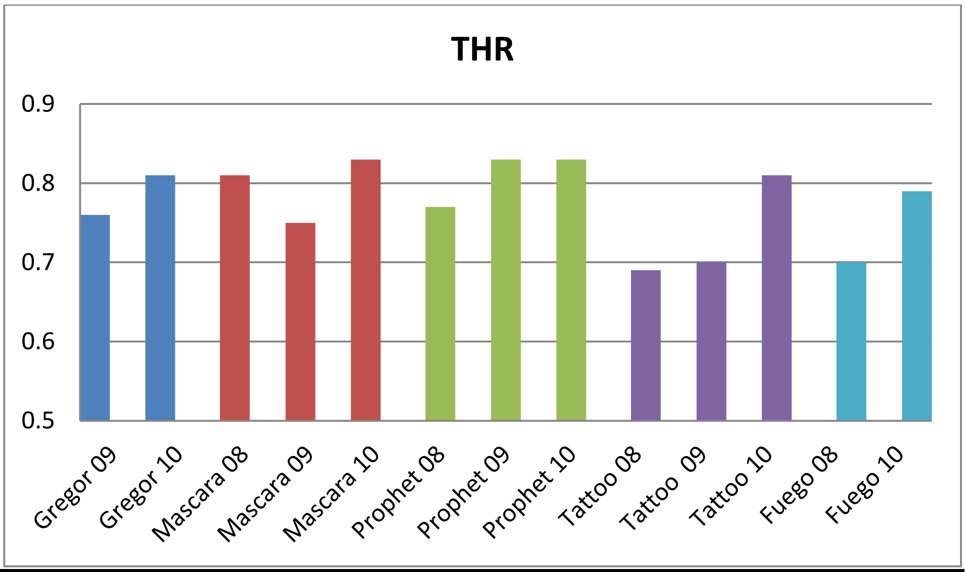


Figure 1 (cont). Standardised Ileal Digestibility of Lysine and Threonine across years

Appendix A

(Animal Feed Science and Technology 175, 158-167)

Standardised Ileal Digestibility of Crude Protein and Amino Acids of UK-Grown Peas and Faba Beans by Broilers

Masey O'Neill HV [a, *], Rademacher M[b], Mueller-Harvey I[c], Stringano E[c], Kightley S[d] and Wiseman J[a]

[a] Division of Animal Sciences, School of Biosciences, University of Nottingham, Sutton Bonington Campus, LE12 5RD, UK

[b] Evonik Degussa GmbH, Rodenbacher Chaussee 4, 63457 Hanau-Wolfgang, Germany

[c] School of Agriculture, Policy and Development, University of Reading, 1, Earley Gate, P.O.Box 236, Reading RG6 6AT, UK

[d] National Institute of Agricultural Botany, Cambridge, CB3 0LE, UK

Abstract

In view of the increasing interest in home-grown legumes as components of diets for non-ruminant livestock and in an attempt to reduce the reliance on imported soya bean meal, two experiments were conducted to evaluate samples of peas and faba beans for their standardised ileal digestibility (SID) of amino acids determined with young broiler chicks. Experiment One evaluated six faba bean and seven pea cultivars and Experiment Two evaluated two faba bean and three pea cultivars as well as a sample of soya bean meal provided as a reference material. Peas and beans were added at 750g/kg as the only source of protein / amino acids in a semi-synthetic diet containing the inert marker titanium dioxide; soya bean meal (SBM) was added, in a control diet, at 500g/kg. Each diet was fed to six replicates of a cage containing two Ross-type broilers for 96 hrs at which point birds were culled allowing removal of ileal digesta. Chemical analyses allowed the calculation of the coefficient of SID of amino acids. There were no differences between samples of the same pulse species ($P>0.05$) but peas had higher values ($P<0.05$), similar to SBM, than beans. Trypsin inhibitor content (expressed as g trypsin inhibitor units /mg sample; TIU) of all pea samples was low and in the range 0.83 – 1.77 mg/kg. There was relatively little variation in bean tannin content and composition amongst the coloured-flowered varieties; however the white-flowered cultivar had no tannins. There was no correlation between tannin content and

coefficient of SID. The content of SID of amino acids (g/kg legume) was higher in SBM when compared with peas and beans by virtue of having higher total concentrations.

Keywords:
Amino acid; bean; broiler; digestibility; pea; protein; tannin, trypsin inhibitor

Abbreviations:
Apparent Ileal Digestibility,AID; Basal Ileal Endogenous Amino Acid Losses (IAALB); Crude protein,CP; Feed Conversion Ratio, FCR; Standardised Ileal Digestibility,SID

Introduction

The European pig and poultry feed industry is becoming increasingly reliant on imported soya bean meal whose higher price, driven partially by EU legislation on use of genetically modified ingredients, is prompting investigation into home-grown protein alternatives. Environmental concerns also drive such research; improving digestibility of both crude protein (CP) and amino acids (AA) decreases nitrogen output of the production system. In general the animal industry must seek viable and sustainable solutions to the sourcing and level of dietary energy and nutrient inputs whilst maintaining an acceptable level of performance and economic output. Developments in sustainability would be enhanced by increased reliance on home-grown feedstuffs. There are a range of protein crops in the UK including rapeseed that, however, needs substantial nitrogen fertilizer inputs that are also imported. Accordingly, this has led to interest in home-grown legumes of which peas (*Pisum sativum*) and faba beans (*Vicia faba*) are the two principal crops of interest. Confidence in either crop as an acceptable feedstuff is however not strong, based on irregularity of supply, the large number of different cultivars / types available and the possible variable presence of anti-nutritional factors; the latter two factors have resulted in considerable variability in nutritional value that is perhaps the main reason why they are not considered more strongly.

Whether or not digestibility of CP and AA from peas is comparable to more commonly used protein sources, such as soya bean meal, is debated in the literature. A recent study has shown that field peas are a viable alternative to soya bean meal in grower and finisher pig diets, in terms of feed:gain ratio and pork quality; it was also demonstrated that there were no effects of pea inclusion on apparent ileal digestibility (AID) of CP (Stein et al., 2004; Friesen et al., 2006; Stein et al., 2006). Other studies in broilers have found that AID of pea CP and AA is decreased compared to soya, but it would still be a viable alternative (Valencia et al., 2009), especially since peas often undergo less processing. However, a recent study has suggested that raw pea starch benefitted, in terms of improved digestibility in broilers, from extrusion (Al-Marzooqi and Wiseman, 2009). Stein and Bohlke (2007) suggest extrusion may also increase standardized ileal digestibility (SID) of CP and AA of peas for pigs compared to non-extruded or pelleted peas. Cowieson *et al.* (2003) suggest that pea meal could be a valuable alternative to soya, especially when diets are supplemented with exogenous enzymes such as amylase, pectinase and cellulase. Beans have been shown to be comparable to soya in terms of nitrogen digestibility for pigs, specifically when the beans were raw (Whittemore and Taylor, 1973).

When pea and bean proteins have been shown to be comparable to soya, there is still considerable variation between cultivars of the same legume species in terms of nutritional value. The AID and SID of CP of different pea cultivars has been shown to vary as has the SID of AA of cultivars of peas and bean in pigs (Mariscal-Landín et al., 2002) and peas in cecectomized broilers (Gabriel et al., 2008). In terms of choosing a legume to replace soya proteins on the basis of digestibility, peas are often found to be superior, compared to lupins (*Lupinus angustifolius)* and beans (Palander et al., 2006). Age of the bird may also have an effect with these sources having increased AID of CP, compared to the control, in birds of 5 weeks of age as opposed to 10 (Palander et al., 2006).

The aim of the current experiment was to investigate the variation in coefficient of SID of CP and AA in broilers of UK-grown legumes and compare the values to those of soya bean meal. The hypotheses tested were that variability within legume species was minimal and that data collected would allow greater confidence in their use.

Material and methods

Legume Samples

Experimental diets were formulated using the ingredients described in Table 1 with legume as the only variable. All diets were manufactured on site at the University of Nottingham, Sutton Bonington Campus. Legumes were ground using a Pulverisette 15 cutting mill (Fritsch GmbH, Idar-Oberstein, Germany) fitted with a 4mm screen and then mixed using a commercial planetary dough mixer. All legumes and diets were stored at ambient temperature. Across the two experiments, a total of eight pea (*Pisum sativum)* and seven bean (*Vicia faba)* cultivars were investigated; they are described in Table 2.

Chick bioassay

The two experiments were undertaken using the same protocol. Day-old, male, Ross strain broilers were sourced (PD Hook Hatcheries Ltd, Thirsk, UK). Experiment one used 156 birds, and experiment two used 84. They were housed in pairs, within 10 g in weight (at 13-days) of each other. Each treatment was fed to 6 replicate cages of two birds per cage. Cages were 37cm wide by 42cm tall by 30 cm deep, contained a roost and were wire bottomed, with provision for collection of excreta. Prior to the adaptation and trial period chicks were fed Chick Starter Crumb (Dodson and Horrell Ltd, Northamptonshire, UK). At day 19 the birds began a 4 day adaptation period, where they were fed the assigned trial diet. The trial period then took place between days 23 and 27, a total of 96 hours. During this time, feed intake was measured and excreta collected. At all times, feed and water were provided on an *ad libitum* basis. During the trial period, temperature was maintained at 21ºC and the birds were kept under artificial light for 23 hours per day, with one hour of dark. The air in the metabolism room was continuously circulated.

The birds were culled on day 28 of the bioassay by asphyxiation with carbon dioxide and cervical dislocation to confirm death. The ileal region of the gut was dissected out from the Meckel's diverticulum to the ileal-caecal junction. This shall be referred to as the ileum, or when describing digestibility coefficients, AID or SID. The ileal contents were carefully collected by squeezing the ileum from one end to the other into a plastic screw-top container. The contents were a pooled sample per cage (two birds). All bird protocols were approved by the relevant Ethical Review Committee and all experimental conditions followed official guidelines for the care and management of birds.

The AID of CP and AA in the assay diets were calculate according to equation (1):

$AID_I = 100\% - [((I_D \times A_F)/(A_D \times I_F)) \times 100\%]$; (1)

where AID_I=AID of CP or AA in the assay ingredient (%), I_D=marker concentration in the assay diet (g/kg DM), A_F=nutrient concentration in ileal digesta (g/kg DM), A_D=nutrient concentration in the assay diet (g/kg DM) and I_F=marker concentration in ileal digesta (g/kg DM).

The SID of CP and AA in the assay diets were calculated by correcting AID of CP and AA for basal ileal endogenous CP and AA losses (IAALB), expressed as g/kg DM intake (DMI). The mean AA composition of basal endogenous protein (g/16 g N) was estimated as 3.9 for isoleucine, 3.8 for leucine, 2.6 for lysine, 0.8 for methionine, 1.7 for cystine, 2.5 for Met+Cys, 2.4 for phenylalanine, 5.7 for threonine, 0.8 for tryptophan, 4.5 for valine, 2.2 for arginine and 2.1 for histidine (Lemme et al., 2004).

The SID of CP and AA in the assay ingredients were obtained according to equation (2):

$SID_I = AID_I + [(IAALB/AA_I) \times 100\%]$; (2)

where SID_I=SID of CP or AA in the assay ingredients (%), AID_I=AID of CP or AA in the assay ingredients (%), IAALB=basal ileal endogenous CP or AA losses (g/kg DMI) and AA_I=CP or AA concentration in the assay ingredients (g/kg DM).

Experiment 1

There were thirteen experimental treatments (thirteen cultivars; Table 2) each fed to 6 replicate cages of two birds per cage. Ileal digesta samples were collected for chemical analysis.

Experiment 2

There were six experimental treatments (six cultivars; Table 2) and one soya bean meal-based control diet (Table 1), each fed to 6 replicate cages of two birds per cage. Ileal digesta samples were collected for chemical analysis.

Laboratory Analysis

For samples of legumes and diets, dry matter (DM) was determined in triplicate samples weighing 500 mg that were dried at 100°C in a forced air convection oven. Due to their small sample size and collection directly into plastic containers, digesta samples were frozen and then freeze-dried when determining dry matter. The concentration of titanium dioxide (employed as an inert marker) was determined in digesta samples using the spectrophotometric method described by Short et al. (1996). Total nitrogen was determined using the Dumas method (AOAC 968.06). Crude protein was calculated by multiplication of total nitrogen by 6.25 (AOAC 1990). The AA contents in the diets and ileal digesta were determined by ion-exchange chromatography with postcolumn derivatization with ninhydrin. Amino acids were oxidized with performic acid, which was neutralized with sodium metabisulfite (Llames and Fontaine, 1994; Commission Directive, 1998). Amino acids were liberated from the protein by hydrolysis with 6 N HCl for 24 h at 110°C. Amino acids were quantified with the internal standard method by measuring the absorption of reaction products with ninhydrin at 570 nm. Tryptophan was determined by HPLC with fluorescence detection (extinction 280 nm, emission 356 nm), after alkaline hydrolysis with barium hydroxide octahydrate for 20 h at 110°C (Commission Directive, 2000). Tyrosine was not determined. The standardised ileal amino acid digestibilities were calculated from the apparent ileal digestibility coefficients by correcting these values for basal endogenous losses (Lemme et al., 2004). It is these SID values that will be presented below.

Bean hulls were removed mechanically and ball-milled for 20 min. Tannin content in hulls was determined in duplicate by adding HCl/butanol (5 ml; 5:95; v/v) to hulls (5 mg) in a test tube and heated for 1 h at 105 °C. Absorbance was measured at 410 nm and the results are reported as absorbance units (Reed, 1986). Tannin content and composition was also analysed in duplicate by thiolysis with benzyl mercaptan, where bean hulls (200 mg) were reacted with benzyl mercaptan/HCl at 40 °C for 1 h as described by Gea et al. (2011). This provided information on the ‘average’ polymer size (or mean degree of polymerization), ratios of procyanidin:prodelphinidin (PC:PD) and epi(gallo)catechin:(gallo)catechin monomeric units (*cis*:*trans*).

Tannin composition was also investigated by MALDI-TOF mass spectrometric analysis as for grapeseed tannins (Frazier et al., 2010). Hulls (5 g) were extracted four times with acetone/water (150 ml, 7:3, v/v) containing ascorbic acid (1 g/l) in an ice-cooled ultrasonic bath for 15 min. The extracted hull residues (5 mg) were subjected to HCl-butanol analysis as described above. The combined extracts were concentrated below 35 °C and the remaining water phase was freeze-dried to yield the crude tannin extract (Stewart et al., 2000). For tannin purification, the crude tannin extract (300 mg) was dissolved in water and applied to a Sephadex LH-20 column (2 cm diameter, 12 cm height) and eluted sequentially with water (100 ml), methanol/water (100 ml; 1:1, v/v), acetone/water (100 ml; 7:3, v/v) and finally with acetone (100 ml) (Sivakumaran et al., 2004). Solvents were evaporated and the aqueous phase was freeze-dried as described above.

Trypsin inhibitor (TI) activity in peas was determined using a method modified from those of Smith (1980) and Kakade et al. (1974). Samples were dried and finely ground, and TI extracted in 0.01M sodium hydroxide. The ability of bovine trypsin to digest N_{α}-Benzoyl-L-arginine 4-nitroanilide hydrochloride (BAPNA) solution, in the presence of the TI sample, was determined colorimetrically. Units are g Trypsin Inhibitor Units / mg sample (TIU)

Statistical analysis

All analyses of variance (ANOVA) were conducted using Genstat v9 (VSN International, Hemel Hempstead, UK). Each trial was analysed separately, initially as a simple factorial using species ((*Pisum sativum* vs *Vicia faba*) (vs SBM in Experiment 2)) as the only factor. Subsequently individual species (*Pisum sativum* vs *Vicia faba*) were analysed using variety as the only factor. Treatments were allocated as a complete randomised design.

Results

Chemical Analyses

Data for CP and amino acid concentrations in legumes are presented in Table 3. As expected, CP levels were higher in beans than peas but there were no differences between cultivars within the same species.

Trypsin inhibitor activity in peas ranged from 0.72 to 1.77 mg/g (Table 3); these figures are low, and well within the accepted range for legumes when fed to poultry (Clarke and Wiseman 2007).

As hulls contain the majority of bean tannins (Hussein et al., 1990; Wang and Ueberschaer, 1990; Merghem et al., 2004), they were isolated and analysed separately. The proportion of hulls in whole beans ranged from 0.15 to 0.18 (Table 4).

The 70% acetone / 30% water extract contains tannins but also other components including polyphenols and water-soluble carbohydrates (Gea et al., 2011). The analyses (Table 4 and 5) clearly differentiate Tattoo (a white-flowered cultivar) from all the others (that are coloured-flowered). There was relatively little variation in condensed tannin levels and composition amongst the coloured-flowered varieties. The HCl-butanol assay levels ranged from 0.97 to 1.46 when hulls were analysed directly and from 0.11 to 0.27 for unextractable tannins in the hull residues. The 'average' tannin polymer size (i.e. mean degree of polymerization) ranged from 6.7 to 11.2, the ratio of procyanidin:prodelphinidin tannins from 22:78 to 34:66 and the ratio of *cis:trans* monomeric units from 26:74 to 33:67 (Table 5).

MALDI-TOF mass spectrometry of the purified tannins confirmed the presence of oligomeric procyandin and prodelphinidin homopolymers and heteropolymers (data not shown). The spectra also revealed that bean tannins contain both A- and B-type tannins. As A-type tannins are difficult to break down into their monomeric flavanol units for subsequent quantitative or qualitative analysis (Mueller-Harvey 1999), bean tannins were purified by Sephadex LH-20 chromatography and weighed (Table 4). This confirmed that white-flowered Tattoo had no measurable tannins in 2008 and 2009 and that there was relatively little variation in tannins amongst the coloured-flowered bean varieties. Hulls yielded between 67 and 116 mg of purified tannins/g DM (Table 4).

Digestibility Experiment 1

The mean values for SID of CP and AA are shown in Table 6. In all cases, (except SID of leucine) peas had better SID of CP and AA than beans (P<0.001). Within species the only effect of cultivar on SID of CP was seen in beans, with Arthur and Wizard having increased SID compared to three of the four other cultivars (P<0.05). Within species, the only effect of cultivar on SID of AA was for leucine, in peas, where Venture and Kahuna had increased SID compared to three of the five other cultivars.

Digestibility Experiment 2

The mean values for SID of CP and AA are shown in Table 7. In all cases, (except SID of lysine and leucine) the mean SID of CP and AA was greater in peas than beans (P<0.05). Soya bean meal was intermediate, in all cases being greater (P<0.05) than or equivalent to the value for beans, and equivalent to or less than for peas. Often, equivalency was due to the number of replicates, and the difference would otherwise be significant. At no point was the SID for soya bean meal superior (P>0.05) to that of peas. Within species, the only effect of cultivar on SID of CP was seen in beans, with Tattoo having increased SID compared to Betty (P<0.05).

All pea cultivars had very low levels of trypsin inhibitor activity and, accordingly, no correlations with SIG were obtained. Tannin analyses are very much more complex and it is difficult to identify one specific fraction that is of nutritional relevance. In any event, the white-flowered variety Tattoo was not superior to coloured-flowered cultivars confirming earlier work that flower colour may not be of nutritional significance (Wareham et al. 1993)

Discussion

The results of the current experiments suggest that peas may be more valuable in poultry diets than beans when comparisons are on the basis of SID (although this superiority is not apparent when the content of SID amino acids g/kg is employed). This is in agreement with Palander *et al.* (2006), who found AID of CP to be in the order peas>lupins>beans when fed to turkeys. In terms of feed conversion ratio (FCR), Farrell *et al.* (1999) suggested the order peas=beans>lupins=chick peas, in one of two similar experiments. In the second experiment Farrell *et al.* (1999) found that FCR did not vary with these legumes; the results of that experiment suggest that the SID of CP/AA of peas is equivalent to or greater than that of soya bean meal. This was unexpected, as the literature generally suggests that the nutritional value of soya bean meal protein would be equivalent or better than that of peas and/or beans. Valencia *et al.* (2009) suggest that coefficient of true ileal digestibility of CP of pea protein concentrate may be equivalent to soya protein concentrate and soya bean meal. In that study, the coefficients of ileal true digestibility (CITD) for leucine and methionine varied with protein source, with protein from soya origin being at least numerically superior. Similarly, it has been shown that FCR is not affected over a 42 day period (age 0-42 days) by inclusion of up to 200g pea or rape meal/kg in place of soya bean meal (McNeill et al., 2004). However, in very young birds, pea-based diets may give significantly reduced Protein Efficiency Ratio (PER) even than a raw soya-based diet (Ravindran et al., 2010). Where difference in the apparent coefficient digestibility of dry matter (ADMD) is reduced by the inclusion of pea in the diet, as opposed to soya bean meal, the use of exogenous enzymes may be useful in maintaining the ADMD (Cowieson et al., 2003).

The current results suggest that there is no difference within species (between varieties) on the SID of CP or AA which disagrees with Mariscal-Landin *et al.* (2002) measured in pigs and Gabriel *et al.* (2008) in broilers. However, Friesen *et al.* (2006) found that in pigs the SID for CP of three pea varieties were not different and were also similar to a mixture of peas. Nalle *et al.* (2010) also found no varietal differences in AID of essential AA of four faba beans and Ravindran *et al.* (2010) found no difference in PER between five pea varieties.

Data for TIA concentrations in the current study revealed that all cultivars had very low concentrations. However, when there is considerable variability in trypsin inhibitor activity between pea samples (Grosjean *et al*., 1993) then there will be effects on standardised ileal digestibility (as reviewed by Crepon, 2006). Consequently, evaluating peas for this variable is considered essential prior to their use in diets for non-ruminants.

Dietary inclusion of tannin-free bean varieties, compared to tannin-containing cultivars of beans, has been found to improve AID of CP (Brufau et al., 1998). This is contrary to the current study. One of the beans tested was a zero-tannin type, the remainder were tannin-containing types. Thus, in the current study, tannin level did not appear to affect AID. White-flowered Tattoo had no tannins as determined through either HCl-butanol analysis or thiolytic degradation and through separate tannin isolation (Tables 4 and 5). Bean tannins contained a high proportion of prodelphinidin (PD) tannins: PC/PD ratios ranged from 22:78 to 34:66. These PD proportions are slightly higher than reported previously (Cransfield et al., 1980): 34:66 to 43:57. Given the findings of Helsper et al. (1993) that higher *cis* epicatechin flavanol contents and higher oligomers (i.e. higher mDP values) enhanced the trypsin inhibitory activity of tannins and that PD tannins tend to have higher biological activities than PC tannins (Wang et al 1996; Maie et al 2003; Barbehenn et al 2006; Brunet and Hoste, 2006), a detailed exploration of bean germplasm might be warranted in the future to select varieties with lower PD and *cis* contents and lower mDP values.

This relative lack of variation in terms of tannin structures and composition amongst the 6 tannin-containing bean varieties contrasts with recent results from screening a sainfoin (*Onobrychis viciifolia*) and willow (*Salix* sp.) germplasm collection (Falchero et al. 2011; Stringano 2011), which exhibited considerable variation. It would, therefore, appear that these coloured-flowered bean cultivars have been bred with relatively similar tannin traits.

Ultimately, the value of any raw material is influenced by energy and nutrient content. Increasing sophistication in diet formulation has resulted in the use of SID amino acid contents and it is this term that allows raw materials to be ranked accurately. Thus, while peas had very similar coefficients of SID to SBM, the latter material is of superior nutritional value because it has great concentrations of total amino acids; this is illustrated in Figure 1 for three amino acids. This might suggest that it may be of interest nutritionally to breed / select home-grown peas and beans with higher essential amino acid contents (Wiseman et al., 2003).

The diets used in the current study were designed to be semi-synthetic, in that they had high levels of inclusion of the test legume (750g/kg) and the legume was the only source of protein. This was intended to promote any differences in digestibility coefficients and is not intended to be entirely reflective of commercial practise. The study of Farrell *et al.*

(1999) did find however, that beans were significantly variable in terms of FCR, with inclusion rate, whereas peas, lupins and chick peas were not. With increasing level of bean inclusion, FCR actually improved (Farrell et al., 1999). In both grower and finisher broiler studies Vadivel and Pugalenthi (2010) found there was no significant effect of increasing inclusion level of velvet bean meal (treated to remove ANFs), in place of soya bean meal, in terms of FCR and PER. However, both appeared to numerically, and linearly, deteriorate.

Conclusion

The results of the current study suggest that UK-grown legumes are valuable in poultry diets and should inform further work into their use as an alternative to other protein sources.

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Table 1. Dietary formulation

Ingredient (g/kg)	Basal legume diet	Soya bean meal diet[a]
Test pea or bean	750	-
Soya bean meal[b]	-	500
Purified starch (maize)	70	195
Purified glucose	70	195
Soya oil	50	50
Vitamin and mineral premix[c]	50	50
Titanium dioxide	10	10
Crude Protein g/kg[d]	160	248
Apparent Metabolisable Energy MJ/kg[d]	11.4	11.4
Calcium g/kg[d]	8.2	9.0
Available Phosphorus g/kg[d]	6.1	6.0

[a] Experiment two only

[b]Harbro Limited, Aberdeenshire, UK; North American origin

[c] Target Feeds, Whitchurch, Shropshire, UK. Content per g of premix: 0.1g phosphorus, 0.017g magnesium, 0.152g calcium, 0.030g sodium, 150 IU vitamin A, 30 IU vitamin D_3, 0.2 IU vitamin E (as α-tocopherol acetate), 0.012mg copper (as copper sulphate), 3.2µg selenium (as selenium BCP).

[d] Estimated for the purposes of dietary design

Table 2. Description of legume cultivars used in experiments one and two.

Species	Variety	Description	Flower	Experiment
Pea	Bilbo	White field pea	White	1
	Genki	Marrowfat field pea	White	1
	Gregor	White field pea	White	2
	Kahuna	Marrowfat field pea	White	1
	Mascara	White field pea	White	1,2
	Nitouche	Blue field pea	White	1
	Prophet	Blue field pea	White	1,2
	Venture	Blue field pea	White	1
Bean	Arthur	Black hilum winter bean	Coloured	1
	Ben	Pale hilum spring bean	Coloured	1
	Betty	Pale hilum spring bean	Coloured	2
	Clipper	Black hilum winter bean	Coloured	1
	Fuego	Pale hilum spring bean	Coloured	1
	Tattoo	Pale hilum spring bean, low tannin	White	1,2
	Wizard	Pale hilum winter bean	Coloured	1

Table 3. Crude protein and amino acid content (g/kg) in different legumes and trypsin inhibitor (TIU) content of peas

A. Peas

g/kg[a]	Bilbo	Gregor	Genki	Kahuna	Mascara n=2[b]	Nitouche	Prophet n=2[b]	Venture
Crude Protein	214	214	207	215	195	200	199	201
Lysine	15.7	14.7	16.1	15.9	14.5	15.5	14.7	15.8
Methionine + Cysine	4.8	4.7	4.9	5.3	4.5	4.6	4.8	4.8
Cystine	2.8	2.8	3.0	3.2	2.7	2.7	2.9	2.9
Threonine	8.2	7.7	8.2	8.4	7.6	8.0	7.8	8.0
Tryptophan	2.1	1.9	1.9	2.1	1.8	1.8	1.9	1.8
Isoleucinecine	8.8	8.5	9.2	9.1	8.3	8.7	8.5	8.9
Leucine	15.5	14.7	15.9	15.6	14.1	15.1	14.5	15.4
Valine	10.2	9.8	10.3	10.5	9.4	9.9	9.7	9.9
Histidine	5.6	5.4	5.5	5.8	5.1	5.2	5.2	5.2
Arginine	21.5	19.8	18.5	20.1	16.3	17.9	16.8	17.3
Phenylalanine	10.1	18.9	10.4	10.3	12.6	10.0	13.0	10.3
TIU (mg/g)[c]	0.93	-	1.02	1.77	0.97	0.72	1.06	1.06

B. Beans

g/kg [a]	Arthur	Ben	Betty	Clipper	Fuego	Tattoo N=2[b]	Wizard	SBM[d]
Crude Protein	237	220	231	235	231	246	243	431
Lysine	15.3	14.4	15.2	15.5	15.3	16.0	15.5	26.2
Methionine + Cystine	5.0	4.2	4.2	4.7	4.3	4.6	5.0	12.0
Threonine	8.4	7.7	8.3	8.3	8.3	8.1	8.4	17.6
Tryptophan	2.1	1.8	2.0	2.1	2.0	2.0	2.2	6.1
Isoleucinecine	9.7	8.9	9.8	9.7	9.6	10.2	10.0	20.3
Leucine	17.3	15.8	17.6	17.3	17.3	18.1	17.7	34.4
Valine	10.9	9.8	10.9	11.0	10.8	11.2	11.1	21.5
Histidine	6.3	5.5	6.3	6.3	6.1	6.4	6.4	11.7
Arginine	20.5	17.4	20.5	20.7	19.9	20.6	22.3	32.3
Phenylalanine	10.1	9.2	18.8	10.1	10.1	13.8	10.4	22.5

[a] Standardized to 880g dry matter /kg

[b] Where n=2, there wer two samples of that variety, one used in each experiment

[c] Units are defined as g Trypsin Inhibitor Units / mg sample (TIU)

[d] Soya Bean Meal

Table 4. Bean grain analysis for proportion of hulls and for yield of purified tannins after Sephadex LH-20 column chromatography (mg/g DM).

Variety	Hull proportion (DM basis)	Yield of purified fraction after Sephadex LH-20 column chromatography	
		Hulls (mg/g DM)	Adjusted for whole beans (mg/g DM)
Tannin-containing			
Arthur	0.164	84.7	11.2
Ben	0.180	116.1	16.6
Clipper	0.175	76.8	10.8
Fuego	0.174	89.3	12.5
Betty	0.173	76.5	10.8
Wizard 2008	0.151	75.7	9.3
Wizard 2009	0.180	67.0	9.5
Tannin-free			
Tattoo 2008	0.150	2.5	0.3
Tattoo 2009	0.155	4.2	0.5

Table 5. Tannin content and composition in hulls as determined by HCl-butanol and thiolysis assays (SD in brackets, n = 2).

	HCl-butanol assay		Thiolysis assay			
Variety	Hulls[a] (AU at 550 nm)	Hull residues[b] (AU at 550 nm)	Tannin (mg/g DM)	mDP[c]	PC:PD[d]	*cis*:*trans*[e]
Tannin-containing						
Arthur	1.32 (0.049)	0.11 (0.010)	3.2 (0.59)	9.8 (0.22)	25:75 (0.3)	26:74 (2.6)
Ben	1.46 (0.092)	0.27 (0.023)	4.1 (0.34)	6.7 (1.85)	27:73 (0.4)	33:67 (3.6)
Clipper	1.45 (0.036)	0.18 (0.035)	3.3 (0.05)	11.2 (1.44)	22:78 (1.5)	31:69 (0.5)
Fuego	1.45 (0.042)	0.23 (0.007)	5.2 (0.32)	8.2 (1.45)	25:75 (1.5)	29:71 (1.3)
Betty	1.42 (0.069)	0.12 (0.007)	7.0 (0.09)	8.5 (1.85)	25:75 (2.3)	31:69 (0.4)
Wizard 2008	1.38 (0.012)	0.14 (0.006)	3.1 (0.02)	8.5 (1.24)	27:73 (1.1)	28:72 (2.8)
Wizard 2009	0.97 (0.030)	0.24 (0.013)	1.3 (0.02)	6.8 (0.03)	34:66 (0.1)	30:70 (0.4)
Tannin-free						
Tattoo 2008	0.00 (0.000)	0.00 (0.000)	0.0 (0.00)	-	-	-
Tattoo 2009	0.00 (0.000)	0.00 (0.000)	0.0 (0.00)	-	-	-

[a] AU: absorbance units at 550 nm of anthocyanidin reaction products from hulls; [b] AU: absorbance units at 550 nm of anthocyanidin reaction products from hulls, which had been exhaustively extracted with 70% acetone; [c] mDP: mean degree of polymerisation; [d] PC:PD: ratio of procyanidin to prodelphinidin tannins; [e] *cis:trans*: ratio of epi(gallo)catechin:(gallo)catechin units in the tannin polymer.

Table 6. Experiment 1: Standardised Ileal Digestibility of Crude Protein and Amino acids

Peas

	Bilbo	Genki	Kahuna	Mascara	Nitouche	Prophet	Venture	sed[a]	P
Crude Protein	0.78	0.84	0.79	0.80	0.76	0.77	0.83	0.036	0.178
Lysine	0.85	0.91	0.87	0.87	0.84	0.85	0.89	0.027	0.097
Methionine + Cystine	0.77	0.84	0.79	0.87	0.76	0.77	0.84	0.053	0.263
Threonine	0.78	0.82	0.79	0.81	0.75	0.77	0.81	0.036	0.361
Tryptophan	0.77	0.83	0.76	0.79	0.76	0.76	0.81	0.035	0.208
Isoleucinecine	0.77	0.86	0.80	0.81	0.76	0.78	0.84	0.039	0.076
Leucine	0.78^{z}	0.86^{y}	$0.80^{y,z}$	$0.81^{y,z}$	0.77^{z}	0.78^{y}	0.85^{y}	0.042	0.005
Valine	0.77	0.84	0.80	0.80	0.76	0.77	0.83	0.037	0.146
Histidine	0.83	0.88	0.85	0.85	0.82	0.83	0.87	0.031	0.242
Arginine	0.88	0.93	0.89	0.88	0.87	0.86	0.91	0.025	0.132
Phenylalanine	0.77	0.85	0.80	0.80	0.75	0.77	0.84	0.037	0.055

Beans, Species

	Arthur	Ben	Clipper	Fuego	Tattoo	Wizard			Species			
							sed[a]	P	Peas	Beans	sed[a]	P
Crude Protein	0.76[x]	0.71[x,z]	0.68[y,z]	0.69[y,z]	0.69[y,z]	0.76[x]	0.032	0.049	0.79[v]	0.72[w]	0.014	<0.001
Lysine	0.80	0.81	0.79	0.79	0.80	0.85	0.030	0.359	0.87[v]	0.78[w]	0.011	<0.001
Methionine + Cystine	0.56	0.59	0.58	0.57	0.62	0.62	0.041	0.538	0.77[v]	0.59[w]	0.015	<0.001
Threonine	0.70	0.71	0.68	0.70	0.69	0.75	0.036	0.462	0.79[v]	0.71[w]	0.014	<0.001
Tryptophan	0.63	0.62	0.63	0.65	0.66	0.71	0.041	0.337	0.78[v]	0.65[w]	0.015	<0.001
Isoleucinecine	0.71	0.70	0.69	0.70	0.69	0.76	0.041	0.448	0.80[v]	0.71[w]	0.016	<0.001
Leucine	0.73	0.72	0.70	0.71	0.71	0.79	0.040	0.333	0.74	0.73	0.017	<0.001
Valine	0.71	0.70	0.69	0.70	0.70	0.77	0.038	0.409	0.80[v]	0.71[w]	0.015	<0.001
Histidine	0.75	0.76	0.74	0.75	0.76	0.81	0.031	0.329	0.85[v]	0.76[w]	0.012	<0.001
Arginine	0.82	0.81	0.80	0.81	0.81	0.87	0.028	0.130	0.89[v]	0.82[w]	0.011	<0.001
Phenylalanine	0.73	0.71	0.70	0.71	0.70	0.78	0.037	0.257	0.80[v]	0.72[w]	0.015	<0.001

[a] sed = Standard error of the difference

[x,y,z] Means within a row, within species, with different superscripts vary

[v,w] Means within a row, between species, with different superscripts vary

Table 7. Experiment 2: Standardised Ileal Digestibility of Crude Protein and Amino acids

	Peas					Beans				Species				
	Gregor	Mascara	Prophet	Sed[a]	P	Betty	Tattoo	sed[a]	P	Peas	Beans	SBM	Sed[a]	P
CP	0.90	0.91	0.89	0.035	0.815	0.81[y]	0.85[z]	0.018	0.04	0.90[w]	0.83[x]	0.83[x]	0.027	<0.001
Lysine	0.84	0.85	0.90	0.049	0.365	0.76	0.82	0.044	0.167	0.87	0.79	0.84	0.047	0.054
Methionine + Cystine	0.72	0.74	0.81	0.064	0.408	0.51	0.62	0.074	0.168	0.76[x]	0.57[w]	0.76[x]	0.069	<0.001
Threonine	0.76	0.75	0.83	0.061	0.355	0.64	0.70	0.049	0.191	0.78[w]	0.67[x]	0.78[w,x]	0.059	0.016
Isoleucinecine	0.75	0.77	0.85	0.068	0.274	0.65	0.74	0.059	0.132	0.80[w]	0.69[x]	0.81[w,x]	0.063	0.034
Leucine	0.76	0.78	0.86	0.066	0.280	0.68	0.75	0.057	0.193	0.80	0.72	0.81	0.060	0.079
Valine	0.75	0.77	0.85	0.066	0.282	0.65	0.73	0.057	0.198	0.79[w]	0.69[x]	0.80[w,x]	0.061	0.026
Histidine	0.83	0.85	0.90	0.048	0.260	0.74	0.81	0.051	0.202	0.86[w]	0.78[x]	0.84[w,x]	0.048	0.029
Arginine	0.87	0.87	0.92	0.042	0.341	0.80	0.84	0.042	0.294	0.89[w]	0.82[x]	0.86[w,x]	0.039	0.047
Phenylalanine	0.78	0.79	0.87	0.063	0.309	0.68	0.75	0.054	0.244	0.81[w]	0.72[x]	0.82[w,x]	0.057	0.032

[a]sed = Standard error of the difference

[b]Soya Bean Meal

[y,z] Means within a row, within species, with different superscripts vary

[w,x] Means within a row, within **or** between species, with different superscripts vary (P<0.05)

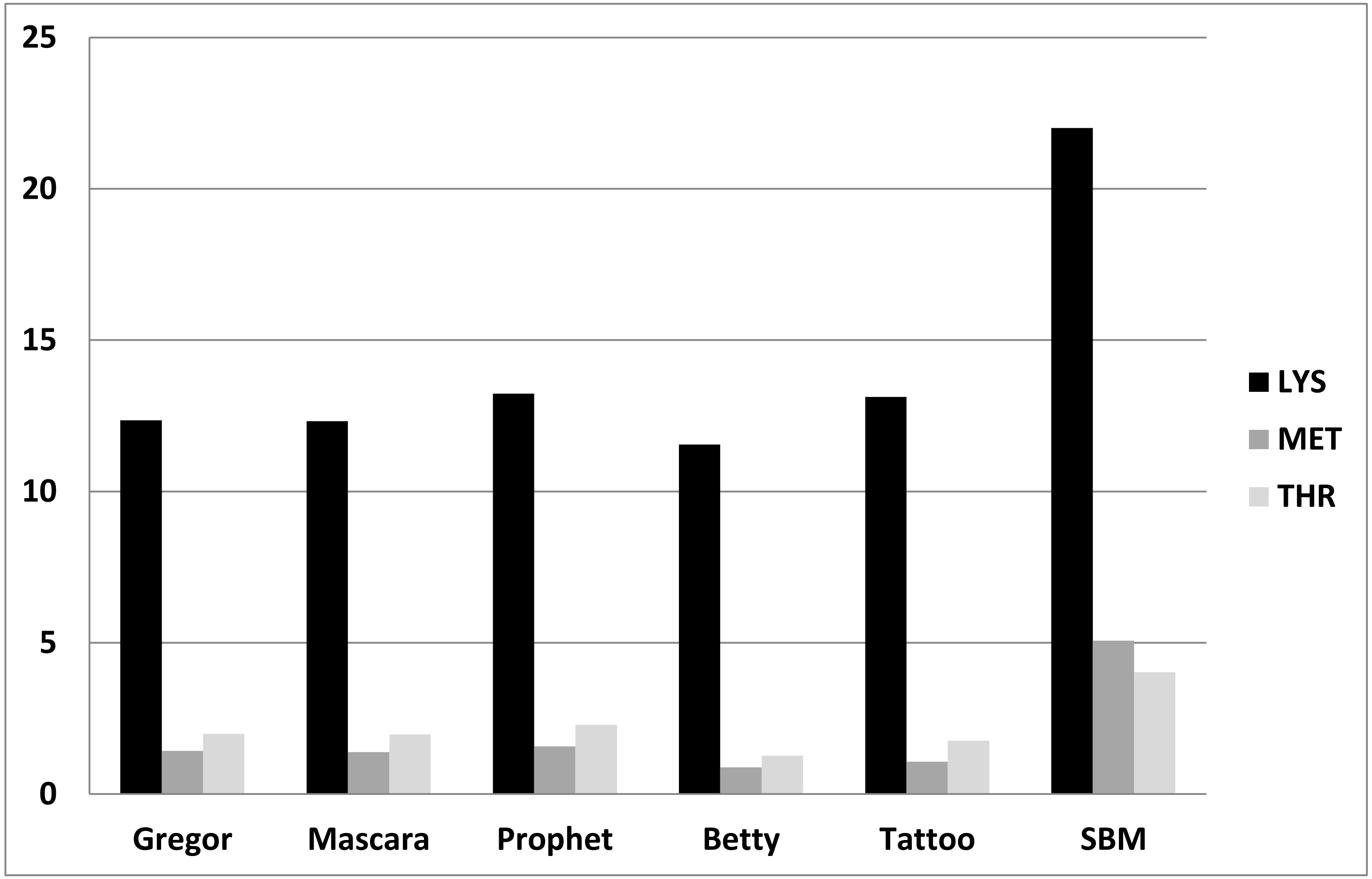

Figure 1. Content of standard ileal digestible amino acids for three samples of peas (Gregor, Mascara, Prophet), two samples of faba beans (Betty and Tattoo) and soya bean meal (SBM); data are g/kg corrected to 880 g DM/kg.

Full report Objective 4: Literature review

Lead authors: Lesley Smith (SRUC).

Executive Summary

- Europe is deficient in the protein sources for livestock nutrition and imports over 70% of the protein used in animal feed. The most commonly imported protein source is soya bean meal (SBM) from North and South America.
- The UK pig industry relies heavily on imported SBM. There are increasing environmental and economical concerns about this reliance on SBM, and thus the sustainability of the UK pig industry. As a consequence there a need to find viable home-grown protein sources for pig diets.
- Grain legumes (peas and faba beans) are home-grown protein sources that could potentially be considered for pig feed.
- The use of peas and faba beans in pig diets has been limited due a long standing association between high inclusions of peas or faba beans in pig diets with poor growth performance.
- This poor performance has been attributed to at least two main factors: (1) peas and faba beans have a deficiency in the essential amino acids methionine, tryptophan and threonine. (2) peas and faba beans contain anti-nutritional factors (ANFs) such as trypsin inhibitors and condensed tannins which affect the digestion of nutrients.
- This review aims to provide quantitative information on the success of genetic improvement on the protein quality and ANF content of peas and faba beans.
- While plant breeding for higher crude protein content is possible, and has been done, high protein content varieties have not been made commercially available.
- In comparison with pig amino acid requirements, peas and beans are low in the amino acids methionine, tryptophan and threonine. Furthermore, there appears to have been little progress in breeding for improved protein quality in both commercial and genetic resources of peas and faba beans.
- Peas and beans contain a number ANFs including lectins (or haemagglutinins); the glucosides vicine and convicine; phytate; and saponins. However, the two most important ANFs found in peas and faba beans to be considered for their use in pig feeds are trypsin inhibitors and condensed tannins.

- The trypsin inhibitor activity (TIA) of faba beans has not been a constraint for their use in pig diets and there has been little need for breeding programmes to reduce trypsin inhibitors in faba beans.
- The TIA of peas has been gradually decreasing over the years, with many modern commercial varieties having a TIA below that which is expected to affect pig performance.
- Plant breeding has also led to many low tannin white flowered varieties of faba beans, while the tannin content of coloured flowered faba beans also appears to have reduced.
- Although there are many processing technologies which can be used to reduce the ANFs in peas and faba beans further, the economics of applying these technologies is questionable.
- Recent trials indicate that high inclusions of peas in grower and finisher pig diets do not affect performance in diets nutritionally balanced for amino acid requirements.
- There are currently no studies testing the effect of high inclusion nutritionally balanced faba bean diets on the performance of grower and finisher pigs.
- Performance trials with peas in starter diets nutritionally balanced for amino acid requirements indicate that including peas up to 360 g/kg does not affect starter pig performance
- There are no studies testing the effect of high inclusion nutritionally balanced faba bean diets on the performance of starter pigs.
- Conclusion: the reduction in ANF’s is not commensurate with the greater inclusion levels of peas that are possible in when diets are nutritionally balanced for amino acid requirements. This indicates that as long is special care is taken during formulation, peas (and potentially faba beans) are a viable home grown protein source for use in grower and finisher pig diets.

Introduction

Europe is deficient in the protein sources required for livestock, importing over 70% of the protein used in animal feed (Crepon, 2006; Baumgartner et al., 2008). The most commonly imported protein source for animal feed is soya bean meal (SBM) from North and South America (Gatel and Grosjean, 1990). The UK pig industry relies heavily on SBM; using national pig performance data (Fowler, 2008) and typical diet formulations, we have estimated that ~200,000 tonnes of SBM is used annually for grower and finisher diets alone. The cost and continuing availability of SBM is influenced by the global market and are therefore subject to rapid fluctuations (Jezierny et al., 2010a). Thus, due to the pig industry's reliance on SBM there are increasing concerns about the sustainability and security of UK pig production, if this raw material continues to be used at the current rate. There are also increasing environmental concerns with SBM as the rapid increase in demand for soya is associated with increasing demands of land use change (Fearnside, 2001). Furthermore, the use of soya bean meal in organic farming is limited due to the ban on both oilseed products processed by solvent extraction, and the use of genetically modified feed ingredients (European Communities, 2007). In order to remain competitive in the global market, promote sustainable pig farming, provide alternatives for organic farming, and reduce the environmental impact of the UK pig industry, there is a need to find a viable home-grown protein source to be used in pig diets.

Given the climatic conditions of the United Kingdom any home grown protein source to be considered for pig feed must be capable of growing in temperate environments. Thus, peas and faba beans which thrive in under cool conditions (Castell, 1990; Thacker, 1990; Duc, 1997) are potential home-grown protein sources that could be considered for pig feed. Peas and faba beans are attractive for use in pig feed as they are relatively high in crude protein and are a good source of the essential amino acid lysine (Castell et al., 1996; Partanen et al., 2003). Another key benefit of peas and faba beans is that legumes have natural nitrogen-fixing abilities which provide assimilated nitrogen to the whole crop rotation, reducing the need for nitrogen fertilisers (Crepon, 2006; Zijlstra et al., 2008; Kopke and Nemecek, 2010). Furthermore, due to their home grown nature peas and faba beans are also associated with reduced transport and improved food security. However, the use of peas and faba beans in pig diets has been limited. A survey carried out within Green Pig to quantify the use of home-grown protein sources in the feeds of UK growing and finishing pigs found that less than 2% of compounders and home-mixers surveyed used peas or faba beans in their pig diets. Furthermore, when peas and faba beans were used in pig diets, inclusion levels in the diet were less than 11% (Smith et al., 2011). The reluctance of the pig industry to include these home grown pulses in pig diets is mainly due a long standing association between high inclusions of peas or faba beans in pig diets with poor growth performance (Castell, 1976; Aherne et al., 1977; Onaghise and Bowland, 1977; O'Doherty and Keady, 2000, 2001; Partanen et al., 2003). This poor performance has been attributed to several factors, but the two main factors are: (1) peas and faba beans have a deficiency in the essential amino acids methionine, tryptophan (Gatel, 1994; Castell et al., 1996; Duc et al., 1999) and threonine (Partanen et al., 2003); (2) peas and faba beans contain anti-nutritional factors (ANFs) such as trypsin inhibitors and condensed tannins which affect the digestion of nutrients (Boisen, 1989; Bond and Duc, 1993). However, advances in plant genetics have promised higher protein content and improved protein quality in terms of amino acid (AA) composition (Monti and Grillo, 1983; de Lumen, 1990; Duc, 1991; Jezierny et al., 2010a). Similarly, plant breeding has allowed the development of peas and faba beans with decreased levels of ANFs, most notably the development of low-tannin (white flowered) faba beans (Bond and Duc, 1993). With the apparent success of plant genetics in tackling these two constraints for using peas and faba beans in animal feed, modern day varieties of peas and faba beans should be better suited to be used in pig feed. The main aim of this review is to provide quantitative information on the progress of genetic improvement on protein quality and reduced ANF content of peas and faba beans. In addition, ANFs could be reduced through processing, and this will be briefly discussed. The review concludes with a brief section on impact of peas and faba beans on pig performance. This has been kept brief, as this has been a major focus of several recent reviews (Gatel, 1994; Crépon et al., 2006; Jezierny et al., 2010a).

Protein quality of peas and faba beans

Crude Protein content of peas and faba beans

The crude protein content of peas can be very variable and ranges from 166 to 277g/kg DM, with an average CP content of approximately 227 g/kg DM (Figure 1). However, it should be noted that the CP of peas has also been shown to be very inconsistent for seeds from the same plant, and even the same pod (Mathews and Arthur, 1985). The crude protein content of faba beans is on average greater than that of peas, but is likewise variable and ranges between 206 and 337 g/kg DM, with an average CP content of 273 g/kg DM (Figure 1). Within the faba been seed itself, the cotyledon portion of the seed has a higher protein content than the hull (Marquardt et al., 1975). At least some of the variability in crude protein for both peas and faba beans can be attributed to the genotype/variety e.g. in peas, for example wrinkled pea varieties have a greater crude protein content than smooth varieties (Edwards et al., 1987; Cousin, 1997) and winter varieties have higher protein contents relative to spring varieties (Gatel and Grosjean, 1990). In contrast to the pea, spring varieties of faba beans appear to have a greater crude protein content than winter varieties of faba beans (Eden, 1968). Moreover, this difference in crude protein content has been shown to remain present when winter and spring varieties are sown and harvested together (Bond and Toynbee-clarke, 1968). Environmental conditions have also been shown to greatly influence the crude protein content of peas and faba beans with location (Ali-Khan and Youngs, 1972; Marquardt et al., 1975; Igbasan et al., 1996), year (Ali-Khan and Youngs, 1972), nitrogen fertilisation (Sosulski et al., 1974; Igbasan et al., 1996) and phosphorus fertilization (Sosulski et al., 1974) affecting the protein content of these legumes.

As well as the large variability in crude protein content of peas and faba beans, the trait shows high heritability estimates (Monti and Grillo, 1983; Duc, 1991), together indicating that there are good opportunities for increasing the crude protein content through genetic selection. However, there are some difficulties in designing breeding programmes which effectively increase protein content without affecting other traits of interest. For example, a negative correlation has been found in many legume species between yield and protein content (Tandon et al., 1957; Kelly and Bliss, 1975; Green et al., 1977). Although, it is expected that progress in breeding for high protein content is still possible as there is enough variation to allow selection of plants with both higher yields and high protein content (Monti and Grillo, 1983). Nonetheless, the crude protein content of peas and faba beans illustrated in Figure 1, suggests that there has been little practical progress in improving crude protein content from 1988 to 2010. Moreover, there appears to be a reduction in the crude protein content of peas and faba beans in recent years. This apparent reduction in crude protein is mainly due to the inclusion of Green Pig samples and UNIP annual crude protein figures for France. Both the Green Pig samples and UNIP figures represent commercially available varieties of peas and faba beans only. In contrast a number of the crude protein figures obtained from the literature include genetic resources, which generally have higher protein contents than commercial varieties (Crepon et al., 2010). Thus, while it seems that breeding for higher crude protein content is possible, and has been done, high protein content varieties have not been made commercially available. However, this may simply be a reflection of priorities in breeding objectives which are likely to focus on yield and disease resistance.

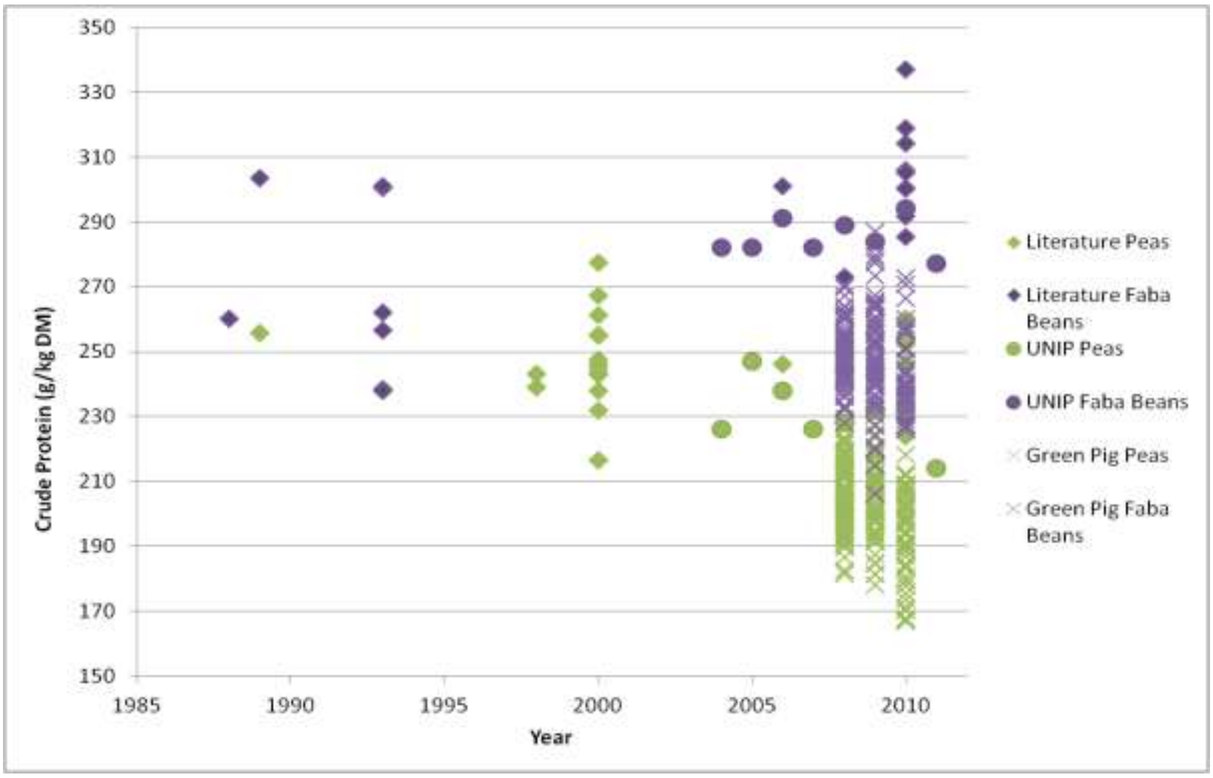

Figure 1. Crude Protein (CP) content (g/kg DM) of peas and faba beans (1988-2010) obtained from the literature[a,b]; UNIP annual CP figures for the French harvests 2004-2011[c,d]; and Green Pig samples from harvests 2008-2010[e,f].

[a]'Year' represents the year of publication

[b]National Research Council (1988); INRA (1989); Jansman et al. (1993a); Bastianelli et al. (1998); Grosjean et al. (2000); Degussa (2006); Zijlstra et al. (2008); Jezierny et al. (2010b); Nalle et al. (2010)

[c] 'Year' represents each harvest year, figures are the mean crude protein content for each harvest year

[d]UNIP, (2011a; 2011b)

[e] 'Year' represents the harvest year

[f]Commercial varieties of peas and faba beans sampled for the Green Pig Project for 3 harvest years (2008-2010). For each harvest year, a selection of commercial varieties of peas and faba beans were sampled over a maximum of 5 different sites, with a maximum of 5 replicates per site. A total of 95, 74 and 59 pea samples in 2008, 2009 and 2010, respectively. A total of 64, 71 and 41 faba bean samples in 2008, 2009 and 2010 respectively.

Amino Acid composition of peas and faba beans

Although higher protein content is a desirable trait in peas and faba beans, protein quality for use in animal feed is based on the content of essential amino acids and their availability to the animal. In terms of protein quality, peas and faba beans have a relatively high lysine content, ranging from 12.4 to 19.9 g/kg DM, and 13.0 to 21.6g/kg DM, for peas and beans respectively (Figure 2). However, in comparison with pig amino acid requirements and the optimum ratios of apparent ileal digestible amino acids relative to lysine, peas and beans are low in the essential amino acids methionine (1.7 to 2.7g/kg DM and 1.6 to 2.9 g/kg DM, for peas and faba beans respectively (Figure 3)), Methionine+Cystine (M+C) (4.5 to 6.9 g/kg DM and 4.0 to 7.0 g/kg DM for peas and faba beans respectively (Figure 4)), tryptophan (1.7 to 2.7 g/kg DM and 1.8 to 3.2 g/kg DM for peas and faba beans respectively (Figure 5)), and threonine (6.7 to 10.1 g/kg DM and 7.1 to 12.8 g/kg DM for peas and faba beans respectively (Figure 6)). Although there is some variation in individual amino acids for peas and faba beans, this is still relatively narrow for plant breeding purposes (Monti and Grillo, 1983; Duc et al., 1999). Additionally, agricultural practices have not been shown to positively affect amino acid composition. For example, although increased application of nitrogen fertilizers have been shown to increase the percentage of amino acids in DM for peas, when the amino acids are expressed on a protein basis, the amino acid concentration in the whole seed actually decreases (Igbasan et al., 1996). This may be due to the strong correlations that exist between crude protein content and individual amino acid content. Amino acid contents on a DM basis are generally positively correlated with total protein contents (Duc et al., 1999). However, when expressed on a protein basis, negative correlations between amino acid concentrations and protein content have been observed for a number of amino acids, including methionine (Boulter et al., 1973; Eppendorfer and Bille, 1974; Holt and Sosilski, 1979; Igbasan et al., 1996). Thus, breeding to improve specific amino acid concentrations whilst maintaining a high protein content can be difficult.

An alternative breeding strategy which may increase methionine content of peas and faba beans is to improve the ratio of the different storage proteins in the seed. The protein of peas and faba beans consist of two types of storage proteins, albumins and globulins. Globulins are the most dominant of the storage proteins and are divided into two types, vicilin (*7S*) and legumin (*11S*). The albumin and legumin fractions have greater concentrations of lysine and the sulphur amino acids, methionine and cysteine, than vicilin. Therefore it is these fractions of the protein that are more likely to have an effect on the protein quality of legume seeds (Bajaj et al., 1971; Monti and Grillo, 1983; Igbasan et al., 1996; Hughes et al., 2001). However, breeding programmes aimed at selection for an improved legumin/vicilin ratio in faba beans, resulted in increased protein contents and consequently a reduction in the concentration of methionine (Sjödin et al., 1981). Thus, care must be taken in breeding programmes to ensure that protein content is unaffected.

Figures 2-6 illustrate the content of lysine, methionine, M+C, tryptophan and threonine in peas and faba beans from 1988 to 2011. Although the Green Pig commercial varieties appear to have lower contents of these amino acids relative to the figures from obtained from the literature (representing a mixture of commercial varieties and genetic resources), the actual differences between the literature figures and the Green Pig figures are in the region of 3 g/kg DM for lysine, less than 0.5 g/kg DM for methionine and tryptophan, 1.0g/kg DM for M+C, and 1.5g/kg DM for threonine. This sample of amino acid contents suggests that there has been very little success or effort in breeding for improved protein quality in both commercial and genetic resources of peas and faba beans over this 22 year period. As with improving protein content, this may be an indication of the selection priorities of plant breeders or a reflection of the difficulties in using classical breeding approaches for improved protein quality e.g. varieties with better protein quality may not have made the recommended list due to poor performance in yield or disease resistance. However, it should be noted that our knowledge and understanding of the genetic and physiological factors that modify the protein content and amino acid composition of peas and faba beans has been rapidly accumulating, and opens up the possibility of using molecular genetic techniques in the future to improve the protein quality of peas and faba beans (de Lumen, 1990).

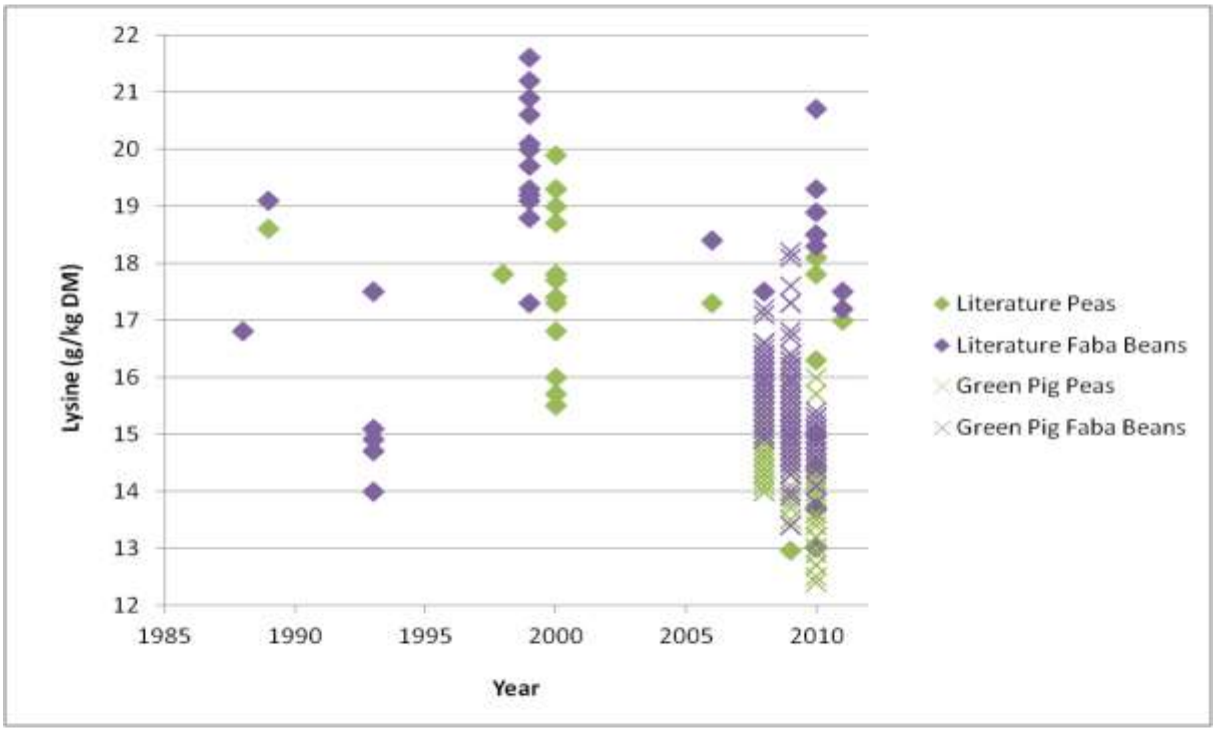

Figure 2. Lysine content (g/kg DM) of peas and faba beans (1988-2011) obtained from the literature[a,b]; and Green Pig samples from harvest 2009-2010[c,d].

[a]'Year' represents the year of publication

[b]National Research Council (1988); INRA (1989); Jansman et al. (1993a); Bastianelli et al. (1998); Duc et al. (1999); Grosjean et al. (2000); Degussa (2006); Zijlstra et al. (2008); Al-Marzooqi and Wiseman (2009); Jezierny et al. (2010b); Nalle et al. (2010); Schumacher et al. (2011)

[c]'Year' represents the harvest year

[d]Commercial varieties of peas and faba beans sampled for the Green Pig Project for 3 harvest years (2008-2010). For each harvest year, a selection of commercial varieties of peas and faba beans were sampled over a maximum of 5 different sites, with a maximum of 5 replicates per site. A total of 95, 74 and 59 pea samples in 2008, 2009 and 2010, respectively. A total of 64, 71 and 41 faba bean samples in 2008, 2009 and 2010 respectively.

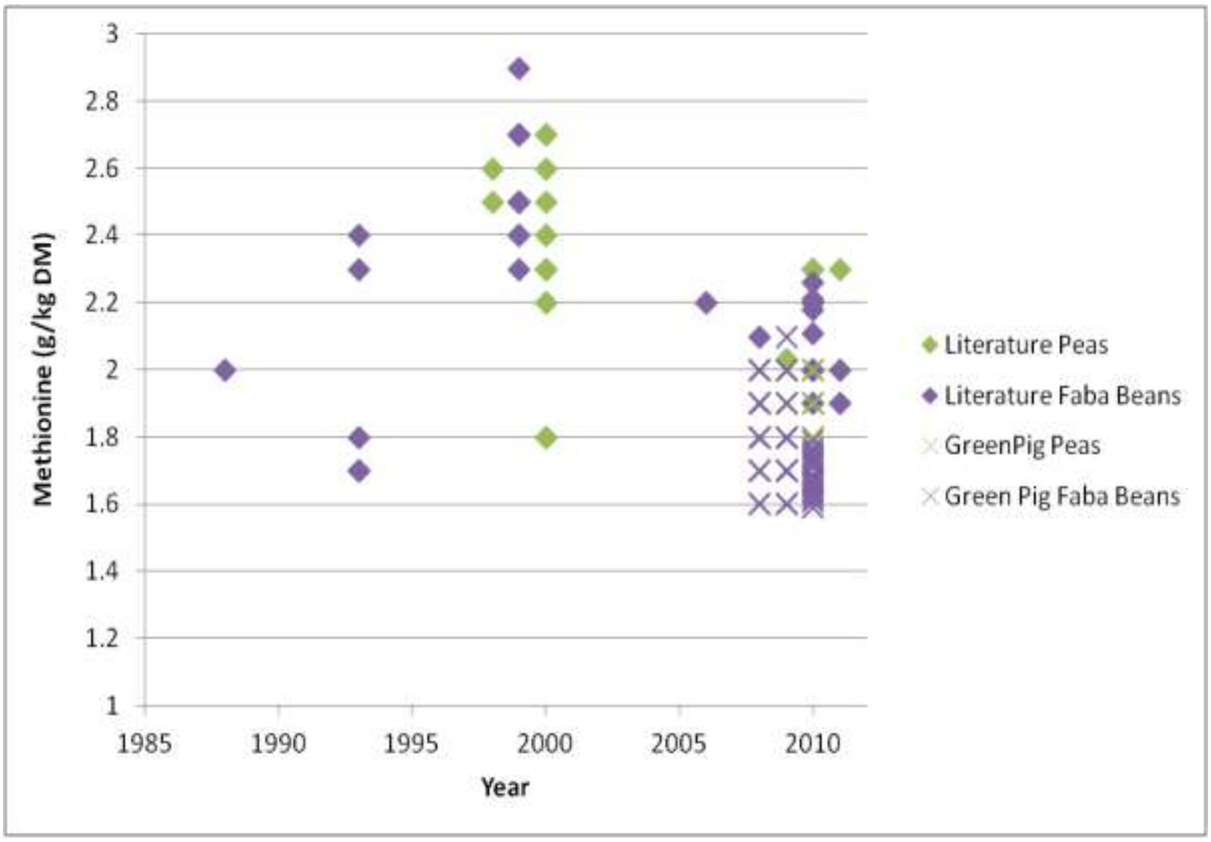

Figure 3. Methionine content (g/kg DM) of peas and faba beans (1988-2011) obtained from the literature[a,b]; and Green Pig samples from harvest 2009-2010[c,d].

[a]'Year' represents the year of publication

[b]National Research Council (1988); Jansman et al. (1993a); Bastianelli et al. (1998); Duc et al. (1999); Grosjean et al. (2000); Degussa (2006); Zijlstra et al. (2008); Al-Marzooqi and Wiseman (2009); Nalle et al. (2010); Schumacher et al. (2011)

[c]'Year' represents the harvest year

[d]Commercial varieties of peas and faba beans sampled for the Green Pig Project for 3 harvest years (2008-2010). For each harvest year, a selection of commercial varieties of peas and faba beans were sampled over a maximum of 5 different sites, with a maximum of 5 replicates per site. A total of 95, 74 and 59 pea samples in 2008, 2009 and 2010, respectively. A total of 64, 71 and 41 faba bean samples in 2008, 2009 and 2010 respectively

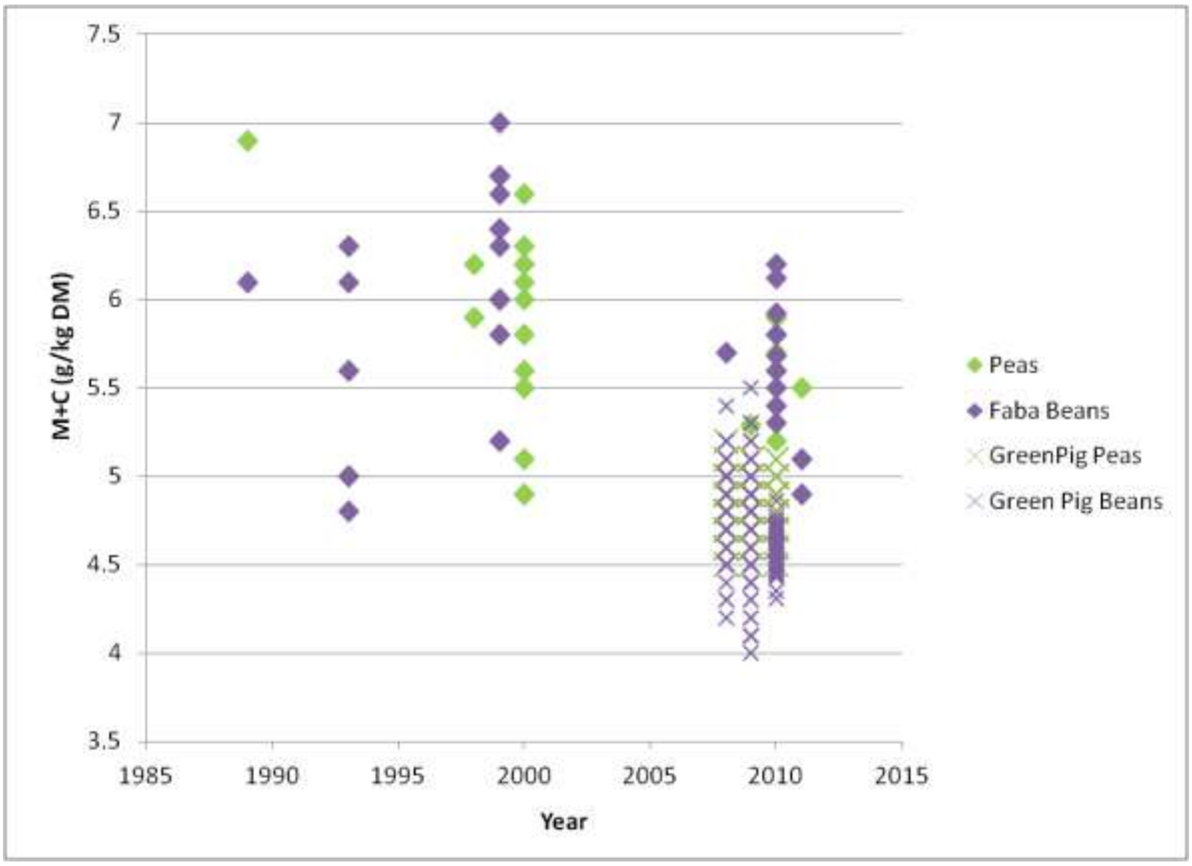

Figure 4. Methionine+Cystine (M+C) content (g/kg DM) of peas and faba beans (1988-2010) obtained from the literature[a,b]; and Green Pig samples from harvest 2009-2010[c,d].

[a]Year' represents the year of publication

[b]Jansman et al. (1993a); Bastianelli et al. (1998); Duc et al. (1999); Grosjean et al. (2000); Zijlstra et al. (2008); Al-Marzooqi and Wiseman (2009); Nalle et al. (2010); Schumacher et al. (2011)

[c]'Year' represents the harvest year

[d]Commercial varieties of peas and faba beans sampled for the Green Pig Project for 3 harvest years (2008-2010). For each harvest year, a selection of commercial varieties of peas and faba beans were sampled over a maximum of 5 different sites, with a maximum of 5 replicates per site. A total of 95, 74 and 59 pea samples in 2008, 2009 and 2010, respectively. A total of 64, 71 and 41 faba bean samples in 2008, 2009 and 2010 respectively.

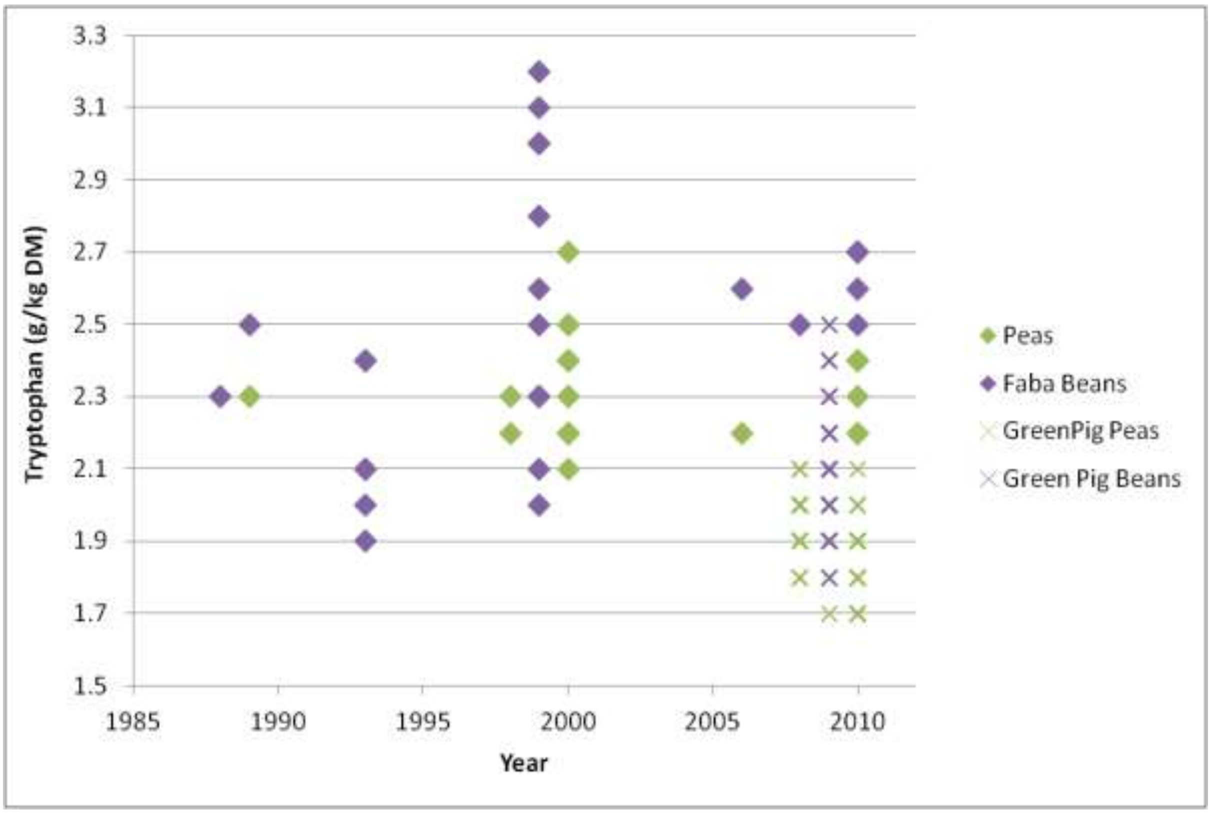

Figure 5. Tryptophan content (g/kg DM) of peas and faba beans (1988-2010) obtained from the literature[a,b]; and Green Pig samples from harvest 2009-2010[c,d].

[a]'Year' represents the year of publication

[b]National Research Council (1988); INRA (1989); Jansman et al. (1993a); Bastianelli et al. (1998); Duc et al. (1999); Grosjean et al. (2000); Degussa (2006); Zijlstra et al. (2008); Jezierny et al. (2010b)

[c]'Year' represents the harvest year

[d]Commercial varieties of peas and faba beans sampled for the Green Pig Project for 3 harvest years (2008-2010). For each harvest year, a selection of commercial varieties of peas and faba beans were sampled over a maximum of 5 different sites, with a maximum of 5 replicates per site. A total of 95, 74 and 59 pea samples in 2008, 2009 and 2010, respectively. There were 71 bean samples from harvest 2009.

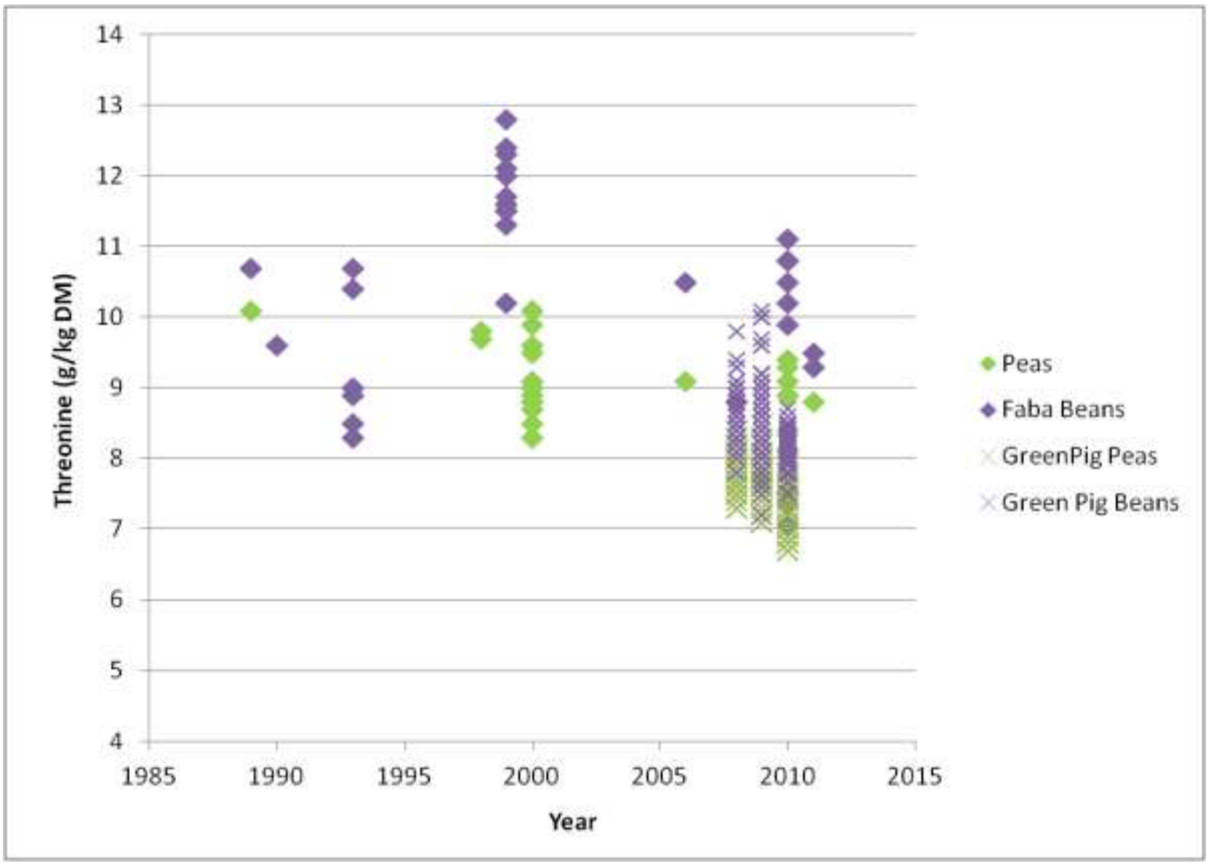

Figure 6. Threonine content (g/kg DM) of peas and faba beans (1988-2010) obtained from the literature[a,b]; and Green Pig samples from harvest 2009-2010[c,d].

[a]Year' represents the year of publication

[b]National Research Council (1988); Jansman et al. (1993a); Bastianelli et al. (1998); Duc et al. (1999); Grosjean et al. (2000); Degussa (2006); Zijlstra et al. (2008); Al-Marzooqi and Wiseman (2009); Nalle et al. (2010); Schumacher et al. (2011)

[c]'Year' represents the harvest year

[d]Commercial varieties of peas and faba beans sampled for the Green Pig Project for 3 harvest years (2008-2010). For each harvest year, a selection of commercial varieties of peas and faba beans were sampled over a maximum of 5 different sites, with a maximum of 5 replicates per site. A total of 95, 74 and 59 pea samples in 2008, 2009 and 2010, respectively. A total of 64, 71 and 41 faba bean samples in 2008, 2009 and 2010 respectively

Antinutritional factors of peas and faba beans

Peas and beans contain a number of substances which are believed to affect both the intake and the utilisation of nutrients which subsequently affects the growth performance of animals These substances are called antinutritional factors (ANFs) and include lectins (or haemagglutinins); the glucosides vicine and convicine; phytate; and saponins. However, the two most important antinutritional factors found in peas and fabe beans which are believed to have the biggest effect on pig performance are trypsin inhibitors and condensed tannins. Thus, here we give a general overview of the ANFs in peas and faba beans but focuses on the two key ANFs, and the success of plant breeding on combating trypsin inhibitors and condensed tannins.

Lectins (or haemagglutinins)

Lectins are a type of protein which has the ability to bind to specific sugars or glycoproteins and cause erythrocyte (red blood cell) agglutination (Liener, 1988), which is why they are often referred to as haemagglutinins. However, the toxic effect of lectins is mainly due to their ability to bind to the epithelial cell lining of the small intestine. This results in damage to the cell wall and subsequently impairment in the absorption of nutrients across the intestinal wall (Liener, 2002). It is also suggested that lectins can modify the immune system of the gut (Pusztai, 1988). However, the lectin activity in legumes can be quite variable. While some legumes, for example kidney beans, have high lectin activity which affects nutritional performance in both humans and livestock, there appears to be low lectin activity for peas and faba beans and relatively few lectin-related toxic effects (Grant et al., 1983). Furthermore, lectins are believed to play a role in the defence mechanisms of legumes, and may aid nitrogen fixation by legumes (Sharon and Lis, 2004), suggesting that the lectins in peas and faba beans may actually be beneficial for their role inn crop rotations.

Vicine and convicine

Vicine and convicine are glucosides that are most notably associated with faba beans, although are present in other grain legumes in low concentrations (Saini, 1993). The main antinutritional effects of these two glucosides are favism (causing haemolytic amaemia) in some genetically susceptible humans (Gupta, 1987; Champ, 2002), and reduced performance in laying hens (Muduuli et al., 1982; Lessire et al., 2005). There are limited studies investigating the antinutritional effects of vicine and convicine on pigs, likely because the effects on pigs appear to be small (Grosjean et al., 2001). Although the importance of vicine and convicine in livestock diets seems to be restricted to laying hens, there has been substantial effort placed on plant breeding to remove these glucosides from faba beans, resulting in the production of low vicine/convicine varieties of faba beans (Duc et al., 1999; Jezierny et al., 2010a). The antinutritional effects in humans may have been a key driver in the breeding effort to deliver these low vicine/convicine varieties. However, it is also unknown to what extent these varieties are available commercially.

Phytate

Phytate (the salt of phytic acid) is the principal storage form of phosphorus in plants. The anitnutitional properties of phytate are due to its ability to form chelates with metal ions such as calcium, magnesium zinc and iron. The resultant compounds are not easily absorbed from the intestine, thus affecting the bioavailability of minerals (Liener, 1988). From a nutritional point of view the effect of phytate is not severe since minerals can often be added as a feed supplement. However, the indigestible nature of the phytate phosphorus is more problematic for phosphorus pollution. The enzyme phytase has the capability to reduce phytates effect on both the bioavailability of minerals and phosphorus pollution. Monogastrics lack phytase and must rely on naturally occurring phytase from plants. However, supplementation of feed with microbial phytase (from *Aspergillus ficuum*) can reduce the antinutritional effects of phytate (Cromwell et al., 1993).

Saponins

Sapinins are glucosides which have a bitter or astringent taste (Curl et al., 1985; Liener, 1988). Additionally they can increase the permeability of the small intestine mucosal cells resulting in an inhibition of active nutrient transport across the intestinal wall (Johnson et al., 1986). However, it should be noted that concentrations of saponins in peas and faba beans are generally low. Furthermore, despite the bitter taste, they do not appear to restrict intake of feed in monogastrics (Castell et al., 1996; Francis et al., 2002).

Trypsin Inhibitors

Trypsin inhibitors (TIs) are peptides which are capable of forming complexes with the proteolytic enzymes (trypsin and chymotrypsin) secreted by the pancreas, which are required for the digestion of protein. There are two types of trypsin inhibitors, the Künitz trypsin inhibitors (associated with soya beans) and the Bowen-Birk trypsin inhibitors, which are found in peas and faba beans (Castell et al., 1996). The antinutritional effect from TIs is a reduction in protein digestibility and subsequently a reduction in growth performance. The pancreas responds to this poor protein digestibility by producing more trypsin/chemotrypsin, causing pancreatic hypertrophy. However, trypsin and chemotrypsin are rich in the sulphur-containing amino acids, thus increased pancreatic activity will create an even greater demand for methionine and cystine (Le Guen and Birk, 1993). A diet containing peas and faba beans which are already deficient in methionine may therefore enhance this problem.

The trypsin inhibitor activity (TIA) of peas measured in trypsin inhibitor units (TIU) ranges from 0.38 TIU/mg DM to 15 TIU/mg DM (Figure 7). Within the pea itself, the trypsin inhibitors are mainly located in the cotyledons which contain approximately thirteen times more TIA than the hulls (Valdebouze and Gaborit, 1985). The TIA content appears to have a strong genetic link, with smooth peas having a higher TIA than wrinkled varieties (Valdebouze and Gaborit, 1985; Castell et al., 1996). Furthermore, winter varieties have higher TIA than spring varieties (Valdebouze et al., 1980; Grosjean et al., 1993; Castell et al., 1996). It should be noted that TIA of peas can also show high intra-varietal variation depending on growing conditions (Valdebouze and Gaborit, 1985; Leterme et al., 1992). The TIA of faba beans is generally lower than peas, ranging between 0.30 TIU/mg DM and 7.41 TIU/mg DM (Figure 7).

There has been some effort to classify low and high legume TIA activity and quantify levels of TIA which will not affect pig performance. Leterme et al. (1992) defines low TIA legumes as below 4 TIU/mg DM, and high TIA legumes as above 6 TIU/mg DM. Grosjean et al. (1993) suggest that seeds with TIA of below 5 TIU/mg DM would not affect pig performance. Using data on TIA activity extracted from the literature (1974-2010), 55% and 91% of the figures on trypsin inhibitor content for peas and faba beans respectively are below 5 TIU/mg DM (Figure 7). This suggests that the trypsin inhibitor content of faba beans has not been a constraint for their use in pig diets, and as such there is little need for breeding programmes to reduce trypsin inhibitors in faba beans. This is further illustrated in Figure 7 where there appears to be no reduction in the TIA of faba beans from 1974 to 2010. In contrast, levels of trypsin inhibitors in peas are more problematic. Figure 7 suggests that there has been a slight reduction in the trypsin inhibitor figures for peas from the literature. However, it should be recognized that figures obtained from the literature will be subject to a time lag between the use of a variety in a study and the subsequent publication of the work. Thus, when the Green Pig commercial varieties from harvests 2009 and 2010 are included, the reduction in TIA is illustrated more dramatically, with 98% of the Green Pig samples having trypsin inhibitor contents below 5 TIU mg DM (Figure 7). Nonetheless, any trypsin inhibitor effect on performance is more likely to be due to the TIA of the whole diet as a result of pulse inclusion level, rather than the TIA of individual peas and faba beans. Batterham et al. (1993) found chickpea meal and pigeon pea meal with a TIA activity of 11.7 TIU mg DM and 9.1 TIU mg DM, respectively included in diets at 75%, resulted in the diet TIA activity of up to 8.93 TIU mg DM, and did not affect the performance of growing pigs. Given these high inclusion rates of the meal, the suggested TIA level of below 5 TIU mg DM for peas and faba beans seems appropriate for commercial inclusion levels, and is unlikely to affect pig performance due to trypsin inhibitors.

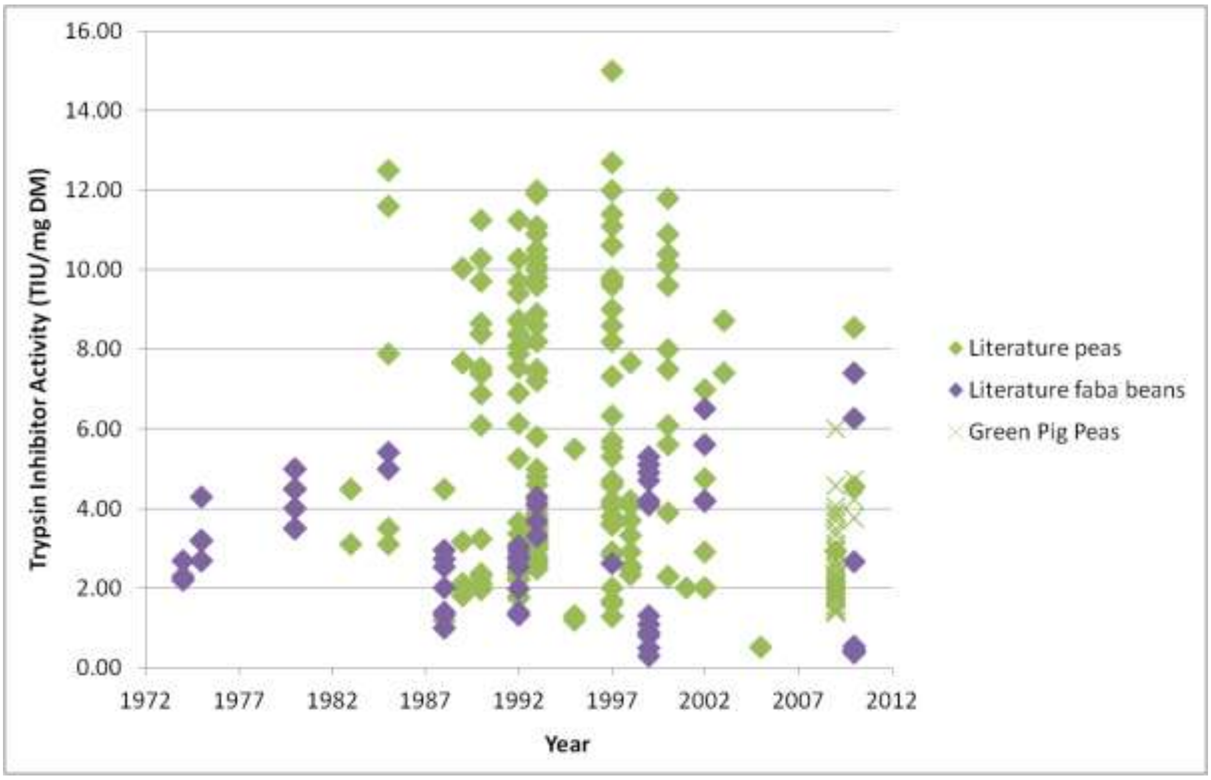

Figure 7. Trypsin Inhibitor Activity (TIA) (TIU/mg DM) of peas and faba beans (1974-2010) obtained from the literature[a,b]; and Green Pig pea samples from harvests 2009-2010.

[a] 'Year' represents the year of publication

[b] Marquardt et al. (1975); Valdebouze et al. (1980); Pisulewski et al. (1983); Valdebouze and Gaborit (1985); Jansman et al. (1988, 1993b); Boisen (1989); Leterme et al. (1989, 1990, 1992); van der Poel et al. (1992a; 1992b); Grala et al. (1993); Grosjean et al. (1993, 2000); Le Guen et al. (1995); Cousin (1997); Vidal-Valverde et al. (1997); Zdunczyk et al. (1997); Wang et al. (1998b); Duc et al. (1999); O'Doherty and Keady (2001); Mariscal-Landin et al. (2002); Salgado et al. (2002); Wiseman et al. (2003); James et al. (2005); Al-Marzooqi and Wiseman (2009); Jezierny et al. (2010b); Nalle et al. (2010)

[c]'Year' represents the harvest year

[d]Commercial varieties of peas samples for the Green Pig project for 2 harvest years (2009-2010). For 2009 a selection of peas were samples over 2 different sites giving a total of 47 samples. For 2010, 3 varieties were selected from 1 site.

Condensed Tannins

Tannins are a group of polyphenolic compounds which are capable of interacting with proteins (Jansman, 1993). Tannins can be divided into two main groups, hydrolysable tannins and condensed tannins (complex flavonoid polymers). In terms of monogastric nutrition, condensed tannins are the most important of the two groups, and are the principal phenolic compounds found in peas and faba beans (Marquardt et al., 1977; Al-Marzooqi and Wiseman, 1998). The antinutritional effect of tannins is due to their ability to form insoluble enzyme-resistant complexes with proteins and carbohydrates, consequently decreasing the digestibility of proteins and carboydrates (Liener, 1988). In addition to inhibiting digestion, tannins are also associated with an astringent taste, which is attributed to tannins ability to bind with the protein in saliva (Wang et al., 1998b), and thus potentially reductions in feed intake.

Genetic selection for tannin free varieties of peas and faba beans is relatively easy as the tannin-free trait is associated with white coloured flowers (Cabrera and Martin, 1989). Moreover, tannins have already been removed from peas, with most commercially available varieties being white flowered (Bond and Duc, 1993). However, tannins are associated with plant defence, and are positively correlated with resistance to microbial infestation and predation (Mehansho et al., 1987; Jansman, 1993). For peas, any susceptibility to pathogens has been overcome mainly by use of chemical fungicides (Bond and Duc, 1993). However, this may be more problematic in organic systems where fungicides need to be avoided.

In contrast to peas, there are both high tannin coloured flowered and low tannin white flowered varieties of faba beans commercially available. There have been many different assays used to estimate the tannin content in plants and the results of the different methods often do not correlate which each other (Bos and Jetten, 1988), making it difficult to compare the tannin content of different faba beans analysed by different assays. One of the most common methods of analysing condensed tannins in the literature is the vanillin-sulphuric acid assays (Mehansho et al., 1987; Jansman, 1993). Thus in order to obtain the most data on condensed tannin content of faba beans, data was only collected from the literature where the vanillin-sulphuric acid assay was used. Within the Green Pig project, the condensed tannin content of 7 varieties of commercial faba beans was measured (Massey O'Neill et al. 2012), however the data is not included here as the HCI-butanol and Thiolysis assay's were used. Figure 8 illustrates the condensed tannin content of faba beans obtained from the literature from 1988 to 2010 using the vanillin-sulphuric acid assay. The condensed tannin content of coloured flowered faba beans ranges between 2.1 to 13.1 mg catechin equivalents/g (Figure

8). In these coloured flowered faba beans, the majority of the condensed tannins are found in the seed coat (Marquardt et al., 1978; van der Poel et al., 1992a). The condensed tannin content of white flowered faba beans is much lower than the coloured flowered faba beans and ranges between 0.1 to 1 mg catechin equivalents/g (Figure 8). There is a preference for using these white flowered low tannin varieties in pig feed, as both the digestibility of crude protein (van der Poel et al., 1992a; Grala et al., 1993; Jansman et al., 1995) and amino acids (Grala et al., 1993) has been found to be higher than the high tannin coloured faba bean. However, low tannin white flowered faba beans are associated with poor emergence caused by a higher susceptibility to disease (van Loon et al., 1989; Kantar et al., 1994, 1996), which subsequently reduces yields. Poor emergence can be rectified by fungicidal seed dressing (Kantar et al., 1994). Although, this approach has been successful for white flowered peas, there is still some uncertainty over the economics of this for faba beans, and plant producers grow more high tannin coloured flowered faba beans than low tannin white flowered faba beans (Duc, 1997). Thus, availability of low tannin faba beans for use in pig feed can often be problematic. However, when considering the tannin content of coloured flowered faba beans there appears to be a reduction in the condensed tannin content of these varieties from 1988 to 2010 (Figure 8). This apparent reduction in tannin content may an artefact of the wide range of tannin analysis used in different studies, resulting in a small sample of these studies used here. This may also be a real effect that has occurred due to plant breeding objectives to reduce the tannin content of coloured flowered varieties whilst maintaining plant defence traits. If this is a real effect, then it is possible that these varieties, which are more readily available than white flowered faba beans, may be included in pig feed at higher inclusion levels than previously thought.

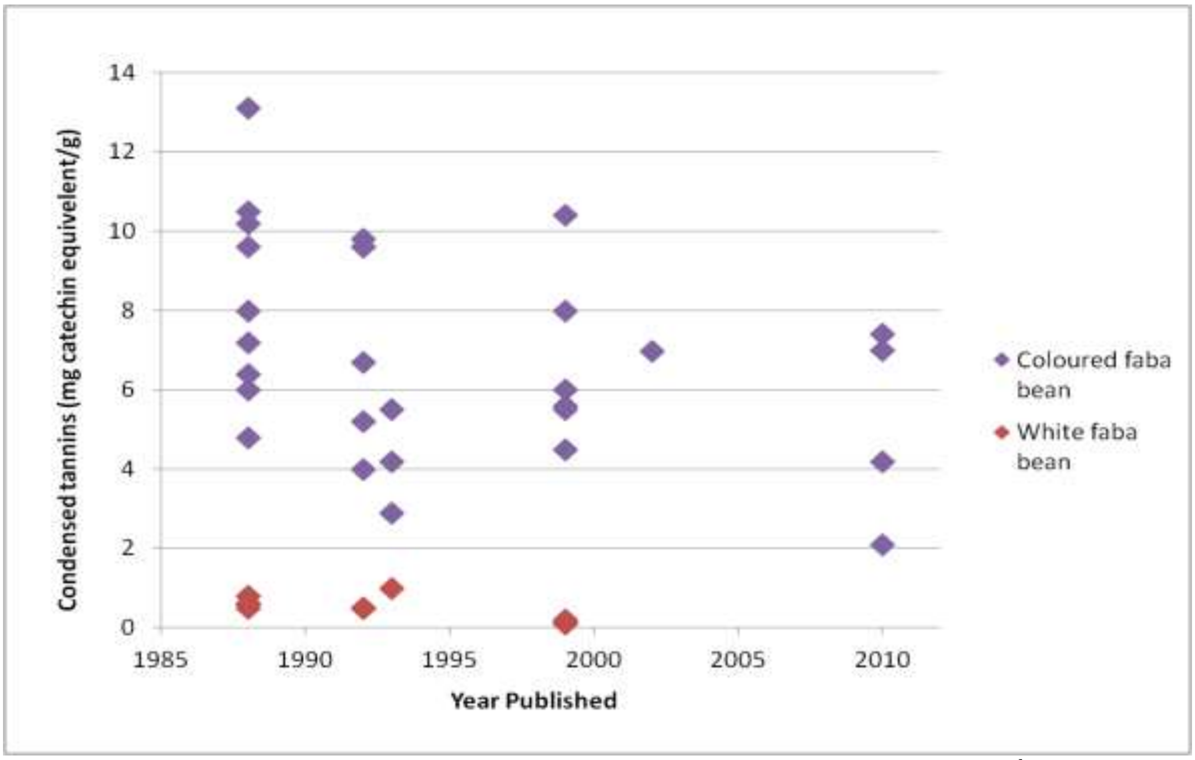

Figure 8. Condensed tannin content of faba beans obtained from the literature[a,b] (1988-2010)
[a] All figures obtained from the literature were analysed by the vanillin-sulphuric acid assay
[b] Bos and Jetten (1988); Jansman et al. (1989; 1993b); van der Poel et al. (1992a; 1992b); Grala et al. (1993); Duc et al. (1999); Jezierny et al. (2010b)

Processing of peas and faba beans for use in pig diets

In order to reduce the effects of the ANFs in peas and faba beans, there are several processing technologies available which may improve the nutritional value of these legumes for use in pig feed. The main processing technologies available can be divided in mechanical or physical processing and heat treatments.

Physical processing

Since the tannins in faba beans are mainly found in the seed hulls, the physical processing method of dehulling has been found, as could be expected, to significantly reduce the tannin concentration (van der Poel et al., 1991). However, it should be noted that the hull portion of faba beans are also higher in the nutritionally limiting sulphur amino acids (Marquardt et al., 1975) and thus dehulling may result in a further reduction in these essential amino acids. In contrast, the main ANF associated with peas, trypsin inhibitors are concentrated in the cotyledon portion of the seed (Valdebouze and Gaborit, 1985) and dehulling is associated with an increase in trypsin inhibitors in both peas and faba beans (Melcion and van der Poel, 1993). Furthermore, the cost of dehulling must also be considered, including finding a use for the hulls once separated, and any nutritional benefits gained from dehulling may prove to be uneconomical.

Heat Treatments

Heat treatments can be considered for reduction or inactivation of heat-sensitive ANFs such trypsin inhibitors, which are denatured by heat processing. Tannins are only partially heat-sensitive and heat processing will only result in a small reduction (Melcion and van der Poel, 1993). However, heat treatments are also associated with changes in the storage proteins which subsequently increase amino acid digestibility (van der Poel et al., 1991). There are numerous methods of heat treatment including dry heating, steam pelleting, extruding, micronization, expanding and autoclaving, which have varying degrees of success in improving the feeding value of peas and faba beans. Some improvements in peas and faba beans associated with heat treatments are a reduction in TIA in both peas and faba beans due to dry heating (Griffiths, 1984; Vidal-Valverde et al., 1997) and autoclaving (Griffiths, 1984). Studies have shown an improvement in amino acid digestibility due to extrusion (O'Doherty and Keady, 2000, 2001; Mariscal-Landin et al., 2002) and micronization (Nyachoti et al., 2006). An increased performance has also been associated with extrusion (Myer and Froseth, 1993; O'Doherty and Keady, 2001) and stem pelleting (Myer and Froseth, 1993). In contrast, other experiments showed no improvement in performance after extrusion (Owusu-Asiedu et al., 2002; Prandini et al., 2005; Stein et al., 2010) or micronization (Owusu-Asiedu et al., 2002) or expansion (O'Doherty and Keady, 2001). The reason for the different responses to heat treatments of peas and faba beans are not clear. However, as with physical processing there is an economic cost associated with the processing of peas and faba beans with heat treatments which may limit the use of these heat treatments in commercial diets.

Growth performance

Grower and finisher pigs

The use of legumes such as peas and faba beans as an alternative protein source in grower and finisher pig diets has long been considered (Table 1). However, early growth trials testing the inclusion of peas and faba beans in grower and finisher pig diets, suggested that inclusion of these pulses in diets greater than 150-200 g/kg has a negative effect on performance (Castell, 1976; Aherne et al., 1977). Thus, risk management during formulation of pig diets has resulted in either low inclusion levels of peas or faba beans, or complete avoidance of using these alternative protein sources in pig diets. Edwards et al. (1987) also found inclusion of peas above 150 g/kg reduced performance of growing and finishing pigs. However, chemical analysis of the diets indicated that the feeding value of peas were overestimated. A subsequent trial using 30% peas in a corrected formulation resulted in no detrimental effect on performance suggesting peas could be used in grower and finisher pig diets at higher inclusion levels as long as special care is taken over formulation to ensure the nutrient requirements of pigs are met. This is in contrast to a number of more recent studies which demonstrated reduced performance in the grower stage for diets with high inclusions of peas (O'Doherty and Keady, 2000, 2001) and faba beans (O'Doherty and McKeon, 2001; Partanen et al., 2003). However, it should be noted that these diets were not formulated to ensure that deficiencies of both methionine and tryptophan in the peas and faba beans did not limit performance. Furthermore, Stein et al., (2004, 2006) demonstrated that when diets were balanced for indispensible amino acids there were no negative affects on performance. Recent advances in feed formulation such as the introduction of standardized ileal digestibility (SID) and the net energy (NE) allow the bioavailability of each of the dietary amino acids and the energy value of the feeds can be more accurately assessed (Noblet and van Milgen, 2004; Stein et al., 2005). Therefore, it should be possible to formulate nutritionally balanced pea and faba bean diets which can meet the requirements of grower and finisher pigs whilst ensuring that performance is unaffected. However, there are currently no studies testing the effect of high inclusion nutritionally balanced faba bean diets on the performance of grower and finisher pigs.

Table 1. Performance trials with peas and faba beans in the diets of growing and finishing pigs (30-110kg).

Reference	Min inclusion (g/kg)	Max inclusion (g/kg)	Max inclusion for no impairment on performance (g/kg)	
			Grower	Finisher
Peas				
Castell (1976)	150	150	150	150
Edwards et al. (1987)	150	450	150	
	300	300	300	
O'Doherty and Keady (2000)	200	400	200	200
Shelton et al. (2001)	671.6	671.6	*	671.6
O'Doherty and Keady (2001)	400	400	*	*
Stein et al. (2004)	120	360	360	360
Stein et al. (2006)	360	660	660	660
Faba beans				
Castell (1976)	75	300	150	150
Aherne et al. (1977)	100	300	200	200
O'Doherty and McKeon (2001)	250	375	*	375
Partanen et al. (2003)	137	317	197	317

*****Performance impaired at all inclusion levels tested

Starter Pigs

As the Green Pig project is primarily concerned with the use of peas and faba beans in grower and finisher pig diets, the use of peas and faba beans in starter diets have not been considered within the project. However, for completeness, here we review the literature detailing performance trials with peas and faba beans in the diets of starter pigs (10-30kg). The use of peas and faba beans in starter diets was not considered until almost a decade after the first studies investigating their use in grower and finisher pigs (Table 2). It has generally been believed that peas and faba beans can not be used in starter diets as young pigs are more sensitive to ANFs (Jansman et al., 1989) and indeed the initial studies have shown very poor performance for starter pigs fed both pea (Bengala Freire et al., 1989; Gatel et al., 1989; Jondreville et al., 1992) and faba bean (Fekete et al., 1985; Skiba, 2000) diets. However, more recent studies have shown that if diets are properly balanced for amino acids it is possible to include peas at far higher levels than previously thought (Owusu-Asiedu et al., 2002; Stein et al., 2004; Prandini et al., 2005; Brooks et al., 2009). Given this evidence, Stein et al. (2010) tested to what extent starter pigs could tolerate peas in nutritionally balanced diets by conducted a dose response experiment including peas up to 600 g/kg. The results suggested that diets including peas up to 360 g/kg did not affect starter performance; however there was a reduction in performance at greater inclusions that could not be attributed to a deficiency in amino acids. As with grower and finisher performance studies, there are no studies testing the effect of high inclusion nutritionally balanced faba bean diets on the performance of starter pigs.

Table 2. Performance trials with peas and faba beans in the diets of starter pigs (10-30kg).

Reference	Min inclusion (g/kg)	Max inclusion (g/kg)	Max inclusion for no impairment on performance (g/kg)
Peas			
Gatel et al. (1989)	300	300	*
Bengala Freire et al. (1989)	150	450	*
Jondreville et al. (1992)	400	400	*
Owusu-Asiedu et al. (2002)	350	350	350
Stein et al. (2004)	60	180	180
Prandini et al. (2005)	200	200	200
Brooks et al. (2009)	200	200	200
Stein et al. (2010)	120	600	360
Faba beans			
Fekete et al. (1985)	100	300	100
Skiba (2000)	80	200	*

*****Performance impaired at all inclusion levels tested

Conclusions

In conclusion, there appears to have been little improvement of pea and faba bean protein quality for use in pig feed, and commercial varieties of peas and faba beans are still deficient in the amino acids methionine, tryptophan and threonine. In contrast, plant breeding appears to have had a slightly greater impact on the ANFs present in peas and faba beans. The TIA of peas has been gradually decreasing over the years, with many current varieties having a TIA below that which is expected to affect pig performance. Plant breeding has also led to many low tannin white flowered varieties of faba beans, while the tannin content of coloured flowered faba beans also appears to have reduced. However, this reduction in ANF's is not commensurate with the greater inclusion levels of peas that are possible in when diets are nutritionally balanced for amino acid requirements. Although further research is required to determine if high inclusion nutritionally balanced faba bean diets detrimentally affect the performance of growing and finishing pigs, this indicates that as long is special care is taken during formulation, peas (and potentially faba beans) are a viable home grown protein source for use in grower and finisher pig diets.

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Full report Objective 5a: Small scale experiments. N-balance.

Lead authors: Julian Wiseman, Gavin White (UoN)

Executive summary

- Four iso-energetic diets balanced for standard ileal digestible lysine were formulated to contain home grown legumes at 30%. Diets were based on peas (Prophet), two cultivars of field beans (Fuego: spring, coloured; Tattoo: white;) and soya bean meal 48 (as the only plant protein source at 14% in grower diets and 12% in finisher diets).
- Each diet was fed to four replicate entire male pigs individually housed in metabolism crates of initial weight 30kg (grower) and a new batch of initial weight 55kg liveweight (finisher) in a 4*4 Latin Square design.
- Analysis of N concentrations in diet and quantitatively collected urine and faeces allowed the calculation of the coefficient of apparent nitrogen digestibility / retention.
- The results showed that treatment had no effect on coefficient of nitrogen digestibility / retention and faecal dry matter contents
- In conclusion, the cultivars of peas and field beans evaluated may be included safely at a rate of inclusion of 30% in iso-energetic diets balanced for standardised ileal digestible lysine, methionine, threonine and tryptophan fed to growing / finishing pigs with no detrimental effects on nitrogen digestibility / retention and faecal dry matter concentration; thus it could be suggested that slurry from animals fed home-grown legumes will not be any different from that arising from the use of soya bean meal as the only plant protein source.

Introduction

The risk of nitrogen leaching from farming systems is considerable and these concerns should also be viewed within the context of the potential for a governmental imposition of a ‘nitrogen tax’ to protect the environment; the development of ‘nitrate vulnerable zones’ is clear evidence of how environmental legislation is impacting on pig production systems. The continued importing of a significant tonnage of protein crops into the UK represents a significant contribution to nitrogen loading of the environment and considerable energy expenditure associated with these imports. It is for these reasons that there is now much interest in using home-grown legumes in compound pig diets. However, for such interest to lead to actual increased usage there needs to be detailed information on nutritional value. The objective of the current trial was to report N balance of diets based on soya bean meal or home-grown legumes fed to growing / finishing pigs fed the same diets as were evaluated in the parallel performance trial (objective 5c).

Method and Materials

Because of resource limitations, only four diets were employed being those containing soya bean meal, peas and the field beans Fuego and Tattoo. Animals were fed the same diets as were evaluated in the parallel performance trial (Objective 5c). Full details of diets are given in the Report on Objective 5c. Each diet was fed to 4 entire male pigs (commercial white hybrid) over 4 collection periods. Each pig was allocated 4 diets over the course of the experimental programme. Thus the design was a 4 x 4 Latin Square.

Diets (pelleted) were offered on a restricted basis, in relation to live weight, two meals per day (see Appendix 1). At feeding, diets were mixed in the approximate proportions water:food 2:1 to avoid dust and spillage. Water was available *ad libitum* from nipple drinkers located in each pen and metabolism crate. Animals of around 25-30kg live weight (grower) were obtained and individually ear-tagged. They were weighed individually and housed individually in the appropriate numbered pen. On completion of the grower phase, procedures were repeated with a second batch of pigs of initial weight 50-55kg (finisher).

Initially, pigs were acclimatised to the twice daily restricted regime, with amounts based on the initial live weight from the moment they are housed. Thus were given the appropriate feed allowance of a standard commercial diet and given <u>one</u> hour to consume this. The protocol also included the following statement: after this time, any remaining food was removed, dried and weighed and discarded. However, during the actual collections, no feed refusals were recorded as pigs consumed all feed at each meal.

Following 5 days of this procedure, the animals were weighed and the experimental diets introduced. On day 12 of the trial, pigs were transferred into metabolism crates. Indigo carmine was added as a dye to the evening meal (at 5g/kg diet). Urine output was quantitatively collected starting at 08.30 the following morning. Collection vessels contained 25ml of 50% v/v sulphuric acid to prevent any evaporative N losses.

Daily urine output was assessed for pH; it was then weighed and a 1% sub sample taken and stored in a 250ml pot, labelled for each pig. The pH of this sample was measured and the sample was frozen. The daily sub sample was placed into the same pot. Remaining urine was discarded.

Faecal collection started on appearance of blue dye in a faecal sample. Faeces were collected quantitatively and placed into a bag, labelled for each pig. Pigs were checked at regular intervals during the day and any faecal output placed into the appropriate bag which was kept frozen.

Urine collection ceased at 08.30 on the morning following addition of indigo carmine to the evening feed and the faecal collection on reappearance of dye in a faecal sample. Thus, faecal output was related to 10 meals (See Figure 1 for summary of total collection procedure). Once all faecal collections had been completed, animals were weighed and transferred to holding pens and the next trial diets allocated at the appropriate level of intake.

At the end of a collection period, faecal samples were thawed overnight, weighed accurately and homogenised in a bakers mixer. Two samples per pig were removed and placed into two 200ml plastic pots (with the weight of added faeces recorded). One pot was frozen dried and the other stored in a freezer.

Diets, faeces and urine were analysed for nitrogen content; and diets and faeces for dry matter. These laboratory analyses allowed the calculation of the coefficients of apparent nitrogen digestibility / retention and faecal dry matter.

Results and Discussion

Diet codes for both grower and finisher are presented in tables 1 and 2 respectively. Mean pH values are presented in Table 3; mean values were always <4.0 and significantly higher (P<0.001) in the finisher phase. There was also a significant (P<0.001) effect of diet with pigs on the control diet (based on SBM) having a higher pH suggesting that these pigs consumed more water (and hence increased volume of urine voided).

Coefficients of apparent nitrogen digestibility retention and faecal dry matter are presented in Tables 4A and 4B respectively for grower and finisher phases. There was no effect of treatment on any of these measurements. This is probably as expected as diets were iso-energetic and, more importantly, balanced for standardised ileal digestible lysine, methionine, threonine and tryptophan. It should be noted that the N balance data (g/day) is included to enable evaluation across dietary treatments and cannot be extrapolated to calculate other measures (e.g. lean meat gain). Table 5 presents raw nitrogen balance data for those interested in subsequent calculations.

The lack of differences in faecal dry matter content is a useful observation given the historically perceived view that pigs fed a diet high in legumes produce faeces with a lower dry matter content. Additionally, there have been suggestions that high levels of field beans can lead to constipation that assumes a higher faecal dry matter content (Pig Progress p 17, vol 28, part 3, 2012). The faecal dry matter results of the current trial do not support these hypotheses.

Table 1. Diets / codes – Grower

GO	GP	GF	GT
1	2	3	4

Table 2. Diets / codes - Finisher

FO	FP	FF	FT
1	2	3	4

GO (Grower diet Soya), GP (Grower Prophet), GF (Grower Fuego), GT (Grower Tattoo)

FO (Finisher Soya), FP (Finisher Prophet), FF (Finisher Fuego), FT (Finisher Tattoo)

Table 3. pH of urine samples

Grower

Diet		Day 1	Day 2	Day 3	Day 4	Day 5	Mean
1	GO	2.7	2.2	2.9	3.0	2.9	2.7
2	GP	2.6	2.2	2.2	2.6	2.5	2.4
3	GF	2.3	2.6	2.1	2.4	2.6	2.4
4	GT	2.5	3.2	2.7	2.4	2.8	2.7
Mean		2.5	2.6	2.5	2.6	2.7	2.6

Finisher

Diet		Day 1	Day 2	Day 3	Day 4	Day 5	Mean
1	FO	3.7	3.3	3.0	3.8	3.4	3.4
2	FP	2.8	2.7	2.9	3.0	2.8	2.8
3	FF	3.0	2.5	3.1	2.7	3.0	2.9
4	FT	3.6	2.6	3.1	3.2	3.0	3.1
Mean		3.3	2.8	3.0	3.2	3.1	3.1

Analysis of variance for urine pH analysis

	Diet	Time	Diet*Time	
P	<0.001	<0.001	0.46	
s.e.d.	0.11	0.08	0.16	
cv%				8.9

Grand mean 2.8

Diet			
1	2	3	4
3.1	2.6	2.6	2.9

Time (G vs F)	
1	2
2.6	3.1

	Time (G vs F)	
Diet	1	2
1	2.7	3.4
2	2.4	2.8
3	2.4	2.9
4	2.7	3.1

Table 4A. Grower: Coefficient of apparent nitrogen digestibility and retention

	Experimental diets						
	1	2	3	4	SED	P	CV%
Coefficient N Dig	0.832	0.809	0.785	0.790	0.0246	0.264	4.3
Coefficient N Retn	0.533	0.535	0.535	0.501	0.0540	0.905	14.5
Faecal DMg/kg	312	324	332	332	21.4	0.769	9.3

Table 4B. Finisher: Coefficient of apparent nitrogen digestibility and retention

	Experimental diets						
	1	2	3	4	SED	P	CV%
Coefficient N Dig	0.795	0.770	0.762	0.787	0.0211	0.416	3.8
Coefficient N Retn	0.512	0.501	0.471	0.511	0.0388	0.704	11.0
Faecal DM g/kg	299	317	317	315	19.6	0.756	8.9

Table 5a. Raw nitrogen balance data per collection (ie 10 meals) in grower pigs

Collection	Pig	Diet		Feed in (g)	N in (g)	N Out (g)		N retained (g)
		Code	Number			Faeces	Urine	Per day
1	1	GO	1	8000	237.3	44.3	95.2	19.6
1	2	GP	2	8000	212.1	42.2	81.5	17.7
1	3	GF	3	8000	217.7	57.2	47.0	22.7
1	4	GT	4	8000	226.0	64.6	56.3	21.0
2	1	GT	4	11100	313.6	61.8	78.0	34.8
2	2	GO	1	10000	296.7	39.5	61.4	39.2
2	3	GP	2	10000	265.1	51.1	43.3	34.1
2	4	GF	3	10000	272.1	50.3	58.8	32.6
3	1	GF	3	11700	318.3	65.1	93.3	32.0
3	2	GT	4	11700	330.5	58.7	119.4	30.5
3	3	GO	1	11700	347.1	70.2	101.8	35.0
3	4	GP	2	11700	310.1	57.5	88.6	32.8
4	1	GP	2	12800	339.3	63.5	89.4	37.3
4	2	GF	3	12800	348.3	72.5	96.1	35.9
4	3	GT	4	12800	361.6	64.5	107.5	37.9
4	4	GO	1	12800	379.7	57.0	112.4	42.1

Table 5b. Raw nitrogen balance data per collection (ie 10 meals) in finisher pigs

Collection	Pig	Diet		Feed in	N in	N Out (g)		N retained (g)
		Code	Number	(g)	(g)	Faeces	Urine	Per day
1	1	FO	1	11700	314.5	65.2	63.6	37.1
1	2	FP	2	11700	295.5	68.4	87.3	28.0
1	3	FF	3	11700	315.8	82.2	105.8	25.5
1	4	FT	4	11700	313.6	72.8	69.7	34.2
2	1	FT	4	12800	343.0	81.5	95.6	33.2
2	2	FO	1	12800	344.0	83.3	94.7	33.2
2	3	FP	2	12800	323.2	80.4	67.7	35.0
2	4	FF	3	12800	345.5	89.0	83.5	34.6
3	1	FF	3	13300	359.0	87.6	104.2	33.4
3	2	FT	4	13300	356.4	81.1	124.3	30.2
3	3	FO	1	13300	357.5	65.9	130.4	32.3
3	4	FP	2	13300	335.9	73.8	94.8	33.5
4	1	FP	2	16000	404.1	88.9	116.5	39.7
4	2	FF	3	16000	431.8	81.8	128.2	44.4
4	3	FT	4	16000	428.8	65.9	110.3	50.5
4	4	FO	1	16000	430.1	80.1	125.1	45.0

Figure 1. Summary of total collection principle

Day/Time	Meal	Faecal collection	Urine collection
1 (pm) Dye			
2 (am)	1	START when dye appears	START at 08:30
2 (pm)	2		
3 (am)	3		
3 (pm)	4		
4 (am)	5		
4 (pm)	6		
5 (am)	7		
5 (pm)	8		
6 (am)	9		
6 (pm) Dye	10		
7 (am)		STOP when dye appears	STOP 08:30
		Faecal output relates to TEN meals	Urine output relates to FIVE days

Appendix 1. Feed Scale appropriate for restricted feeding

Calculation of the daily amount to be offered is based on the current estimate for DE requirements (2.621 x Liveweight$^{0.63}$), the estimated DE value of the diet (14.0 MJ/kg as fed) and the degree of feed restriction imposed (90%). The following amounts will be offered:

Live weight	Calculated daily intake	Amount to be offered (twice daily)
30	1.44	0.72
35	1.58	0.79
40	1.72	0.86
45	1.85	0.93
50	1.98	0.99
55	2.10	1.05
60	2.22	1.11
65	2.34	1.17
70	2.45	1.22
75	2.56	1.28
80	2.66	1.33
85	2.77	1.38
90	2.87	1.43
95	2.97	1.48
100	3.07	1.53
105	3.16	1.58

Full report Objective 5b1: Effect of gradually replacing soya bean meal with peas or faba beans in grower and finisher pig diets on performance and carcass quality.

Lead authors: Lesley Smith and Jos Houdijk (SRUC)

(please note this is written in style for submission to Journal of Animal Science, e.g. feed to gain ratio is used rather than feed conversion ratio)

Executive summary

- To reduce reliance on importing soya bean meal (SBM), in temperate environments peas and faba beans may be an alternative protein source for pig diets. We assessed the effects of increasing dietary peas and faba bean inclusion levels on grower and finisher pig performance, and carcass quality.
- There were nine diet treatments tested on both grower (30-60kg) and finisher (60-100kg) pigs in a dose response feeding trial. The control diet included SBM at 140 and 120 g/kg for grower and finisher pigs, respectively, whilst in the test diets, faba beans or peas were included at 75, 150, 225 and 300 g/kg, by gradually and completely replacing SBM. Diets were formulated to be iso-energetic for NE and with the same standard ileal digestible lysine content.
- Each diet was fed *ad libitum* to 4 groups of 4 terminal line grower or finisher pigs for 4 weeks, after a 1 week adaptation period. Weekly live weights for individual pigs, and pen intakes were recorded to assess ADG, ADFI and G:F. Finisher pigs were then slaughtered at a commercial slaughter house to record carcass quality and assess skatole and indole concentration in the backfat.
- There were no significant effects on grower ADG, ADFI and G:F. However, pulse inclusion *per se* reduced finisher BWG (P = 0.04), with a significant quadratic effect of pulse inclusion (P = 0.03), as BWG tended to reduce over initial inclusion levels only. There were no associated significant effects on ADFI or G:F, and pea and faba bean diets resulted in similar finisher growth performance. Increasing pulse inclusion linearly increased fecal DM content, both in grower pigs (P = 0.02) and finisher pigs (P = 0.003). There were no significant effects on carcass quality or backfat skatole levels. However backfat indole concentration linearly reduced with increasing pulse inclusion (P = 0.05).
- It is concluded that peas and faba beans may be a viable alternative to SBM in pig diets.

Introduction

The most common protein source used worldwide in pig feed is soya bean meal (SBM). However, in temperate environments soya bean is difficult to cultivate and the pig industry relies heavily on SBM imported, especially from South America. There are increasing concerns about the sustainability and security of pig production, if this raw material continues to be used at the current rate. There are also environmental concerns with SBM as the rapid increase in demand for soy is associated with increasing demands of land use change (Fearnside, 2001). Thus, there is a need to find a viable alternative protein source for pig diets. In temperate environments, grain legumes such as peas and faba beans are potential protein sources that could be considered for pig feed.

It has long been thought that the use of peas and faba beans in pig diets are limited due to the presence of anti-nutritional factors and a deficiency in the essential amino acids methionine and tryptophan (Gatel, 1994), and indeed high inclusions of peas and faba beans in pig diets have been associated with reduced pig performance (Crepon, 2006), but also with boar taint indicators (Madsen et al., 1990). However, with the introduction of standardized ileal digestibility (SID) for AA and the NE system, the bioavailability of each dietary AA and feed energy value can be more accurately assessed (Stein et al., 2005), allowing the formulation of nutritionally balanced peas and faba bean diets which can meet the requirements of pigs. Here we aim to assess the effects of including different levels of peas or faba bean in nutritionally balanced pig diets at the expense of SBM, on the growth performance of grower and finisher pigs, and carcass quality. Specifically, we test the hypothesis that pig performance and carcass quality will be negatively affected when peas and faba beans are included in the diet above a certain threshold level.

Materials and Methods

Animals and Housing

One-hundred and forty four terminal line grower pigs (initial BW ± SE of 30.5 ± 0.1 kg) and one-hundred and forty four terminal line finisher pigs (initial BW of 60.8 ± 0.2 kg) were selected from a commercial pig herd (Large White x Landrace). Pigs were previously fed commercial SBM-based diets and were allocated to one of nine diet treatments for each of the grower (30-60kg) and finisher (60-100kg) growing periods, balanced for litter, origin and sex. They were placed in 4.5 × 10 m^2 size pens, with 4 pigs per pen (2 entire males and 2 females), and 4 pens per diet treatment. Grower and finisher groups were housed on concrete floors with shavings and access to *ad libitum* drinking water. Start dates for each diet treatment were staggered in accordance with pen and pig availability. Diet treatments were randomly allocated to available pen and start dates. The four replicates for each diet treatment were tested in time, and the experiment was conducted from October 2009 to November 2010. Ambient room temperature ranged between 13 and 23 °C.

Diets and Performance Measures

Commercial sources of peas (variety Prophet), faba beans (colored-flowered spring beans, variety Fuego) and SBM were obtained for the experiment (Table 1). Nine diet treatments were formulated in order to be tested on both grower and finisher pigs in a dose response feeding trial (Tables 2 and 3). The control diet, with no peas or faba beans included, contained SBM at 140 and 120 g/kg for grower and finisher pigs, respectively. In the pulse-containing diets, peas or faba beans were included at 75, 150, 225 and 300 g/kg, gradually and completely replacing SBM. Diets were formulated to be iso-energetic for NE, with the same standard ileal digestible lysine (SID Lys) content, and to meet the minimum requirements of methionine, threonine, tryptophan, calcium and digestible phosphorus (BSAS, 2003) by modifying the inclusion of soy oil, pure amino acids and macro-minerals. Pulses replaced SBM on a SID Lys basis, and wheat levels were varied to complete the feeds. Other ingredients were kept constant and included barley, molasses, rapeseed meal, wheatfeed and trace element / vitamin premix. To ensure the diets were fresh over the whole course of the experiment, diets were manufactured over two batches, with batch 1 being tested on replicates 1 and 2, and batch 2 tested on replicates 3 and 4. However, one consignment of the commercially sourced peas and faba beans was used in both batch 1 and batch 2 diets.

Each diet was fed *ad libitum* to 4 groups of 4 grower and finisher pigs Diets were fed for 4 weeks, after a 1 week adaptation period. To ensure there were no carryover effects from the grower into the finisher stage, separate groups of grower and finisher pigs were used to test the grower and finisher diets, respectively. Weekly live weights for individual pigs, and pen intakes were recorded to assess ADG (g/pig/day), ADFI (g/pig/day) and G:F (g/g). Pen fecal scores and individual cleanliness and health scores were taken twice a week using a subjective score ranging from 1-4 (Wellock et al., 2006). Visual fecal (1 = firm, 2 = soft, 3 =

mild diarrhea, and 4 = severe diarrhea), cleanliness (1 = clean, 2 = light contamination with fecal material, 3 = contaminated, and 4 = heavily contaminated), and health (1 = no signs of ill health, 2 = some signs of ill health, 3 = clear indications of ill health, and 4 = seriously ill) scores were assessed by the same trained individuals. To support the fecal scores, fresh fecal samples were collected from each pen on days 22, 23 and 24 of the trial, and then mixed to provide one composite mean sample per pen. Each sample was dried in a hot air oven to constant weight provide a pen fecal dry matter estimate (DM g/kg).

Slaughter and Carcass Quality Measurements

At the end of the study, one hundred and eight finisher pigs (3 full replicates, with a final BW of 96.0 ± 0.4 kg) were transported to a commercial slaughter house. Pigs were slaughtered via electrical stunning, followed by exsanguinations, and carcasses were dehaired via scalding, eviscerated, and split vertically down the midline. Hot carcass weights were obtained and backfat was measured at the P2 site using an Introscope optical probe (SFK, Denmark). Carcasses were then allowed to chill for 24hrs before recording cold carcass weights. Backfat samples were taken from the mid back line on the split carcass in the shoulder region just below the head on entire male pigs for analysis of skatole and indole, which are associated with pork 'boar' taint (Annor-Frempong et al., 1997a). Lean percentage (% Lean= 66.5-0.95 x P2 + 0.068 x cold carcass weight) (Warriss, 2010) and killing-out percentage (KO% = hot carcass weight/live weight x 100) were calculated for each pig. Skatole and indole concentration in the backfat samples were quantified using the Likens-Nickersin method (Annor-Frempong et al., 1997b).

Analytical methods

Diets were milled through a 1-mm screen prior to analysis and all analyses were carried out in duplicate. CP, Na, Ca and P content were analyzed based on standard methodology (AOAC, 1988). ADF and NDF were determined according to Van Soest et al. (1991). The AA contents in the peas, SBM and wheat were determined by near Infrared Reflectance Spectroscopy (NIRS). Samples are radiated with NIR-light and the reflectance is analyzed as compared to a ceramic plate. The resulting spectrum, caused by specific absorbences due to initiated vibrations or rotations of molecule parts, contains information about the sample ingredients. With the MPLS (modified partial least square) algorithm the correlations between spectral data points and the amino acid reference data (wet chemistry) are analyzed and a prediction model (NIR calibration) is developed. Due to a lack of reference data there were no NIR calibration available for faba beans. The AA content of the faba beans and the diets were determined by ionexchange chromatography with postcolumn derivatization with ninhydrin. Amino acids were oxidized with performic acid, which was neutralized with sodium metabisulfite (Llames and Fontaine, 1994). Amino acids were released from the protein by hydrolysis with 6N HCL for 24 h at 1108C and were quantified with the internal standard method by measuring the absorption of reaction products with ninhydrin at 570 nm. Tryptophan was determined by HPLC with fluorescence detection (extinction 280 nm, emission 356 nm) after alkaline hydrolysis with barium hydroxide octahydrate for 20 h at 110°C (Commission Directive, 2000).

Statistical Analysis

Both performance and slaughter/carcass quality data were analyzed using the GENSTAT REML procedure with contrast statements to locate treatment effects of pulse inclusion *per se*, pulse type, and linear or quadratic pulse inclusion level effects. For all the grower performance data (ADG, ADFI and G:F) and fecal DM content, group was included as the random effect. Similarly for finisher G:F, KO%, skatole and indole concentration, group was included as the random effect in the model. For finisher ADG, ADFI, P2 and % Lean, there was a significant effect of season, thus the random model included group nested in season. Where significant, initial BW and sex were included as covariates. Therefore, in the final models initial BW was used as a covariate for grower ADG; initial BW and sex was used as a covariate for finisher ADG; and sex was used as a covariate for P2 value. The skatole and indole data from the backfat samples were $\log_{10}$ transformed prior to analysis, and reported as backtransformed mean with lower and upper backtransformed standard error ranges. Fecal, health and cleanliness scores are reported descriptively as they essentially did not vary (see Results).

Results

ADG, ADFI and G:F of grower and finisher pigs are shown on Table 4. The mean ADG, ADFI and G:F for the grower pigs were 869 ± 41 g/pig/day, 1964 ± 81 g/pig/day and 0.44 ± 0.009 g/g respectively. The mean ADG, ADFI and G:F for the finisher pigs were

1000 ± 40 g/pig/day, 2580 ± 934 g/pig/day and 0.38 ± 0.009 g/g respectively. There were no significant effects of feeding treatment on grower ADG, ADFI and G:F. In contrast, pulse inclusion *per se* reduced finisher ADG (P = 0.04), but there was no significant associated reduction in ADFI or increase in G:F. Pea and faba bean diets resulted in similar finisher growth performance, but there was a significant quadratic effect for finisher ADG, where ADG tended to decrease over initial increments of pulse inclusion and then increased over further and final increments in pulse inclusion levels, again without significantly impacting finisher ADFI and G:F.

Table 5 shows the estimated fecal DM content for the grower and finisher pigs. The mean fecal DM content was 256 ± 6.1 g/kg and 255 ± 5.1 g/kg for grower and finisher pigs, respectively. There was a significant effect of pulse inclusion *per se* on fecal DM content, where pulse inclusion *per se* increased fecal DM content of both grower (P = 0.006) and finisher (P = 0.03) pigs. There was a significant linear effect for both grower (P = 0.02) and finisher (P = 0.003) pigs where fecal DM content increases with increasing pulse inclusion, although for grower pigs this is likely to be mainly due to the lower DM content of the control SBM diet. There was also a significant quadratic effect for the fecal DM content of grower pigs due to a decrease in the fecal DM content of pigs pea diet tended to reduce at the final inclusion level.

The subjective pen fecal, individual health and individual cleanliness scores were 1 for the grower pigs throughout the course of the trial. For the finisher pigs, thirty five out of the thirty six pens scored a fecal score of 1 throughout the experiment, whilst one pen had a fecal score of 2 on day 14 of the trial. Throughout the rest of the trial, the fecal scores for that pen were also 1. For individual cleanliness scores, one hundred and forty three pigs out of the one hundred and forty four pigs on trial scored 1 throughout the trial, whilst 1 individual pig had a cleanliness score of 2 on day 14 of the trial. Throughout the rest of the trial, the cleanliness scores for that pig were 1. All finisher pigs in the trial had a health score of 1 throughout the trial.

Table 6 shows the slaughter measures (P2, Lean meat % and KO%) and backfat skatole and indole levels. The mean P2, lean meat % and killing out % were 11.6 ± 0.6 mm, 60.5 ± 0.5 % and 77.6 ± 1.5 % respectively. The mean skatole and indole concentration in the backfat was 0.08 (0.048-0.139) µg/g and 0.03 (0.026-0.046) µg/g respectively. There were no significant effects of feeding treatment on P2, % Lean, KO% and backfat skatole levels. However there was a significant overall linear reduction in concentration of indole in backfat with increasing pulse inclusion (*P* = 0.05).

Discussion

The use of legumes such as peas and faba beans as an alternative protein source in pig diets has long been considered. However, early growth trials testing the inclusion of peas and faba beans in pig diets, suggested that inclusion of these pulses in pig diets greater than 20% had a negative effect on performance (Castell, 1976; Aherne et al., 1977; Gatel and Grosjean, 1990). Thus in addition to the cost constraints of using peas or faba beans in pig feed (Crepon, 2006), risk management during formulation of pig diets has further resulted in either low inclusion levels of peas or faba beans, or complete avoidance of using these alternative protein sources in pig diets. These negative effects on performance have largely been attributed to antinutritional factors (e.g. trypsin inhibitors in peas, and condensed tannins in faba beans) and consequently plant breeding efforts have produced new cultivars of peas and faba beans with decreased ANFs (e.g. zero-tannin faba beans) (Jezierny et al., 2010). However, peas and faba beans have also been generally found to be deficient in methionine and tryptophan (Gatel, 1994). There has been limited efforts in breeding for improved protein quality in peas and faba beans, and analysis of the modern cultivars of peas (var. Prophet) and faba beans (var. Fuego) used in this study confirm peas and faba beans are still deficient in these indispensible amino acids relative SBM (Table 1). Nonetheless, performance studies supplementing high pea inclusion pig diets with inclusion of pure methionine or tryptophan to correct for this deficiency have shown performance comparable to a SBM control diet (Gatel and Grosjean, 1990). Similarly, a small number of trials supplementing faba bean diets with amino acids demonstrate improved performance (Crepon, 2006), suggesting that higher inclusions of peas and faba beans may be used in pig diets provided they are well balanced for the limiting amino acids. The results of our current study confirm this position.

Here the diets were formulated using standardized ileal digestibility (SID) and the NE system in order to produce nutritionally balanced diets and meet the minimum requirements of the grower and finisher pig for SID Lys and NE (BSAS 2003). Peas and faba beans were included at gradually increasing inclusion levels in order to determine a threshold inclusion level where performance is negatively affected. However, inclusion of peas or faba beans in the grower diets up to and including the highest inclusion level, in the absence of SBM, did not affect any of the performance measures. This is in contrast to a number of studies which demonstrated reduced performance in the grower stage for diets with high inclusions of peas (O'Doherty and Keady, 2000, 2001) and faba beans (O'Doherty and McKeon, 2001; Partanen et al., 2003). However, it should be noted that the diets in the aforementioned studies were not formulated to ensure that deficiencies of both methionine and tryptophan in the peas and faba beans did not limit performance. Furthermore, the results here are in agreement with recent studies investigating inclusion of peas on pig performance, where diets were balanced for indispensible amino acids and no negative effects on performance were observed (Stein et al., 2004, 2006).

In the finisher diets, there was an effect of diet treatment on finisher ADG, where the SBM control diets resulted in a greater ADG relative to the pulse diets *per se*. In addition, there was a biologically unclear quadratic relationship for pulse inclusion level. This was unexpected as previous studies which have shown any negative effects on performance have generally suggested these effects to occur during the grower stage, but not during the finisher stage (O'Doherty and Keady, 2001; O'Doherty and McKeon, 2001; Shelton et al., 2001; Zijlstra et al., 2008), and more over at levels above a certain threshold rather than at lower inclusion levels observed here. Although the basis of this response remains unclear, the chemical analyses of the experimental diets suggest that this response in unlikely due to variation in amino acid or calculated DE contents (Table 3). Furthermore, it should be noted that there was no effect of replacing SBM for peas or faba beans on ADFI or G:F.

In this study, the grower and finisher diets were tested on different groups of pigs, thus we are unable to test the effect of the diet treatments over the combined grower and finisher period. However, given that there was no effect found during the grower period, it might be expected that any effects of pulse inclusion over the whole grower and finisher period would be small or not present in the first place, which is in agreement with studies on peas reported elsewhere (Stein et al., 2006).

Legume seeds have relatively high concentrations of oligosaccharides (raffinose and stachyose) which are water soluble carbohydrates that are indigestible in the small intestine of monogastric animals (Houdijk et al. 2002). Once these oligosaccharides reach the lower intestinal tract, they are available for fermentation by intestinal bacteria. Excessive consumption of fermentable carbohydrates can result in loose feces or diarrhea (Saini, 1989; Jezierny et al. 2010) and has been associated with adverse affects on growth and feed intake in growing pigs (Ferguson et al. 2003). However, the fecal DM contents measured in this trial indicated that there was more water in the feces of pigs fed the SBM control diets compared to those fed the pea or faba beans diets, suggesting that the inclusion of peas and faba beans may actually assist with water absorption in the large intestine. The subjective visual fecal and cleanliness scores further show that no loose feces or diarrhea occurred in pigs fed any of the pulse diets, including the diets with the highest concentrations of peas and faba beans (300 g/kg of peas or faba beans) where dietary oligosaccharide concentration would be greatest. Our observations agree with van Meulen and Jansman (2010) who found that pea and faba bean hulls increased intestinal fluid absorption in enterotoxigenic *Escherichia coli* infected piglets. Although, the functional basis of these observations requires further investigation, it can be concluded that high levels of peas and faba beans in nutritionally balanced growing and finishing pig diets unlikely result in loose feces or diarrhea.

There was no effect of diet treatment on any of the carcass measurements taken at the slaughterhouse. This is in agreement with a range of studies showing no effect of pea or faba bean diets on slaughter measures (Castell, 1976; Onaghise and Bowland, 1977; Edwards et al., 1987; O'Doherty and Keady, 2000; Partanen et al., 2003; Stein et al., 2006). Additionally, the mean P2 values were not significantly higher than the 12mm upper limit for premium carcass payment in the UK (Kyriazakis and Whittemore, 2006), suggesting there are no negative effects on slaughter measures associated with including peas and faba beans in the diet at the expense of SBM.

Skatole, in addition to androstenone is considered a main contributor of 'boar taint' in pork, and diet can play an important role in the control of skatole (Lundström et al., 1988). Madsen et al. (1990) suggested the inclusion of peas in pig diets resulted in increased skatole concentration. However, in this trial although the lowest inclusion level of peas (7.5g/kg) showed a numerically greater skatole concentration in the backfat relative to the SBM diet, this was not significant or evident in any other inclusion level of pea diets. Furthermore, there was no significant effect of either home grown pulse inclusion *per se* or peas diets versus faba bean diets on skatole concentration. High indole concentrations have been shown to have an effect on perception of taint, especially when skatole concentrations are low (Annor-Frempong et al., 1997b). However, in this study pulse inclusion tended to reduce indole concentration, although the size of the effect was small and perhaps biologically irrelevant. Therefore, our data support the view that pea and faba bean inclusion in nutritionally balanced pig diets will not influence the relationship between skatole and indole in the perception of taint. The skatole and indole levels observed are in agreement with O'Doherty and Keady (2000) who showed that pig diets containing 400g/kg of peas in did not affect the concentration of skatole and indole in the backfat compared to feeding SBM-based diets. Furthermore, the mean skatole concentrations determined for all diets were below the currently accepted threshold levels of 0.2 μg/g backfat for 'boar' taint detection (Lundström et al., 2009). This is in agreement with taste panel studies showing no effect of high inclusions (>300g/kg) of peas or faba beans in pig diets on meat quality or palatability of the pork, including overall off flavors (Partanen et al., 2003; Stein et al., 2006).

In conclusion results from the present study indicate that up to 300g/kg inclusion of peas and faba beans in nutritionally balanced grower and finisher pig diets may slightly reduce growth rate in finisher pigs but is unlikely to affect the overall growth performance of pigs from grower to slaughter, their fecal consistency and their meat quality characteristics. Thus, peas and faba beans are a potentially viable alternative to SBM for use in nutritionally balanced grower and finisher pig diets. However, there are other issues that will dictate the level of inclusion of such pulses in pig diets. As well as their price (Crepon, 2006), their inclusion will be determined by issues of land availability. Finally the environmental impact of the inclusion of peas and faba beans in pig diets will need to be considered (Topp et al., 2012; Leinonen et al., 2012) in order to assess their sustainability.

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Table 1. Analysed composition of main ingredients that are varied in the diets (as-fed basis) i.e. peas (var. Prophet), faba beans (var. Fuego), soya bean meal (SBM) and wheat.

	Peas[1]	**Faba[1] beans**	**SBM[2]**	**Wheat[2]**
DE (MJ/kg)[3]	14.91	14.19	15.54	14.28
Nutrients (g/kg)				
CP	185.3	245.5	460.3	105.3
ADF	70.9	137.5	49.0	29.0
NDF	97.9	155.8	73.8	81.6
Na	0.03	0.08	0.01	0.03
Ca	1.2	1.3	3.8	0.4
P	23.8	32.6	59.9	28.7
Indispensable AA (g/kg)				
Arg	14.3	23.5	34.6	4.0
His	4.5	7.1	12.8	1.8
Ile	8.2	10.7	21.4	2.7
Leu	13.9	19.5	35.9	5.2
Lys	14.4	16.5	29.3	3.2
Met	1.8	1.9	6.5	1.4
Phe	9.5	11.2	23.9	3.9
Thr	7.5	9.2	18.6	2.7
Trp	1.8	2.4	6.6	1.1
Val	9.0	12.1	22.6	3.9

[1] Analyzed composition determined from the commercially sourced peas and faba beans used.

[2] Analyzed composition determined from the average of batch 1 and batch 2 SBM and wheat samples

[3]Calculated as DE (MJ/kg DM) = 17.47 + 0.0079×CP + 0.0158×EEAH – 0.0331×Ash – 0.0140× NDF, where EEAH is lipid extraction with an organic solvent after acid hydrolysis (McDonald et al 2002).

Table 2. Composition of experimental diets (as-fed basis) tested on grower pigs (30 to 60kg)

Feeding treatment	Control	Pea (g/kg diet)				Faba bean (g/kg diet)			
		75	**150**	**225**	**300**	**75**	**150**	**225**	**300**
Ingredients (g/kg)									
Peas var. Prophet	-	75	150	225	300	-	-	-	-
Faba bean var. Fuego	-	-	-	-	-	75	150	225	300
Soya bean meal (48% CP)	140	105	70	35	-	105	70	35	-
Wheat	446	406	365	324	283	408	370	331	293
Barley	128	128	128	128	128	128	128	128	128
Molasses-beet	30	30	30	30	30	30	30	30	30
Rapeseedmeal (ext)00	70	70	70	70	70	70	70	70	70
Wheat feed 8.5% CF	150	150	150	150	150	150	150	150	150
Soya acid oil, 50% FFA	11	11	11	11	11	9	7	5	3
Dicalcium phosphate, 18% P	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Premix[1]	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Limestone	11.6	11.8	11.9	12.1	12.2	11.6	11.7	11.7	11.7
Salt	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Lysine HCI	1.50	1.65	1.80	1.95	2.1	1.54	1.58	1.62	1.66
Methionine	0.06	0.21	0.36	0.50	0.65	0.22	0.38	0.54	0.7

Threonine	0.05	0.31	0.58	0.84	1.1	0.23	0.40	0.58	0.75
Tryptophan	-	0.05	0.10	0.15	0.2	0.04	0.07	0.11	0.14
Calculated analysis									
NE (MJ/kg)	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3
SID Lys (g/kg)	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1
digP (g/kg)	2.5	2.2	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Analysed composition[2]									
DE (MJ/kg)[3]	13.29	13.23	13.33	13.15	13.05	13.25	13.27	13.01	13.05
Nutrients (g/kg)									
CP	160.6	160.9	155.1	158.4	141.1	165.5	163.5	158.5	160.4
ADF	55.3	67.3	67.2	72.4	63.0	65.1	80.2	80.3	81.2
NDF	136.5	147.0	135.5	140.6	139.8	143.0	140.1	149.0	149.2
Ca	8.1	8.9	8.8	8.5	8.7	8.6	8.5	8.5	8.9
Na	1.4	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4
P	5.6	5.8	5.5	5.3	5.2	5.8	5.7	5.7	5.6
Indispensable AA (g/kg)[4]									
Arg	10.0	10.2	10.2	9.9	9.4	10.6	11.6	11.6	11.6
His	4.2	4.2	4.1	3.9	3.7	4.3	4.3	4.3	4.3

Ile	6.4	6.4	6.2	6.0	5.6	6.4	6.5	6.5	6.3
Leu	11.7	11.5	11.2	10.7	10.0	11.8	11.8	11.8	11.7
Lys	8.8	9.0	9.3	9.3	9.2	9.1	9.6	9.6	9.4
Met	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.6
Phe	7.7	7.6	7.4	7.2	6.8	7.7	7.4	7.4	7.2
Thr	6.1	6.1	6.4	6.2	6.3	6.3	6.4	6.4	6.4
Trp	2.3	2.3	2.2	2.1	2.0	2.3	2.2	2.2	2.2
Val	7.7	7.8	7.6	7.4	7.0	7.8	7.9	7.9	7.7

[1] Provides the following quantities of vitamins per kilogram of complete diet: vitamin A, 10,000 IU; vitamin D_3, 2,000 IU; vitamin E, 50 mg; vitamin B_1, 2 mg; vitamin B_2, 3 mg; vitamin B_6, 2 mg; vitamin B_{12}, 30 mg; vitamin K, 1 mg; nicotinic acid, 20 mg; pantothenic acid, 10 mg; Fe (as $FeSO^4H_2O$), 100 mg; Mn (as MnO), 50 mg; Cu (as $CuSO_4$) 20mg; Zn (as ZnO) 100.6 mg; I (as $Ca(IO_3)_2$), 1mg; Se (as ($NaSeO_4$), 0.3 mg)

[2]Analyzed composition determined from the average of batch 1 and batch 2 diet samples.

[3]Calculated as DE (MJ/kg DM) = 17.47 + 0.0079×CP + 0.0158×EEAH – 0.0331×Ash – 0.0140× NDF, where EEAH is lipid extraction with an organic solvent after acid hyrdrolisis (McDonald et al 2002).

[4]AA figures standardized to a dry matter content of 88%

Table 3. Composition of experimental diets (as-fed basis) tested on finisher pigs (60 to 100kg)

Feeding treatment	Control	Pea (g/kg diet)				Faba bean (g/kg diet)			
		75	**150**	**225**	**300**	**75**	**150**	**225**	**300**
Ingredients (g/kg)									
Peas var. Prophet	-	75	150	225	300	-	-	-	-
Faba bean var. Fuego	-	-	-	-	-	75	150	225	300
Soya bean meal (48% CP)	120	90	60	30	-	90	60	30	-
Wheat	264	219	173	128	83	221	177	134	91
Barley	284	284	284	284	284	284	284	284	284
Molasses-beet	30	30	30	30	30	30	30	30	30
Rapeseedmeal-00	70	70	70	70	70	70	70	70	70
Wheat feed 8.5% CF	200	200	200	200	200	200	200	200	200
Soy oil	10	10	10	10	10	8	7	5	3
Dicalcium phosphate, 18% P	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Premix[1]	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Limestone	11.3	11.4	11.4	11.5	11.5	11.3	11.2	11.2	11.1
Salt	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Lysine HCI	0.60	0.6	0.6	0.6	0.6	0.49	0.37	0.26	0.14
Methionine	-	0.10	0.20	0.30	0.40	0.09	0.19	0.28	0.37

Threonine	-	0.08	0.15	0.23	0.30	-	-	-	-
Tryptophan	-	-	-	-	-	-	-	-	-
Calculated analysis									
NE (MJ/kg)	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
SID Lys (g/kg)	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
digP (g/kg)	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Analysed composition[2]									
DE (MJ/kg)[3]	13.35	13.28	13.07	13.10	12.73	13.11	12.89	12.95	12.69
Nutrients (g/kg)									
CP	160.2	154.2	151.6	146.9	140.8	156.8	158.9	158.1	157.2
ADF	63.3	51.4	50.3	49.7	47.9	70.9	78.6	89.9	94.4
NDF	131.4	142.1	145.9	145.6	156.5	145.1	152.3	156.0	165.3
Ca	8.4	8.8	8.8	8.7	8.2	8.2	8.5	8.4	8.8
Na	1.5	1.5	1.5	1.5	1.4	1.5	1.5	1.5	1.6
P	5.9	6.0	5.7	5.6	5.3	5.9	5.9	5.9	6.0
Indispensable AA (g/kg)[4]									
Arg	10.2	10.0	9.9	9.7	9.7	10.6	11.0	11.4	11.9
His	4.2	4.1	4.0	3.7	3.7	4.2	4.2	4.3	4.3

Ile	6.4	6.3	6.1	5.7	5.7	6.4	6.4	6.4	6.3
Leu	11.5	11.1	10.9	10.0	10.0	11.5	11.6	11.6	16.6
Lys	8.3	8.1	8.2	8.4	8.4	8.2	8.4	8.5	8.7
Met	2.7	2.5	2.5	2.5	2.5	2.5	2.5	2.4	2.4
Phe	7.7	7.3	7.2	6.7	6.7	7.4	7.5	7.3	7.2
Thr	6.1	5.9	5.8	5.7	5.7	5.9	6.0	5.9	5.9
Trp	2.4	2.2	2.1	1.8	1.8	2.3	2.2	2.1	2.0
Val	7.9	7.7	7.6	7.1	7.1	7.9	7.9	7.9	7.9

[1] Provides the following quantities of vitamins per kilogram of complete diet: vitamin A, 10,000 IU; vitamin D_3, 2,000 IU; vitamin E, 50 mg; vitamin B_1, 2 mg; vitamin B_2, 3 mg; vitamin B_6, 2 mg; vitamin B_{12}, 30 mg; vitamin K, 1 mg; nicotinic acid, 20 mg; pantothenic acid, 10 mg; Fe (as $FeSO^4H_2O$), 100 mg; Mn (as MnO), 50 mg; Cu (as $CuSO_4$) 20mg; Zn (as ZnO) 100.6 mg; I (as $Ca(IO_3)_2$), 1mg; Se (as ($NaSeO_4$), 0.3 mg)

[2]Analysed composition determined from the average of batch 1 and batch 2 diet samples

[3]Calculated as DE (MJ/kg DM) = 17.47 + 0.0079×CP + 0.0158×EEAH – 0.0331×Ash – 0.0140× NDF, where EEAH is lipid extraction with an organic solvent after acid hydrolysis (McDonald et al 2002).

[4]AA figures standardized to a dry matter content of 88%.

Table 4. Effect of diet treatment on growth performance of grower and finisher pigs.

Feeding treatment with pulse inclusion levels (g/kg)		Grower Pigs			Finisher Pigs		
		ADG (g/day)	ADFI (g/day)	G:F	ADG (g/day)	ADFI (g/day)	G:F
Control	-	823	1857	0.44	1083	2697	0.40
Pea	75	898	1975	0.45	975	2482	0.40
	150	836	1829	0.45	936	2463	0.39
	225	918	2030	0.44	967	2576	0.38
	300	834	1922	0.43	1003	2580	0.38
Faba bean	75	852	1979	0.43	1024	2529	0.39
	150	858	2000	0.43	1011	2675	0.37
	225	899	2069	0.44	980	2588	0.39
	300	907	2013	0.45	1032	2633	0.39
SEM		41	81	0.009	40	934	0.009
P-value (contrasts)							
Control-Pulse *per se*		0.24	0.18	0.59	0.04	0.13	0.18
Peas vs Bean		0.81	0.20	0.27	0.15	0.16	0.99
Linear inclusion		0.24	0.19	0.55	0.15	0.63	0.08
Quadratic inclusion		0.47	0.40	0.72	0.03	0.12	0.29

Table 5. Effect of diet treatment on fecal DM of grower and finisher pigs.

Feeding treatment with pulse inclusion levels (g/kg)		Grower Fecal DM content (g/kg)	Finisher Fecal DM content (g/kg)
Control	-	238	244
Pea	75	262	253
	150	261	253
	225	262	261
	300	250	260
Faba bean	75	249	245
	150	260	255
	225	257	268
	300	261	257
SEM		6.1	5.1
P-value (contrasts)			
Control - Pulse *per se*		0.006	0.03
Peas vs Bean		0.67	0.84
Linear inclusion		0.02	0.003
Quadratic inclusion		0.01	0.28

Table 6. Effect of feeding treatment on P2, % Lean, KO% and backfat skatole and indole levels.

Feeding treatment with pulse inclusion levels (g/kg)		P2 (mm)	Lean (%)	KO (%)	Skatole (µg/g backfat)	(µg/g backfat)
Control	-	11.9	60.3	78.0	0.08 (0.05-0.15)	0.04 (0.03-0.06)
Pea	7.5	11.1	60.8	76.0	0.14 (0.08-0.24)	0.04 (0.03-0.05)
	15	11.3	60.8	78.0	0.04 (0.02-0.06)	0.03 (0.02-0.04)
	22.5	11.3	60.7	77.1	0.04 (0.02-0.06)	0.02 (0.02-0.03)
	30	11.9	60.4	77.3	0.09 (0.05-0.15)	0.03 (0.02-0.03)
Faba bean	7.5	11.7	60.5	79.4	0.11 (0.06-0.17)	0.04 (0.03-0.06)
	15	12.3	59.9	78.8	0.11 (0.06-0.18)	0.05 (0.04-0.07)
	22.5	11.8	60.3	77.8	0.07 (0.04-0.11)	0.03 (0.02-0.03)
	30	11.1	60.8	75.9	0.08 (0.05-0.13)	0.03 (0.03-0.04)
SEM		0.6	0.5	1.5	-	-
P-value (Contrasts)						
Control vs Pulse *per se*		0.49	0.59	0.77	0.80	0.28
Pea vs Bean		0.19	0.25	0.42	0.42	0.11
Linear inclusion level		0.51	0.64	0.46	0.49	0.05
Quadratic inclusion level		0.99	0.98	0.56	0.61	0.92

Full report Objective 5b2: Effects of dietary inclusion levels of white flowered faba beans to replace soya bean meal on grower pig growth performance.

Lead authors: Lesley Smith and Jos Houdijk (SRUC).

Executive Summary

- In temperate environments, grain legumes such as peas and faba beans are an attractive alternative for use in pig feed.
- Performance trial 1 investigated the effect of peas and coloured flowered faba beans on pig growth performance and carcass quality. However, coloured flowered varieties of faba beans are associated with condensed tannins which have the ability decreasing the digestibility of proteins and carbohydrates potentially reduce in feed intake.
- Genetic selection for tannin free varieties of faba beans is relatively easy and as a result there are high tannin coloured flowered varieties of faba beans and low tannin white flowered varieties of faba beans available.
- For completeness an additional trial was conducted to evaluate the effects of including white flowered low tannin faba beans in nutritionally balanced pig diets at the expense of SBM (performance trial 2).
- The availability of low tannin faba beans for use in pig feed can be problematic and the volumes of low tannin faba beans sourced for demonstration trial 1 only allowed for the testing of grower low tannin faba bean diets in a dose response trial.
- Performance trial 2 tested five diet treatments (SBM control, 75, 150, 225 and 300 g/kg low tannin faba beans (var. Tattoo)) in a dose response feeding trial, gradually and completely replacing SBM.
- There were no significant effects of feeding treatment on average daily gain (ADG) or average daily feed intake (ADFI). However there was a significant quadratic relationship for feed conversion ratio (FCR) (P=0.05), where FCR tends to increase over initial increments of tattoo inclusion and then decrease at the final inclusion level of tattoo inclusion.
- The quadratic relationship found appears to be largely due to a lower FCR observed in the SBM control diet suggesting that there is reduced nutrient digestibility in the tattoo diets relative to the SBM diets. However, it should also be noted that this quadratic relationship is only based on limited replication for the SBM control diet.

- In conclusion, the present study indicates that up to 300g/kg inclusion of low tannin faba beans in nutritionally balanced grower diets does not affect ADG or ADFI of grower pigs. However, care may have to be taken in ensuring formulations have adequate information on the digestible nutrient profile of low tannin beans used in diets. Thus, low tannin varieties of faba beans are viable home grown protein source in pig feed. Although their practical use in commercial pig feed may be limited by availability.

Introduction

In temperate environments, grain legumes such as peas and faba beans are an attractive alternative for use in pig feed. As part of the Green Pig project, small scale performance trials were carried out to investigate the effect of peas and coloured flowered faba beans on pig growth performance and carcass quality (performance trial 1). However, coloured flowered varieties of faba beans are associated with condensed tannins which have the ability to form insoluble enzyme-resistant complexes with proteins and carbohydrates, consequently decreasing the digestibility of proteins and carbohydrates (Liener, 1988). In addition to inhibiting digestion, tannins are also associated with an astringent taste, which is attributed to tannins ability to bind with the protein in saliva (Wang et al., 1998), and thus potentially reductions in feed intake.

Genetic selection for tannin free varieties of faba beans is relatively easy as the tannin-free trait is associated with white coloured flowers (Cabrera and Martin, 1989), and as a result plant breeding has resulted in high tannin coloured flowered varieties of faba beans and low tannin white flowered varieties of faba beans. There is a preference for using these white flowered low tannin varieties in pig feed, as both the digestibility of crude protein (van der Poel et al., 1992; Grala et al., 1993; Jansman et al., 1995) and amino acids (Grala et al., 1993) has been found to be higher than the high tannin coloured faba bean. Thus, for completeness an additional trial was conducted to evaluate the effects of including white flowered low tannin faba beans in nutritionally balanced pig diets at the expense of SBM. However, due to poor yields and the economics for plant producers, the availability of low tannin faba beans for use in pig feed can be problematic. Indeed sourcing low tannin faba beans for this additional Green Pig trial (performance trial 2) was difficult, and the volumes sourced only allowed for the testing of grower low tannin faba bean diets in a dose response trial. Thus, the aim of this performance trial 2 is to assess the effects of including different levels of white flowered low tannin faba beans in nutritionally balanced pig diets at the expense of SBM, on the growth performance of grower pigs.

Materials and Methods

Initially, performance trial 2 was to run at the same time as performance trial 1 (testing peas (Prophet) and coloured flowered faba beans (Fuego), allowing use of the same control diets (SBM diet) tested. However, problems due to sourcing of low tannin faba bean resulted in the postponement of performance trial 2 until the end of performance trial 1. Consequently, additional SBM diets were re-run performance trial 2. However, resources only allowed 2 replicates of the SBM control diets to be tested in this trial.

Animals and Housing

Seventy two terminal line grower pigs (initial BW of 29.7 ± 0.2kg [mean ± SE]) were selected from a commercial pig herd (Large White x Landrace). Pigs were allocated to one of five diet treatments, balanced for litter and sex. There were 4 pigs per pen (2 entire males and 2 females), and 4 pens per experimental diet (low tannin bean) treatment. There were 2 pens per control diet treatment. Start dates for each diet treatment were staggered in accordance with pen and pig availability. Diet treatments were randomly allocated to available pen and start dates. The replicates for each diet treatment were tested in time, and the experiment was conducted from August 2010 to November 2010. Pigs were housed in $4.5m^2$ pens on concrete floors with shavings and access to *ad libitum* drinking water. Ambient room temperature ranged between 13 and 21°C.

Diets and Performance Measures

Commercial sources low tannin faba beans (white flowered spring beans, variety Tattoo) and SBM were obtained for the experiment (Table 1). Five diet treatments were formulated in order to be tested on grower pigs in a dose response feeding trial (Tables 2). The control diet, with faba beans included, contained SBM at 140. In the low tannin faba bean diets, low tannin faba beans were included at 75, 150, 225 and 300 g/kg, gradually and completely replacing SBM. Diets were formulated to be iso-energetic, with the same standard ileal digestible lysine (SID Lys) content, and to meet the minimum requirements of methionine, threonine, tryptophan, calcium and digestible phosphorus (BSAS, 2003) by modifying the inclusion of soya oil, pure amino acids and macro-minerals. Pulses replaced SBM on a SID Lys basis, and wheat was varied to close the mass balance (Table 1). Other ingredients were kept constant and included barley, molasses, rapeseed meal, wheat feed and trace element / vitamin premix.

Each low tannin bean diet was fed *ad libitum* to 4 groups of 4 grower pigs, while the SBM control diet was fed *ad libitum* to 2 groups of 4 grower pigs. Diets were fed for 4 weeks, after a 1 week adaptation period. Weekly live weights for individual pigs, and pen intakes were recorded to assess average daily gain (ADG, g/pig/day), average daily feed intake (ADFI, g/pig/day) and feed conversion ratio (FCR as ADFI/ADG).

Statistical Analysis

The GENSTAT REML procedure with contrast statements to locate treatment effects of low tannin faba bean inclusion *per se*, linear and quadratic low tannin faba bean inclusion level effects. For all the grower performance data (ADG, ADFI, FCR and faecal DM content), group was included as the random effect. Where significant, initial body weight (BW) and sex were included as covariates. Therefore, in the final models initial BW was used as a covariate for grower ADG.

Table 1. Analysed composition of main ingredients that are varied in the diets (as-fed basis) e.g. peas (var. Prophet), faba beans (var. Fuego), soya bean meal, and wheat.

	Tattoo beans[1]	**SBM[2]**	**Wheat[2]**
DE (MJ/kg)	13.2	15.5	14.3
Nutrients (g/kg)			
CP	250.9	460.3	105.3
ADF	83.6	49.0	29.0
NDF	159.9	73.8	81.6
Na	0.04	0.01	0.03
Ca	1.27	3.8	0.4
P	46.7	59.9	28.7
Indispensable AA (g/kg)			
Arg	22.2	34.6	4.0
His	6.4	12.8	1.8
Ile	10.9	21.4	2.7
Leu	19.0	35.9	5.2
Lys	16.3	29.3	3.2
Met	1.8	6.5	1.4
Phe	10.9	23.9	3.9
Thr	8.7	18.6	2.7
Trp	2.1	6.6	1.1
Val	12.0	22.6	3.9

[1] Analysed composition determined from one consignment of commercially sourced low tannin faba beans
[2] Analysed Composition determined from the average of batch 1 and batch 2 SBM and wheat sample

Table 2. Composition of experimental diets (as-fed basis) tested on grower pigs (30 to 60kg)

Feeding treatment	**SBM**	**Tattoo faba bean (g/kg diet)**			
		75	**150**	**225**	**300**
Ingredients (g/kg)					
Faba bean var. Tattoo	-	75	150	225	300
Soya bean meal (48% CP)	140	105	70	35	0
Wheat	446	405	363	321	279
Barley	128	128	128	128	128
Molasses-beet	30	30	30	30	30
Rapeseedmeal (ext)00	70	70	70	70	70
Wheat feed 8.5% CF	150	150	150	150	150
Soya acid oil, 50% FFA	11	12	14	15	16
Dicalcium phosphate, 18% P	5.5	5.4	5.4	5.3	5.2
Premix[1]	2.5	2.5	2.5	2.5	2.5
Limestone	11.6	11.7	11.8	11.8	11.9
Salt	3.3	3.3	3.3	3.3	3.3
Lysine HCI	1.50	1.6	1.6	1.7	1.7
Methionine	0.06	0.3	0.4	0.6	0.8
Threonine	0.05	0.2	0.4	0.5	0.7
Tryptophan	-	0.2	0.3	0.5	0.6
Calculated analysis					
NE (MJ/kg)	9.3	9.3	9.3	9.3	9.3
SID Lys (g/kg)	8.1	8.1	8.1	8.1	8.1
digP (g/kg)	2.5	2.5	2.5	2.5	2.5

Table 2 (continued)

Feeding treatment	**SBM**	**Tattoo faba bean (g/kg diet)**			
		75	**150**	**225**	**300**
Analysed composition[2]					
DE (MJ/kg)	13.29	13.25	13.27	13.01	13.05
Nutrients (g/kg)					
CP	160.6	165.5	163.5	158.5	160.4
ADF	55.3	65.1	80.2	80.3	81.2
NDF	136.5	143.0	140.1	149.0	149.2
Ca	8.1	8.6	8.5	8.5	8.9
Na	1.4	1.4	1.4	1.4	1.4
P	5.6	5.8	5.7	5.7	5.6
Indispensable AA (g/kg)[3]					
Arg	10.0	10.6	10.9	11.2	11.2
His	4.2	4.3	4.3	4.2	4.1
Ile	6.4	6.5	6.4	6.4	6.0
Leu	11.7	11.8	11.6	11.5	11.2
Lys	8.8	9.1	9.3	9.5	9.3
Met	2.7	2.6	2.6	2.6	2.6
Phe	7.7	7.6	7.5	7.3	6.9
Thr	6.1	6.1	6.0	6.1	6.2
Trp	2.3	2.4	2.4	2.4	2.4
Val	7.7	7.8	7.7	7.6	7.3

[1] Provides the following quantities of vitamins per kilogram of complete diet: vitamin A, 10,000 IU; vitamin D_3, 2,000 IU; vitamin E, 50 mg; vitamin B_1, 2 mg; vitamin B_2, 3 mg; vitamin B_6, 2 mg; vitamin B_{12}, 30 mg; vitamin K, 1 mg; nicotinic acid, 20 mg; pantothenic acid, 10 mg; Fe (as $FeSO^4H_2O$), 100 mg; Mn (as MnO), 50 mg; Cu (as $CuSO_4$) 20mg; Zn (as ZnO) 100.6 mg; I (as $Ca(IO_3)_2$), 1mg; Se (as $(NaSeO_4)$, 0.3 mg)

[2]AA figures standardized to a dry matter content of 88%

Results

Table 3 shows the ADG, ADFI and FCR of pigs. The mean ADG, ADFI and FCR for pigs (±SE) were 816 (±36) g/pig/day, 1840 (±85) g/pig/day and 2.27 (±0.08) respectively. There were no significant effects of feeding treatment on ADG or ADFI. However there was a significant quadratic relationship for FCR (P=0.05), where FCR tends to increase over initial increments of tattoo inclusion and then decrease at the final inclusion level of tattoo inclusion.

Table 3. Effect of diet treatment on growth performance of grower pigs.

Feeding treatment with pulse inclusion levels (g/kg)		ADG (g/day)	ADFI (g/day)	FCR
SBM	-	789	1671	2.13
Tattoo	75	800	1916	2.38
	150	833	1852	2.28
	225	793	1868	2.36
	300	864	1896	2.20
SEM		36	85	0.08
P-value (contrasts)				
Control vs Tattoo *per se*		0.51	0.09	0.11
Linear inclusion level		0.27	0.19	0.65
Quadratic inclusion level		0.75	0.30	0.05

Discussion

The negative effects faba beans on pig performance have largely been attributed to condensed tannins, and consequently plant breeding efforts have produced new low tannin cultivars of faba beans (Jezierny et al., 2010). However, faba beans have also been associated with deficiencies in methionine and tryptophan (Gatel, 1994) and there have been limited efforts in breeding for improved protein quality in both low tannin and tannin containing faba bean. Analysis of the low tannin faba bean (var. Tattoo) used in this study confirm that low tannin faba beans are still more deficient in these indispensible amino acids than SBM. Zijlstra (2008) found that provided the diets were nutritionally balanced, low tannin faba beans could be included up to 300 g/kg in the diets of grower pigs without affecting ADG or ADFI. However, the low tannin faba beans diets still contained some SBM in order to meet the requirements for the grower pig. Here the diets tattoo faba beans were included at gradually increasing inclusion levels, with no SBM included at the highest low tattoo level (300g/kg). The diets were formulated using standardized ileal digestibility (SID) and the NE system in order to produce nutritionally balanced diets and meet the minimum requirements of the grower pigs for SID Lys and NE (BSAS 2003). In these nutritionally balanced diets inclusion of low tattoo faba beans in the grower diets up to and including 300 g/kg, in the absence of SBM, did not affect ADG or ADFI. There was however a significant quadratic relationship for FCR. Although there is no significant effect of control vs tattoo *per* se, the quadratic relationship found appears to be largely due to a lower FCR observed in the SBM control diet. This suggests that there is reduced nutrient digestibility in the tattoo diets relative to the SBM diets. This is in contrast to the results observed in demonstration trial 2, where there was no effect of pea or coloured flowered faba beans on any of the performance measures. Diets were formulated using book values (Premier Nutrition, 2008) for AA digestibility of general white flowered faba beans, and thus it is possible that the AA digestibility of Tattoo may have been overestimated. However, it should also be noted that this quadratic relationship is only based on 2 replicates for the SBM control diet.

In conclusion, the present study indicates that up to 300g/kg inclusion of low tannin faba beans in nutritionally balanced grower diets does not affect ADG or ADFI of grower pigs. However, care may have to be taken in ensuring formulations have adequate information on the digestible nutrient profile of low tannin beans used in diets. Thus, low tannin varieties of faba beans are viable home grown protein source in pig feed. Although their practical use in commercial pig feed may be limited by availability.

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Report of Objective 5c: Pig growth trial with experimental slaughter

Lead authors: Gavin White, Julian Wiseman (University of Nottingham)

Executive Summary

- Five iso-energetic diets balanced for standard ileal digestible lysine were formulated to contain home grown legumes at 30%. Diets were based on peas (Prophet), three cultivars of field beans (Fuego: spring, coloured; Tattoo: white; Wizard: winter coloured) and soya bean meal 48 (as the only plant protein source at 14% in grower diets and 12% in finisher diets).
- Each diet was fed to eight replicate entire male pigs individually housed of initial weight 30kg up to 55kg live weight (grower) and then to approximately 95kg live weight (finisher). Animals were slaughtered in the Nottingham Experimental Abattoir and detailed carcass measurements undertaken.
- The results showed that treatment generally had no effect on performance (daily live weight gain, feed intake, feed conversion ratio). However, there was a trend (P=0.067) for both feed intake and feed conversion ratio to be influenced by treatment, with pigs fed diets based Tattoo having the lowest feed intake and best FCR over the entire trial (grower / finisher combined). There was also a trend (P=0.065) for daily live weight gain to be influenced by treatment, with pigs fed diets based on Wizard having the highest in the grower phase.
- Results also showed that replacing SBM with peas or beans did not affect finisher apparent total tract N digestibility, faecal dry matter content, weight of intestines and their contents, lean tissue pH, carcass quality / lean meat content and skatole / indole concentrations in the maximum shoulder fat region with all data being considerably below the accepted minimum.
- It was concluded that the cultivars of peas and beans evaluated may be included safely at a rate of inclusion of 30% in iso-energetic diets balanced for standardised ileal digestible lysine fed to growing / finishing pigs with no detrimental effects on performance, faecal dry matter concentration, carcass quality or skatole levels.

Introduction

The Programme Management Group had discussed the results of the performance / carcass assessment trial undertaken at SAC and agreed that a more detailed performance and carcass quality data in a trial undertaken at Nottingham with individually-housed pigs over a longer period than the trial at SAC would provide a very useful data-set. Pigs were fed the trial legume diets from the start of the grower phase and throughout the finisher phase up to slaughter weight.

The objective of the trial was to evaluate performance and carcass quality (a very much more comprehensive data-set than possible from a commercial abattoir and collecting backfat samples for indole / skatole analysis) of pigs diets containing legumes (one sample of peas, three of field beans to include one winter variety) compared with a control based on soya bean meal as the only plant protein source ; diets were isoenergetic and balanced for standard ileal digestible lysine, methionine, threonine and tryptophan. The trial was over two phases: grower (30-55kg) and finisher (55-95kg).

Method and Materials

Diets

One batch of peas (var Prophet) and three of field beans (var. Fuego spring-coloured, Tattoo white, Wizard winter coloured) and one batch of soya bean meal 480g CP/kg were obtained. Peas and beans were added at a rate of 300g/kg and soya bean meal (at a rate of 140g/kg for grower diets or 120g/kg finisher diets) into pelleted diets that were isoenergetic and balanced for standard ileal digestible lysine, methionine, threonine and tryptophan . Details, including calculated nutrient and energy concentrations together with determined crude protein, are provided in tables 1A (Grower diets) and 1B (Finisher diets).

Animals

Entire male pigs from a commercial white genotype (initial weight 31 +/- 1.9kg) were used, housed in UoN’s New Pig Growth Building maintained under appropriate conditions for the grower / finisher pig. Pigs were housed in individual pens. Each diet was fed to eight replicate pens giving 40 in total. Grower pigs were transferred onto the same diet in the Finisher phase (thus pigs fed ‘control’ in the grower phase were transferred to ‘control’ in the finisher phase).

Procedure

Diets were to be offered *ad libitum* requiring feed to be in front of animals at all times. Pigs were fed from a bucket containing a weighed amount of feed located outside each pen. Once the bucket is empty, a further amount was weighed into it. To maintain freshness of feed and measure daily feed intake, troughs were cleaned weekly, with any feed remaining within being weighed before being discarded. Feed remaining was dried to account for soiling (e.g. urine). Water was available *ad libitum* from nipple drinkers located in each pen. Animals were weighed weekly and weekly feed intake data were obtained.

Daily live weight gain was determined as the linear slope of the regression of live weight (y axis) against time (x axis); this allowed a calculation of the precise time (in days) taken for a pig to grow from 30-55 kg (grower), 50-95 kg (finisher) and 30-95 kg (overall). Subsequently, the exact feed intake over all three periods was obtained, allowing feed conversion ratio to be calculated. Calculating daily feed intakes would not produce a valid data-set as intakes increases during each of the two phases. This approach is more accurate than basing calculations simply on start and finish live weights / feed intakes (as a regression approach over time reduces reliance on just a start and finish weight) and removes the need to weigh pigs every day when they are approaching 55 kg (end of grower phase) and 95 kg (end of finisher phase). Details are presented in Figure 1.

Nitrogen digestibility

A faecal sample was collected from each pig on each of 5 days prior to diet changeover/slaughter. Daily samples for each pig were bulked in a freezer until analysis. Subsequently, nitrogen concentration in the faeces was determined and the coefficient of total tract apparent digestibility (CTTAD) of N could be calculated for each pig during the grower and finisher phases.

Slaughter procedure

Animals were slaughtered as near as possible to 95kg; animals were weighed immediately prior to slaughter with feed offered up until the time that animals were transported to the abattoir. Slaughter was by electrical stunning followed by exsanguination at which point blood samples were collected in heparinised tubes, frozen at -20C for storing and possible future analysis. Following scalding and dehairing, pigs were opened and the intestine tied at the end of the terminal ileum and 10 cm anterior. Digesta in this region was collected and frozen at -20 °C. This collection of ileal digesta was to allow subsequent analysis of Coefficient of Ileal Apparent Digestibility (CIAD) for Nitrogen across dietary treatments.

Following evisceration, small and large intestines were weighed separately full and then empty when digesta had been removed. Carcass measurements (conducted on the left hand side 45 minutes post slaughter were pH and temperature of L dorsi and hot P2. Further measurements were taken 24 hours post slaughter and a shoulder fat sample (~100mm x 50mm) for skatole analysis, frozen at -20 °C.

Lean Mass (LM) was calculated from the standard BPEX equation based on P2 and Cold Carcass Weight (CCW): LM%= 66.5 - (0.95*P2) + (0.068*CCW). Further carcass assessments (length / area of specific tissues) are detailed in Figure 2.

Results and Discussion

Performance data are presented in Table 2 for daily live weight gain (DLWG, kg), total feed intake over the three experimental periods (FI, kg) and feed conversion ratio over the three experimental periods (FCR). The only notable data were a strong trend for an effect of treatment on DLWG (P=0.065) in the grower phase with pigs fed diets based on Wizard having the highest (1.02kg) compared to the control pigs having the lowest (0.92kg). In addition, there was a strong trend for an overall effect of treatment on FI and FCR (P=0.067) with the control treatment having the highest FI (177kg) and worst FCR (2.72). This response was attributable primarily to variations in FI, not in DLWG.

Although numerical differences elsewhere were not statistically significant nor were there any trends (P<0.1), they could be of some importance commercially. For example in the finisher phase FCR for the control was 3.05 (the worst) compared with 2.90 (the best, obtained with animals fed Tattoo the white-flowered field bean). Nevertheless, the overall conclusion is that, when peas and faba beans are supplemented in grower and finisher diets that are formulated to be iso-energetic and balanced for SID Lysine (and the other amino acids, to include methionine as levels are low in peas and faba beans), there are no problems with respect to performance when compared to a diet based on SBM as the only plant protein source. In addition, pigs appear to be able to tolerate both peas and field beans at a rate of inclusion of 30% in both grower and finisher phases. This is in marked contrast to conventional advice where a maximum of 15% and 20% for field beans is suggested respectively for grower and finisher pigs and a maximum of 25% for peas (Pig Progress p 17, vol 28, part 3, 2012).

Coefficient of Total Tract Apparent Digestibility (CTTAD) values for Nitrogen during the grower and finisher phases are shown in Tables 3A and 3B respectively. Although the grower phase data indicated a highly significant dietary effect between treatments, it should be noted that, at processing, it was observed that some of the faecal samples appeared to exhibit a degree of contamination with straw (likely eaten before bedding was removed from the animals prior to faecal collection). With this in mind, the CTTAD Nitrogen values for the grower phase have been included for completeness but should be interpreted with some caution. A similar problem was not observed for the finisher phase faecal samples and, accordingly, these CTTAD data are more robust for interpretation. During the finisher phase, no significant dietary differences were observed in CTTAD values ($P = 0.434$). These data and the observed lack of any dietary effect on Nitrogen digestibility are in good agreement with the CTTAD values seen in the parallel metabolism trial (Objective 5a) suggesting that the legume diets had no detrimental effects on nitrogen digestibility when fed to growing/finishing pigs.

Faecal dry matter values are also presented in Tables 3A and 3B. There were no significant dietary differences observed in either the grower or finisher phases of the trial. Although faecal dry matters in the current study were lower (for all treatments) than observed in the corresponding metabolism trial, a similar lack of significant effect was also observed in the latter study between SBM and legume diets. It is possible that the differences in absolute faecal DM values between the two studies could be an effect of trial design (diets were offered on a restricted basis (0.90 of *ad libitum*) in the metabolism trial, whereas pigs were fed *ad-libitum* in the current growth study).

Ileal N values were higher than expected, which had the effect of lowering the resulting CIAD values for nitrogen (data not shown). It is postulated that the elevated N content of the ileal digesta arose from a higher than expected degree of endogenous losses (intestinal cells sloughed from the gut) following stunning at the time of slaughter, resulting in underestimation of digestibility. This effect of slaughter method on ileal nitrogen digestibility has been reported in pigs when assessing comparative practices: stunning vs. anaesthesia (Prawirodigdo et al 1998; Brit J of Nut 80, pp183-191). Accordingly, it is proposed that any future trial protocols should refrain from using a similar technique at slaughter to determine apparent ileal digestibility of N.

Weight of intestines and their contents are presented in Table 4. Expressing empty (E) intestine weight as a proportion of full (F) intestine weight would give an indication of whether treatment was influencing digesta mass (to include possibly fibre, although all diets were formulated to have very similar neutral detergent fibre levels, and gas, although the latter has minimal mass). There were no significant nor trends for treatment effects, again being contrary to some suggestions that high dietary levels of field beans can create a large volume of gas and lead to constipation and thus larger gut volumes in adult sows.

Initial carcass assessments are presented in Table 5. There were no treatment effects on killing out % (confirming that there were no differences in intestinal contents described above) with data ranging from 72.0 (Tattoo field beans) to 73.8 % (Prophet peas). Further carcass assessments are presented in Table 6. Low pH post slaughter / rapid decline of pH can indicate a risk of PSE meat developing resulting from the combination of the rate of decline (within 45 minutes instead of 6-8 hours) and the heat generated by the associated metabolic activity which gives the meat PSE. Often these animals will not have an exceptionally low ultimate pH. This is best characterised as being associated with the "halothane" genotype. A low ultimate pH tends to give a poor water holding capacity. The pH develops at the normal rate (6-8 hours) but the carcass pH gets lower than normal (normal being pH 5.3-5.8). It is generally not as negative as PSE, the muscle is relatively normal texture but has high drip loss. It tends to be associated with the RN genotype typically in Hampshire breeds (Lonergan and S. M. Lonergan 2007. J. Anim. Breed. Genet. 124 Suppl 1: pp19-26). Pigs on the control diet had the lowest pH 45 minutes post slaughter (6.1, P=0.104; others 6.3-6.5) but treatment differences 24 hours post slaughter had disappeared (range 5.4-5.5, P=0.343). Visually, there was no evidence for PSE.

Measurements of carcass lean and fat are presented in Tables 7 and 8. All data were analysed using carcass weight 24 hours post slaughter as a covariate. The range in P2 was 10-11 mm with no significant treatment effects; lean meat % (Table 9) ranged from 60.7 to 62.1%, again with no significant treatment effects. There was a suggestion that pigs fed on Tattoo (treatment 4) were leaner with lowest minimum mid back (P=0.029), anterior gluteus medius (P=0.092) and K values (P<0.001) but, as none of these is used in assessing total lean, differences are not important. Having said that, these more detailed carcass analyses are worthy of a further comment. When examining fat measurements as a whole, pigs fed on the control SBM diet tended to have more K, maximum shoulder and minimum gluteus medius fat. They also had smallest B value, a measurement of lean tissue.

Skatole and indole data are presented in Table 10. ANOVA was based on original raw data and log transformed data in view of the non-normal distribution of the former data. There were no significant differences in either initial data or those analysed with maximum shoulder fat depth as a covariate (to account for concentrations being influenced by amount of fat, although there was no significant effect of the covariate). Although there is the suggestion that the currently agreed threshold for skatole of 0.20-0.25 µg/g might be too high (Bonneau and Chevillon 2012; Meat Science 90, 2, pp330-337)**, a**ll data in the current trial were well below these limits (between 1/4 and 1/3 of the current), so there is no risk of taints associated with feeding either peas or field beans at rates of inclusion of 30%.

Table 1A. Diets (Grower)

Diet code	Control	Prophet	Fuego	Tattoo	Wizard
	1	**2**	**3**	**4**	**5**
	Ingredients (g/kg)				
Soya bean meal 48	140				
Peas (Prophet)		300			
Beans (Fuego)			300		
Beans (Tattoo)				300	
Beans (Wizard)					300
Wheat	446	283	293	280	293
Barley	128				
Molasses-beet	30				
Rapeseed meal	70				
Wheat feed	150				
Soya oil	11	11	3	16	3
Lysine HCl	1.50	2.10	1.66	1.70	2.00
Methionine	0.06	0.65	0.70	0.8	1.0
Threonine	0.05	1.10	0.75	0.70	1
Tryptophan	0	0.20	0.14	0.05	0
Dicalcium phosphate	5.5	5.5	5.5	5.2	6.0
Limestone	11.6	12.2	11.7	11.9	12.0
Salt	3.3	3.3	3.3	3.3	3.0
Premix	2.5				
Calculated Nutrient analysis (g/kg unless otherwise stated					
NE (MJ/kg)	9.3				
DE (MJ/kg)	13.6				
CP (determined)	191.1	185.4	165.7	170.1	176.6
SID Lysine	8.1				
Total Lysine	9.6				
Methionine	2.4				
Methionine + Cystine	4.8				
Threonine	5.3				
Tryptophan	1.5				
Calcium	7.2				
Digestible P	2.5				
NDF	130				

Table 1B. Diets (Finisher)

Diet code	Control	Prophet	Fuego	Tattoo	Wizard
	1	**2**	**3**	**4**	**5**
	Ingredients (g/kg)				
Soya bean meal 48	120				
Peas (Prophet)		300			
Beans (Fuego)			300		
Beans (Tattoo)				300	
Beans (Wizard)					300
Wheat	264	83	91	79	91
Barley	284				
Molasses-beet	30				
Rapeseed meal	70				
Wheat feed	200				
Soya oil	11	11	3	16	3
Lysine HCl	10	10	3	15	3
Methionine	0.60	0.60	0.14	0.11	0.23
Threonine	0	0.40	0.37	0.42	0.38
Tryptophan					
Dicalcium phosphate	4.5				
Limestone	11.6	12.2	11.7	11.9	12.0
Salt	11.3	11.5	11.1	11.1	11.1
Premix	2.5				
Calculated Nutrient analysis (g/kg unless otherwise stated)					
NE (MJ/kg)	9.0				
DE (MJ/kg)	13.2				
CP (determined)	180.1	168.0	157.8	168.7	167.5
SID Lysine	7.1				
Total Lysine	8.4				
Methionine	2.1				
Methionine + Cystine	4.2				
Threonine	4.6				
Tryptophan	1.3				
Calcium	6.8				
Digestible P	2.4				
NDF	180				

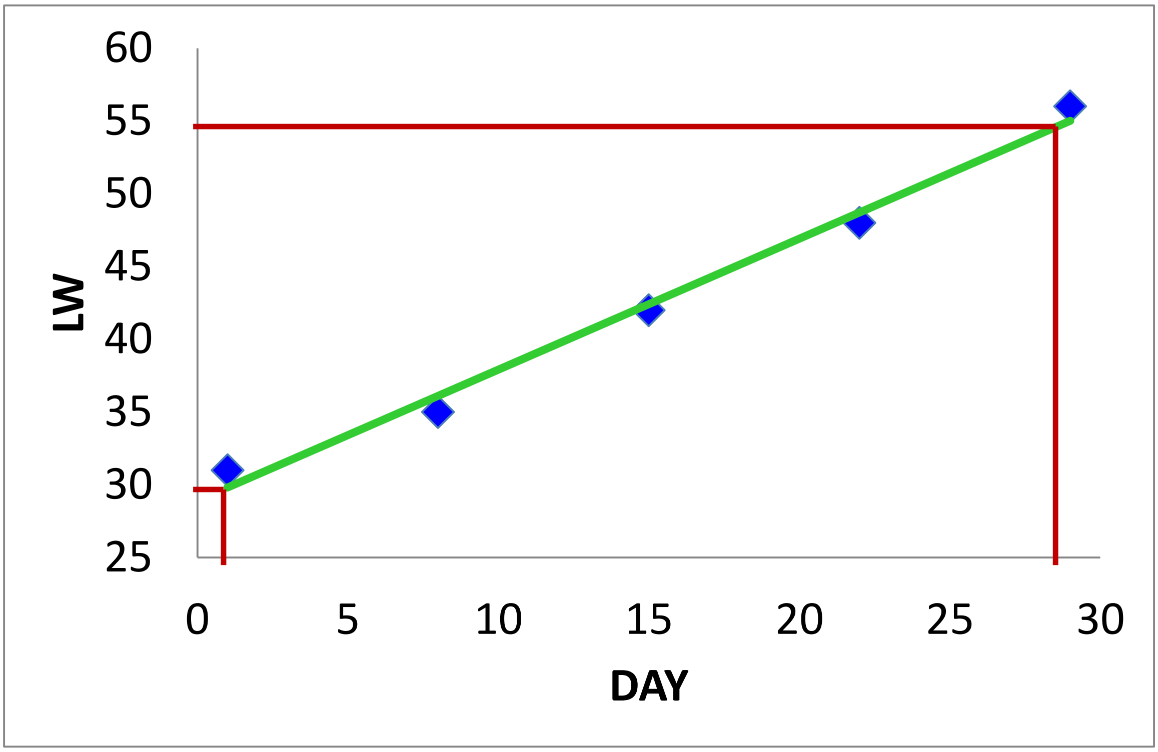

Figure 1. Calculation of live weight gain and time taken to grow over precise live weight range.

Blue symbols are weekly weights. In this example, the linear equation: y = 28.9 (+/- 0.97) + 0.90x(+/-0.054)x; variance accounted for 98.6% . Slope of the linear equation is the daily live weight gain (DLWG – 0.900 kg). Solving the linear equation when b (intercept) is 30 (start of trial) and then 55 (end of grower phase):

- Gives the number of days required to grow 25kg (30 to 55kg)
- Allows the calculation of the actual days when the pig weighed 30 and 50kg
    - Leads to calculation of the actual feed intake between 30 and 55kg
    - Actual feed intake / live weight gain (25kg) = FCR
        - Daily feed intake is not a meaningful measurement as pigs increase intake daily

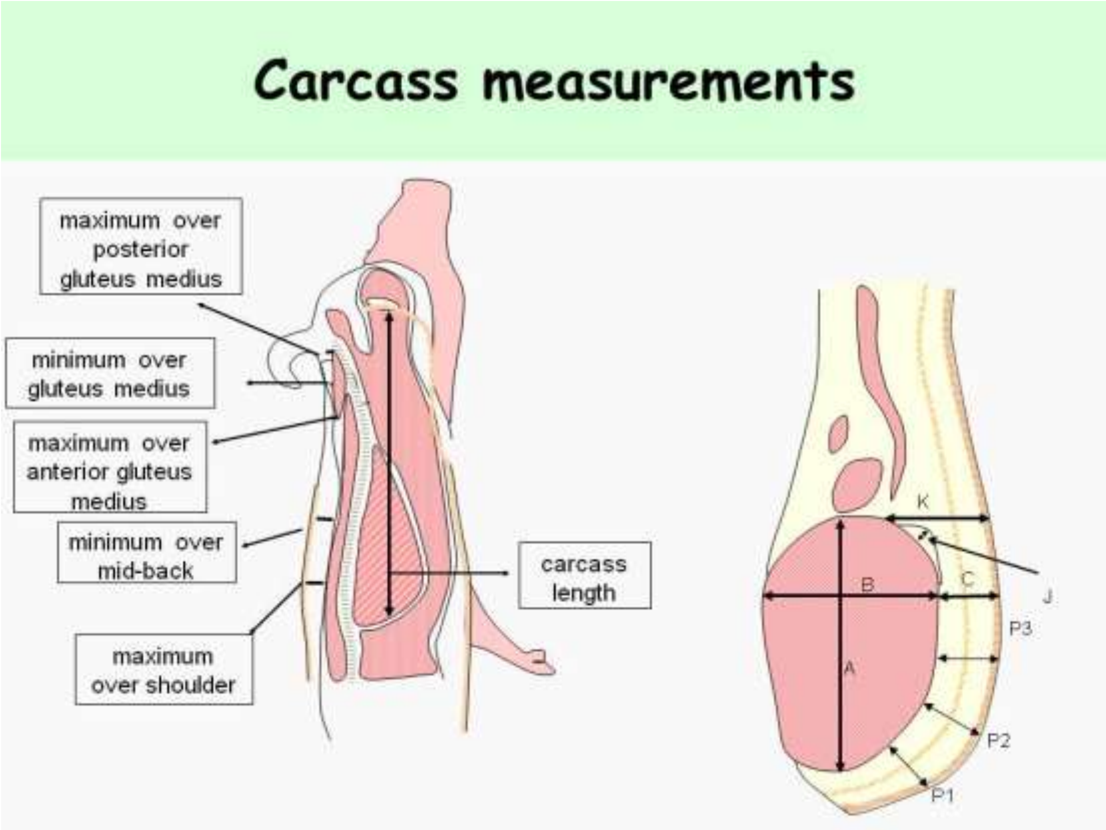

Figure 2. Carcass assessments (24 hours post slaughter)

Table 2. Performance

Grower (30 – 55kg)

	Diet					SED	P	CV%
	1	2	3	4	5			
DLWG	0.92	0.95	0.99	0.96	1.02	0.035	0.065	7.2
FI	48	48	46	46	47	1.8	0.838	7.8
FCR	1.92	1.91	1.86	1.85	1.87	0.074	0.834	7.8

Finisher (55 – 95 kg)

	Diet					SED	P	CV%
	1	2	3	4	5			
DLWG	1.13	1.19	1.17	1.10	1.14	0.045	0.400	7.9
FI	122	119	118	116	122	4.2	0.588	5.2
FCR	3.05	2.97	2.95	2.90	3.04	0.104	0.588	5.2

Overall (30 – 95kg)

	Diet					SED	P	CV%
	1	2	3	4	5			
DLWG	1.05	1.08	1.10	1.06	1.05	0.034	0.422	6.4
FI	177	168	172	160	174	5.9	0.067	7.0
FCR	2.72	2.58	2.65	2.46	2.67	0.091	0.067	7.0

Table 3. Coefficient of Total Tract Apparent N Digestibility and faecal dry matter

Grower

	Diet					SED	P	CV%
	1	2	3	4	5			
CTTAD	0.770	0.686	0.648	0.747	0.669	0.028	<.001	8.1
Faecal DM (g/kg)	264	259	262	263	265	12.25	0.990	9.0

Finisher

	Diet					SED	P	CV%
	1	2	3	4	5			
CTTAD	0.756	0.735	0.753	0.769	0.740	0.039	0.434	5.2
Faecal DM (g/kg)	261	278	270	272	279	7.64	0.179	5.6

Table 4. Intestine measurements (kg)

	Diet					SED	P	CV%
	1	2	3	4	5			
SI Full	3.7	4.1	3.8	4.1	3.9	0.31	0.665	15.6
SI Empty	1.9	2.2	2.0	2.1	2.0	0.12	0.264	12.0
E / F	0.53	0.54	0.53	0.51	0.52	0.040	0.982	15.1
LI Full	4.7	4.5	5.0	4.6	5.2	0.28	0.153	11.8
LI Empty	1.6	1.6	1.8	1.6	1.9	0.11	0.055	12.6
E / F	0.35	0.36	0.36	0.36	0.37	0.021	0.924	14.8

Table 5. Live weight at slaughter, carcass weights 24hrs post slaughter (kg), KO %

	Diet					SED	P	CV%
	1	2	3	4	5			
LW	94	98	98	100	98	1.3	0.010	2.7
CW	68	72	70	72	71	1.2	0.017	3.4
KO%	72.3	73.8	72.0	72.5	72.4	0.75	0.178	2.1

Table 6. Carcass temperature and pH

	Diet					SED	P	CV%
	1	2	3	4	5			
T 45m pm	40.1	37.9	39.1	39.0	39.2	0.87	0.196	4.5
T 24h pm	2.8	2.7	2.4	2.7	2.8	0.22	0.488	16.4
pH 45m pm	6.1	6.3	6.5	6.3	6.4	0.15	0.104	4.6
pH 24h pm	5.5	5.4	5.5	5.4	5.5	0.06	0.343	2.1
pH change	0.6	0.8	1.0	0.9	0.9	0.13	0.081	30.7

Table 7. Whole carcass measurements (mm) with analysis of covariance (Covar) on carcass weight 24hrs post slaughter

	Diet					SED	P	P Covar	CV%
	1	2	3	4	5				
P2 (probe)	11.3	10.7	9.7	9.9	11.1	0.80	0.193	0.205	14.4
Length	815	813	837	821	819	8.5	0.212	0.505	2.0
Max Shoulder	33	32	30	30	31	1.4	0.320	0.066	8.7
Min Mid Back	13	12	13	10	13	1.1	0.029	0.013	16.5
Ant Glut Med	18	16	14	14	15	1.5	0.092	0.189	18.8
Min Glut Med	10	10	8	9	9	1.1	0.221	0.073	23.6
Post Glut Med	19	18	18	17	17	1.7	0.732	0.405	17.5

Table 8. Split carcass measurements (mm) with analysis of covariance (Covar) on carcass weight 24hrs post slaughter.

	Diet					SED	P	P Covar	CV%
	1	2	3	4	5				
P1	9.1	8.3	8.1	8.1	8.6	0.67	0.589	0.237	15.1
P2	9.5	8.1	7.9	8.5	8.6	0.68	0.224	0.135	15.3
P3	10	13	8	8	9	2.7	0.413	0.972	53.0
A	89	92	92	92	92	2.5	0.800	0.706	5.1
B	58	58	59	56	56	2.0	0.377	<0.001	6.8
C	9.2	8.4	7.9	7.9	8.7	0.64	0.263	0.285	14.4
K	16.1	14.0	12.9	11.1	13.4	0.93	<0.001	0.013	13.1
J	2.8	2.0	2.3	1.5	2.0	0.66	0.501	0.668	57.2

Table 9. Calculated % Lean

	Diet					SED	P	CV %
	1	2	3	4	5			
LM %	60.7	61.1	62.1	61.8	60.7	0.72	0.208	213

Table 10. Indole and Skatole (µg/g fat) with analysis of covariance (COVAR) on maximum shoulder fat.

Raw data

	Diet					SED	P	P COVAR	CV%
	1	2	3	4	5				
Indole	0.02	0.02	0.04	0.02	0.03	0.011	0.464	0.692	54.6
Skatole	0.07	0.04	0.06	0.06	0.06	0.016	0.591	0.692	54.6

Log transformed: (log(data x 1000))

	Diet					SED	P	P COVAR	CV%
	1	2	3	4	5				
Indole	1.3	1.3	1.4	1.2	1.4	0.11	0.440	0.282	15.8
Skatole	1.7	1.6	1.7	1.8	1.7	0.13	0.610	0.550	15.1

Full report Objective 6: Translate experimental findings to applicable management strategies by conducting large scale demonstration trials

Lead authors: Lesley Smith and Jos Houdijk (SRUC).

Executive Summary

- The Green Pig project has demonstrated the succesful replacement of SBM with both peas and faba beans up to 30% inclusion in nutritionally balanced diets in two small scale trials. To test the applicability of these findings to commercial pig farming, four large scale farm demonstration trials were conducted at three different conventional pig farms. A further trial under organic conditions was planned, but stopped after one round. Consequently, this is reported as an observation.
- Demonstration trial 1 and 2 tested three grower and finisher diet treatments, Control SBM diet, 30% peas and 30% faba beans in pigs housed on slats (1) and straw (2).
- Demonstration trial 1 and 2 showed that using peas or faba bean in commercial pig diets, in the absence of SBM does not affect performance or slaughter measures.
- Demonstration trial 3 tested two grower and finisher diet treatments, Control SBM diet and 25% faba bean diet.
- Demonstration trial 3 showed no detrimental effect of 25% faba bean inclusion on performance or slaughter measures.
- Demonstration trial 4 tested one experimental diet, 25% faba bean diet, compared to average farm performance figures from the 3 months during which the trial was conducted.
- Demonstration trial 4 showed pigs fed the 25% faba bean diet resulted in more favourable performance figures relative to national finisher performance figures. However, the performance of pigs fed the 25% faba bean diet was slightly lower relative to the farms average performance figures. This may be due to the lack of replication in the initial part of the trial. The bean diet also resulted in a lower backfat measurement at the P2 site relative to average farm data.
- The organic observation (trial 5), though inconclusive, is sufficiently encouraging to warrant further investigation on greater use of home grown peas and faba beans in organic systems of pig production.
- Overall the conventional demonstration trials suggest that peas and faba beans are a viable home-grown alternative to SBM in commercial grower and finisher pig diets.

Introduction

The most common protein source used worldwide for pig feed is soya bean meal (SBM) (Gatel and Grosjean, 1990). However, in temperate environments soya bean is difficult to cultivate and the pig industry relies heavily on SBM imported from North and South America. There are increasing concerns about the sustainability and security of pig production, if this raw material continues to be used at the current rate. There are also environmental concerns with SBM as the rapid increase in demand for soya is associated with increasing demands of land use change (Fearnside, 2001). Thus, there is a need to find a viable alternative protein source to be used in pig diets.

The Green Pig Project is investigating the potential of peas and faba beans as an alternative home grown protein source for grower and finisher pig feed. Peas and faba beans are relatively attractive for animal feed purposes as they are high in crude protein and are a good source of the essential amino acid lysine (Castell et al., 1996; Partanen et al., 2003). Another key benefit of peas and faba beans is that legumes have natural nitrogen-fixing abilities which provide assimilated nitrogen to the whole crop rotation, reducing the need for nitrogen fertilisers (Crepon, 2006; Zijlstra et al., 2008; Kopke and Nemecek, 2010). Furthermore, due to their home grown nature peas and faba beans are also associated with reduced transport and improved food security. However, the use of peas and faba beans in pig diets has been limited. A survey carried out to quantify the use of home-grown protein sources in the feeds of UK growing and finishing pigs found that less than 2% of compounders and home-mixers surveyed used peas or faba beans in their pig diets. Furthermore, when peas and faba beans were used in pig diets, inclusion levels in the diet were less than 11% (Smith et al., 2011). The reluctance of the pig industry to include these home grown pulses in pig diets is mainly due a long standing association between high inclusions of peas or faba beans in pig diets with poor growth performance (Castell, 1976; Aherne et al., 1977; Onaghise and Bowland, 1977; O'Doherty and Keady, 2000, 2001; Partanen et al., 2003). Recent studies have shown if diets are nutritionally balanced for amino acid requirements, high inclusion pea diets will not affect performance (Stein et al., 2004, 2006). Furthermore, the Green Pig project has demonstrated the succesful replacement of SBM with both peas and faba beans up to 30% inclusion in nutritionally balanced diets in two small scale trials. The first trial was a dose response feeding trial showing no effect of increasing pea or faba bean inclusion from 7.5% pea or faba bean inclusion up to 30% pea or faba bean inclusion on pig performance or carcass quality (Smith et al., 2012a; b). The second performance trials then demonstrated no effect on performance or carcass quality of

30% inclusion pea or faba bean diets relative to a SBM control diet (White et al., 2012a; b). Thus, in order to test the applicability of these findings to commercial pig farming, three large scale farm demonstration trials were conducted at three different conventional pig farms. A further trial under organic conditions was planned, decisions outwith Green Pig. Consequently, this is reported as an observation. All demonstration trials and the organic observation were conducted at commercial farms under the supervision of BPEX and followed BPEX protocols, and their collective aim was to demonstrate that replacing soya bean meal (SBM) with peas or faba beans in grower and finisher pig diets under commercial conditions would not detrimentally affect pig performance.

The Demonstration Trials

Demonstration Trial 1 and 2

Demonstration Farm, Animal and Housing

Demonstration trial 1 and 3 were conducted by Midland Pig Producers (MPP) at their large commercial farm (450 sows) in Staffordshire. The trials were conducted in three different sheds encompassing two different types of housing system, slats (trial 1) and straw housing (trial 2). A total of 1230 terminal line pigs (approx. 35kg) were allocated to one of the three diet treatments in one of the three sheds. There was one slatted shed containing 30 pens (11 pigs per pen), with 10 replicates per diet. Straw shed 1 contained 24 pens (25 pigs per pen), with 8 replicates per diet. Straw shed 2 contained 6 pens (50 pigs per pen), with 2 replicates per diet. Pigs had *ad libitum* access to food and water.

Diets, Performance and Slaughter Measurements

There were three diet treatments (Control SBM diet, 30% Peas and 30% Beans) fed throughout the trial (pigs 35-110kg), with two formulations for each diet treatment for the grower (pigs 35-60kg) (Table 1) and finisher stage (pigs 60-110kg) (Table 2). Diets were fed as dry pelleted compound diets. Pen live weight was recorded at the start of the trial, when the diet changed to the finisher formulation, and when pigs were sent to slaughter. Feed given and all refusals were recorded on a pen basis. Pig performance was assessed by calculating body weight gain (BWG, g/pig/day), average daily feed intake (ADFI, g/pig/day) and feed conversion ratio (FCR, ADFI/BWG) on a pen basis. All deaths were recorded, and the total number of pig days was used to calculate BWG and ADFI on a pig/day basis. A subjective dung score (score 1-5), where 1 represented hard faeces and 5 represented watery, mucous like faeces, was recorded on a pen basis. At the end of the study pigs were slaughtered at a commercial slaughter house at approx 110kg, over 8 different slaughter days. At the slaughter house, pH value at 45 minutes *post-mortem* (pH_{45}) was recorded as an estimation of meat quality characteristics. In addition, carcass weight (hot and cold), and backfat at the P2 site (mm) were recorded. Lean meat percentage (% Lean= 66.5-0.95 x P2 + 0.068 x cold carcass weight) was calculated for each pig.

Statistical Analysis

As trial 1 and 2 were effectively run together, all statistics included housing system (slats and straw) as a treatment effect, although it should be noted that the work was not undertaken to compare different finishing systems. Performance measures (BWG, ADFI and FCR) were analysed using ANOVA to test the treatment effects of diet (control, pea and bean diet) and house type. Start weight was found to be a significant covariate for FCR, and thus included in the model as a covariate. Pen nested in Batch was included in the model as a block effect for both BWG and FCR. As numbers of pigs sent for slaughter varied for each slaughter day, giving unbalanced groups, pH_{45}, P2 value, and % Lean were analysed using REML to test the treatment effect of diet and house type. Slaughter Day was included as the random effect in the model. The slaughter data (P2 probe value and cold carcass weight) was also subjected to q-box-analysis (qbox), a commercial tool developed by Harbro Ltd, which analyses the level of output in relation to the slaughter contract specification.

Table 1. Diet formulations for the grower pigs (35-60kg) in Trials 1 and 2.

Ingredients (g/kg)	Control SBM	30% Pea	30% Faba beans
Wheat	322.0	146.0	271.0
Barley	250.0	250.0	150.0
Peas	0.0	300.0	0.0
Beans	0.0	0.0	300.0
Biscuit 136	80.0	80.0	80.0
Wheat Feed	25.8	0.0	0.0
Soya 48	98.0	0.0	0.0
Rapeseed Ext	110.0	110.0	81.0
DDGS Ensus ana	75.0	75.0	75.0
Limestone	12.2	10.0	10.2
DCP 0.18	0.2	0.0	0.0
Salt	2.7	0.55	2.8
Sodium Bicarb	0.0	3.0	0.0
Lysine Liq 50	6.6	5.1	5.9
Liq meth	1.0	1.8	2.3
Threonine	1.3	1.6	1.8
Fat 0.16	0.0	0.26	1.9
Fat 0.16 spy	3.0	4.4	5.0
Tryptopham	0.0	0.40	0.47
230656 Fin (R16552)	2.0	2.0	2.0
Rouxmol	10.0	10.0	10.0
Natuphos 500L	0.1	0.1	0.1
Valine	0.0	0.14	0.15

Table 2. Diet formulations for the finisher pigs (60-110kg) in Trials 1 and 2

Ingredients (g/kg)	**Control SBM**	**30% Pea**	**30% Faba beans**
Wheat	257.0	100.0	101.0
Barley	250.0	240.0	250.0
Peas	0.0	300.0	0.0
Beans	0.0	0.0	300.0
Biscuit 136	56.0	44.8	78.0
Wheat Feed	150.0	79.0	35.3
Soya 48	47.6	0.0	0.0
Rapeseed Ext	125.0	125.0	125.0
DDGS Ensus ana	75.0	75.0	75.0
Limestone	13.2	13.3	12.8
Salt	2.4	2.4	2.2
Lysine Liq 50	6.8	3.0	3.3
Liq meth	0.86	1.2	1.3
Threonine	1.2	0.92	0.86
Fat 0.16 spy	3.0	3.0	3.0
Tryptopham	0.0	0.18	0.22
230656 Fin (R16552)	2.0	2.0	2.0
Rouxmol	10.0	10.0	10.0

Results and Discussion

There were no significant diet effects on BWG (P=0.36) (Figure 1), ADFI (P=0.41) (Figure 2) or FCR (P=0.81) (Figure 3). There was an effect of housing type on BWG (P<0.001), with pigs in straw housing having a greater BWG relative to slatted housing (Figure 1); ADFI (P<0.001) with in straw housing having a greater ADFI than pigs in slatted housing (Figure 2); FCR (P<0.001) (Figure 3), with pigs in the straw housing having a greater FCR relative to those pigs in the slatted housing. Dung scores for all pens throughout the trial were recorded as 2, (slightly soft faeces). Thus, the performance results (BWG, ADFI and FCR) and dung score indicate that the use of peas and faba beans in commercial pig diets do not affect performance.

Pork with a pH_{45} of less than 6 is likely to present PSE characteristics (pale, soft, exudative meat) (Garrido et al., 1994), thus the pH value at 45 minutes *post-mortem* was measured in order to determine if diet treatment affected potential PSE characteristics in the meat. There was no effect of diet (P=0.52) or housing type (P=0.37) on pH_{45} (Figure 4). However, there was a tendency for a diet x housing interaction (P=0.056), where pH_{45} was greater in pigs fed a pea diet in slatted housing relative to pigs fed the SBM control diet in the straw housing (Figure 4). However, all pH_{45} values were greater 6 indicating that diet treatment did not promote PSE characteristics in the meat. There was no significant diet effect on P2 value (P=0.30) (Figure 5) or estimated % Lean (P=0.37) (Figure 6). As with the performance measures, there was a significant effect of housing type on P2 value (P<0.001), where P2 value of pigs in straw housing was greater than the P2 value of pigs in slatted housing; and on % Lean (P<0.001), where the % Lean of pigs in straw housing was lower relative to that of pigs in the slatted housing. However the mean P2 values were all lower than the 12mm upper limit for premium carcass payment in the UK (Kyriazakis and Whittemore, 2006), suggesting there are no negative effects on slaughter measures associated with including peas and faba beans in the diet at the expense of SBM in nutritionally balanced diets. The qbox results show that 79%, 70% and 76% of the slaughtered pigs fed the control SBM, pea and faba bean diets respectively met the slaughter contract specification (dark shaded area) (Figure 7) and therefore full contract payment was made for these animals. The return per animal was then calculated based on the slaughter contract specification giving £125.23/pig, £125.19/pig and £125.89/pig for control SBM, pea and faba bean diets respectively. Thus, there was no effect of diet on the return from the slaughter house.

Thus, this trial has shown that using peas or faba bean in nutritionally balanced commercial pig diets, in the absence of SBM does not affect performance or slaughter measures. Furthermore, there is no difference between the pea and faba beans diets, suggesting that both peas and faba beans are suitable alternatives for SBM, and that farmers can choose the home-grown protein source which is most available to them.

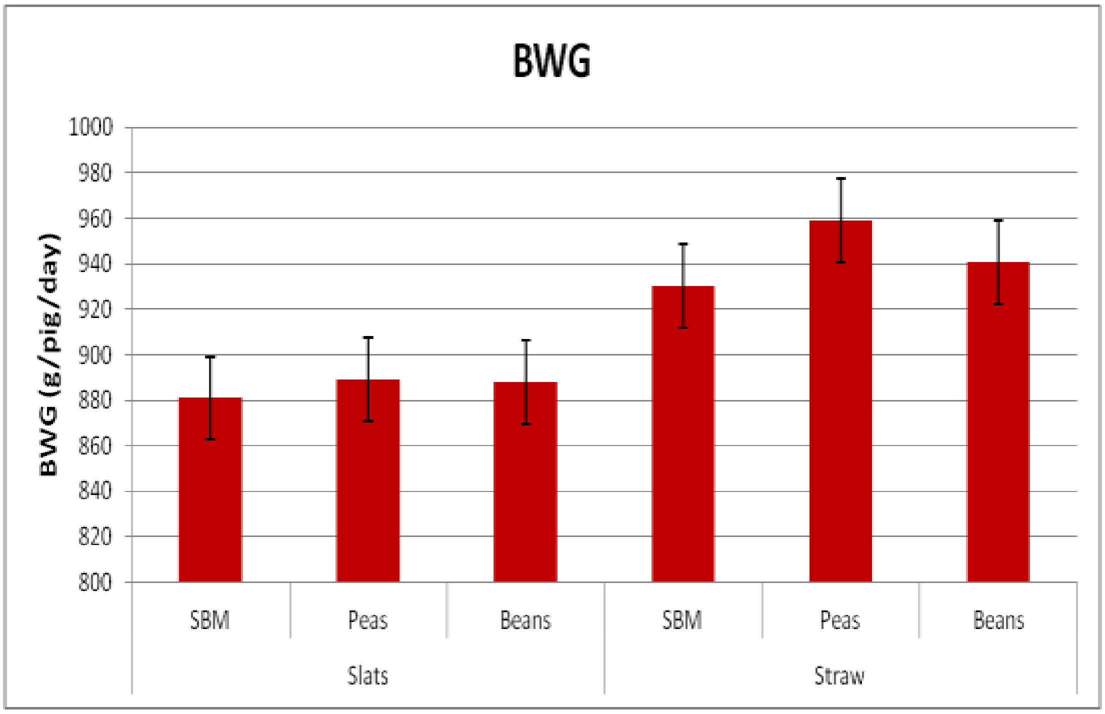

Figure 1. The body weight gain (BWG) (g/pig/day) of pigs (35-110kg) fed control SBM, pea and bean diets housed on a slatted system (trial 1) or straw system (trial 2).

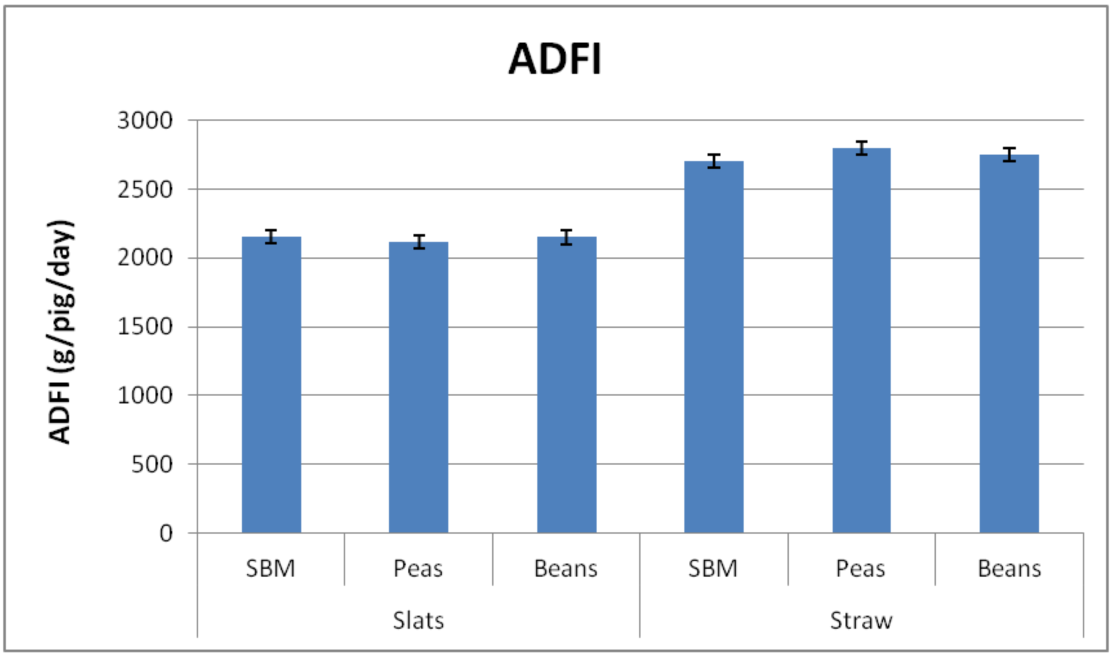

Figure 2. Average daily feed intake (ADFI, g/pig/day) of pigs (35-110kg) fed control SBM, pea and bean diets housed on a slatted system (trial 1) or straw system (trial 2).

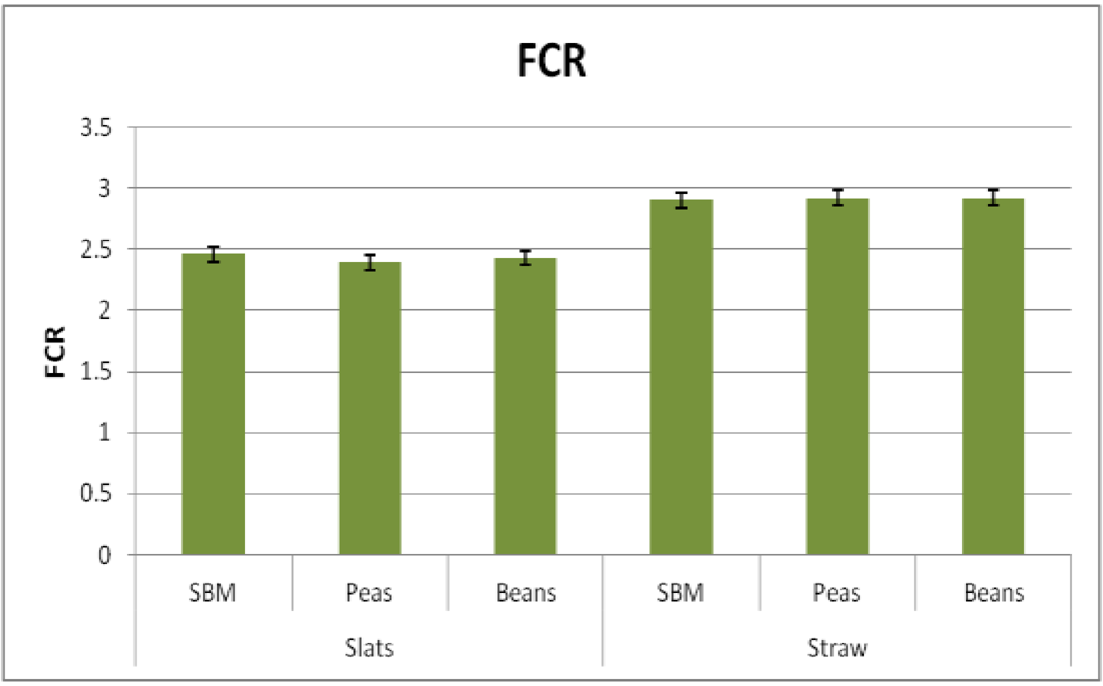

Figure 3. FCR of pigs (35kg-110kg) fed control SBM, pea and bean diets housed on a slatted system (trial 1) or straw system (trial 2).

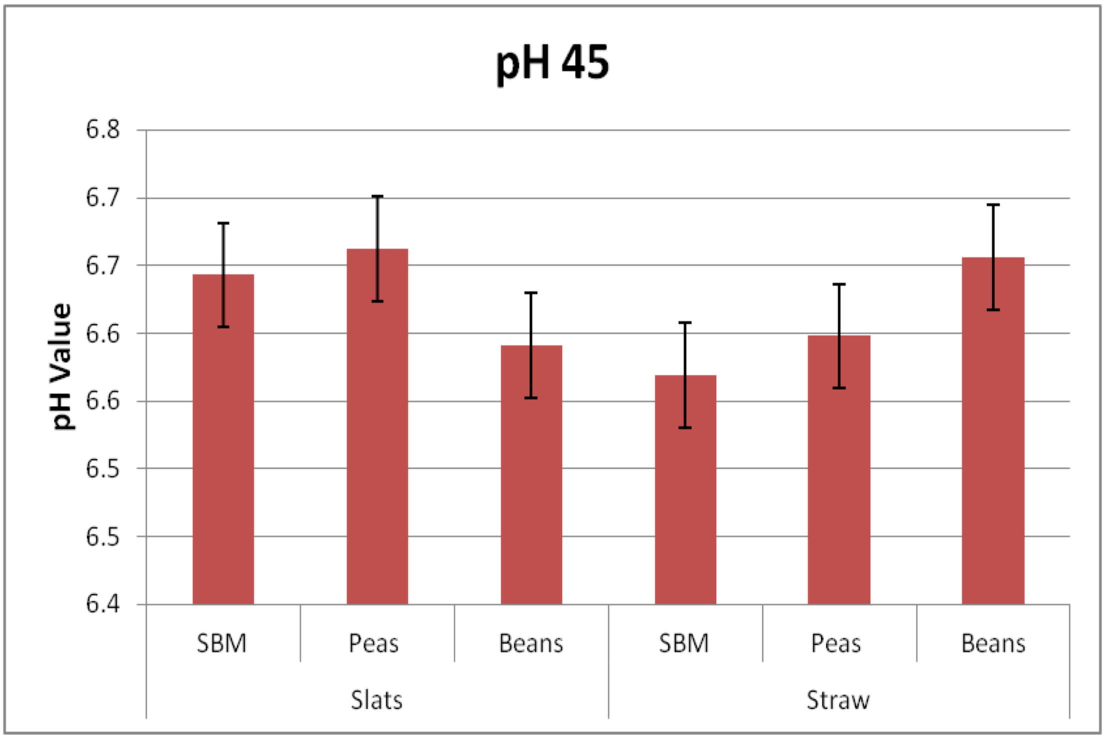

Figure 4. pH value at 45 minutes *post-mortem* (pH_{45}) of pigs fed control SBM, pea and bean diets housed on a slatted system (trial 1) or straw system (trial 2).

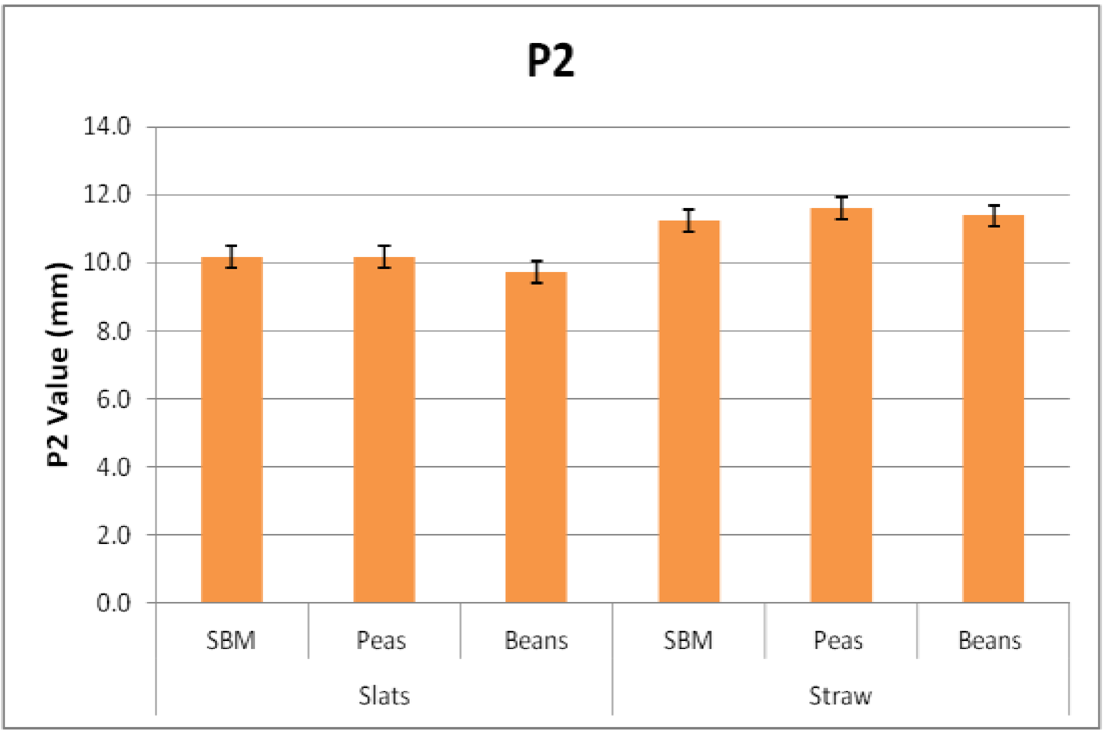

Figure 5. Backfat depth at the P2 position fed control SBM, pea and bean diets housed on a slatted system (trial 1) or straw system (trial 2).

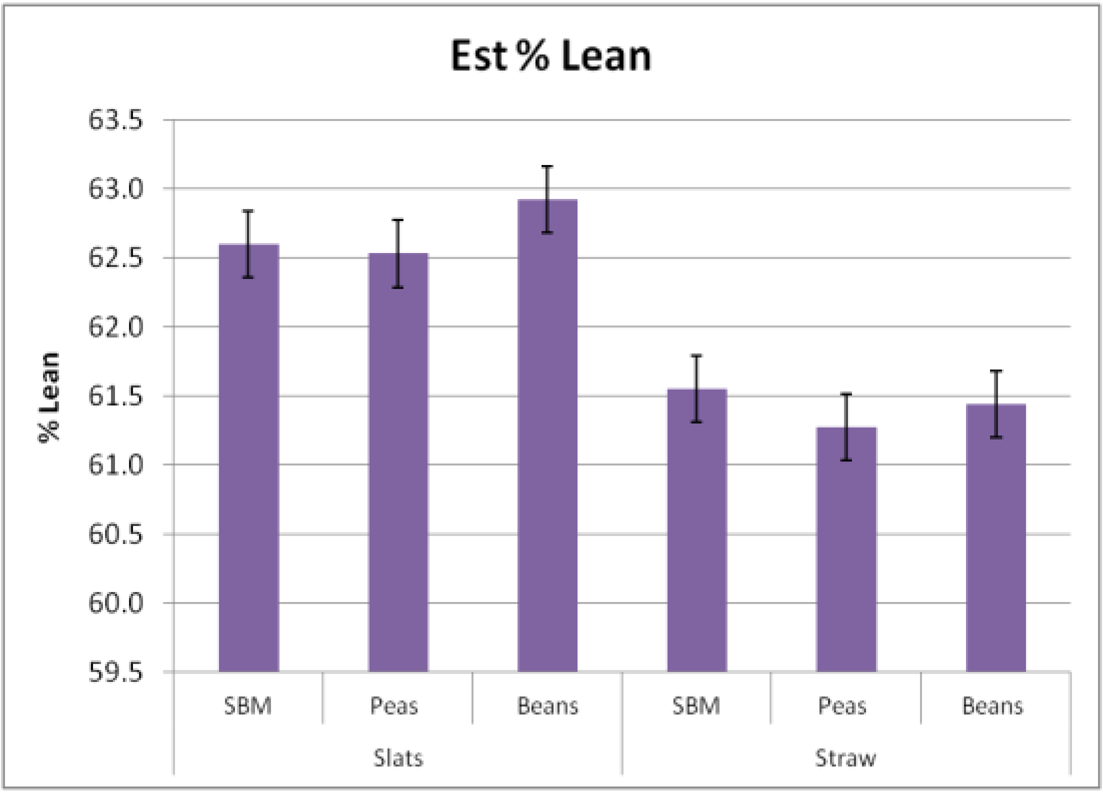

Figure 6. Estimated lean meat percentage of fed control SBM, pea and bean diets housed on a slatted system (trial 1) or straw system (trial 2).

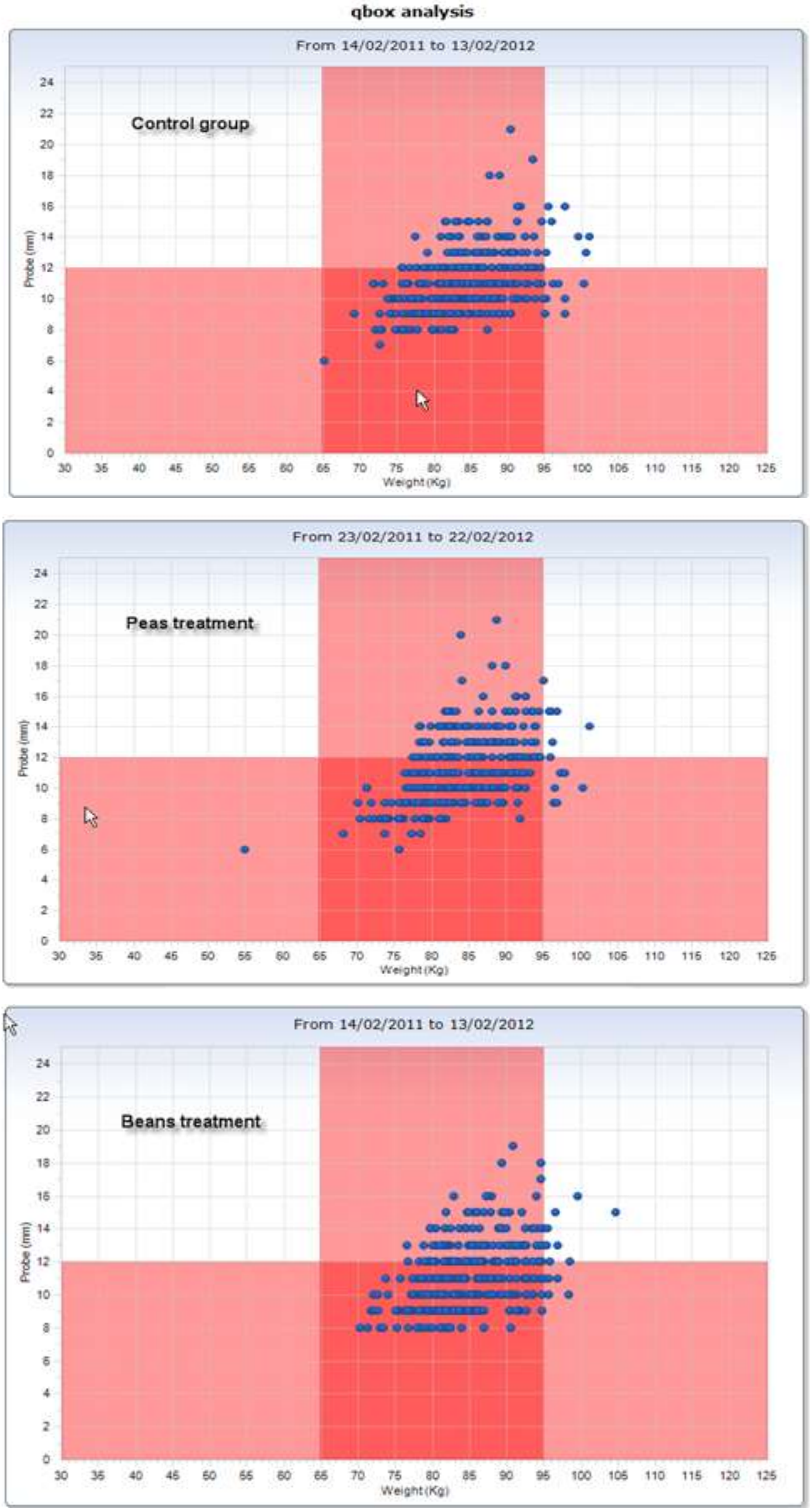

Figure 7. qbox analysis of P2 probe (mm) and cold carcass weight fed control SBM, pea and bean diets housed on a slatted system (trial 1) or straw system (trial 2).

Demonstration Trial 3

Demonstration Farm, Animals and Housing

Demonstration trial 3 was conducted by BOCM Pauls on a large commercial pig farm where 322 terminal line pigs (approx. 35kg) were allocated to one of two diet treatments. There were 7 pens per diet treatment (23 pigs per pen). Pigs had *ad libitum* access to food and water.

Diets, Performance and Slaughter Measurements

There were two diet treatments, a control diet SBM diet and a 25% faba bean diet fed throughout the trial (pigs 35-110kg), with two formulations for each diet treatment for the grower (pigs 35-60kg) and finisher stage (pigs 60-110kg). The control diet contained 12% and 7.6% SBM in the grower and finisher formulations respectively. Whilst there was no SBM in the finisher faba bean diet, the grower faba bean diet still contained 5% SBM. This arose from mill operational constraints on upper level of faba bean inclusion. Diets were fed as dry pelleted compound diets. Pen live weight was recorded at the start of the trial, approximately every 15 days throughout the trial, and at slaughter. Feed given and all refusals were recorded on a pen basis were recorded on the same days as pen live weight. Pig performance was assessed by calculating body weight gain (BWG, g/pig/day), average daily feed intake (ADFI, g/pig/day) and feed conversion ratio (FCR, ADFI/BWG) on a pen basis. All deaths were recorded, and the total number of pig days was used to calculate BWG and ADFI on a pig/day basis. At the end of the study pigs were slaughtered at a commercial slaughter house at approx 110kg, over 4 different slaughter days. At the slaughter house, sex, carcass weight (hot and cold), and backfat at the P2 site (mm) were recorded. Lean meat percentage (% Lean= 66.5-0.95 x P2 + 0.068 x cold carcass weight) was calculated for each pig.

Statistical Analysis

Performance measures (BWG, ADFI and FCR) were analysed using ANOVA to test the treatment effects of diet (control and faba bean diet) with pen included in the model as a block effect. As numbers of pigs sent for slaughter varied for each slaughter day, giving unbalanced groups, P2 value, and % Lean were analysed using REML to test the treatment effect of diet and sex. Slaughter Day and Pen was included as the random effect in the model.

Results and Discussion

There was no significant diet effect on BWG (P=0.82) (Figure 8), ADFI (P=0.39) (Figure 9) or FCR (P=0.67) (Figure 10). Similarly, there was no effect of performance on P2 value (P=0.89) (Figure 11), or estimated lean meat percentage (P=0.95) (Figure 12). However, there was a sex effect on the slaughter measures, where Gilt P2 value was greater than Boar P2 value (P<0.001) (Figure 11), and consequently gilt lean meat percentage was lower than boar lean meat percentage (P<0.001) (Figure 12) confirming that boars are consistently leaner than gilts at slaughter. Thus the trial indicates that there is no detrimental effect of 25% pulse inclusion on performance or slaughter measures, and that faba beans are a viable home-grown alternative to SBM in commercial grower and finisher pig diets.

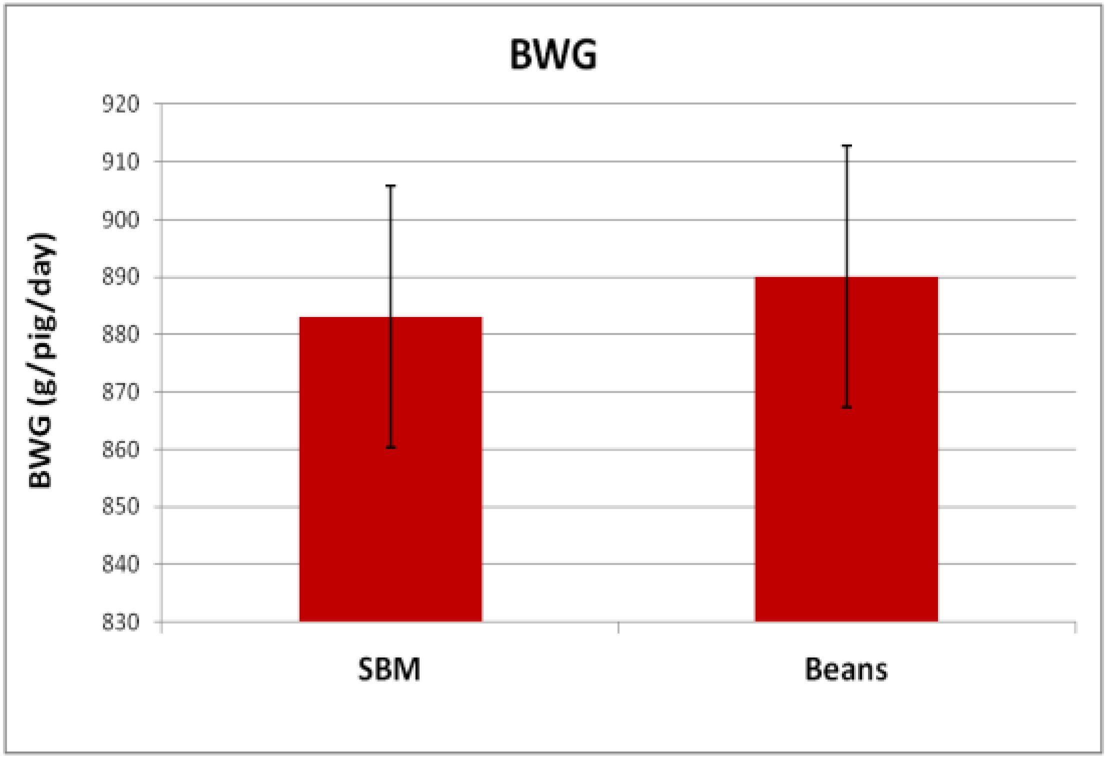

Figure 8. The body weight gain (BWG) (g/pig/day) of pigs (35-110kg) from demonstration trial 3 fed control SBM and bean diets.

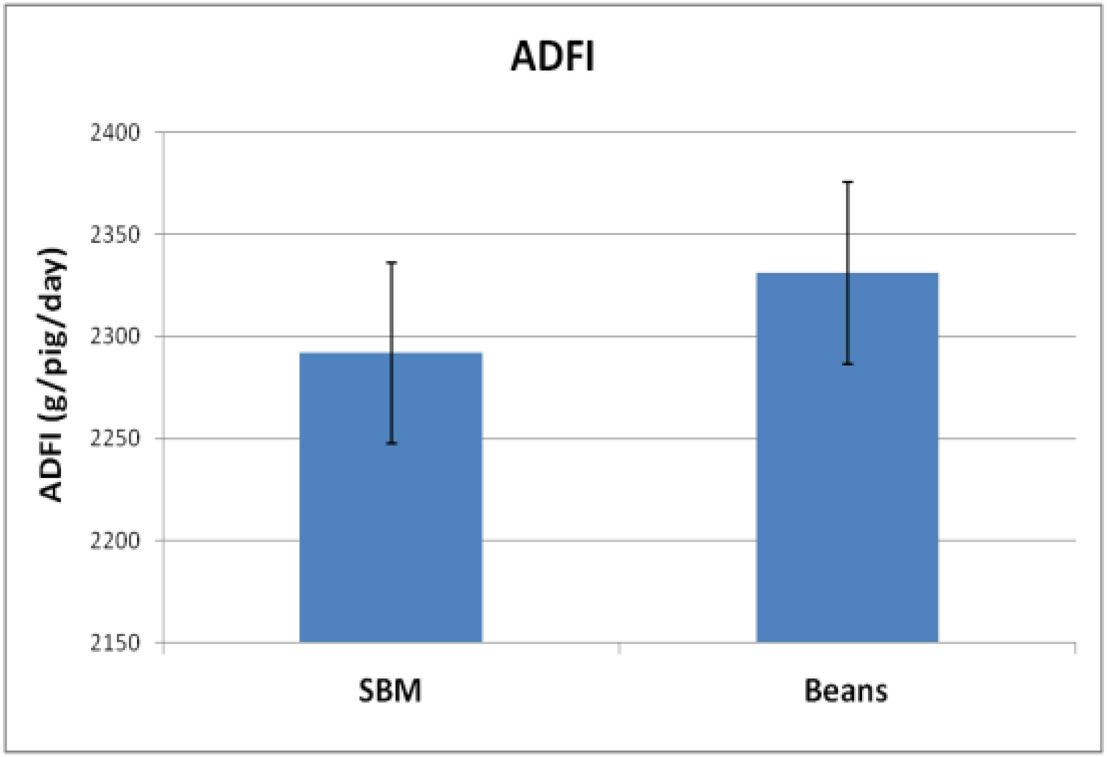

Figure 9. Average daily feed intake (ADFI, g/pig/day) of pigs (35-110kg) from demonstration trial 3 fed control SBM and bean diets.

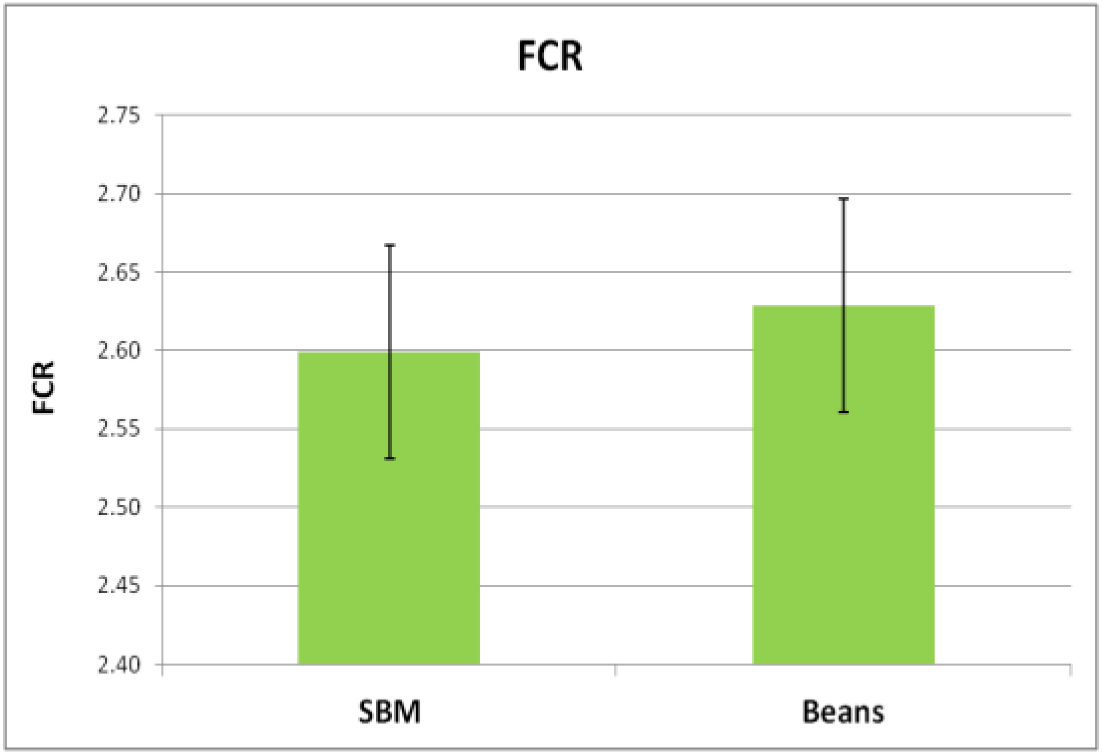

Figure 10. FCR of pigs (35kg-110kg) from demonstration trial 3 fed control SBM and bean diets.

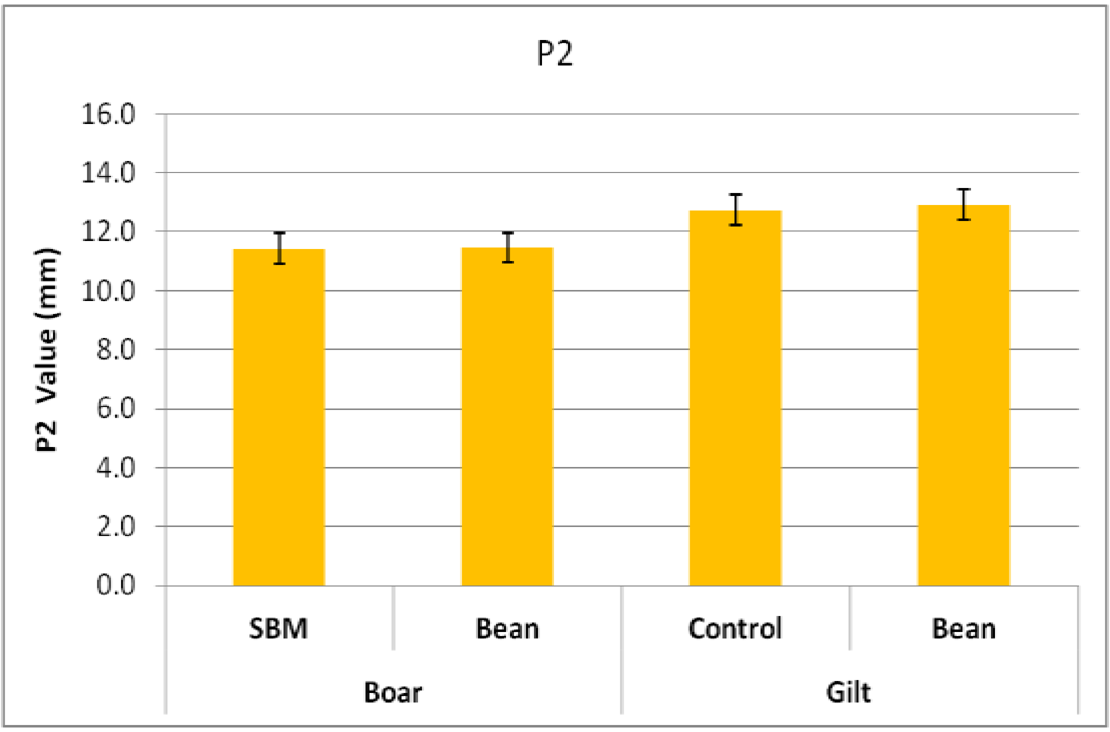

Figure 11. Backfat depth at the P2 position of boars and gilts from demonstration trial 3 fed control SBM and bean diets.

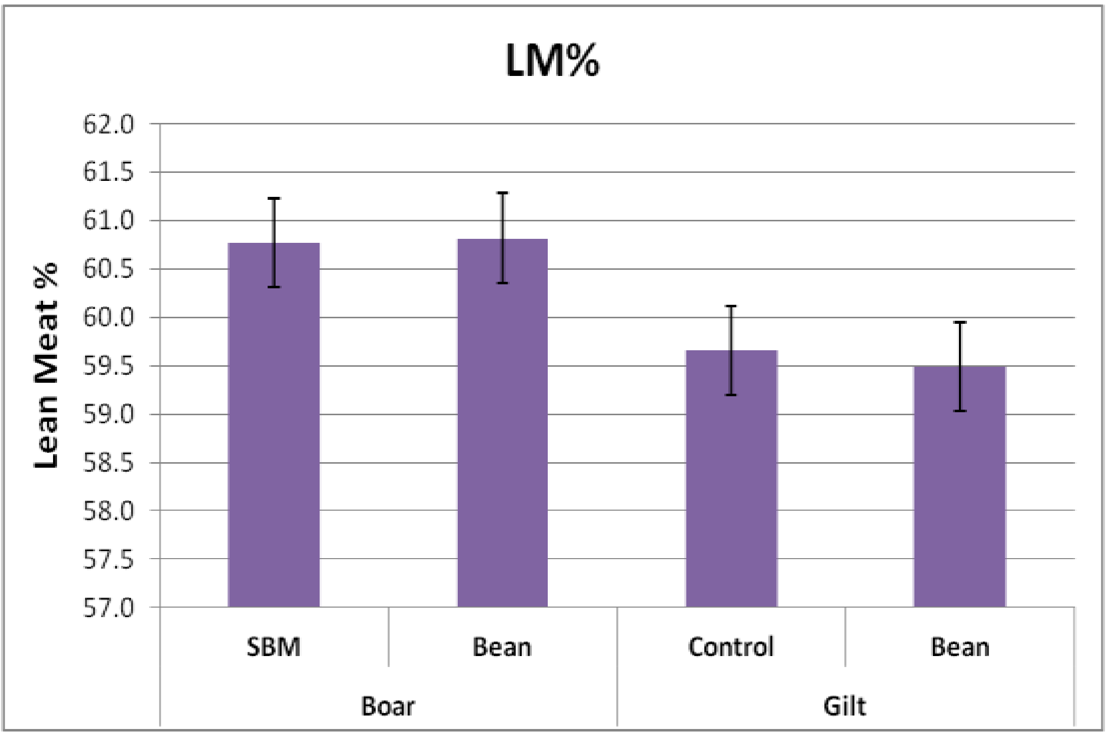

Figure 12. Estimated lean meat percentage of boars and gilts from demonstration trial 3 fed control SBM and bean diets.

Demonstration Trial 4

Demonstration Farm, Animals and Housing

The demonstration trial was conducted at on large commercial pig farm in the North East of England. In contrast to Trials 1, 2 and 3, this is a whole farm demonstration, where data from the experimental diet (referred to as the Bean diet) are compared to average farm performance figures from the 3 months during which the trial was conducted, rather than compared with data from pigs fed a standard diet at the same time. Average farm figures relate to pigs approx. 40kg to slaughter. Thus all animals described below will be fed the experimental bean diets. 210 terminal line pigs (approx 40kg) were allocated to 4 pens (approx. 60-80 pigs per pen) housed on straw with *ad libitum* access to food and water. Pigs remained in these pens until approx 50kg (straw period). Pigs were then reallocated to new slatted accommodation (slatted period). During the straw period there were 2 deaths, thus for the slatted accommodation, 208 pigs (approx 50kg) were reallocated to 10 pens (19-23 pigs per pen). As with the straw period, pigs had *ad libitum* access to food and water during the slatted period.

Diets and Performance Measurements

The normal compound diet used on the farm contained 19.7 and 15% SBM for the grower and finisher stage respectively. The test diets were dry compound diets and both the grower and finisher stage diets contained 25% faba beans. The test diets also contained 10% and 7% SBM for the grower and finisher stage diets respectively. During the straw period, all trial pigs were bulk weighed at upon entering and leaving the straw accommodation. During the slatted period, total pig weight upon entering and leaving the slatted accommodation was measured on a pen basis. Feed was given on a bag basis and recorded in bulk for the straw period, and on a pen basis for the slatted period. No refusals were recorded for the straw period. All refusals during the slatted period were recorded on a pen basis.

Pig performance was assessed by calculating body weight gain (BWG, g/pig/day), average daily feed intake (ADFI, g/pig/day) and feed conversion ratio (FCR, ADFI/BWG) for all experimental pigs during the straw period, and on a pen basis during the slatted period. All deaths were recorded, and the total number of pig days was used to calculate BWG and ADFI on a pig/day basis. At the end of the study pigs were slaughtered at a commercial slaughter house at approx 100kg, over 4 different slaughter days. Backfat at the P2 site (mm) was recorded for a subset of the trial pigs (90 pigs) over each of the slaughter days (19-28 pigs per slaughter day).

Analysis

As trial pigs are bulk weighed during the straw period, there is no replication during the straw period. Furthermore, trial pigs are remixed into different sized groups at the start of the slatted period and straw data does not directly relate to the slatted data. Therefore we are unable to apply statistical analysis to this data set. However, the slatted period does have 10 replicates/pens for the bean diet, and therefore the mean performance measures (BWG, ADFI and FCR) with standard errors have been calculated for this period only. In order to compare average farm performance data with the bean diets, the same overall period on the farm must be compared. The average farm performance figures for the farm cover pigs from 40kg to slaughter. The standard management on the trial farm is to house pigs in straw yard pens for pigs 40-50kg, then relocate pigs to smaller slatted pens from 50kg to slaughter. Therefore, the average farm performance data relates to both the straw and slatted periods of the trial. Thus, the overall straw and slatted period data has been combined to compare bean diet performance with average farm performance data. However, the combined straw and slatted data is not replicated and care must be taken in interpretation of these results. The P2 values are replicated over the 4 different slaughter days, and the mean P2 value (mm) with standard error has been calculated.

Results and Discussion

Considering the replicated slatted period (pigs approx. 50kg to slaughter) of the trial only, the bean diets resulted in higher than average body weight gain (Figure 13) and lower than average feed conversion ratio (Figure 15) relative to 2011 BPEX performance figures for finishing herds (784 g/pig/day and 2.82 for BWG and FCR, respectively) (BPEX, 2012). This indicated that the bean diet did not result in detrimental effects on performance during the slatted period in relation to national performance figures.

The combined straw and slatted period (50-100kg) showed a reduction in body weight gain (Figure 13) and feed intake (Figure 14) relative to the slatted period alone (Figures 13 and 14). Whilst this may arise from a dilution effect from the inclusion of the younger pigs (40-50kg), the combined Bean diet figures also show a slightly lower body weight gain and feed intake compared to the average farm performance figures (Figures 16 and 17). This reduced weight gain may be related to reduced feed intake for the younger pigs during the straw period and may therefore reflect a palatability issue. Despite the apparent reduction in performance for the combined straw and slatted period relative to average farm performance data, bean diets resulted in a similar feed conversion ratio (Figure 18) compared to the average farm performance data suggesting that the bean diet did not affect the efficiency which the pig utilised the feed. However, there were no refusals recorded for the straw period which could suggest that even less feed was consumed than the quantity of feed given. Therefore, it can not be excluded that actual feed conversion ratio on the bean diet over the combined straw and slatted period may be even slightly better (lower) than the FCR calculated here.

The bean diets resulted in a lower backfat measurement at the P2 site relative to average farm data (Figure 19), which supports the above suggestion of an overall improved FCR. Furthermore, the average P2 value for the bean diets was below the 12mm upper limit for premium carcass payment. Thus, 25% bean diets do not negatively affect the leanness of pigs at slaughter.

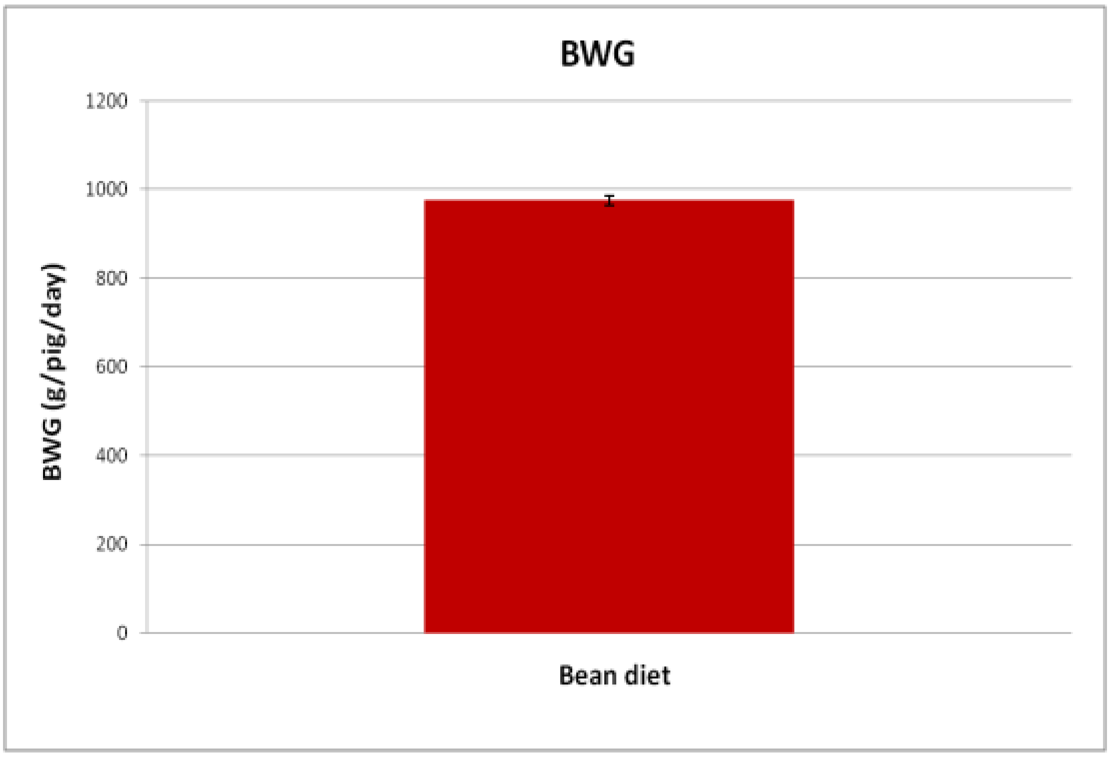

Figure 13. Body weight gain (BWG, g/pig/day) for replicated slatted period (pigs approx. 50-100kg) from demonstration trial 4.

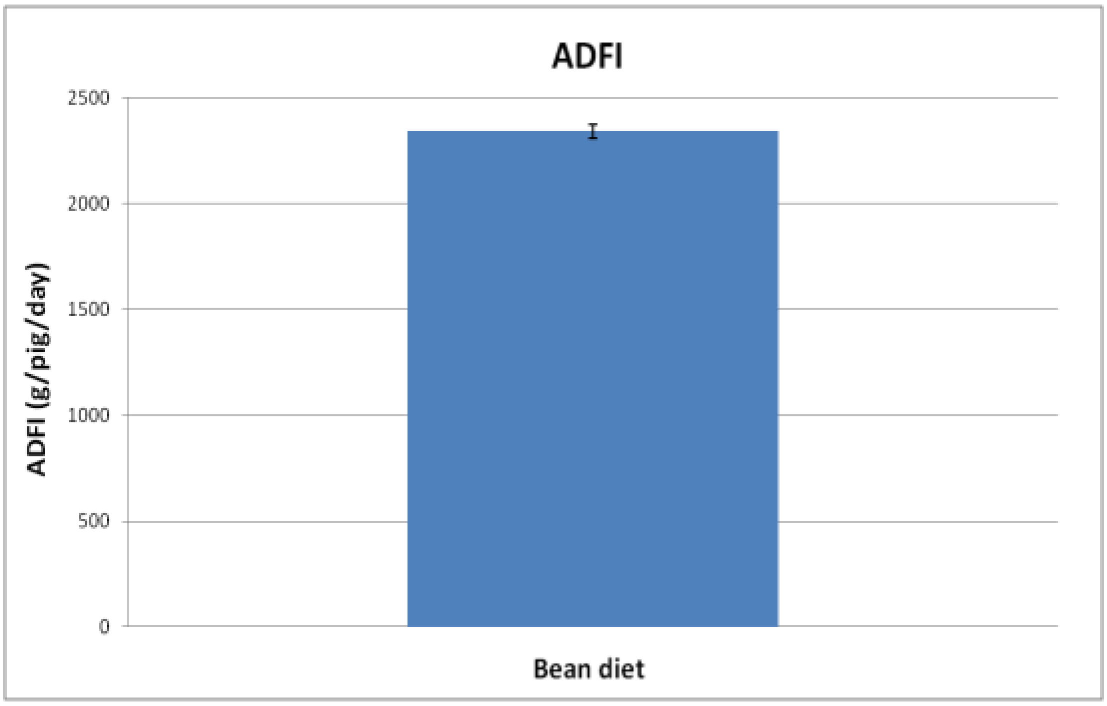

Figure 14. Average daily feed intake (ADFI, g/pig/day) for replicated slatted period (pigs approx. 50-100kg) from demonstration trial 4.

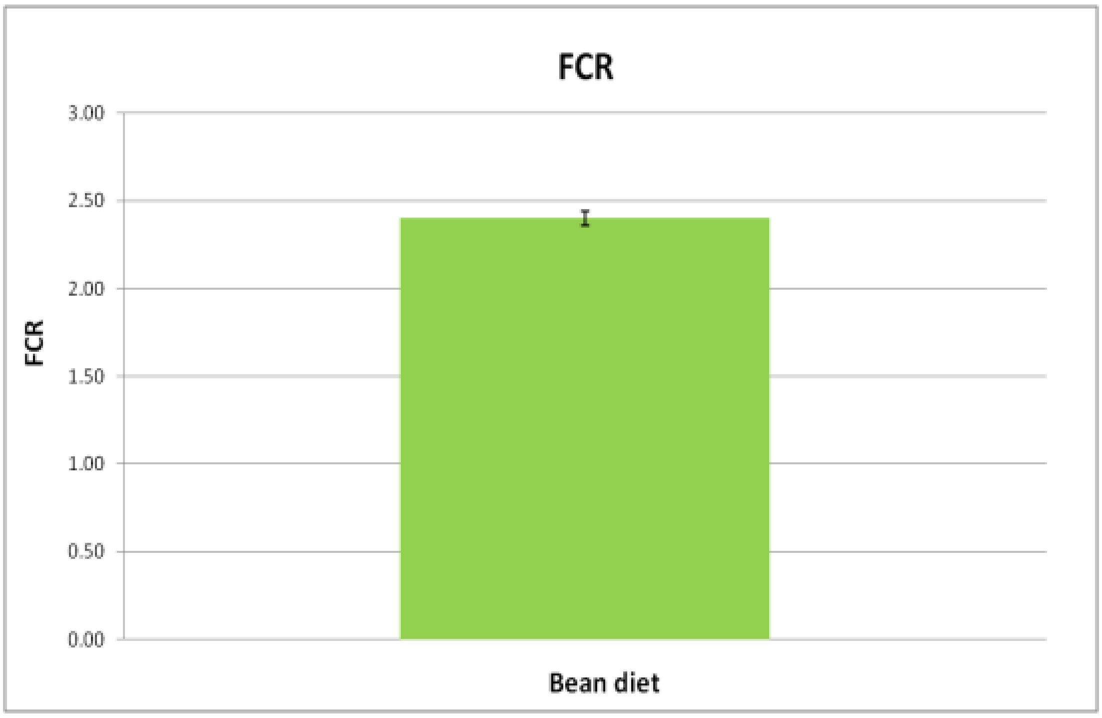

Figure 15. Feed conversion ratio (FCR, ADFI/BWG) for replicated slatted period (pigs approx. 50-100kg) from demonstration trial 4.

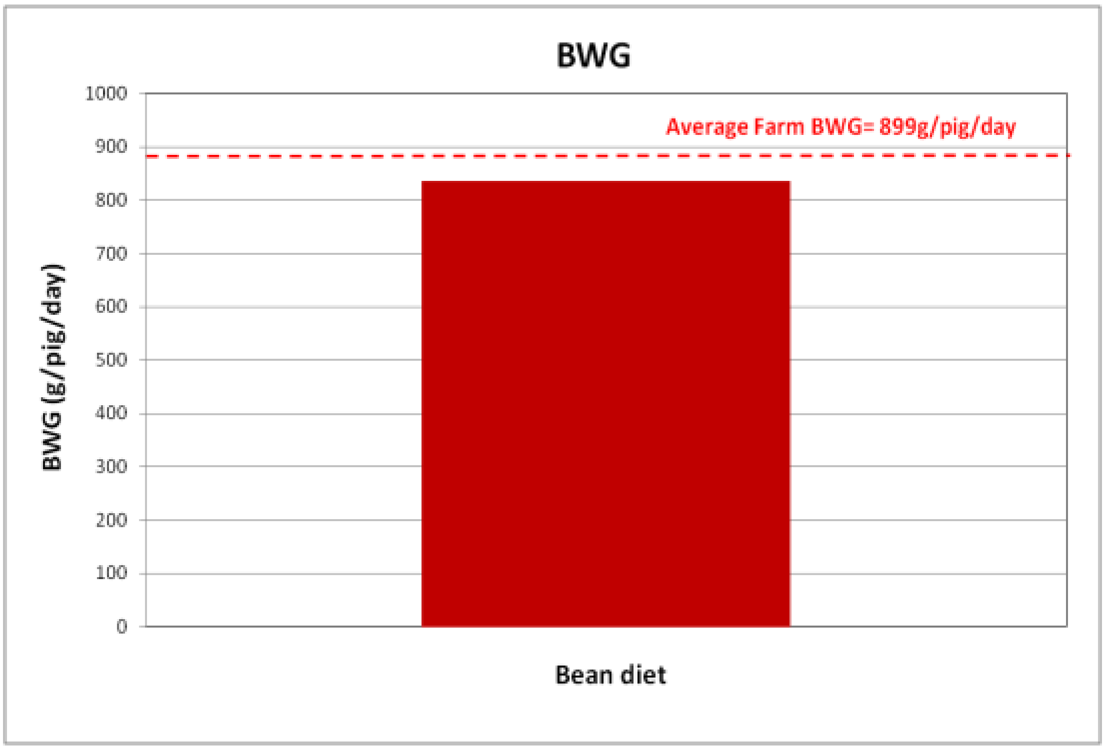

Figure 16. Body weight gain (BWG, g/pig/day) for combined straw and slatted period (pigs approx. 40-100kg) from demonstration trial 4, relative to the average farm BWG during the same 3 month period.

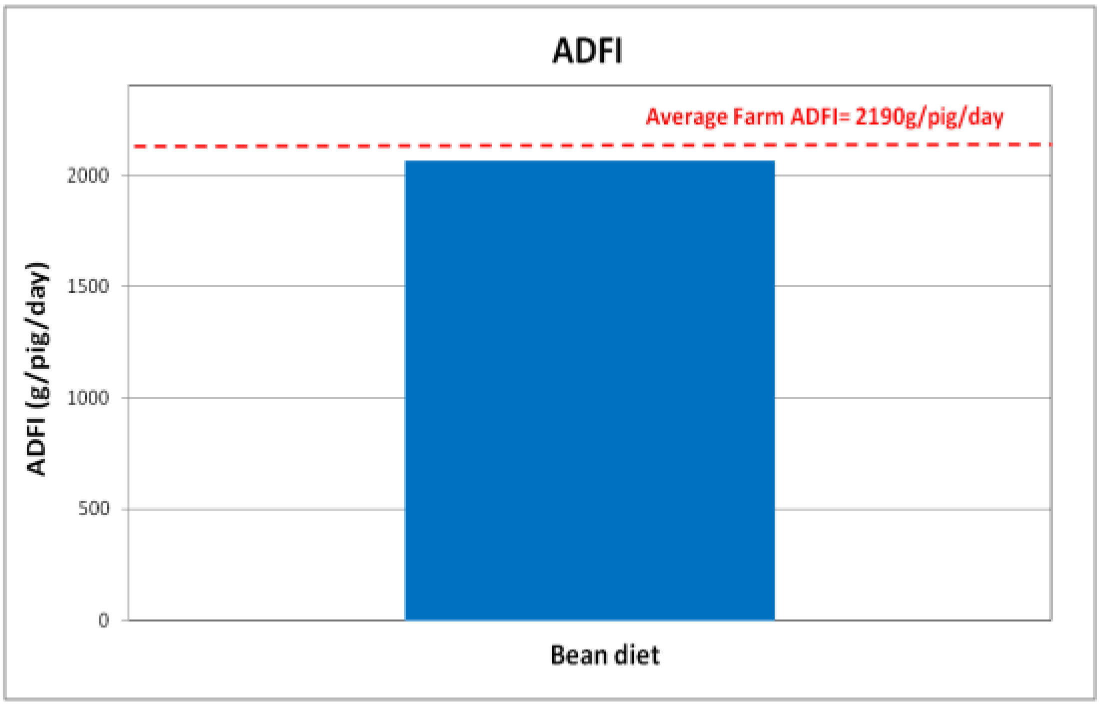

Figure 17. Average daily feed intake (ADFI, g/pig/day) for combined straw and slatted period (pigs approx. 40-100kg) from demonstration trial 4, relative to the average farm ADFI during the same 3 month period.

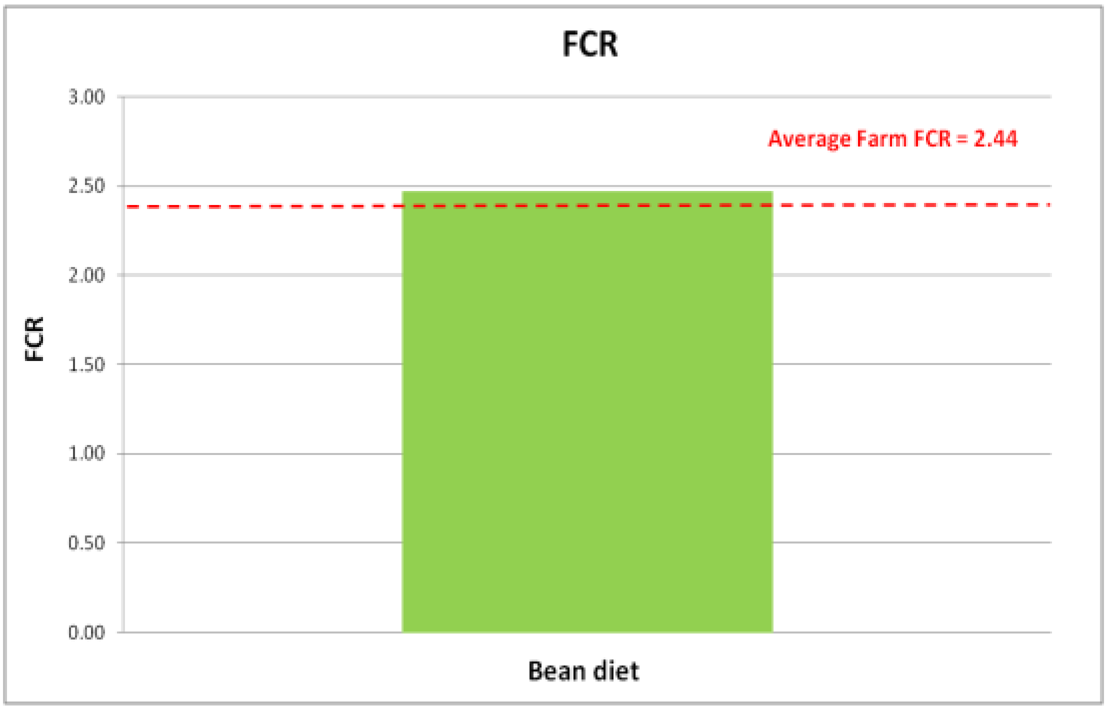

Figure 18. Feed Conversion Ratio (FCR, ADFI/BWG) for combined straw and slatted period (pigs approx. 40-100kg) from demonstration trial 4, relative to the average farm FCR during the same 3 month period.

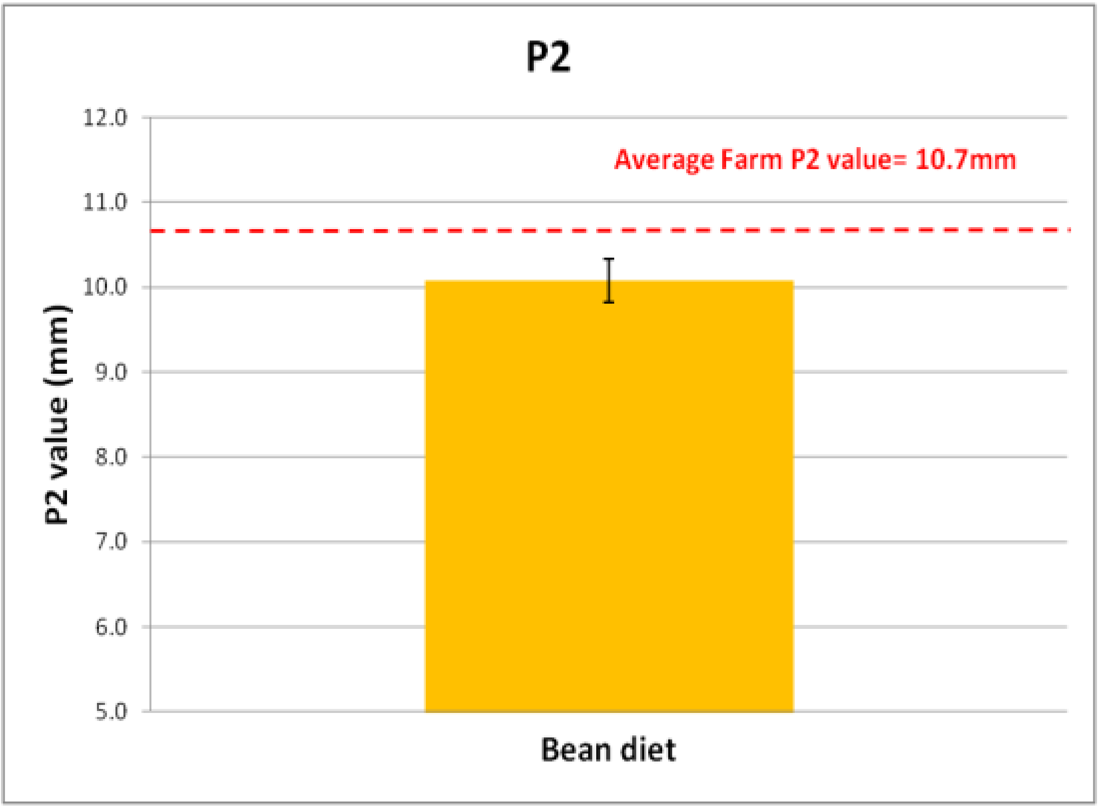

Figure 19. Backfat (mm) at the P2 site of pigs from demonstration trial 4 fed the bean diet, relative to the average farm P2 backfat value (mm).

Organic Observation

Observation Farm, Animals and Housing

The organic observation (trial 5) was conducted by the Soil Association (Peter Melchett) at an organic farm with 29 Tamworth crossed with Duroc x Saddleback pigs (approx. 25kg) were allocated to one of two diet treatments. Pigs were housed outdoors in 1 of 2 fields for the course of the trial which lasted 107 days during the winter (December to March). Field 1 had 14 pigs, Field 2 had 15 pigs. Pigs had *ad libitum* access to food and water.

Diets and Performance Measurements

There were two diet treatments (Control SBM diet and a home-grown pulse diet) fed throughout the trial (pigs 25-100kg), with two formulations for each diet treatment for the grower and finisher stage. The organic control grower diet contained 11.9% SBM, 12% Peas and 3% Beans; and the organic control finisher diet contained 6.3% SBM, 19% Peas and 6% Beans. Both the grower and finisher organic control SBM diets was fed to pigs in Field 1. The organic home-grown grower pulse diet contained 32.5% dehulled peas and 3% beans; and the organic home-grown finisher pulse diet contained 25.6% dehulled peas and 15% Beans. Both the grower and finisher organic home-grown pulse diet was fed to pigs in Field 2. Diets were fed as dry pelleted compound diets. Individual live weight was recorded at the start of the trial and when pigs were sent to slaughter. Feed given and all refusals were recorded on a field basis. Pig performance was assessed by calculating body weight gain (BWG, g/pig/day). Average daily feed intake (ADFI, g/pig/day) and feed conversion ratio (FCR, ADFI/BWG) were calculated per field (and therefore per diet). All deaths were recorded, and the total number of pig days was used to calculate ADFI on a pig/day basis. A subjective dung score (score 1-5), where 1 represented hard faeces and 5 represented watery, mucous like faeces, was recorded throughout the observation on a field basis. At the end of the study pigs were slaughtered at a commercial slaughter house at approx 100kg. All pigs were sent for slaughter on the same day. At the slaughter house, carcass weight (hot and cold), and backfat at the P2 site (mm) were recorded. Lean meat percentage (% Lean= 66.5-0.95 x P2 + 0.068 x cold carcass weight) was calculated for each pig.

Analysis

As the two diets are only tested on one field of pigs each, there is no replication and this must be considered an observation rather than a demonstration trial. Thus, no statistical analysis can be applied and only the mean values per diet have presented.

Results and Discussion

Numerically, the BWG of the pigs fed the home-grown pulse diet was approximately 20g lower than the pigs fed the SBM control diet (Figure 20). However this may have been due to a lower ADFI for the pigs fed the home grown pulse diet (ADFI = 2632 g/pig/day) relative to pigs fed the SBM control diet (ADFI = 2922 g/pig/day). This suggests that further replicated studies are required to investigate if there may be a palatability issue with the home grown diets which is affecting feed intake. The FCR of the pigs fed the home-grown diet (FCR=3.91) was lower than the FCR of pigs fed the SBM control diet (FCR=4.21) suggesting that potential beneficial effects of home grown pulse diets on FCR should be investigated further. The dung scores of both home-grown pulse fed pigs and SBM control pigs were similar (Figure 21). The slaughter data suggests potential benefits of increased leanness in pigs fed the home grown pulse diets relative to the SBM control diet (Figs. 22 and 23). However there may also be an effect of a lower killing out percentage for pigs fed home grown diets relative to the SBM control diet (Figure 24). Taken all together, the outcome of this observation, though inconclusive, are sufficiently encouraging to warrant further investigation on greater use of home grown peas and faba beans in organic systems of pig production through undertaking replicated trials as done under conventional conditions within Green Pig. Since the latter conclude that peas and faba beans can replace SBM in nutritionally balanced diets, there is reason to assume this could also be the case for organic pig production systems. .

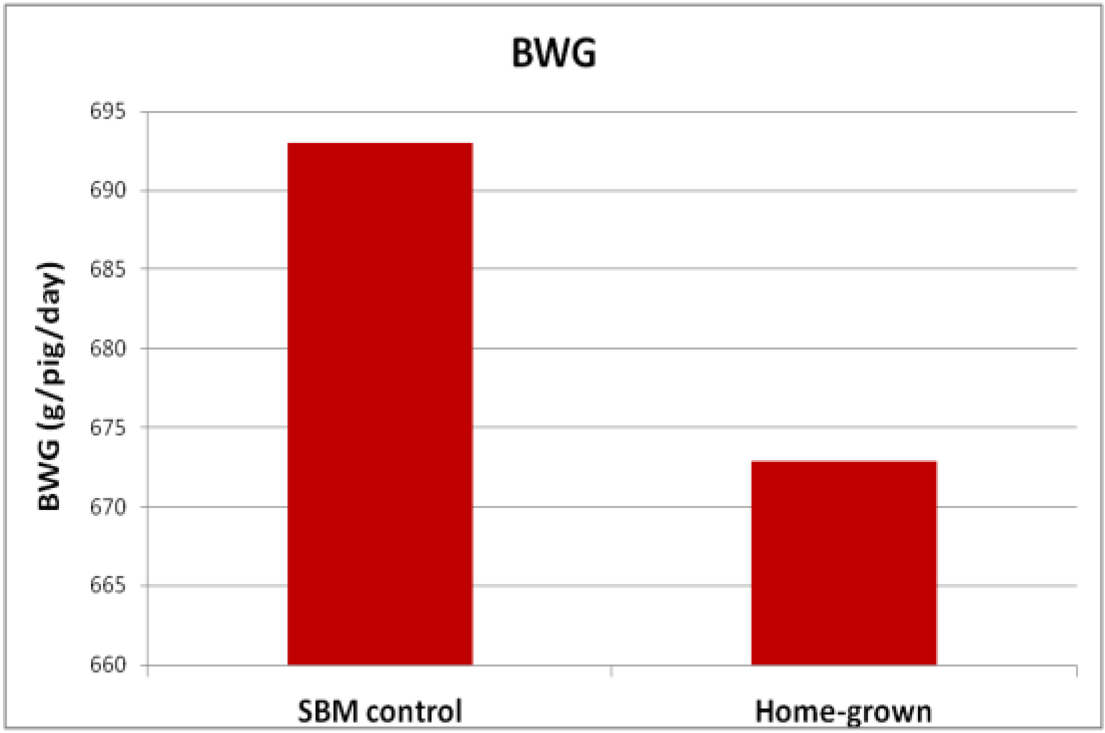

Figure 20. The body weight gain (BWG) (g/pig/day) of pigs (25-100 kg) from the organic observation (trial 5) fed control SBM and home-grown pulse diets.

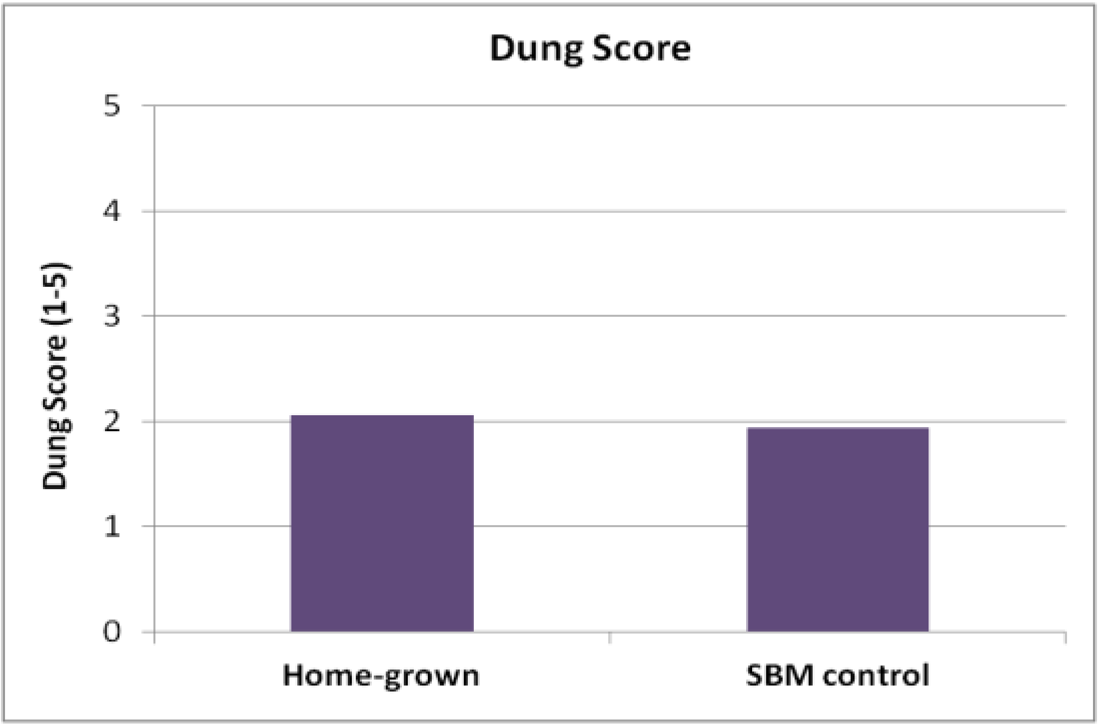

Figure 21. Dung score (1-5) of pigs (25-100 kg) from the organic observation (trial 5) fed control SBM and home-grown pulse diets.

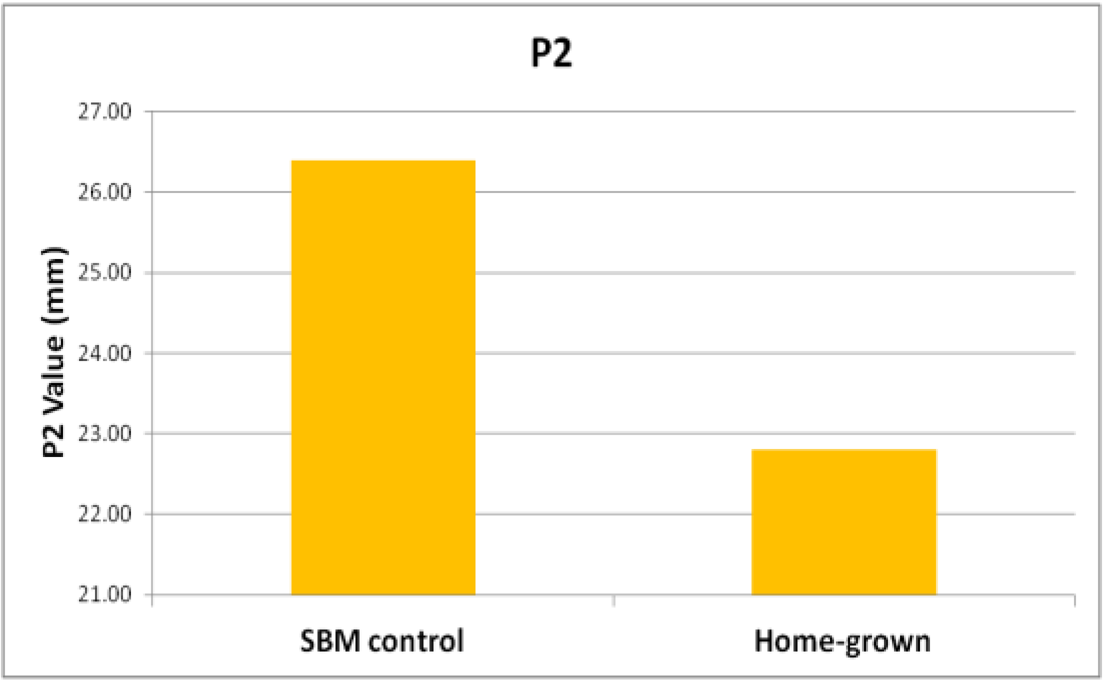

Figure 22. Backfat depth at the P2 position of pigs (25-100 kg) from the organic observation (trial 5) fed control SBM and home-grown pulse diets.

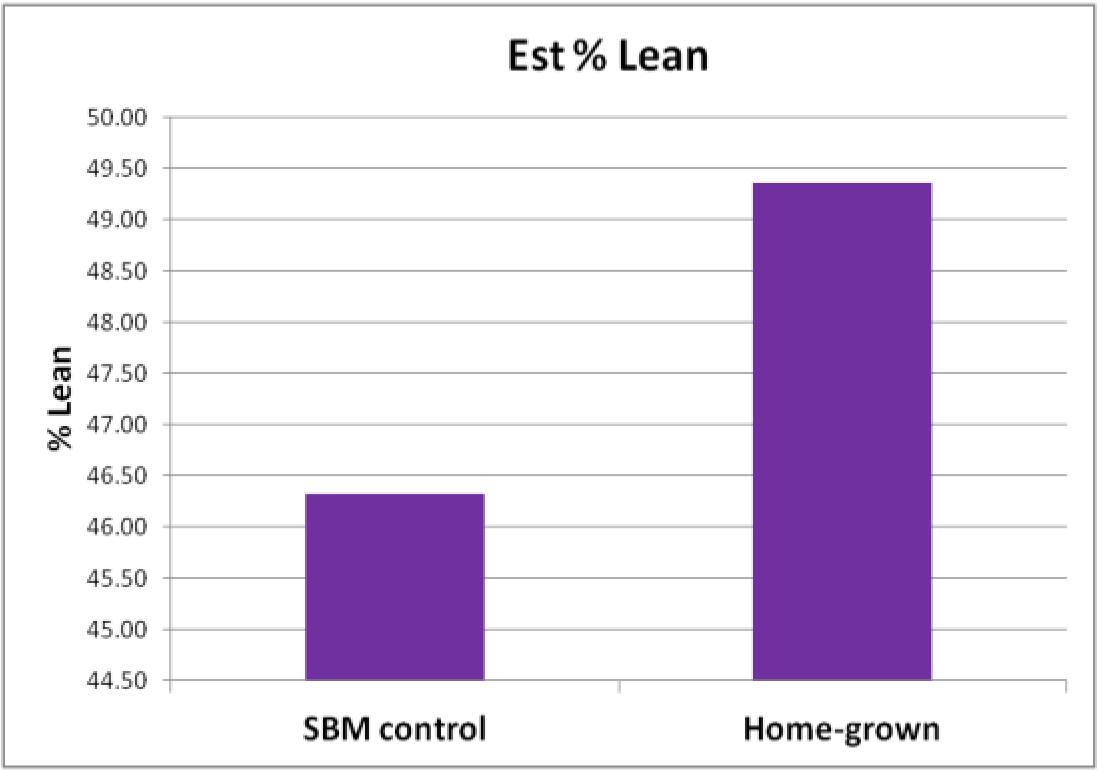

Figure 23. Estimated lean meat percentage of pigs (25-100 kg) from the organic observation (trial 5) fed control SBM and home-grown pulse diets.

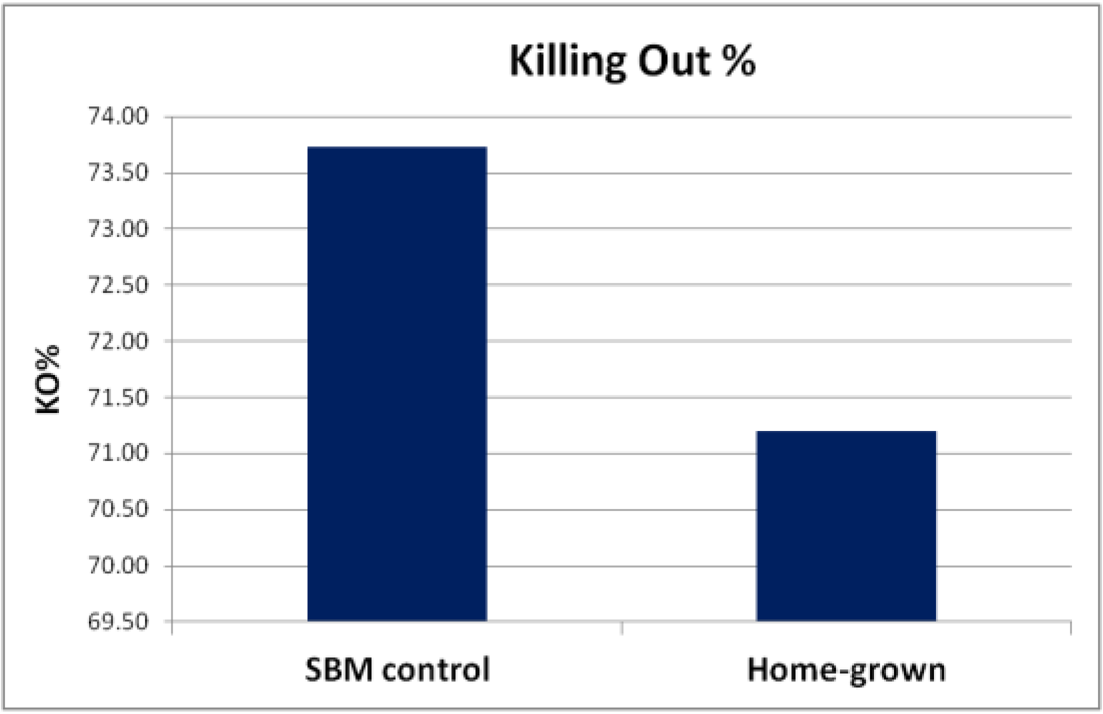

Figure 24. Killing Out percentage of pigs (25-100 kg) from the organic observation (trial 5) fed control SBM and home-grown pulse diets.

Overall Discussion and Conclusions

Demonstration trials 1, 2 and 3 showed no detrimental effect of high inclusion of home grown pulses (e.g. peas or beans) on performance or slaughter measures of pigs under commercial conditions. Furthermore, demonstration trials 1 and 2 showed high inclusion of peas and faba beans is possible in commercial grower and finisher pig diets even in the complete absence of SBM in the diet. This is in agreement with previous studies investigating high inclusion of peas in grower and finisher pig diets (Stein et al., 2004) and the small scale studies carried out within the green pig project investigating higher inclusions of both peas or faba beans in grower and finisher pig diets (Smith et al., 2012a; b; White et al., 2012a; b).

Although the bean diet in demonstration trial 4, with 25% inclusion of faba beans resulted in decreased performance in terms of body weight gain and feed intake in the combined straw and slatted period, relative to the average farm performance data, feed conversion ratio was unaffected. However, it should be noted that this indication is based on a non-replicated observation for the combined straw and slatted period. In contrast, for the replicated slatted period, performance of pigs on bean diet is comparable or better than national performance figures (BPEX, 2012). There was also no detrimental effect on P2 values obtained at slaughter. Thus, the demonstration trial 4 has indicated that a 25% inclusion of faba beans in commercial rations can be included without affecting performance.

The organic observation (trial 5) demonstrated that it is possible to formulate grower and finisher organic diets with higher inclusions of home grown peas and faba beans and no SBM. Additionally, the observations on performance and slaughter measures are sufficiently encouraging to investigate the use of home grown peas and faba beans in organic pig diets further using replicated demonstration trials.

In conclusion, the conventional large scale commercial demonstration trials have shown very positive results of using high inclusion pea or bean diets under commercial conditions. The results further suggest that peas and faba beans are a viable home-grown alternative to SBM in commercial grower and finisher pig diets.

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Full report Objective 7: Life cycle assessment rerun based on project outcomes.

Lead authors: Davide Tarsitano, Kairsty Topp and Bert Tolkamp (SRUC).

Executive Summary

- The aim of Objective 7 was to apply the outcomes of the project to a revised LCA, Two scenarios have been considered, the large scale conventional trial and the organic observation.
- The LCA design and assumptions for the large scale trial are comparable to the original LCA presented in Objective 1.
- The diets composition for the large scale experiment has been modified in order to account for the outcome Objectives 2 to 6.
- Three diets have been considered: Peas, beans and soya bean meal (SBM), the later is the only one which uses SBM as source of protein and therefore the only one affected by land use change.
- The estimated global warming potential the absence of land use change is 1.78, 1.79 and 1.85 kg CO_2eq/kg LWG for the pea, bean and SBM based diet. However, if the SBM is considered to be associated to land use change the emissions for the SBM based diet increased to 2.52 kg CO_2eq/kg LWG.
- The LCA assumption for the organic observation is that farmer is a home mixer, with SBM and sunflower meal imported in the UK from sources not associated to LUC, i.e. European countries. The fertiliser consists in the pig excretion deposited one per rotation on the field. Pesticide and slurry storage are not considered.
- Two diets have been considered, control which include SBM imported from EU and test where the only source of protein is from combination of peas and beans.
- In this organic farming system, the GWP for the organic SBM and pea/bean only scenarios were 1.70 and 1.47 kg CO_2eq/kg LWG; this ~15% reduction largely arose from reduced transport of SBM and less barley inclusion.

Introduction

The main goal of Objective 7 was to apply the outcomes of the project to a revised LCA. Therefore, the methodology highlighted in the section description of Objective 1 was used to assess the environmental burdens per kg pig related to the large scale conventional trial and the abbreviated organic trial, referred to as organic observation (see below). The functional unit was again the growth of 1 kg pig. Values expressed this way can be converted to values expressed per kg carcass gain by dividing with 0.78 (large-scale experiment) or 0.725 (organic trial) and to values expressed per kg lean by dividing with 0.62 (large-scale experiment) and 0.48 (organic trial).

Large scale experiment

The LCA design for the large scale trial is comparable to the original LCA presented in Objective 1. The main differences are the pig model parameterisation and the proportion of peas, beans, soya bean meal (SBM) and other ingredients in the diets. The crop production and manure storage component were unchanged.

To bring the pig model predictions of weight gain and feed intake in agreement with the observed values, some small adaptations were made in model parameters. Maintenance energy requirements were increased with an activity allowance of 15%, and mature lipid size was increased to 115 kg. These adaptations resulted in total gains and feed intakes that were similar to those observed in the large-scale experiment. In addition, animal weight gain was modelled for the grower (35 – 60 kg) and the finisher (60 – 110 kg) phase. Thus, the functional unit for the conventional LCA rerun was a kg of pig live weight gain, where pigs were growing 75 kg from 35 kg live weight to 110 kg live weight).

The diet composition and nutritional values for each of the three diets (based on SBM, peas or beans) are summarized in Tables 1 and 2.

Table 1. The ingredient composition (g/kg) of the conventional grower and finisher diets used in the LCA for the large-scale pig experiment carried out during the project.

Period	Grower			Finisher		
Type	Soya	Peas	Beans	Soya	Peas	Beans
SBM	98.0	0.0	0.0	47.6	0.0	0.0
Peas	0.0	300.0	0.0	0.0	300.0	0.0
Beans	0.0	0.0	300.0	0.0	0.0	300.0
Barley	250.1	249.8	150.4	249.9	240.2	250.0
Wheat	322.0	146.0	271.0	257.0	100.0	101.0
Rapeseed meal	110.0	110.0	110.0	125.0	125.0	125.0
Wheatfeed	25.8	0.0	0.0	150.0	79.0	35.3
Fat supplement	3.0	4.7	6.9	3.0	3.0	3.0
Minvit	27.1	25.7	25.7	27.6	27.7	27.0
Lysine	6.6	5.1	5.9	6.8	3.0	3.3
Meth	1.0	1.8	2.3	0.9	1.2	1.3
Threonine	1.3	1.6	1.8	1.2	0.9	0.9
Biscuit 136	80.0	80.0	80.0	56.0	44.8	78.0
DDGS Ensan	75.0	75.0	75.0	75.0	75.0	75.0

Table 2. The nutritional characteristics of the conventional grower and finisher diets used in the LCA for the large-scale pig experiment carried out during the project. Values are expressed in MJ/kg (for ME) or in g/kg (for the remainder).

Period	Grower			Finisher		
Type	Soya	Peas	Beans	Soya	Peas	Beans
ME	13.1	13.2	13.1	12.6	12.8	12.7
NDF	144	145	146	176	162	167
CP	181	182	176	172	191	182
Lys	10.9	11.2	11.2	10.3	10.8	10.7
Meth	7.0	6.7	6.7	6.7	6.6	6.7
Thr	7.3	7.5	7.5	6.9	7.2	7.2
Tryp	2.1	2.1	2.1	2.0	2.1	2.0

Additional ingredients

In the Large scale experiment two additional ingredients have been used, in comparison with the diets formulated for the original LCA (Objective 1): Biscuit 136 and DDGS Ensan. A value of 0.01 kg CO_{2eq}/kg LWG and 0.15 kg CO_{2eq}/kg LWG respectively have used. While their EP and AP has not been considered due to the limited information available in the literature. However this assumption does not have an effect on the diets comparison.

Organic observation

Organic pig production is considerably different from the conventional management, with implications for LCA calculations, as highlighted in Table 3. A main difference is in the use of fertiliser; in organic farming systems, the only form of N that is possible to be applied to the field for crop production is animal excretion. It is assumed that the pigs are kept on the field, which will subsequently be used for the production of feed, and the animal excretions are directly deposited on the soil. This approach implies therefore that slurry storage tanks are not used. The stocking density is the only control available to the farmer to regulate the organic N inputs. In this study, a stocking density of 10 heads/ha was adopted following the Soil Association guidelines (Anna Bassett, personal communications) and the total amount of organic N introduced is 110 kg N/ha, considering an annual organic pig excretion of 10.6 kg N/ha (Anonymous, 2012).

Table 3. Differences between organic and conventional pig production, with implication for LCA calculations.

	Organic	Conventional
Fertiliser	Animal excretion, input control by animal stocking density	Combination of manure and inorganic fertiliser
Manure management	Not required	Stored in Slurry tank and spread on the field
Livestock	Kept outdoor on the field	Kept indoor, housing
Pesticide/Herbicide	Not done	2-3 applications per year

The pig diet is also considerably different due to the limitations in the type of ingredients that can be used. The farmer is assumed to be a home-mixer and as for the conventional scenario (Objective 1), most of the ingredients have been produced in the farm and through the management and timing of crop rotations the diet ingredients are not limited in their availability. SBM is imported from organic and sustainable sources. Hence, the impact of LUC is excluded in the model.

In order to fulfil the feeding requirement three rotations have been employed. Their composition has been designed by the Soil Associations (Anna Bassett, personal communications), and therefore they can be regarded as a realistic for an UK organic farm (Table 4).

Table 4. The rotations used in the organic scenario. (*) indicates under-sown crops and (+) stands for pigs on the field.

Year	Rotation 1	Rotation 2	Rotation 3
I	Grass/Clover	Grass/Clover	Grass/Clover
II	Grass/Clover+	Grass/Clover+	Grass/Clover+
III	Spring barley	Spring Wheat	Winter Wheat
IV	Spring Peas	Spring Wheat	Winter Wheat
V	Winter vetch	Spring Oat	Winter Bean
VI	Spring wheat*	-	Winter Wheat
VII	-	-	Winter Oat*

The LCA methodology presented in Objective 1 has therefore been considerably simplified to account for the organic production system characteristics. Organic fertiliser is the only fertiliser inputs considered and volatilisation and leaching from a manure storage tank have not been estimated as the animal excretion is directly deposited on the field.

Crop Production

The crop production has been modelled using a tier I approach. Representative crop yields have been based on experts' knowledge (Table 5). Therefore, the crops have been assumed to be produced under normal temperature, nitrogen or water stress for UK conditions.

Table 5. Assumed yields for the considered crops; the average (B_{mid}), maximum and minimum yield, B_{high} and B_{low} respectively are reported in tDW/ha assuming 85% dry weight.

	Crop biomass		
	B_{low} (tDW/ha)	B_{mid} (tDW/ha)	B_{high} (tDW/ha)
Triticale	3.7	4.35	5
Winter wheat	4.25	5	5.75
Spring peas	3.1	3.7	4.25
Spring beans	2.5	4	6
Spring Wheat	4.25	5	5.75
Winter Oat	4.25	5	5.75
Winter beans	3.4	4	4.6
Winter Vetch	1.802	2.12	2.438
Clover/grass	5.36	6.7	8.04

The equation for the direct N_2O emissions has been modified to account for only organic fertiliser and crop residues (eq. 1). Based on IPCC (2006) for outdoor pigs, a notable change is in the assumption that 2 % (EF_{3prp}) of the applied N in the form of excretions is lost.

$$N_2O = CF * (F_{ON} + F_{CR}) * EF_{3prp} \qquad \text{Eq 1}$$

Where

EF_{3prp} is the emission factor developed for N_2O emissions from N excretion.

F_{SN} is the annual amount of synthetic fertiliser that it is applied on the considered field (kg N/y)

F_{ON} is the amount of organic N that has been applied to the field (kg N/y)

F_{CR} is the N in the crop resides that are left in the field and therefore return to the soil (kg N/y)

CF is the conversion factor from N2O-N to N2O, and it is the ratio of the atomic weight of the two molecules, i.e. 44/28.

The spring wheat and oats in rotation I and III have been under-sown with clover; this management practice in an organic rotation is used to increase the available N. The LCA accounts for the clover in the calculation for the crops residues and in the leaching and volatilisation from the organic N present in the soil.

Pig model and diets

In the planned organic trial, two diets were used, a control diet (including SBM) and a test diet (which did not including SBM but has an increased contents of both peas and beans). The composition of the diets differed for the rearer and the finisher phase. The Pig model was set to simulate the growth of organic pigs with diet compositions as used in the organic trial (control and test) for pigs in the rearer (24 – 60 kg) and finisher (60 – 97.5 kg) phase. Thus, the functional unit for the organic LCA was a kg of pig live weight gain, where pigs were growing 73.5 kg from 24 kg live weight to 97.5 kg live weight). To bring the model predictions of gain and feed intake in agreement with the observed values, some adaptations were made to the initial parameter values. The growth rate parameter was decreased to 0.009 and the daily maintenance ME requirements were substantially increased by substituting the initial constant in the allometric equation (of 1.63) with 3.5.

As the organic trial had to be stopped after one replicate due to operational reasons, no conclusions can be drawn from the effect of diet on pig performance. Moreover, growth performance under organic conditions is much more variable than under conventional conditions, largely due to the wide variety of breeds, diets and farming conditions used. Therefore, outcomes from this LCA should, at best and in line with the outcome of the organic trial, be considered as inconclusive observations, though sufficiently encouraging as preliminary observations for further research.

The diet composition and nutritional values for the organic LCA are summarised in Tables 6 and 7.

Table 6. The ingredient composition (g/kg) of the grower and finisher diets used in the LCA that compared diets with (Control) or without (Test) soya in the organic observation within the project.

Period	Rearer		Finisher	
Type	Control	Test	Control	Test
Barley	200.0	58.4	227.4	122.6
Wheat	231.4	330.2	200.0	260.3
Peas	120.0	325.0	190.0	256.0
SBM	119.4	0.0	62.6	0.0
Beans	30.0	80.0	60.0	150.0
Rapeseed	110.0	100.0	35.0	0.0
Wheatfeed	56.0	80.0	100.0	150.0
Minvit	23.2	26.4	25.0	28.6
Molasses	0.0	0.0	20.0	0.0
Triticale	80.0	0.0	30.0	0.0
Oats	0.0	0.0	0.0	32.5
Sunflower meal	30.0	0.0	0.0	0.0

Table 7. Nutritional characteristics of the organic rearer and finisher diets used in the LCA. Values are expressed in MJ/kg (for metabolisable energy, ME) or in g/kg (for the remainder).

Period	Rearer		Finisher	
Type	Control	Test	Control	Test
ME	12.9	13.0	12.5	12.5
CP	196	183	174	161
Lys	10.0	10.0	8.8	8.8

Additional Ingredients

The diets composition for the Organic observation use molasses and mineral, that has been assumed to have a GWP equivalent to 0.4 kg CO_2eq/kg (Eriksson, 2004) but as for the LCA setup for Objective 1 and for the Large Scale experiment the EP and AC have not been considered due to limited information in the literature. Sunflower meal is also included and a GWP of 0.46 kg CO_2eq/kg. This value is based on the estimated carbon footprint for sunflower oil reported in the Feedprint database (Feedprint, 2011) and the allocation factors described in Cederberg and Mattsson (2000), Table 7.

Table 8. The mass and economic allocations factors for the co-products.

Crop	Mass allocation		Economic allocation	
	Oil/flour	Meal	Oil/flour	Meal
Sunflower	0.4	0.6	0.75	0.25

Results and discussion

The main goal of Objective 7 was to investigate the environmental impact of scenarios that utilise home-grown protein sources in the pig diets, using information generated from Objectives 2 to 6.

One of the outcomes of Objective 2 was that confidence in home grown pulses for pig feeds could increase if higher dietary inclusion levels could be used in order to reduce reliance on SBM without negative consequences on pig performance. It was also identified that possible environmental benefits of using peas and faba beans over SBM may not be a main reason for the industry to increase pulse usage.

Objective 3 demonstrated that there is little variation between pea and faba bean varieties in terms of amino acid contents and digestibility. Therefore, it is unlikely that variety choice could strongly affect the use of pure amino acids. A "what-if" scenario also demonstrated that overall impact of reducing pure methionine use on environmental burdens per kg LWG is limited. Even if novel pea or faba bean varieties could result in a reduction of 50% in pure methionine usage, then then would only translates in a reduction of 0.5% in the GWP per kg LWG.

The literature review (Objective 4) confirms that amino acid composition of peas and faba beans has not changed over the last few decades, and that despite hardly any reduction in the concentration of anti-nutritional factors (trypsin inhibitors and condensed tannins) that more recent studies suggest that higher levels of peas and faba beans may be possible without detrimental effects on growth performance. The latter is likely the outcome of current feed formulations based on net energy and standardised ileal digestible amino acid digestibility, rather than digestible energy and digestible amino acids levels.

Indeed, Objective 5 studies show in small scale work that higher levels are possible and can completely replace SBM without impact on performance, N-balance and carcass traits. However, since these were based on experimental diets that were formulate to pursuit a hypothesis, rather than commercially relevant through least cost formulation, using their outcome for an LCA would be misleading. Rather, the key for the rerun of the LCA would be related to commercial trials, informed by Objective 5 outcomes, and run with commercially formulated diets.

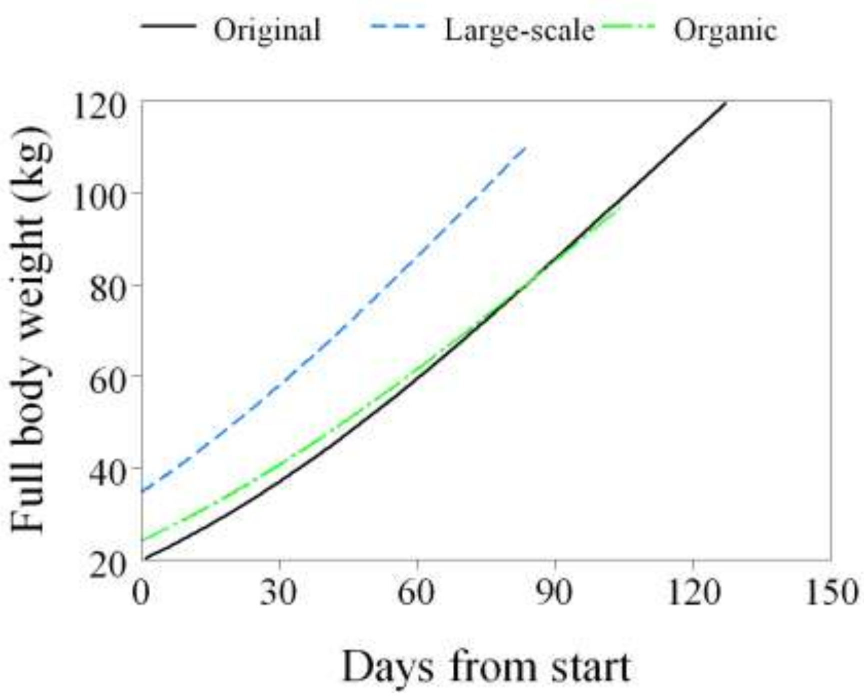
Therefore, the global warming, eutrophication and acidification potential have been evaluated for two demonstration trials, one under conventional conditions and one under organic conditions. The analysis of the LCA results has focused in each case on the comparison between diets to assess the possible benefit of replacing SBM as a main source of protein in pig diets. It is important to note that the objective of this work was to compare environmental burdens per kg LWG for different diet scenarios within conventional and organic production systems, and not to compare environmental burdens of pig production between conventional and organic systems *per se*.

We first present the differences in the simulated pig growth and excretion models between the Objective 1 (original), the conventional and organic scenarios. This is then followed by presenting the results for the large-scale and organic LCAs.

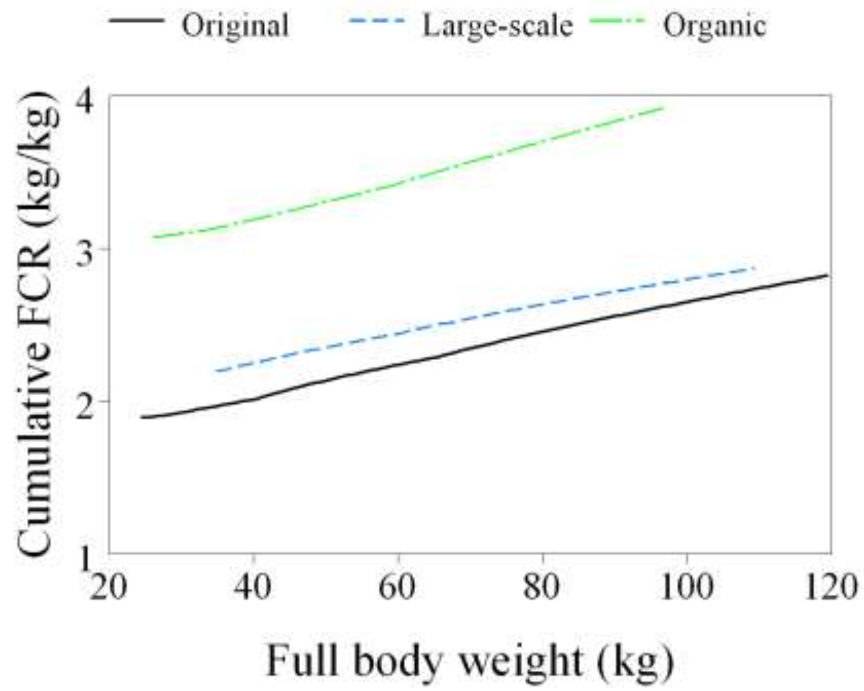
Pig growth, FCR and N-excretion according to the simulation models

The weight curves of the three growth models that were used in the LCAs are presented in Figure 1a. Pig growth from a start weight of 35 kg in the large-scale trial was slightly higher (900 g/d, from 35 to 110 kg) than that predicted by the model for the initial LCA (845 g/d from 20 to 120 kg), while that derived form the organic observation was slightly lower (736 g/d from 24 to 97.5 kg). Total N excretion per kg grown pig was 55.3 g/kg (original LCA, Objective 1), 59.2 g.kg (large-scale experiment, Objective 7) and 94.8 g/kg (organic trial, Objective 7; Figure 1c).

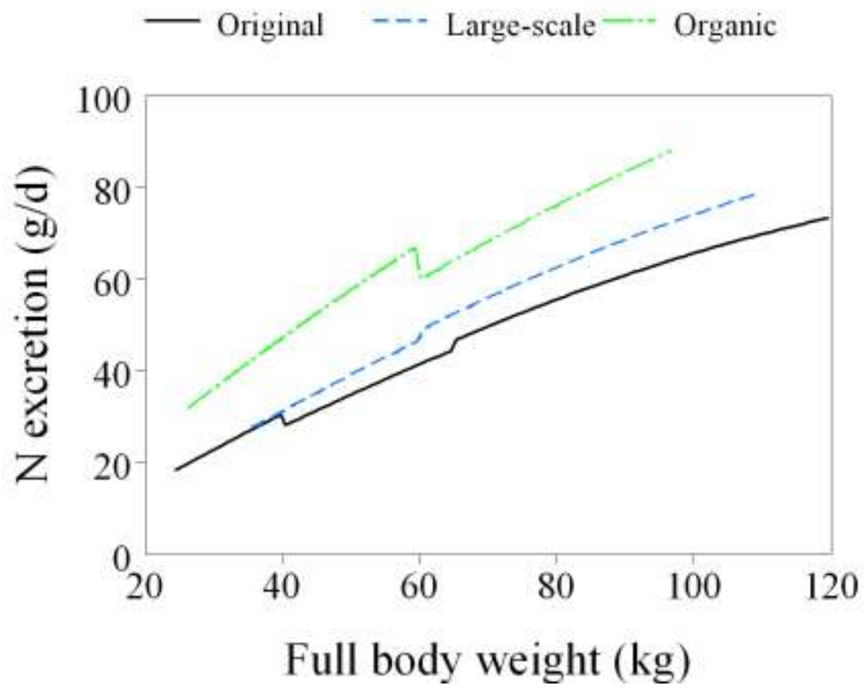
The predicted (cumulative) FCR increased with increasing body weight in all cases (Figure 1b), as expected. Values were very similar at a given weight for the initial analysis and the model predictions for the conventional large scale trial (although the first ones were slightly optimistic). FCRs were considerably higher for the organic pigs (the observed FCR for the two diets was around 4 at the end of the observation, similar to the model simulations). This is probably largely due to increased maintenance energy requirements since these pigs were housed outdoors (more activity) and the observation took place out during winter months (more energy required to maintain body temperature). For that reason, the model that was used to simulate the organic trial was based on a considerably higher parameter value for ME maintenance requirements.


Original
Large-scale
Organic
Full body weight (kg)
120
100
80
60
40
20
0
30
60
90
120
150
Days from start

A


Original
Large-scale
Organic
Cumulative FCR (kg/kg)
4
3
2
1
20
40
60
80
100
120
Full body weight (kg)

B

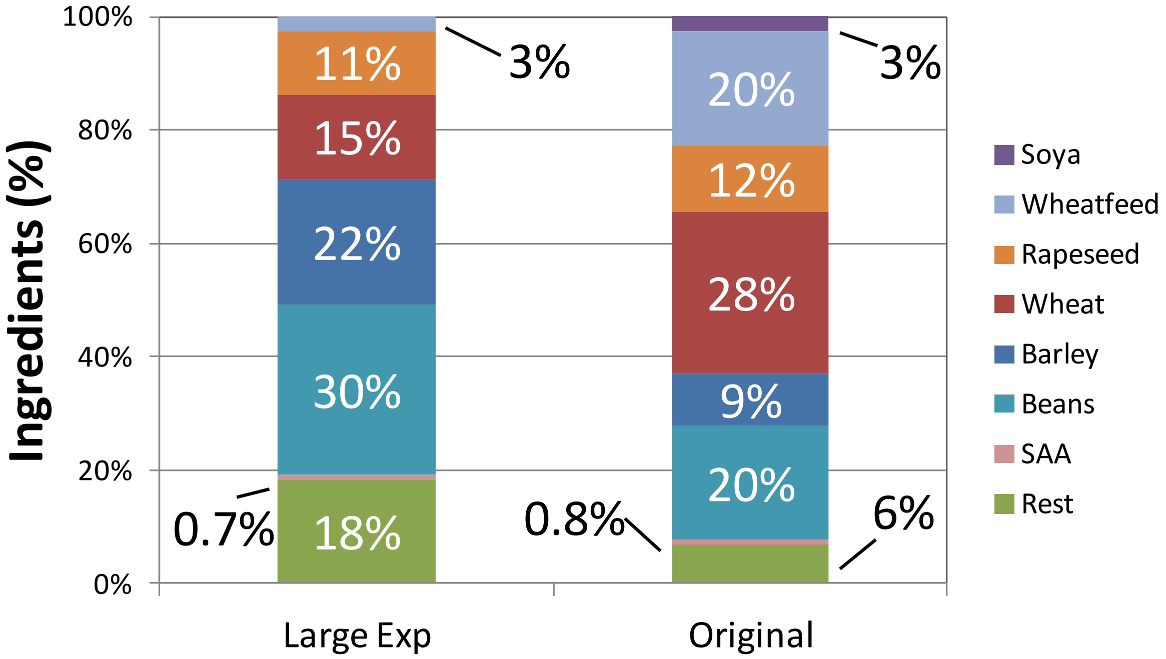


C

Figure 1. Development of body weight in relation to start day (A) and of Feed Conversion Ratio (FCR, B) and N excretion in relation to full body weight (C) of pigs as predicted by the pig growth models used for the three LCAs.

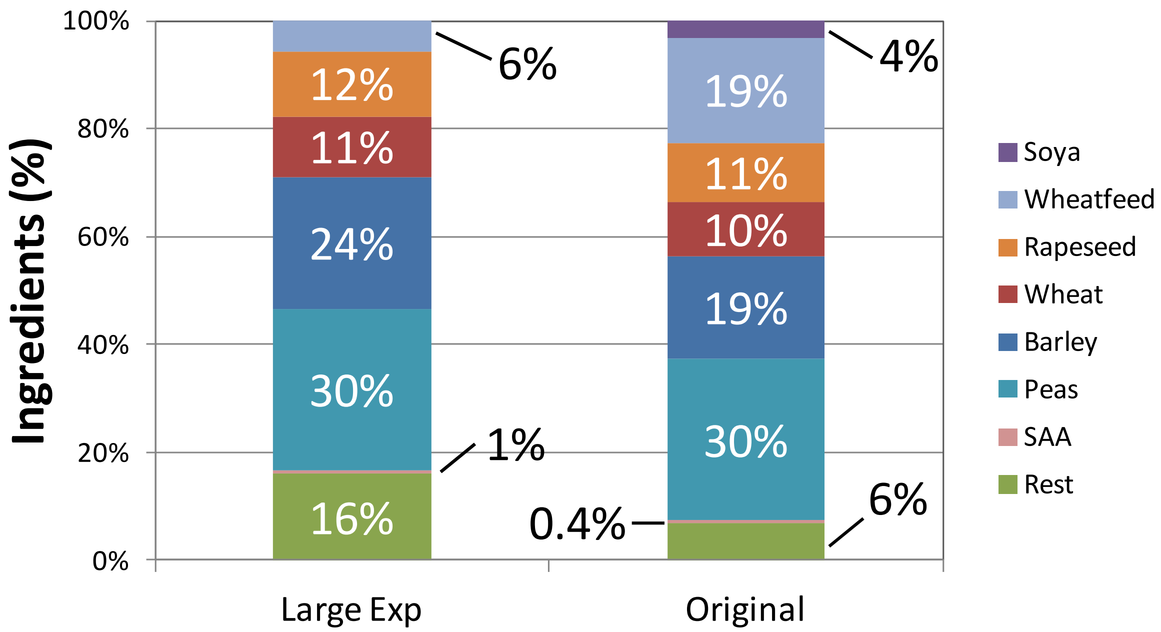
Excretions of N in slurry are relevant because of their environmental consequences and therefore were predicted by the model. The predictions of N excretion in relation to body weight are presented in Figure 1c. In all simulations these increase with pig weight. Sudden changes are predicted when diet composition changes from starter to grower to finisher (initial LCA), from grower to finisher (simulated large scale trial) and from rearer to finisher (simulated organic observation). Depending on the changes in ME and CP contents of the used diets, such sudden changes in N-excretion can consist of a decrease or an increase.

The assessment of the GWP for the large scale experiment has highlighted a similar trend in the emission for the three diets under investigation as that shown in Objective 1. An overview of the differences in diet composition of the pea-, beans- and SBM-based diets between the conventional management and the large scale trial is reported in Figure 2a, b and c. The peas and beans diets have comparable GHG emissions, 1.78 and 1.79 kg CO_{2eq}/kg LWG. However, the emissions associated with the SBM diet are higher if LUC is included, 2.52 kgCO_{2eq} /kg LWG (Figure 3). The effect of LUC is only noticeable in the diet that uses SBM as the main source of protein because in the large-scale trial, as informed by Objectives 4 and 5, no SBM was deemed needed in the pea- and bean-based diets.



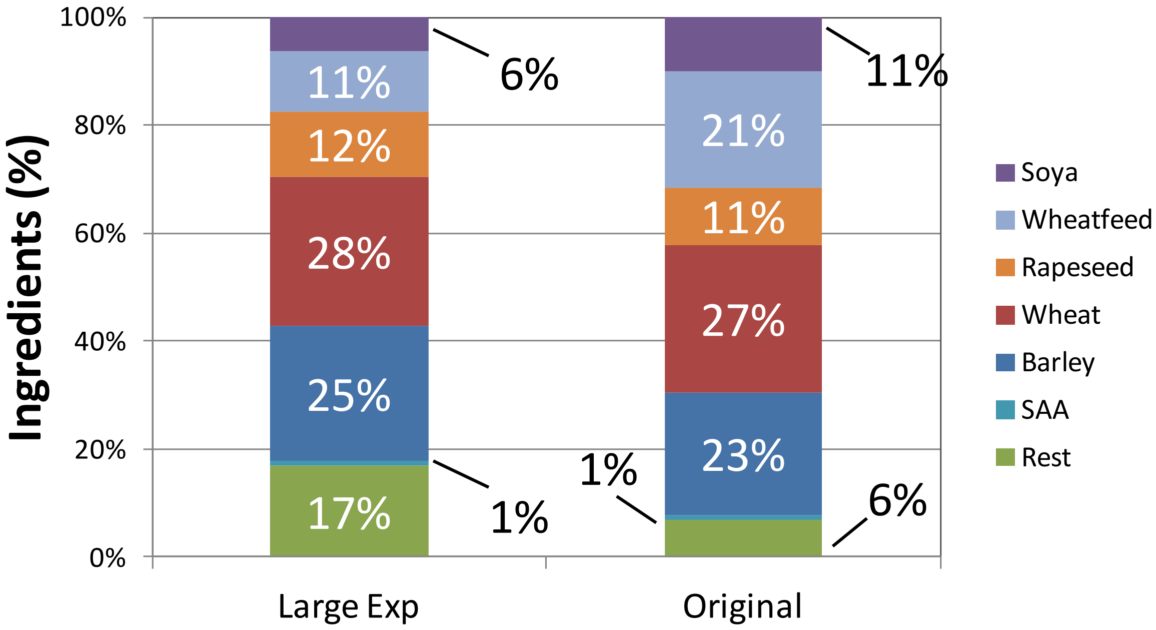
Ingredients (%)
100%
80%
60%
40%
20%
0%
11%
15%
22%
30%
18%
3%
0.7%
20%
12%
28%
9%
20%
3%
0.8%
6%
Large Exp
Original
Soya
Wheatfeed
Rapeseed
Wheat
Barley
Beans
SAA
Rest

a)



Ingredients (%)
100%
80%
60%
40%
20%
0%
12%
11%
24%
30%
16%
6%
1%
19%
11%
10%
19%
30%
4%
0.4%
6%
Large Exp
Original
Soya
Wheatfeed
Rapeseed
Wheat
Barley
Peas
SAA
Rest

b)



c)

Figure 2. A comparison of the average ingredient composition of the diets based on beans (a), peas (b) and SBM (c) modelled in the original LCA (Objective 1) and those used in the large scale trial. The category labelled "Others" comprises: minerals, vitamins, molasses, lysine, M+C and threonine. In addition in the large experiment diets the following ingredients were also included: biscuit meal, DDGS and valine.

The relative contribution of each process in the total GWP is summarised in table 9. The three diets show a similar trend, with the crop production and slurry storage tank as the main contributor with an average of 41% and 28% respectively if SBM is derived from soya sources that are not associated to land conversion (Figure 6a). However, if LUC is considered the SBM diet is characterised by nearly a third increase in the total emission associated to the CO_2 emissions following land conversion (Table 9).

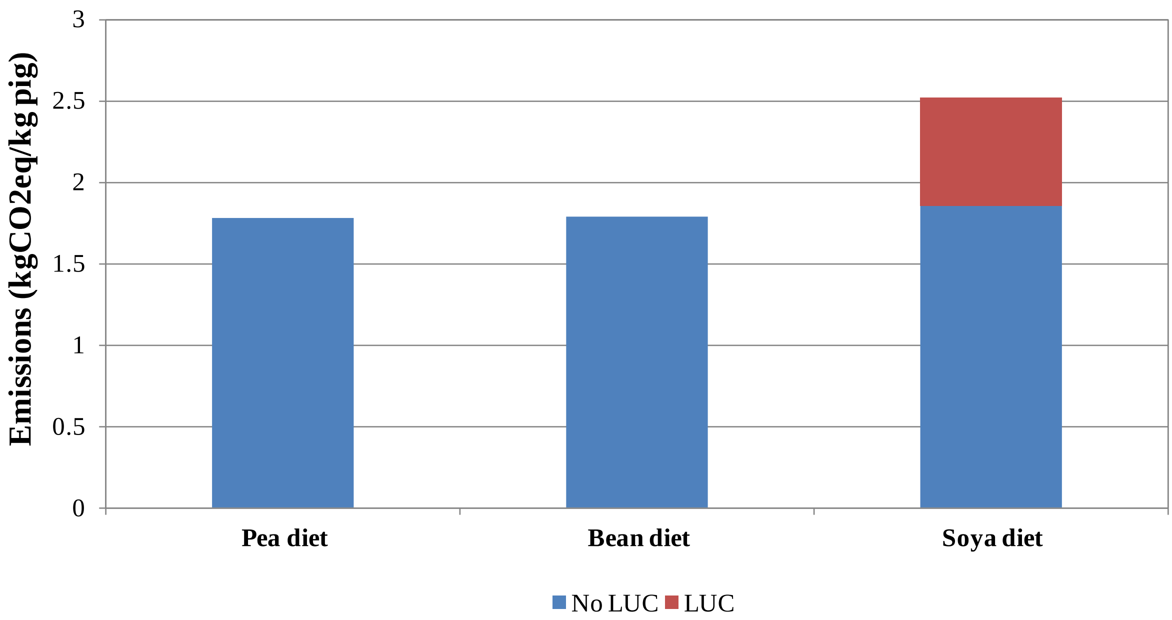


Figure 3. Greenhouse gas emissions associated with diets based on peas, beans or soya as main protein sources when taking account of land use change for soya production (LUC) and excluding LUC form the budged (NoLUC).

Table 9. The proportions of total greenhouse gas emissions associated with pig production systems based on mainly peas, beans or soya as protein source for the pig diets that can be attributed to the different underlying processes when land use change (LUC) is not accounted for in the production of soya and included in the total evaluation.

	No LUC			LUC		
	Pea diet (%)	Bean diet (%)	SBM diet (%)	Pea diet (%)	Bean diet (%)	SBM diet (%)
Crop production	41.52	40.94	39.08	41.52	40.94	55.18
Slurry/CH4	28.12	28.01	27.09	28.12	28.01	19.93
enteric CH4	9.83	9.79	9.47	9.83	9.79	6.97
Buildings, etc.	10.34	10.30	9.97	10.34	10.30	7.33
AA additives	3.85	4.28	5.16	3.85	4.28	3.80
Rest	4.74	5.07	4.68	4.74	5.07	3.44
Transport	1.59	1.61	4.54	1.59	1.61	3.34

The eutrophication and acidification potential associated with the three diets is consistent with the GWP findings. Peas and beans diets have a comparable impact while the SBM diet shows a higher impact due to the transport from South America (table 10).

However, these results are different from the conventional management scenario (LCA Objective 1) as SBM is not present in the pea and bean diet and the total proportion of SBM in the SBM-based diet was reduced by 50%.

Table 10. Eutrophication and acidification associated with the three diet scenarios for the large-scale trial.

	Pea diet	Bean diet	SBM diet
Eutrophication (kg PO_4eq/kg LWG)	0.008	0.007	0.014
Acidification (kg SO_4eq/kg LWG)	0.020	0.020	0.06

The analysis of the LCA results on the basis of the large scale trial reinforces the conclusion derived from the original LCA (Objective 1). The three diets have comparable emissions if LUC is not considered. However, the SBM based diet is strongly penalised once the GHG emission associated with land conversion is included in the emissions budget.

LCA Organic Trial

The results from the organic observation LCA have been evaluated in order to establish and compare the environmental impact of a control diet which uses SBM (9%), peas (16%) and beans (5%) and a test diet which has only peas (29%) and beans (12%) as sources of protein (Figure 7). The two diets show a GWP emission of 1.70 kg CO_2eq/kg LWG and 1.47 kg CO_2eq/kg LWG for the control and test diet respectively. In agreement with the conventional large scale trial, these are rather similar as SBM production is not associated with deforestation, therefore excluding any LUC effect. The ~15% difference arises from reduced land transport for SBM and lower inclusion of barley. Most of the emissions are associated with crop production, 79% and 80% respectively, with the enteric methane emissions contributing only for 12% of the total emissions (Table 11).

The estimated eutrophication and acidification potentials associated with the two diets show that the control diet has a higher environmental impact than the test diet (Table 12). The main contributor to this difference is the transport of soymeal; a detail overview is reported in the Appendix.

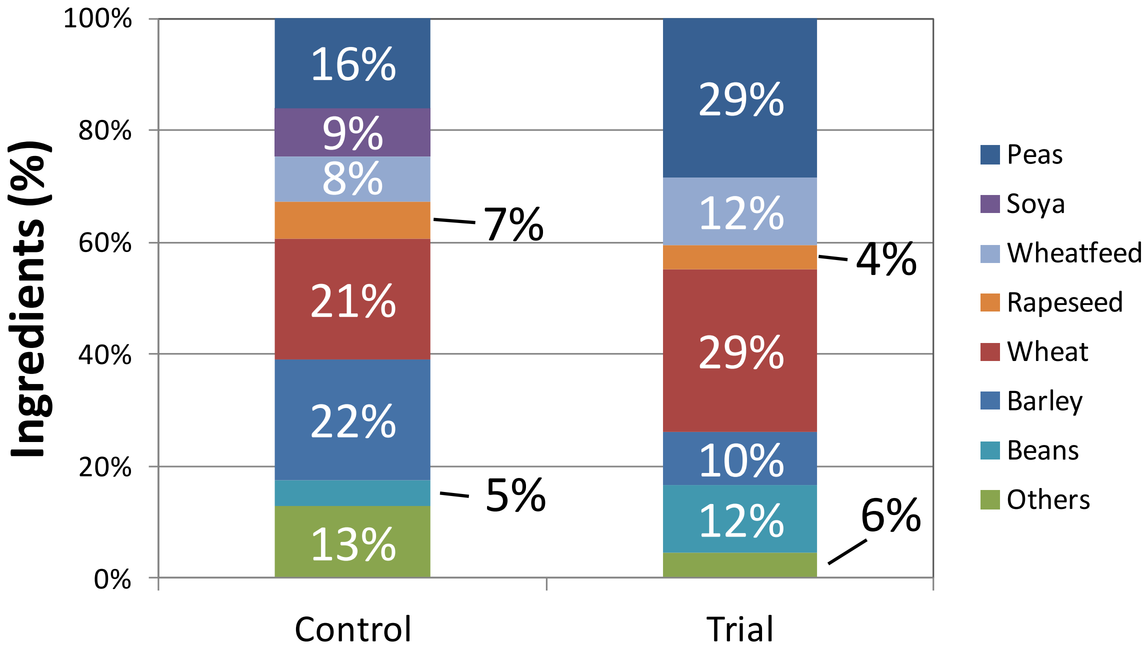


Figure 7. A comparison of the average ingredient composition of the organic control diet (a) and trial diets (b). The category labelled "Others" comprises minerals, vitamins, molasses, oats and sunflower expeller.

Table 12. Contributions of the different processes to GWP associated with the two diet scenarios modelled for the organic trial.

	Control	Test
Crop production	74%	81%
Enteric CH_4 emissions	11%	12%
Buildings, etc.	1%	1%
Additives	3%	3%
Transport	11%	2%

Table 13. Eutrophication and acidification associated with the two diet scenarios modelled for the organic observation.

	Control diet	Test diet
Eutrophication (kg PO4eq/kg LWG)	0.01	0.005
Acidification (kg SO4eq/kg LWG)	0.032	0.008

Conclusions

The LCA results from the two considered scenarios demonstrate that from an environmental point of view the use of home grown beans and peas in grower and finisher pig diets is associated with similar emissions to the traditional SBM based diets if the soya is derived from sources that are not associated with deforestation or other forms of land use change. Consequently, these conclusions are similar for conventional and organic settings. However, if soya is cultivated on land that has been converted from natural to crop land in the last 20 years, the SBM used in the diet is associated with a large carbon footprint, and this penalizes the SBM based diets. The emissions associated with LUC have a high degree of uncertainty due to the complexity of the system. However, it is important to note that if any GWP is associated with LUC, the SBM diets will always have a higher impact than diets based on other protein sources such as beans and peas. The acidification and eutrophication potential associated with diets based on SBM are considerably and systematically higher than those associated with diets based on peas and/or beans, mainly as a result of transport-based emissions.

References

See Objective 1 report.

Appendix Objective 7.

Table A1. Total ingredient requirements (in kg) for the whole of the growing period for the large-scale experiment LCA.

Diet	SBM Diet (kg)	Peas Diet (kg)	Beans Diet (kg)
Barley	56.082	54.508	49.636
Wheat	61.865	25.413	33.669
Peas	0	67.302	0
Soya	13.943	0	0
Beans	0	0	67.302
Rapeseed	27.071	27.071	25.193
Wheat feed	25.607	12.606	5.633
Fat	0.673	0.781	0.926
Min-Vit	6.166	6.081	5.934
Molasses	0	0	0
Lysine	1.513	0.809	0.909
Methionine	0.202	0.308	0.356
Threonine	0.276	0.25	0.254
Biscuit 136	14.118	12.33	17.628
DDGS Ensan	16.826	16.826	16.826
Tryptophan	0	0.055	0.066
Valine	0	0.009	0.01
Total	224.342	224.349	224.342

Table A2. Proportions of total greenhouse gas emissions associated each diets ingredients and system processes for the Large Scale Experiment LCA.

	No LUC			LUC		
	Bean Diet (%)	Pea Diet (%)	SBM Diet (%)	Bean Diet (%)	Pea Diet (%)	SBM Diet (%)
Barley	7.81	7.08	7.74	7.81	7.08	5.69
Wheat	3.39	4.48	7.95	3.39	4.48	5.85
Peas	9.85	0.00	0.00	9.85	0.00	0.00
Soya	0.00	0.00	2.12	0.00	0.00	27.99
Beans	0.00	9.70	0.00	0.00	9.70	0.00
Rapeseed meal	2.54	2.36	3.09	2.54	2.36	2.28
Wheat feed	0.84	0.37	1.65	0.84	0.37	1.21
SAA additives	3.85	4.28	5.16	3.85	4.28	3.80
Rest, additives	4.74	5.07	4.68	4.74	5.07	3.44
Field op	7.40	7.28	5.92	7.40	7.28	4.36
Fertiliser	4.91	4.80	6.15	4.91	4.80	4.52
Pesticides, etc	0.25	0.25	0.28	0.25	0.25	0.21
Transport	1.59	1.61	4.54	1.59	1.61	3.34
Grain drying	4.53	4.62	4.17	4.53	4.62	3.07
Slurry storage	28.12	28.01	27.09	28.12	28.01	19.93
Building energy	10.34	10.30	9.97	10.34	10.30	7.33
Enteric CH4	9.83	9.79	9.47	9.83	9.79	6.97

Table A3. Eutrophication and acidification potential associated with the three diet scenarios modelled for the Large experimental trial. "Field Op" refers to the field operations activities, their contributions are reported in Table A8.

	Pea diet		Bean diet		SBM diet	
	Eutrophication ($kgPO_4/kgLWG$)	Acidification ($kgSO_x/kgLWG$)	Eutrophication ($kgPO_4/kgLWG$)	Acidification ($kgSO_x/kgLWG$)	Eutrophication ($kgPO_4/kgLWG$)	Acidification ($kgSO_x/kgLWG$)
Barley	0.00241	0.00704	0.00220	0.00641	0.00211	0.00723
Wheat	0.00103	0.00297	0.00116	0.00394	0.00252	0.00723
Pea	0.00218	0.00012	-	-	-	-
SBM	-	-	-	-	0.00097	0.00552
Bean	-	-	0.00167	0.00011	-	-
Rapeseed	0.00123	0.00414	0.00097	0.00385	0.00134	0.00452
Wheatfeed	0.00052	0.00149	0.00058	0.00197	0.00048	0.00006
SAA	0.00020	0.00062	0.00022	0.00069	0.00029	0.00091
FarmOp	0.00017	0.00117	0.00056	0.00340	0.00744	0.04270
Total	0.00755	0.01690	0.00737	0.02040	0.01420	0.06160

Table A4. Eutrophication and acidification potential for the field operations associated with the three diet scenarios modelled for the large scale experiment.

		Pea diet		Bean diet		SBM diet	
		Eutrophication ($kgPO_4$/kgLWG)	Acidification ($kgSO_x$/kgLWG)	Eutrophication ($kgPO_4$/kgLWG)	Acidification ($kgSO_x$/kgLWG)	Eutrophication ($kgPO_4$/kgLWG)	Acidification ($kgSO_x$/kgLWG)
Field Op	Nox	0.00015	0.00083	0.00015	0.00083	0.00013	0.00068
	Sox	-	0.00003	-	0.00003	-	0.00003
Transport	Nox from fuel per diet (kg/kg LWG)	0.00002	0.00009	0.00040	0.00220	0.00730	0.03900
	Sox from fuel per diet (kg/kg LWG)	-	0.00001	-	0.00013	-	0.00228
Pesticide production	Pesticide production per diet	-	0.00005	-	0.00003	-	0.00005
Fertiliser Prod N	acidification per diet	-	0.00005	-	0.00006	-	0.00006
Fertiliser Prod P	acidification per diet	-	0.00009	-	0.00008	-	0.00005
Fertiliser Prod K	acidification per diet	-	0.00003	-	0.00003	-	0.00000
Total		0.00017	0.00117	0.00056	0.00336	0.00741	0.04270

Table A5. Total ingredient requirements (in kg) for the whole of the growing period of the organic trial LCA.

Diet	Control Diet (kg)	Test Diet (kg)
Barley	62.545	27.631
Wheat	61.846	84.07
Peas	46.455	82.713
Soya	25.145	0
Beans	13.697	34.86
Rapeseed meal	19.386	12.32
Wheatfeed	23.568	34.86
Fat	0	0
Minvit	7.025	8.02
Molasses	3.334	0
Triticale	14.857	0
Oats	0	5.417
Sunflower exp.	12.031	0
Total	289.889	289.891

Table A6. Proportions of total greenhouse gas emissions associated each diets ingredients and system processes for the Organic LCA.

	Control Diet (%)	Test Diet (%)
Barley	23.59	11.88
Wheat	11.23	17.41
Peas	7.78	15.80
Soya	4.41	0.00
Beans	2.30	6.68
Rapeseed	3.75	2.72
Wheatfeed	2.14	3.61
Triticale	0.51	0.00
Oats	0.00	1.01
Sunflower exp	2.44	0.00
Ingredients, additives	3.36	2.96
Field op	10.65	13.44
Fertiliser	0.00	0.00
Pesticides, etc	0.00	0.00
Transport	9.48	2.25
Grain drying	6.50	8.71
Slurry storage	0.00	0.00
Building energy	1.12	1.28
Enteric CH4	10.74	12.25

Table A7. Eutrophication and acidification potential associated with the three diet scenarios modelled for the Organic trial. "Field Op" refers to the field operations activities, their contributions are reported in Table A8.

	Control diet		Test diet	
	Eutrophication ($kgPO_4/kgLWG$)	Acidification ($kgSO_x/kgLWG$)	Eutrophication ($kgPO_4/kgLWG$)	Acidification ($kgSO_x/kgLWG$)
Barley	0.00113	-	0.00050	-
Wheat	0.00180	-	0.00244	-
Pea	0.00085	-	0.00151	-
SBM	-	-	-	-
Bean	-	-	-	-
Rapeseed meal	0.00056	0.00220	0.00042	0.00094
Wheat feed	0.00089	-	0.00002	-
Field Op	0.00510	0.02920	0.00091	0.00710
Total	0.01000	0.03100	0.00571	0.00832

Table A8. Eutrophication and acidification potential for the field operations associated with the two diet scenarios modelled for the organic LCA.

		Control diet		Test diet	
		Eutrophication	Acidification	Eutrophication	Acidification
		($kgPO_4$/kgLWG)	($kgSO_x$/kgLWG)	($kgPO_4$/kgLWG)	($kgSO_x$/kgLWG)
Field Op	Nox	0.00022	0.00120	0.00022	0.00310
	Sox	-	0.00005	-	0.00004
Transport	Nox from fuel per diet (kg/kg LWG)	0.00490	0.02640	0.00069	0.00370
	Sox from fuel per diet (kg/kg LWG)	-	0.00153	-	0.00022
Pesticide production	Pesticide production per diet	-	-	-	-
Fertiliser Prod N	acidification per diet	-	-	-	-
Fertiliser Prod P	acidification per diet	-	-	-	-
Fertiliser Prod K	acidification per diet	-	-	-	-
Total		0.00517	0.02910	0.00091	0.00709

Full report Objective 8: Dissemination.

Lead authors: Jos Houdijk and Lesley Smith (SRUC).

Executive Summary

- Green Pig has resulted in more than 100 dissemination activities, targeting wide range of audiences, including policy makers, pulse growers, feed manufacturers, pig producers, retailers/consumers and scientists.
- There was a peak output in Year 1, mainly related to press release with follow-ups and Green Pig awareness presentations, and Year 4, mainly related to promoting the outcome of the large scale farm demonstration trials and presenting Green Pig outcomes at BSAS 2012.
- Commercial audiences (pulse growers, feed manufacturers and pig producers) have received a steady output of disseminations throughout, including through agricultural shows where attention is drawn through a large inflatable Green Pig.
- Targeted activities have informed Defra-policy makers especially in Year 4.
- Dissemination will not stop at final project report submission; activities are planned around releasing a summarized version of the final report, an overview paper is planned for the 2013 Nottingham Feed Conference and several articles are in preparation for submission to peer reviewed journals
- The dissemination SharePoint will remain open for Green Pig partners for the foreseeable future.

Introduction

At project inception it was envisaged to devise a dissemination plan early on during the project implementation, in order to manage dissemination activities throughout the project. Whilst such a plan was not formally in place until a special sub-group meeting during Year 4 that targeted dissemination plans (see below), a SharePoint site was up and running throughout the project to log activities, to keep each other informed, and to share outputs for further disseminations. The special sub-group meeting concluded that dissemination efforts could be streamlined by being seen as serving different audiences, and the following five were identified: policy makers, pulse growers, feed manufacturers, pig producers and retailers. The scientific community was not specifically targeted as an audience, though expected to be addressed through academic partners anyway. The focus on the five end-user audiences reiterated the near market nature of Green Pig. Attribution of activities to specific audiences is based on perception of audience present, rather than feed back from the activities.

Results

The Green Pig dissemination SharePoint, which is available to all Green Pig partners through secured log-in, listed 111 entries by 1 October 2012. These included a wide range of dissemination activities, ranging from initial press release and follow up appearances in (on-line) trade journals, Green Pig awareness meetings, to presenting first outcomes at meetings, in trade journals, site visits, open days, radio interviews and ranged from press release. Table 1 provides an overview of these activities, and below they are analysed with regards to activities per year, per audience and per year-audience combination.

Figure 1 shows the activity numbers recorded per year over the life time of the project. It is clear there were more activities during Years 1 and 4, which arose mainly from press release and Green Pig awareness presentations, and from promoting the outcome of the demonstration trials and BSAS presentations in 2012. This clearly demonstrates that although small scale experiments were on-going prior to Year 4, it is the large scale commercial testing that attracts most attention. This advocates the benefit, or perhaps necessity, of inclusion of such translational demonstration trials in projects that aim to increase industry confidence in raw materials, or in fact in any new concept. It also highlights that it takes time to gather sufficiently robust data to present at learned societies like BSAS, and that consequently earlier outputs could perhaps *a priori* not have been expected. Lastly, the number of activities in Year 5 is small but biased due to the fact that Year 5 consists of 3 months only. Furthermore, more activities are planned upon final project report submission through publicising a summary to many audiences, presenting an overview paper at Nottingham Feed Conference 2013 and submission of research articles to peer reviewed journals.

Figure 2 shows the activity recorded per audience. Several activities have targeted each audience identified, though it is clear that dissemination activities were relatively more to the more industrial end-user audiences, i.e. pulse growers, feed manufacturers and pig producers. To a large extent, this is what could be expected from a LINK project, and it demonstrates good connectivity between Green Pig partners and these end users. It is also clear that retailers were likely less targeted as audience. The need to inform retailers was identified during the dissemination subgroup meeting, but since retailers were not directly involved in Green Pig as an industrial partner, it was concluded it would be difficult, and perhaps politically not correct, to target specific retailers with Green Pig outputs. The latter would be required to potentially result in retailers promoting pork production using home grown raw materials, which could attract a premium on meat sales and through market mechanism lead to higher pig prices, allowing producers to use the currently more expensive peas and beans as SBM alternatives. Therefore, an effort was undertaken during Year 4 to broadly inform the retailers through articles in trade magazines, and involvement of umbrella organisations.

Figure 3 shows Green Pig activities per project year per audience. This breakdown shows that activities towards the industrial end-user audiences have been more or less steady throughout the life time of the project, whilst those targeting researchers and policy makers clearly increased during the last year.

As already mentioned, dissemination will not stop at final project report submission; activities are planned around final report delivery, and as highlighted by many of the industrial sponsors, the overall outcomes of Green Pig will remain relevant for the years to come, especially if affordable SBM availability reduces. Therefore, it is expected that Green Pig will continue to feature in future open days, agricultural shows, trade fairs etc, and to draw attention, a giant inflatable green pig has been designed, based on the Green Pig logo (Figure 4), and this will be available to any Green Pig partner for dissemination purposes.

Conclusion

Green Pig had set out to undertake a significant number of dissemination activities. With more than 100 activities recorded, this objective was achieved. Green Pig dissemination activities will continue for the foreseeable future, and the SharePoint site with its output will remain available to Green Pig partners for many years to come.

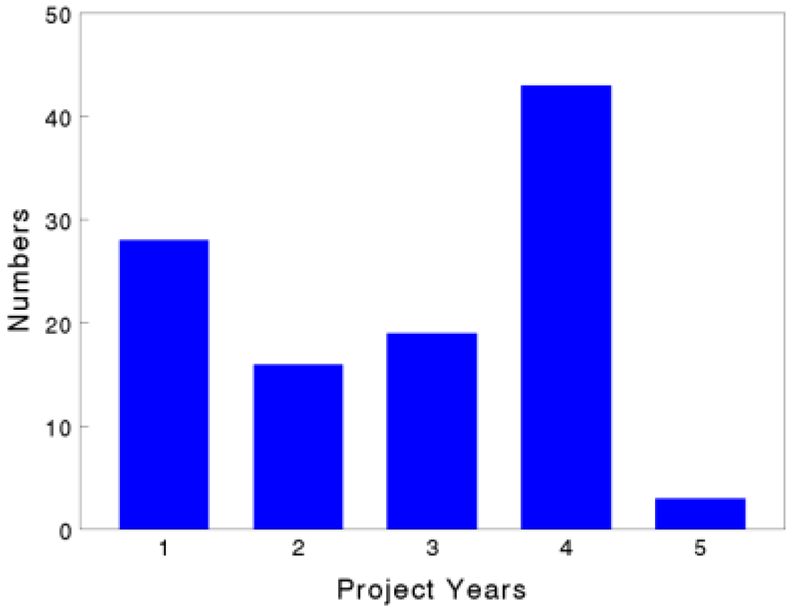


Figure 1. Green Pig activities as recorded in its SharePoint log per project year.

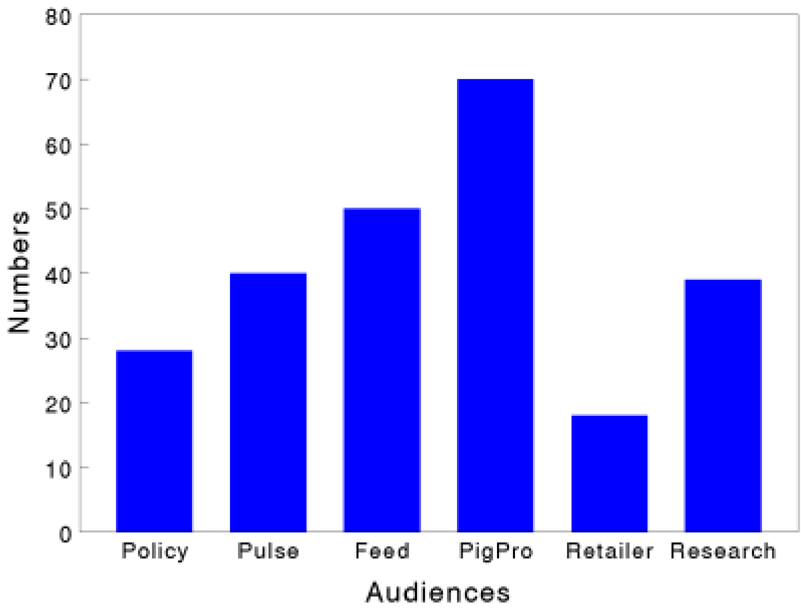


Figure 2. Green Pig activities as recorded in its SharePoint log per audience (policy makers, pulse growers, feed manufacturers, pig producers, retailers and researchers).

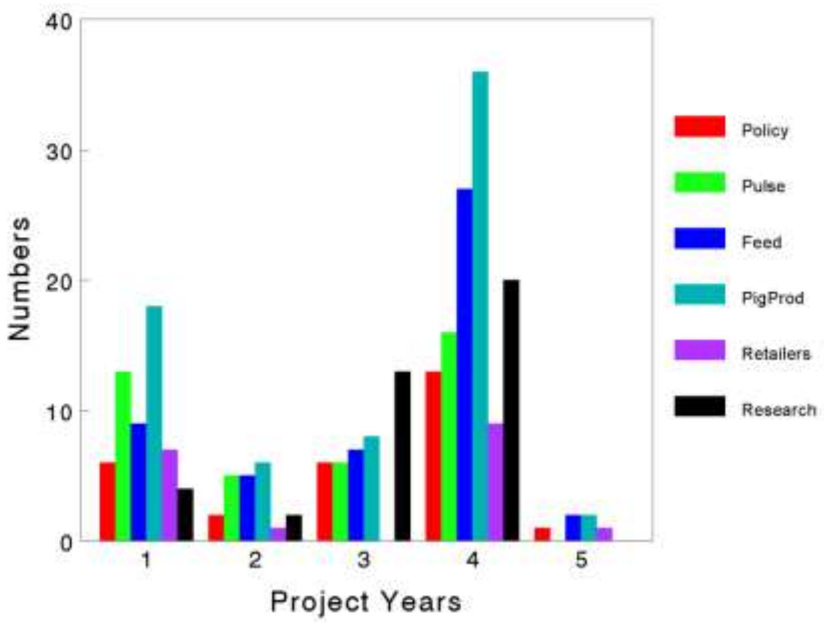


Figure 3. Green Pig activities as recorded in its SharePoint log per year per audience (policy makers, pulse growers, feed manufacturers, pig producers, retailers and researchers).

Figure 4. Creating awareness with a giant inflatable Green Pig.

Table 1. Overview of Green Pig KT activities recorded between 1 July 2008 and 1 October 2012 to different audiences (policy makers, pulse growers, feed manufacturers, pig producers, retailers and scientific community).

Year	Ref	KT type	Month	Narrative	Policy	Pulse	Feed	Pig	Retailer	Science
1	1	Online Article	Aug-08	SAC research page	*	*	*	*	*	*
1	2	Online Article	Aug-08	Yorkshire Post	*	*	*	*	*	
1	3	Online Article	Aug-08	ASRP (Atlantic Swine Research Partnership) newsletter			*	*		*
1	4	Online Article	Aug-08	Pig progress.net			*	*		
1	5	Online Article	Aug-08	The Grocer	*				*	
1	6	Online Article	Aug-08	The Pig Site				*		*
1	16	Online Article	Aug-08	Pig World				*	*	
1	19	Online Article	Aug-08	The Pig Site				*		
1	20	Online Article	Aug-08	Scottish Parliament	*					
1	7	Online Article	Sep-08	SAC News	*	*	*	*	*	
1	8	Online Article	Sep-08	FARMINGUK		*		*	*	
1	9	Online Article	Nov-08	Hexham Courant		*		*	*	
1	10	Online Article	Jan-09	HGCA web site agenda		*				
1	11	Online Article	Jan-09	HGCA web site JH presentation		*				
1	24	Oral Presentation	Jan-09	Jos presented at the HGCA/PGRO Oilseeds & Pulses Conference		*				

Year	Ref	KT type	Month	Narrative	Policy	Pulse	Feed	Pig	Retailer	Science
1	12	Online Article	Feb-09	First4farming		*		*		
1	13	Online Article	Feb-09	Pig progress.net			*	*		
1	14	Online Article	Feb-09	Farmers Weekly		*				
1	15	Online Article	Feb-09	Farmers Weekly				*		
1	17	Online Article	Feb-09	Canadian Agriculture News		*		*		
1	22	Online Article	Feb-09	APS		*	*			
1	23	Online Article	Feb-09	Pork World			*	*		
1	18	Online Article	Apr-09	Scottish Parliament Debate	*					
1	25	Survey	May-09	Lesley distributed Green Pig Survey at Pig and Poultry Live 2009				*		
1	21	Online Article	Jun-09	Farm business				*		
1	26	Poster	Jun-09	Jos presented poster at Cereals 2009			*	*		
1	29	Poster	Jun-09	Jos and Lesley presented poster at PGRO Open Day 2009		*				
1	64	Paper & oral presentation	Jun-09	Stephen, K. L., Tolkamp, B. J., Topp, C. F. E., Houdijk, J. G. M. and Kyriazakis I. (2009) Environmental impacts of UK pig production systems: Analysis using Life Cycle Assessment. *Aspects of Applied Biology* 93, *Integrated Agricultural Systems: Methodologies, Modelling and Measuring*, pp. 39-45.						*

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2	27	Article	Jul-09	J Houdijk (2009) Increasing the use of home-grown pulses in pig nutrition - the Green Pig project. The Pulse Magazine Summer 2009 Journal of the Processors and Growers Research Organisation p 7.		*				
2	28	Radio	Jul-09	Green Pig features in a radio interview (Lincs FM, Farming Programme		*	*			
2	30	Leaflet	Sep-09	Summary of Green Pig work for SAC KT document distributed to Scottish Pig farmers				*		
2	31	Presentation	Dec-09	Summary of Green Pig work included in KT presentation for NFUS working group.	*			*		
2	32	Article	Dec-09	S Kightley (2009) Green Pig project into its second year. Landmark magazine December 2009. The Journal of the NIAB Association.		*	*			
2	33	Poster and Farm visit	Jan-10	NFUS Working group visit - Lesley showed group round the Green Pig rooms and distributed A4 size poster	*			*		
2	34	Oral presentation	Jan-10	The Green Pig project was referred to at the HGCA/PGRO Oilseeds and Pulse Conference in Peterborough		*				
2	35	Article	Apr-10	A Biddle (2010) An Update on the Green Pig project. The Pulse Magazine Spring 2010 Journal of the Processors and Growers Research Organisation p 9.		*				
2	36	Abstract	Apr-10	WPSA/BSAS Conference Proceedings -Masey O'Neill, Rademacher and Wiseman (2010) Crude protein and amino acid digestibility of 13 varieties of UK-grown peas and beans for broilers						*

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2	37	Oral Presentation	Apr-10	WPSA/BSAS Conference Oral presentation -Masey O'Neill, Rademacher and Wiseman (2010) Crude protein and amino acid digestibility of 13 varieties of UK-grown peas and beans for broilers						*
2	38	Poster and Farm visit	May-10	Mike Varley (BPEX) - Lesley showed Mike around the Green Pig rooms and distributed A4 size poster				*		
2	39	Poster and Farm visit	May-10	Visit from Dr Rebecca Morrison and Mr Mark Mills from Rivalea, Australia. Lesley showed visitors round the Green Pig room and distributed A4 size poster				*		
2	41	Online Article	May-10	Press article in Farmers Weekly covering Nell's WPSA presentation			*			
2	42	Online Article	May-10	Press article online at the first4farming web site covering Nell's WPSA presentation			*			
2	43	KT document	May-10	KT document to be distributed to Evonik customers worldwide summarising the digestibility work in poultry			*			
2	40	Poster and Farm visit	Jun-10	NPA - Zoe Davis and Barney Kay. Lesley showed visitors round Green Pig room and distributed A4 size poster.				*	*	
3	44	Oral Presentation	Jul-10	Lesley presented at PGRO Trials day		*				
3	45	Radio Interview	Jul-10	Radio interview about Green Pig with Sally Elkington (LINCs FM)		*				
3	46	Oral Presentation	Oct-10	LS presents the survey at SAC KT day	*		*	*		*

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3	47	Hand-out	Oct-10	Hand-out on Green Pig project and survey at SAC's Pig KT day	*		*	*		*
3	48	Oral Presentation	Nov-10	SFT pig conference - LS and JH present overview of project			*	*		*
3	49	Paper	Nov-10	SFT pig conference - Paper on project to accompany the oral presentation			*	*		*
3	50	Oral presentation	Nov-10	LS presents overview of Green Pig project to Bob Watson (Chief scientific officer for Defra)	*					
3	51	Article	Jan-11	Anthony writes article on the feeding value of peas and beans for PGRO pulse agronomy guide 2011		*				
3	52	Oral presentation	Jan-11	JH presents overview of project for ORC producer conference		*	*	*		*
3	53	Abstract	Jan-11	Abstract for ORC producer conference		*	*	*		*
3	55	Presentation	Jan-11	Salvador presented update of project at Oilseeds and Pulses Conference		*				
3	54	Paper	Feb-11	Paper submitted paper to Animal Feed Science and Technology						*
3	56	Oral presentation	Apr-11	BSAS oral presentation - Smith LA, Houdijk JGM, Kyriazakis I (2011) The Green Pig survey: constraints of using peas and faba beans in growing and finishing pig diets.						*
3	57	Abstract	Apr-11	BSAS conference proceedings - Smith LA, Houdijk JGM, Kyriazakis I (2011) The Green Pig survey: constraints of using peas and faba beans in pig diets.						*

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3	58	Oral presentation	Apr-11	Pinder presented overview of the project in a Defra internal seminar	*					
3	59	Presentation	Apr-11	Nitrogen and Global change conference 2011 oral presentation - Topp CFE, Tolkamp BJ, Houdijk JGM, Stephen KL, Kyriazakis I (2011) Environmental analysis of pig production systems: the production of home-grown proteins.	*					*
3	60	Abstract	Apr-11	Topp CFE, Tolkamp BJ, Houdijk JGM, Stephen KL, Kyriazakis I (2011) Environmental analysis of pig production systems: the production of home-grown proteins. *Nitrogen and Global change, Key findings - future challenges. 11-14 April 2011. Edinburgh International Conference Centre, Edinburgh, UK.*	*					*
3	61	Online Article	Apr-11	The environmental consequences of using home-grown legumes as a protein source in pig diets (Green Pig Project)				*		*
3	62	Poster	Jun-11	Roslin Institute Building (RIB) Industry open day - Green Pig poster			*	*		*
4	63	Article	Jul-11	Q&A article in the Organic Farming Magazine		*		*	*	*
4	65	Publication	Sep-11	BPEX (2011) Green Pig Project - Survey Results. BPEX research into Action.			*	*		*
4	66	Article	Dec-11	Organic farming Magazine Winter Issue, article on the Green Pig project		*		*	*	*
4	68	Article	Dec-11	QMS Scottish Farmer page: Article giving overview of the Green Pig Survey		*	*	*		

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4	69	Abstract	Jan-12	ORC producer conference abstract. Smith & Houdijk (2012). Peas and faba beans as home grown alternatives for soya bean meal in fattening pig diets. 18th-19th Jan 2012. Aston University, Birmingham		*	*	*		*
4	70	Oral Presentation	Jan-12	Smith LA & Houdijk JGM (2012). Peas and faba beans as home grown alternatives for soya bean meal in fattening pig diets. ORC Producer conference, 18th-19th Jan 2012. Aston University, Birmingham		*	*	*		*
4	77	Oral presentation	Jan-12	PGRO Road show; an overview of the project and outcomes. Escrick, York. Kev Stickney presenting 24/01/12		*		*	*	
4	77	Oral presentation	Jan-12	PGRO Road show; an overview of the project and outcomes. Thornhaugh, Peterborough. Kev Stickney presenting 25/01/12		*		*	*	
4	77	Oral presentation	Jan-12	PGRO Road show; an overview of the project and outcomes. Enstone, Chipping Norton. Kev Stickney presenting 30/01/12		*		*	*	
4	77	Oral presentation	Jan-12	PGRO Road show; an overview of the project and outcomes. Shifnal, Shropshire. Martin Barker presenting 31/01/12.		*		*	*	
4	77	Oral presentation	Jan-12	PGRO Roadshow; an overview of the project and outcomes. Ickworth, Bury St Edmunds. Kev Stickney presenting. 1/02/12.		*		*	*	
4	78	Email update	Jan-12	PGRO Pulse Market update - Green Pig gets a mention		*				

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4	79	Leaflet	Jan-12	2 page leaflet for Dalton Seeds giving a summary of project outcomes, circulated to 250 contracted pea growers in the Lincolnshire and East Anglia area.		*				
4	80	Articles	Feb-12	2 articles in the Pulse Magazine. The magazine was circulated with Farmer's Weekly to 22,000 on the circulation list		*				
4	67	Publication	Mar-12	BPEX Case study of the Green Pig Large Scale Trials at MPP, published on BPEX web site and for Andrew McWhir (Defra policy) to include in report on sustainable agriculture				*		
4	81	Meeting	Mar-12	PGRO with Kev Stickney hosted a visit from Pulse Canada.to promote Green Pig project outcomes.		*	*			
4	82	Telephone meeting	Mar-12	LS promoted project Green Pig to Ruth Clements (FAI Farms, Oxford). Discussed project outcomes with regard to the European Core II Organic Programme project 'The improved contribution of local feed to support 100% organic feed supply to pigs' and poultry'	*					*
4	83	Article	Mar-12	Article in 'The Grocer' Magazine highlighting the Green Pig project - 'Pulses for pigs could cut imports of soy', p 34. Circulation 31000.					*	
4	103	Article	Mar-12	Finger on the Pulse'. Farm Contractor and Large Scale Farmer - Agronomy special. March 2012. Article reports Kev Stickney's presentation at the PGRO Road shows.		*	*			

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4	71	Abstract	Apr-12	Smith LA, Houdijk JGM, Kyriazakis I (2012) Effects of increasing dietary inclusion levels of peas and faba beans to replace soya bean meal on pig growth performance. BSAS, 24th-25th April. Nottingham University	*		*	*		*
4	72	Abstract	Apr-12	Smith LA, Houdijk JGM, Homer D, Kyriazakis I (2012) Effects of using peas and faba beans to replace soyabean meal on carcass quality in pigs. BSAS, 24th-25th April. Nottingham University	*		*	*		*
4	73	Abstract	Apr-12	White G, Wiseman J (2012) Using home-grown peas and beans to replace soyabean meal does not impair nitrogen balance in pigs. BSAS, 24th-25th April. Nottingham University	*		*	*		*
4	74	Abstract	Apr-12	White, G, Wiseman J, Smith LA, Houdijk JGM, Kyriazakis I (2012) Nutritional value of diets for growing/finishing pigs containing high levels of home grown legumes compared with one based on soya bean meal 1. Growth performance. BSAS, 24th-25th April. Nottingham University	*		*	*		*
4	75	Abstract	Apr-12	White G, Smith LA, Homer D, Wiseman J, Houdijk JGM, Kyriazakis I (2012) Nutritional value of diets for growing/finishing pigs containing high levels of home grown legumes compared with one based on soya bean meal. 2. Carcass quality. BSAS, 24th-25th April. Nottingham University	*		*	*		*

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4	76	Abstract	Apr-12	Topp CFE, Tarsitano D, Tolkamp B, Houdijk J, Kyriazakis I (2012) Quantifying the environmental benefits of using home grown protein sources as alternatives to soyabean meal in pig production throughout life cycle assessment. BSAS, 24th-25th April. Nottingham University	*		*	*		*
4	85	Article	Apr-12	Farmers Weekly 'Study shows higher levels of pulses could be fed to pigs'			*	*		
4	86	Report	Apr-12	Progress towards a sustainable future for livestock farming' - several references to the Green Pig project and includes the BPEX case study on the MPP large scale trials				*		
4	94	Article	Apr-12	Article in Feed Compounder Magazine. Smith & Houdijk (2012) The Green Pig project: peas and faba beans in pig diets. Feed Compounder 32 (4) 23-25.			*	*		
4	84	Article	Apr-12	Article on meatinfo.co.uk 'increase use of pulses for 'greener' pigs, trial advises				*		
4	87	Article	May-12	Farmers Weekly article on BSAS presentations from Green Pig			*	*	*	
4	88	Presentations	May-12	Green Pig BSAS presentations	*		*	*		*
4	89	Presentations	May-12	Green Pig BSAS presentations	*		*	*		*
4	90	Presentations	May-12	Green Pig BSAS presentations	*		*	*		*
4	91	Presentations	May-12	Green Pig BSAS presentations	*		*	*		*

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4	92	Presentations	May-12	Green Pig BSAS presentations	*		*	*		*
4	93	Presentations	May-12	Green Pig BSAS presentations	*		*	*		*
4	95	Article	May-12	Perkins (2012) Soy: assessing the future for feed. Meat Trade Journal. May 2012. 18-20. Reference to the Green Pig project within the article.				*		
4	96	Article	May-12	Beans meanz a little less reliance on volatile soya' Pig World May 2012. Reference to the Green Pig project within the article			*	*		
4	97	Article	May-12	Mileham A (2012) Increase pulses use for 'greener' pigs. Meat trade journal 2012. p2. Article on the MPP large scale trial.		*	*	*		
4	98	Poster	May-12	Poster at the Pig and Poultry Fair 2012 on MPP large scale trials 'Home-grown peas and faba beans can replace SBM in commercial'			*	*		*
4	99	Leaflet	May-12	2 page leaflet summarising outcomes from the project, handed out at SAC stand, Harbro stand, BOCM Pauls stand and BPEX stand at Pig and Poultry Fair 2012			*	*		*
4	100	Article	Jun-12	Pig world published the BPEX case study on the MPP large scale trials. Pig World, June 2012, p36-37			*	*		
4	101	Show	Jun-12	PGRO at Cereals 2012 with giant inflatable Green Pig, Poster on MPP trials (KT ref no 95), and 2 page leaflet (KT ref no 96)			*	*		
5	102	Open day	Jul-12	PGRO at Pulse Day with giant inflatable Green Pig, Poster on MPP trials (KT ref no 95), and 2 page leaflet (KT ref no 96)			*	*		

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5	104	Article	Jul-12	Small article drawing attention to Green Pig. Pig World July 2012, p 12				*		
5	105	Briefing	Jul-12	Soya reliance and sustainability within the UK Pig Industry; Defra Food Supply Chain Mitigation Working Group, 10th July 2012	*		*		*	
5	106	Paper	Aug-12	Masey-O'Neill HV, Rademacher M, Mueller-Harvey I, Stringano E, Kightley S, Wiseman J, 2012. Standardised ileal digestibility of crude protein and amino acids of UK-grown peas and faba beans by broilers. Animal Feed Science and Technology 175, 158-167.			*			*
5	107	Article	Sep-12	QMS R&D 2011/12 – "Home-grown peas and faba beans can replace soya bean meal in commercial pig diets" and "The Green Pig Survey: Constraints of using peas and faba beans in growing and finishing pig diets."		*	*	*	*	