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# Optimising the use of home-grown oilseeds and pulses as protein sources in feeds for table chickens

by

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**ABSTRACT**

The UK broiler industry depends upon imported soya. Other protein sources are used with caution because of risks to performance and litter quality, or of meat taint. A better understanding of the young chicken's intake and growth responses to these ingredients would enable a more flexible approach to their use in broiler diets and would assist UK arable growers in the development of home markets.

This project examined the broiler's intake and growth responses to increasing dietary concentrations of UK grown rapeseed meal (Study 1A), whole rapeseed (Study 1B), field peas (Study 2A) and field beans (Study 2B). In Study 3, the effects of increasing substitution rates of a soya protein mix (SPM) with a non-soya protein mix (NSPM), including UK grown rapeseed, peas and beans, on intake and growth responses were examined. The protein mixes were calculated to have similar nutrient contents. In all studies the diets were formulated to be iso-energetic and iso-nitrogenous. The dietary treatments were applied separately to males and females and each diet x sex treatment combination was replicated. A controlled environment facility with 72 pens, each pen housing 22 day-old (age 0 days) chicks was used.

Rapeseed meal fed at up to 60 g/kg between day-old and 42 days of age did not depress performance. Broilers fed up to 160 g/kg rapeseed meal in the starter (0 to 21 days of age), followed by 0 g/kg rapeseed meal in the finisher (22 days to 42 days of age) performed similarly to broilers fed 0 g/kg to 42 days of age. Whole rapeseed fed at up to 100 g/kg linearly depressed weight gain, probably through reduced feed intake. The possibility that this was due to an antinutritional effect of glucosinolates could not be ruled out.

In broilers having atypically variable performance, peas could be fed up to 200 g/kg between day-old and 42 days of age, and field beans could be fed up to 160 g/kg from day-old to 21 days of age, followed by up to 120 g/kg from 22 days to 42 days of age, without depressing performance.

Broiler live weight at 42 days of age was reduced by feeding 0% and 100% SPM and maximised when feeding between about 50% and 75% SPM. Feed intakes to 42 days of age were similarly affected. Feed conversion efficiency (FCE) to 42 days of age was maximised by feeding 100% SPM. Birds fed 0% and 100% SPM were poorly feathered at 42 days of age. Although the possibility that antinutritional factors depressed performance in birds fed a low %SPM cannot be ruled out, it is thought that amino acid deficiencies and imbalances reduced performance at both 0% and 100% SPM.

It is possible to substitute soya with a mix of UK proteinaceous ingredients to quite high levels (up to 75% substitution with the protein mix reported, which was rich in rapeseed meal (372.0 g/kg NSPM)) without reducing live weight. FCEs might be reduced however, and so this approach will depend on the relative prices of ingredients and the value of chicken meat.

**SUMMARY**

The UK poultry industry is very dependent on imported soya as a protein source. This renders the industry vulnerable to fluctuations in the international soya market. Furthermore the effect of the demand for land for growing non-GM soya for the European poultry industry has some potentially damaging environmental effects, particularly in the rain forests of South America. This series of experiments was designed to offer some of the information necessary if UK and EU grown protein sources are to be used in greater quantities in poultry feeds. Potentially useful protein rich ingredients are rapeseed and its derivatives, and field peas and field beans.

These ingredients have often been excluded from UK broiler diets, or included only at low concentrations in the finisher ration, because of concerns about the potential adverse effects of antinutritional factors on the growth of the young bird and on meat quality.

Historically, glucosinolates were a particular problem with rapeseed, the metabolites being toxic to the bird. Even if the metabolism of glucosinolates could be prevented in the seed by processing methods, bacterial metabolism in the gut of the bird could not be avoided. Erucic acid was also a problem, which meant that rapeseed oil was limited to industrial uses. The introduction of double zero rapeseed varieties however, bought about new opportunities for feeding rapeseed to poultry. Double zero varieties have low glucosinolate and erucic acid contents (5% or less erucic acid in the oil and 3 mg or less total glucosinolates per g meal), and they are known as canola[1] in Canada.

Another antinutritional factor present in rapeseed, which causes concern, is sinapine. This is because of the possibility of one of its metabolites imparting a 'fishy taint' in brown eggs and chicken meat.

Tannins and phytic acid are also present in rapeseed, both of which interfere with the availability of nutrients.

Field peas are not usually fed to UK broilers in any significant quantities, but this is not the case in France. France is one of Europe's main pea growing countries and the French poultry industry is an important market for the product.

[1] The term "canola" identifies rapeseed and its products of recently developed Canadian varieties that contain 5% or less erucic acid in the oil and 3 mg or less total glucosinolates per g meal (Salmon *et al.,* 1981).

White flowered pea varieties are favoured, as they are free from tannins. Although peas contain antinutritional factors with trypsin inhibitor activity, which depresses protein digestibility, these antinutritionals are readily destroyed during steam pelleting.

The crude protein content of peas is variable, being influenced by agronomic and environmental factors, and there are varietal differences. The amino acid contents of peas vary linearly with crude protein content.

Field beans contain tannins, which reduce protein digestibility, and it is their high tannin content that has historically limited the use of field beans in poultry diets. Other antinutritional factors present in beans are vicine and covicine, but whilst they reduce egg size and limit the inclusion of beans in diets for laying hens they are not thought to cause particular problems to young growing birds.

However, beans have much lower crude protein content than soya bean meal, and beans are much less rich in lysine and tryptophan, and slightly less rich in methionine than soya.

A review of published literature found considerable differences in the published recommended maximum dietary concentrations for feeding rapeseed meal, field peas and field beans to broiler chickens. This might have been due to differences in the nutrient content and contents of antinutritional factors of rapeseed meal, field peas and field beans between studies. Often studies compared only two or three concentrations of the raw material, which did not allow maximal concentrations to be identified.

Hence, the use of UK-blends of: 1) rapeseed meal; 2) whole rapeseed; 3) field peas, and; 4) field beans, fed at a range of dietary concentrations, which allow for the testing of broiler intake and growth responses, was thought to be worthwhile. Mostly, in the UK it is not possible to source a named variety of rapeseed, field peas and field beans, and rapeseed meal is only available as a blend. Furthermore, it is not possible to accommodate variety, agronomic and environmental differences in a feeding study, which aims to address the broilers' responses to dietary concentration, as the facility needed would be vast. A final step, after the determination of broiler intake and growth responses, was to test the substitution of soya protein with a non-soya protein mix, which comprised UK-grown blends of rapeseed, field peas and field beans at 'non-problematic' concentrations and with the two protein mixes calculated to be nutritionally similar.

Thus, the project's main objectives were:

- To determine the broiler's intake and growth responses to increasing dietary concentrations of UK-grown blends of rapeseed meal and UK-grown blends of whole rapeseed.
- To determine the broiler's intake and growth responses to increasing dietary concentrations of UK-grown blends of field peas and UK-grown blends of field beans.

- To determine the broiler's intake and growth responses to increasing substitution rates of a soya protein mix (SPM) with a non soya protein mix (NSPM), calculated to be nutritionally similar.

Other objectives were related to the determination of the effects of the test ingredient concentration on litter friability, litter dry matter and nitrogen contents, hock burn damage and the liver and spleen concentration of zinc, copper, cobalt and manganese.

The project consisted of three feeding studies. In the first study, rapeseed meal (Study 1A) was fed at 0 g/kg to 160 g/kg in the starter (0-21 days of age) and at 0 g/kg to 60 g/kg in the finisher ration (22-42 days of age), and whole rapeseed (Study 1B) was fed at 0 g/kg to 100 g/kg in the starter and finisher rations. A common control of 0 g/kg rapeseed was used. There were nine dietary concentrations of rapeseed meal and six concentrations of whole rapeseed. The diets were each fed separately to the males and females. There were three replicates each of the male and female pens of the control diet, and there were two replicate pens of each of the other rapeseed meal treatment x sex combinations and three replicate pens of each of the other whole rapeseed meal treatment x sex combinations. This provided a total of 68 pens.

In the second study, field peas (Study 2A) were fed at 0g/kg to 200 g/kg in the starter (0-21 days of age) and finisher (22-42 days of age) rations. Field beans (Study 2B) were fed at 0 g/kg to 160 g/kg in the starter and at 0 g/kg to 120 g/kg in the finisher. There were nine dietary concentrations of field peas and of field beans, and a separate control diet of 0 g/kg was used for each test ingredient. Two replicate pens of each of the treatment diets x sex combinations were used and this provided a total of 72 pens.

Importantly in both Studies 1 and 2, within the range of concentrations of test ingredient used, the diets were formulated to be iso-energetic and iso-nitrogenous.

In study 3, a SPM (271.0 g/kg full-fat soya and 729.0 g/kg soya 50) was increasingly substituted (0-100%) with a NSPM, which was calculated to be nutritionally similar. The NSPM comprised 372.0 /kg rapeseed meal, 50.3 g/kg whole rapeseed, 48.0 g/kg field beans, 52.0 g/kg field peas, 22.1 g/kg synthetic lysine, 36.2 g/kg synthetic threonine and 419.4 g/kg maize gluten. There were nine substitution rates of the SPM with the NSPM. The diets were fed separately to the males and females. Two replicate pens of each of the treatment diets x sex combinations were used and this provided a total of 72 pens. The diets were formulated to be iso-energetic and iso-nitrogenous.

In all three studies, House 1 on the poultry unit at ADAS Gleadthorpe was used. Each of the wood and wire pens within the house measured 1.75 m x 1.55 m and contained 22 birds. The bedding material was woodshavings litter to a depth of five cm at day-old and one tube feeder and four nipple drinkers were

provided in each of the pens. A target brooding temperature of 31 °C at day-old was reduced by 1°C on alternate days until a temperature of 21°C was achieved. The target post brooding temperature was 21°C.

Measurements were made of live weight and feed intake at intervals throughout the 42-day growing period. Feed conversion efficiencies (FCEs) were calculated. Litter friability was assessed at about 21 days and 41 days of age and core litter samples were taken at about 41 days of age for the determination of dry matter, total nitrogen, uric acid-nitrogen, ammonium-nitrogen and pH. The birds were assessed at about 41 days of age for hock burn damage using a published subjective scoring system. Samples of the liver and spleen were taken at 41 days of age to determine the contents of zinc, copper, cobalt and manganese. The diets were sampled and the nutrient contents were determined. In the test ingredient, the contents of some of the important antinutritional factors were determined (e.g. glucosinolate, sinapine and erucic acid contents of rapeseed meal and whole rapeseed). The intakes of antinutritional factors at the different dietary concentrations of test ingredients were calculated if it was thought to be appropriate in achieving an understanding of the study results.

The data were analysed using a number of statistical techniques (response curve fitting, ANOVA, covariate analysis, Duncan's multiple range test, Kruksal-Wallis test and Freidman's test) using the software packages GenStat 5 (release 4.1) and Statistica (version 5.5A).

The costs of the treatment diets and the gross margins of live weight sales minus feed costs were calculated using prices that were current at the time of each study.

The analysis of samples of rapeseed meal and whole rapeseed used in Study 1A and 1B for glucosinolate and erucic acid contents confirmed that blends of double zero varieties had been sourced. The glucosinolate contents of rapeseed meal and whole rapeseed were 7 μmol/g and 17 μmol/g, respectively. The erucic acid contents of the ingredients were less than 0.29% of the oil and 0.10% of the oil, with the oil contents being 34.0 g/kg for rapeseed meal and 505.0 g/kg for whole rapeseed, respectively. The sinapine content of rapeseed meal was 11.7 g/kg, which was similar to recently published values for canola meal. The blend of whole rapeseed had a sinapine content of 10.5 g/kg.

It was found that feed intake to 42 days of age was affected by rapeseed meal ($p<0.05$), but not in a consistent way. Effects of rapeseed meal on live weight were not progressive at 42 days of age, and the work led to the tentative suggestion that the highest inclusion level used, namely 60 g/kg, did not depress performance. This was reflected in an analysis of financial margins of live weight value over feed cost, at least for price sets appropriate at the time (mid 2002 to late 2003). The result suggests that higher inclusion levels should be included in future work, but the approaches would need to be different as it would not be

possible for practical finisher diets to be iso-energetic at concentrations of greater than 60 g/kg. Birds fed high levels of rapeseed to 21 days (80 g/kg to 160 g/kg), and then no rapeseed had similar weights at 42 days to those fed no rapeseed throughout. FCEs to 42 days of age were not affected by the dietary concentration of rapeseed meal.

Whole rapeseed, included at up to 100 g/kg, linearly depressed the live weight of males at 42 days of age ($p<0.01$), and that of females at several ages including 42 days ($p<0.01$ at 14 days, 35 days and 42 days of age and $p<0.05$ at 21 days of age). This was through reduced feed intake to 42 days of age (males $p<0.05$ and females $p<0.001$) as FCEs to 42 days of age were not affected by dietary whole rapeseed concentration.

Birds fed 20 g/kg, 40 g/kg and 60 g/kg whole rapeseed, as opposed to meal, had lower feed intakes and live weight gains to 42 days of age than birds fed corresponding concentrations of rapeseed meal ($p<0.05$ for both feed intake and live weight). The differences in feed intakes and live weight gains between birds fed the two categories of rapeseed could not be explained by differences in the nutrient content and ME value of the diets. There were however, large differences in glucosinolate intake to 42 days of age between birds fed whole rapeseed and birds fed rapeseed meal (maximum about 8 000 µmol/bird *versus* 2 050 µmol/bird, respectively). Thus, an antinutritional effect of glucosinolates in birds fed whole rapeseed cannot be ruled out. However, they do not appear to have impacted on the digestion and absorption of nutrients as surmised from the lack of an effect on FCEs.

Other workers have reported that rapeseed glucosinolates might be important in reducing feed intake and live weight gain during early life. The mechanisms for such effects have not been identified.

Except at the higher concentrations of whole rapeseed (80 g/kg and 100 g/kg), sinapine was not thought to have been an important antinutritional factor. Whether at the higher concentrations of whole rapeseed, sinapine depressed feed intake and live weight gain is not known.

Mortality to 42 days of age was not affected by feeding rapeseed meal up to 160 g/kg in the starter ration and up to 60 g/kg in the finisher ration, or by feeding whole rapeseed up to 100 g/kg in both the starter and finisher rations. Mean mortality to 42 days of age was 4.8% and 3.3% in birds fed rapeseed meal and whole rapeseed, respectively. These levels were similar to, or better than commercial broiler mortality rates to 42 days of age as experienced at the time of the study.

The number of birds culled due to leg abnormalities was very low at only two birds out of 748 birds fed rapeseed meal and three birds out of 748 birds fed whole rapeseed. This is encouraging as work carried out in the 1980s indicated that the varieties of rapeseed available at that time seemed to cause a high incidence

(about 15% to 20%) of culls due to leg abnormalities. The mechanism by which rapeseed affected leg health was not identified.

Leg weakness was a particular problem in the 1980s and since then there have been improvements in the leg health of broilers through selection against tibial dyschondroplasia, better management practices and improved nutrition. Dyschondroplasia, valgus and varus deformities, slipped gastrocneumius tendons and rotational deformities, as reported by authors feeding rapeseed meal in the 1980s, were more common at that time than they are today.

The litter remained mostly friable throughout the growing period and hock burn damage at 41 days of age was minimal irrespective of dietary rapeseed meal or whole rapeseed concentration. Neither litter moisture nor total litter nitrogen content was affected by dietary rapeseed concentration (meal or whole seed). Litter ammonium-nitrogen contents were affected by dietary whole rapeseed concentration, but not in a consistent manner ($p<0.01$). Although this is difficult to explain it is likely that the feeding of rapeseed influences gut bacterial populations and this might impact on the availability of nitrogen in the droppings.

Despite concerns about phytate complexes reducing the bioavailability of zinc and other divalent metal ions, liver and spleen stores of zinc at 21 days and 42 days of age were not affected by dietary rapeseed meal concentration.

Although the eating quality of broilers fed rapeseed meal or whole rapeseed was not examined in this study, it is an important issue and so the potential for 'off' or 'fishy' taint in rapeseed fed broiler meat was assessed by examining the literature. It seems that rapeseed at practical concentrations of up to 100 g/kg is unlikely to adversely affect broiler meat flavour, but caution is warranted if higher concentrations are used and the diets contain fishmeal and supplementary methionine and choline.

In Study 2A, the blend of field peas used contained antinutritional factors having trypsin inhibitor activity (1.65 mg/g peas), and they contained considerable quantities of tannins (17 150 mg/kg). Trypsin inhibitor activity was not thought to have been a problem as the diets were steam pelleted at a temperature, which would have been expected to destroy them. The presence of tannins however, meant that the blend did not comprise the more favourable white-flowered varieties.

The blend of field beans used in Study 2B was rich in tannins (24 150 mg/kg) as expected.

In the work on peas and beans (studies 2A and 2B), broiler performance was variable, for reasons which are not known but which may have been due to the age of the parent flock(s). The chicks were very large at day-old (mean 45 g/bird), suggesting that the fertilised eggs were from end of lay breeder hens. There were also

significant differences in chick weight at day-old between replicate groups randomly allocated to the pea study ($p<0.001$). Variability in day-old live weight does influence subsequent performance. Thus, this was taken into account when analysing the data: day-old chick weight was a covariate.

As performance was variable in the control fed birds (0 g/kg field peas and 0 g/kg field beans) the findings cannot be explained in terms of the potential effects of antinutritional factors present in either peas or beans. Furthermore, the dietary concentration of tannins and other antinutritional factors would have increased with dietary field pea or field bean content and there was no evidence of either a linear depression in performance or increasing variability in performance with increasing dietary concentrations of peas or beans.

There is recent evidence that choice fed broilers select against diets containing high concentrations of pea meal (200 g/kg), and this might be expected to increase the variability in feed intake of broilers fed peas but again it does not account for variable feed intakes in control fed birds.

Disease did not appear to have been an issue as mortality to 42 days of age was low (mean 3.3% in pea fed birds and 3.8% bean fed birds). Litter friability was good throughout most of the growing period and litter dry matter contents at 41 days of age were acceptable, although tending to be perhaps a little low in birds fed 0 g/kg peas. However, scouring was not evident in any of the treatment or replicate groups.

The control and uniformity of temperature within the house was good and so this was not a factor, which contributed to the variable performance.

The findings of this study suggest that in broilers having atypically variable performance, feeding peas up to 200 g/kg between day-old and 42 days of age, or feeding field beans up to 160 g/kg between day-old and 21 days of age, followed by up to 120 g/kg field beans from 22 days to 42 days of age, did not generally reduce broiler performance. As the dietary concentrations of field peas or field beans increased the costs of the diets increased and this impacted on the gross margins of live weight sales minus feed costs. It is important to note however, that the latter findings are not static. They will change as the relative prices of ingredients change, and with relative changes in the value of chicken meat at the time of consideration. In some market conditions feeding peas or beans might be more favourable than feeding high quantities of soya.

Dietary field pea or field bean concentration did not affect the storage of zinc, manganese, copper and cobalt in the liver and spleen at 42 days of age. The findings suggest that for the concentrations of field peas and field beans used in this study, antinutritional factors present in peas or beans do not impact on the bird's storage and therefore availability of trace elements for physiological and metabolic processes.

There were two main findings from Study 3, one of which was that the 100% SPM diet did not maximise feed intake and live weight gain in broilers grown to 42 days of age, but it did maximise FCE. Feed intake between day-old and 42 days of age was highest when feeding between 50.0% and 75.0% SPM. Male live weight at 42 days of age was highest when feeding between 37.5% and 75.0% SPM, whereas female live weight at 42 days of age was highest when feeding between 50.0% and 100.0% SPM. The relationships between dietary %SPM and feed intake and between dietary %SPM and live weight at 42 days of age were curvilinear ($p<0.001$ in all cases).

The second main finding is evident from the above information but it is mentioned here for clarity. The complete substitution of SPM with NSPM was not successful in terms of bird performance. There was a pronounced depression in feed intake and live weight at 42 days of age when feeding 0.0% SPM.

Thus, neither the 0.0% nor 100.0% SPM diets were optimal in terms of their nutrient content and/or contents of antinutritional factors. The suggestion of nutrient insufficiency is further supported by the finding that both males and females fed either 0.0% or 100.0% SPM were poorly feathered at 42 days of age, whereas feathering was normal in birds fed the intermediate diets (12.5% to 87.5% SPM).

In trying to determine the reasons for poor performance in birds fed the two extreme diets the following were considered: 1) the determined nutrient contents of the diets; 2) the presence and contents of antinutritional factors, and 3) factors that may have exacerbated nutritional imbalances or deficiencies.

There were discrepancies between the determined and calculated lysine, methionine, cystine and threonine contents of the diets. Except for threonine, the discrepancies between determined and calculated amino acid contents were greatest in the starter ration, with better agreement in the grower and finisher rations. The determined lysine content of the starter ration was low compared with target when the dietary SPM was greater than 62.5%, and the determined methionine, methionine plus cystine and threonine contents were all low compared with target at 100.0% SPM. The published limiting order of amino acids in soya bean meal is 1) methionine plus cystine, 2) threonine, 3) lysine and valine, 4) non-specific nitrogen and 5) histidine.

The poor growth of birds fed 100.0% SPM was probably due to limited intakes of lysine, methionine, cystine and threonine, and poor feathering due to limited intakes of methionine, cystine and threonine. Production requirements for all of these amino acids are far greater in the young bird than the requirements for maintenance.

Discrepancies in threonine content between calculated and determined values were apparent in the starter, grower and finisher rations. The largest discrepancies occurred with the lower dietary %SPM treatments

(25.0% SPM or less). There was a large excess of threonine in the starter, grower and finisher rations when the dietary SPM content was 25.0% or less.

The supply of methionine plus cystine relative to lysine was low in most dietary starter rations, but particularly at 25.0% or less SPM. The supply of threonine relative to lysine was mostly higher than published optimal values: only diets containing 87.5% and 100.0% SPM had a near-optimal ratio. In diets containing 25.0% or less SPM the supply of threonine relative to lysine was greatly in excess of published recommendations. Thus, in diets containing 25.0% or less SPM an excess of threonine could have increased the relative deficiency of methionine and cystine, and an otherwise presumed adequate dietary supply of lysine might have become limiting.

Low feed intakes in birds fed the 25.0% or less SPM diets could have been due to the imbalance of dietary amino acids. However, lower feed intakes in birds fed a low dietary %SPM did not fully account for the loss of live weight gain as FCEs to 42 days of age were poorer ($p<0.001$). The birds were using the feed less efficiently for growth. Whether this was due more to a nutrient deficiency, than due to the contents of antinutritional factors present in the proteinaceous ingredients is difficult to ascertain with certainty.

The maximum concentrations of rapeseed meal, whole rapeseed, field beans and field peas were 105.3 g/kg, 14.2 g/kg, 13.6 g/kg and 14.7 g/kg, respectively and this was in the 0.0% SPM starter ration. Of these, perhaps the only ingredient included at a concentration sufficient to cause concern was rapeseed meal. Whole rapeseed was also considered however, because of the common antinutritional factors in whole rapeseed and rapeseed meal, namely glucosinolates and sinapine.

The total amount of rapeseed meal fed to 42 days of age was higher in Study 3 than in Study 1A. Thus, it is possible that in Study 3, the concentration of rapeseed meal in diets having a low %SPM (perhaps 37.5% SPM or less) might have impacted on feed intake and live weight gain to 42 days of age. The maximum total glucosinolate intake to 42 days of age (from rapeseed meal and whole rapeseed) was 4 300 μmol/bird in Study 3. This was similar to the glucosinolate intake of birds fed 60 g/kg whole rapeseed in Study 1B and feed intakes and live weight gains to 42 days of age were depressed in the latter birds.

Other workers have reported lower feed intakes and poorer growth in broilers fed similar or marginally higher concentration of rapeseed meal than those used in Study 3. However, in published work, often when rapeseed meal intake impacted on live weight gain this was without affecting FCE. In study 3 FCE to 42 days of age was reduced as the dietary %SPM fell ($p<0.001$).

The outdoor temperatures experienced during the post brooding period of this study were high, and it was not possible to achieve an indoor target post brooding temperature of 21°C. The maximum post brooding temperature during this study was greater than 25°C for 17 days, and it was greater than 30°C for five days.

The broiler is sensitive to ambient temperature: it influences feed intake, growth and fat deposition. Any nutrient deficiency would have been exacerbated due to high indoor ambient temperatures and lower than expected feed intakes.

Litter friability was good throughout the study and hock burn damage was not a problem.
There were effects of dietary %SPM on litter nitrogen, ammonium-nitrogen and uric-acid nitrogen contents at 41 days of age ($p<0.05$). The lowest plant available nitrogen content of the litter manures was achieved with the 0.0% SPM diet. There is a need for a better understanding of the utilisation of plant proteins for lean growth in broilers and the effects on nitrogen excretion and losses due to ammonia emissions.

The work has produced information on recommended maximum dietary concentrations for use in broiler feeds, and it is identified some knowledge gaps. The practical conclusions are as follows:

1. Rapeseed meal may be included in starter and finisher rations at concentrations of up to 60 g/kg without apparent ill effects on live weight gain or FCE, but assuming no taint problems. According to the literature available meat taint problems are unlikely to be incurred at this concentration, but caution is warranted if the feed contains fishmeal, and possibly supplementary choline and methionine.

2. Whole rapeseed may be included in starter and finisher rations at concentrations of up to 100 g/kg in the starter and finisher rations without apparent ill effects on FCE, although feed intake and live weight is expected to be depressed. This assumes that there are no taint problems. The risk of incurring 'fishy' taint when feeding whole rapeseed is probably similar to that for rapeseed meal, provided that the sinapine contents are similar, and that the oil does not impact on the fatty acid composition so as to increase the likelihood of meat rancidity. As for rapeseed meal, caution is warranted if feeding whole rapeseed with fishmeal, and possibly supplementary methionine and choline.

3. A mix of alternative proteins to soya is likely to be better than relying on one or two alternatives. This might help to dilute some of the antinutritional factors present. It is possible to substitute soya with a mix of UK proteinaceous ingredients to quite high levels (up to 75% substitution with the protein mix reported) without reducing live weight. FCEs might be reduced however, and so this approach will depend on the relative prices of ingredients and the value of chicken meat at the time of consideration.

There will be a need to pay careful attention to the supply and balance of essential amino acids if performance is to be optimised when using protein sources other than soya.

4. Except for birds fed rapeseed meal, gross margins of live weight gain minus feed costs were reduced by the move away from soya based diets. This was mostly due to increased diet costs, which were probably exacerbated by diet formulation constraints.

The relevance of the work to levy payers is that the findings provide technical support for the use of rapeseed meal and whole rapeseed in UK broiler feeds. The uptake of the results by the UK broiler industry will depend however, on market dynamics and knowledge transfer.

**TECHNICAL DETAIL**

The work consisted of three studies: the first was on rapeseed meal and whole rapeseed, the second was on peas and beans, and the third was on substituting soya with a UK grown protein mix.

Study 1 Rapeseed meal and whole rapeseed

This study investigated the effects of increasing dietary concentrations of UK-grown blends of double zero rapeseed meal and double zero whole rapeseed on broiler performance, mortality, litter quality and hock burn damage.

*Introduction*

The UK poultry industry is heavily dependent on the use of imported soya as a protein source. The profitability of the UK broiler industry is vulnerable to soya price fluctuations, as the broiler meat price responds to different markets, namely the UK, EU and global markets for chicken meat.

The scale of UK soya requirements for broiler production alone is impressive. In 2003, 836 million broilers were produced in the UK (Defra, 2004). If all of these birds were fed a diet containing 200 g/kg soya and feed intake averaged about 4.5 kg/bird to 42 days of age, then the amount soya used would be 752 196 t. Furthermore, the requirements for soya in the late 1990s became increasingly specific, in that most large broiler companies were demanding non-GM soya.

The demand for Brazilian non-GM soya led to increases in the rate of deforestation (People and Plant.net, 2003, 2004 citing research by the Brazilian National Institute for Space Research). In the year August 2001 to August 2002, 25 000 square km of virgin rainforest were cut down and this was mostly accounted for by expanding farmland for soya production.

The rainforests account for only 2% of the earth's surface but they are home to 40 to 50% of the world's plant and animal species (*loc. sit.*), or about 30 million species. The Amazon is of special significance: it has an area of 4.1 million square km and contains 30% of all of the world's known plant and animal species, which are endemic to the region. A continued high rate of destruction of this unique habitat will have serious implications for the survival of many of these species.

Furthermore, the Amazon produces one fifth of the world's oxygen (People and Planet.net). It is predicted that at the current rate of deforestation this will significantly reduce the annual world production of oxygen and increase the amount of carbon dioxide emissions. This could lead to global warming and erratic weather patterns.

Replacing some or all of the soya in UK broiler feeds with UK-grown protein sources would favour UK arable producers and the feed processing industry. It would reduce the air miles incurred for broiler production. 'Soya substitutes' would however, have to be economically viable and animal health and welfare must not be compromised.

One proteinaceous UK-grown ingredient that is perhaps under utilised in broiler feeds is rapeseed. Historically, rapeseed (*Brassica napus, B. campestris*) could not be fed to broilers because of its high total glucosinolate content, whose breakdown products are toxic to chickens. These breakdown products are isothiocyanates, organic thiocyanates, nitriles and 5-vinyloxazolidine-2-thione (goitrin) (McDonald *et al*., 2002). These have a variety of toxic effects such as goitres and liver and kidney poisoning (*loc.sit*).

The breakdown of glucosinolates can occur either in the seed prior to consumption, or in the gut of the bird through the action of bacterial thioglucosidases (McDonald *et al.*, 2002). Thus, even if the action of endogenous myrosinase is prevented by pre-treating the seed (reviewed by Naczk *et al.,* 1998), the degradation of glucosinolates in the bird cannot be prevented.

New opportunities for feeding rapeseed to broilers have arisen through genetic selection for varieties that are low in glucosinolate content: the so-called double zero varieties. Larbier and Leclercq (1994) reported glucosinolate contents of between 150 μmol/g and 200 μmol/g in unselected single zero varieties. van Kempen and Jansman (1994) cited similar values of between 150 μmol/g and 180 μmol/g oil free dry matter for high glucosinolate varieties. By comparison, double zero varieties may have glucosinolate levels of 50 μmol/g dry matter (Larbier and Leclercq, 1994), or between 20 μmol/g and 30 μmol/g glucosinolates in the oil free dry matter according to van Kempen and Jansman (1994). Modern varieties may have less.

In double low varieties only the following out of the 27 rapeseed glucosinolates are of quantitative importance: progoitrin, gluconapin, glucobrassicanapin, napoleiferin, glucobrassicin and neoglucobrassicin (van Kempen and Jansman, 1994). There are, however, other antinutritional factors present in rapeseed, including phenolics, erucic acid and phytic acid (Larbier and Leclercq, 1994; van Kempen and Jansman, 1994; Naczk *et al.,* 1998). They may affect performance, bird health or meat flavour.

The predominant phenolics in rapeseed are phenolic acids and tannins (Naczk *et al.,* 1998). The content of phenolic acids in rapeseed meal is up to five times higher than those found in soya bean meals (reviewed by Naczk *et al.,* 1998 citing work adapted from Kozlowska *et al.,* 1991 and Naczk *et al.,* 1986).

Sinapine (sinapolycholine) is a choline ester of sinapic acid and accounts for 80% of the total phenolic acids in rapeseed meal, with free sinapic acid and insoluble phenolics accounting for the remainder (Shahidi and Naczk, 1992, cited by Qaio and Classen, 2003). The sinapine content in rapeseed meal has been shown to range from 6 g/kg to 30 g/kg depending on cultivar, growing conditions and location (Krygier *et al.,* 1982 and Lacki and Duvnjak, 1996 cited by Qaio and Classen, 2003).

The content of sinapine is maximum between the final stage of the green seeds and the beginning of their browning, reaching a stable level at the stage of ripeness (Naczk *et al.,* 1998). Jensen *et al.,* (1991 cited by Naczk *et al.,* 1998) reported that heating reduced the sinapine content of rapeseed meal, but it was accompanied by an increase in the content of lignin-type products.

Amarowicz *et al.,* (1995, cited by Naczk *et al.,* 1998) reported that the moisture content of seeds (within the range of 65.0 g/kg to 125 g/kg) did not affect the total content of phenolics in the cake obtained by pressing the oil. The total content of phenolics also remained unaffected during three-months storage at 20°C (Amarowicz *et al.,* 1995, cited by Naczk *et al.,* 1998).

Processing of rapeseed to protein concentrates using two successive batch extractions or counter-current (4-, 5- or 6-stages) extractions with water, 70% ethanol, acetone-methanol-water, methanol-aqueous ammonia or acidified methanol reduced the content of phenolic acids by 60% to 97% (Naczk *et al.,* 1998 citing Dabrowski and Sosulski, 1983). However, Kozlowska and Zadernowski (1983 cited by Naczk *et al.,* 1998) reported that seven consecutive extractions with 70% ethanol were required to reduce the concentration of phenolics to trace levels.

Sinapine is thought to possess a number of antinutritional effects in monogastrics, and to contribute to the dark colour, and the bitter, sour and astringent tastes of rapeseed meal (see review by Naczk *et al.,* 1998; Qaio and Classen, 2003). In genetically predisposed brown layers the incomplete metabolism of sinapine results in a fishy egg taint (Hobson-Frohock *et al.,* 1973 and Fenwick *et al.,* 1984).

The antinutritional effects of sinapine may also be related to sinapinic acid, which is released by bacterial hydrolysis in the gut (Qaio and Classen, 2003). Oxidised phenolic compounds are thought to bind essential amino acids, forming complexes, which cannot be absorbed.

Qaio and Classen (2003) however, reported that rapeseed meal sinapine does not cause toxicity or an antinutritional effect in broilers at dietary concentrations of up to 300 g/kg rapeseed meal. Neither was feed palatability for broilers affected by rapeseed meal sinapine at a rapeseed meal concentration of up to 300 g/kg.

Tannins are complex phenolic compounds present in raw plant materials (Larbier and Leclercq, 1994; Naczk *et al.,* 1998). Phenolic compounds are derivatives of benzoic acid and canammic acid. These derivatives are obtained by the fixation of hydroxyl or methoxy groups. There are two types of tannins: condensed tannins and hydrolysed tannins. Condensed tannins are substances polymerised to a greater or lesser extent with four or six hydroxylated flavans (Naczk *et al.,* 1998). They are also known as proanthocyanidines because they liberate antocyanidines through acid hydrolysis (*loc. sit*.). Hydrolysable tannins are also present, which consist of phenolic acids and carbohydrates.

Amongst phenolic substances, tannins are the compounds with the greatest antinutritional activity (Larbier and Leclercq, 1994). Condensed tannins are particularly abundant in the hull of rapeseed. They can precipitate proteins, including digestive enzymes. It is thought that phenol-protein complexation is usually the result of the formation of hydrogen bonds and hydrophobic interactions (Hagerman and Butler, 1980 cited by Naczk *et al.,* 1998), particularly under acidic conditions (McManus *et al.,* 1985 cited by Naczk *et al.,* 1998). This leads to a general reduction in digestibility, primarily of proteins, and to a lesser extent starch.

Kozlowska and Zadernowski (1988 cited by Naczk *et al.,* 1998) reported that the formation of phenol-protein complexes in rapeseed products can be indirectly concluded from the amount of extractable soluble matter in 80% ethanol as this soluble matter is rich in phenolics. They also found that more ethanol-soluble matter was extracted from rapeseed products as the pH of the extraction solution was increased.

Shahidi and Naczk (1988, 1989 cited by Naczk *et al.,* 1998) found that canola[1] meals (Canadian rapeseed) contained 0.68% to 0.77% condensed tannins. In later work, Naczk *et al.,* (1994 cited by Naczk *et al.,* 1998) found differences in tannin contents between cultivars and due to environmental growing conditions.

Naczk *et al.,* (1998) suggested that condensed tannins present in the hulls may contribute to the astringent taste of rapeseed meals.

Coultate (1996) explained that erucic acid, or cis-13-docosenoic acid, is a characteristic component of rapeseed oils. It causes lipid disorders in rats fed at high levels.

Phytate (myo-inositol-1, 2, 3, 4, 5, 6-hexakis (dihydrogen phosphate)) contributes a major proportion of the total phosphorus found in plant-derived feedstuffs. In rapeseed meal, 80.5% of the total phosphorus is bound to phytic acid and cannot be metabolised by animals (Segueilha *et al.,* 1992).

The phytate complex may also include amino acids, and if so this reduces the availability of rapeseed amino acids. Ravindran *et al.,* (1999 cited by Newkirk and Classen, 2001) reported that phytase added to a wheat-casein diet improved amino acid utilisation in broilers.

Naczk *et al.,* (1998) reported that phytic acid can bind mono and divalent metal ions to form complex phytates, thus reducing their bioavailability (citing Erdman, 1979; Cheryan, 1980; Cosgrove, 1980, Maga, 1982; Morris, 1986; Hallberg, 1987; Thompson, 1990). A reduction in the bioavailability of several metals, notably zinc, in the presence of phytic acid has been reported (Erdman, 1979; Jones, 1979; Cheryan, 1980; Maga, 1982).

There is considerable caution in feeding rapeseed to broilers, as the young bird is thought to be particularly sensitive to its antinutritional factors. Often rapeseed is excluded from the starter ration and only included at modest concentrations, if at all, in the finisher ration.

Rapeseed is conventionally processed to oil and meal by employing an extraction process, which is an adaptation of soyabean technology adjusted to high oil content, small seed size and presence of glucosinolates (review by Naczk *et al.,* 1998, citing Unger, 1990). The meal after oil extraction contains about 400 g/kg protein (Naczk *et al.,* 1998) and the amino acids of rapeseed are not sensitive to commercial processing or extraction with methanol-ammonia/hexane (Naczk *et al.,* 1998 citing Shahidi and Naczk, 1992). However, later work by Newkirk *et al.,* (2003) contradicts the latter, as commercial desolventization and toasting processes were found to reduce the content and the apparent ileal digestibility of many amino acids in canola meal.

Pastuszewska *et al.,* (2003) wrote about differences in protein and amino acid digestibility in rapeseed meal due to genetic and environmental factors, but processing conditions in the oil factory were reported to have the greatest impact. Excessive heating of rapeseed meal during industrial toasting decreased the available lysine content and ileal digestibility of amino acids in pigs (Grala *et al.,* 1994).

Both the lower protein digestibility of rapeseed meal than that of soya bean meal, and the depressive effect of heating on rapeseed meal, are attributed to the higher proportion of protein bound to fibre (Pastuszewska *et al.,* 2003 citing Bell *et al.,* 1998 and Buraczewska *et al.,* 1998) and to greater endogenous gut nitrogen losses (Pastuszewska *et al.,* 2003 citing Grala *et al.,* 1998 and Jondreville *et al.,* 2000). Total tract apparent protein

digestibility in canola based diets averages about 74% in poultry (Simbaya *et al.,* 1996 citing Thomke *et al.,* 1983 and Zupriza *et al.,* 1991).

Rapeseed meal has a low available energy value for broilers due to its high fibre content (Simbaya *et al.,* 1996). They suggested that the ME value of canola meal is about 8.4 MJ/kg for poultry, and on average, this is 1.2 MJ/kg lower (on an as-fed basis) than that of 44% soya bean meal.

Simbaya *et al.,* (1996) reported on in-vitro and in-vivo studies examining the use of exogenous enzymes for improving the metabolisable energy value and availabilities of protein and phosphorus in canola-based diets. They concluded that there is potential for the development of an effective "cocktail" of enzymes. The development of an effective carbohydrase preparation was thought to be important.

It is not common to feed whole rapeseed to broilers, as there are concerns about palatability and digestibility. Whole rapeseed, by virtue of the oil content, is higher in metabolisable energy and this makes it a more useful ingredient in the higher energy broiler finisher rations.

Khattak *et al.,* (1995) fed up to 300 g/kg whole rapeseed for a 28-day period from seven days of age and found no effect on feed intake or live weight gain when compared with birds fed a wheat, maize and soya-based diet.

This study examined the effects of increasing dietary concentrations of UK-grown blends of double zero rapeseed meal and double zero whole rapeseed on the growth responses to 42 days of age of broilers, and on litter quality and hock burn damage.

*Materials and methods*

There were two concurrent broiler studies, one of which addressed the feeding of double zero rapeseed meal, and the other addressed the feeding of double zero whole rapeseed. In both studies, blended sources of UK-grown double zero rapeseed were used and the growth and performance responses of male and female broiler chickens to 42 days of age were studied separately.

A key principle of the studies was for the treatment diets to be iso-energetic and iso-nitrogenous. Thus, the maximum concentration of either rapeseed meal or whole rapeseed used was determined during the process of diet formulation, and it was reached when the diets exceeded an acceptable tolerance for variance in metabolisable energy (ME) value and contents of crude protein, lysine, methionine and threonine.

Within the range of rapeseed concentrations fed, the number of intermediate dietary concentrations was maximised, but with replication at each dietary concentration x sex treatment combination. This approach enhanced the statistical determination of growth responses for the males and females.

A two-stage ration programme consisting of a starter (fed from day-old to 21 days of age) and finisher ration (fed from 22 days to 42 days of age) was used.

UK-grown blends of double zero rapeseed meal and double zero whole rapeseed were used in this study. The determined nutrient contents and the contents of some of the known antinutritional factors present in rapeseed are given in Tables 1 and 2.

Table 1. Determined nutrient content of UK-grown double zero rapeseed meal and UK-grown double zero whole rapeseed (g/kg fresh basis) used in this study

| Nutrient (g/kg) | Rapeseed meal | Whole rapeseed |
|---|---|---|
| Dry matter | 880.0 | 919.0 |
| Crude protein[1] | 334.0 | 193.0 |
| Oil[2] | 30.0 | 505.0 |
| Sugar[3] | 73.0 | 50.0 |
| Starch[4] | 18.0 | 40.7 |
| Available lysine | 16.2 | N/A |
| Methionine | 5.6 | N/A |
| Threonine | 11.9 | N/A |
| Estimated ME (MJ/kg)[5] | 7.5 | N/A[5] |

[1]Dumas

[2]Acid hydrolysed

[3]Luff Schoorl

[4]Polarimetric

[5]Calculated using the Hartell equation as given below.

[6]Not appropriate to calculate using the Hartell equation because of the high oil content

Hartell equation

Estimated ME (MJ/kg) = (0.1551 x %crude protein content) + (0.3431 x % oil content) + (0.1669 x %starch content) + (0.1301 x %total sugar content)

Table 2. Determined contents of some antinutritional factors present in UK-grown double zero rapeseed meal and UK-grown double zero whole rapeseed (unit fresh weight) used in this study

| Antinutritional factor | Rapeseed meal | Whole rapeseed |
|---|---|---|
| Total glucosinolates[1] | 7.0 μmol/g | 17.0 μmol/g |
| Sinapine[2] | 11.7 g/kg | 10.5 mg/kg |
| Tannins[3] | 2.7% | N/A |
| Chlorogenic acid | 1869 mg/kg | 2016 mg/kg |
| Erucic acid (C22:1 (13)) | <0.29% of oil (oil content 34.0 g/kg) | <0.10% of oil (oil content 505.0 g/kg) |
| Dry matter | 888.0 g/kg | 919.0 g/kg |

[1]Total glucosinolates determined by HPLC

[2]Sinapine determined as sinapine hydrogen sulphide and corrected for recovery.

[3]Tannins are polyphenolic compounds with medium to high molecular weights extracted from oil-free feed/plant material with hot water. The tannin in the extract is defined as that which can reduce cold standard potassium permanganate solution with indigo carmine indicator expressed as quercitannic acid.

Study 1A – Dietary rapeseed meal concentrations

Nine concentrations of double zero rapeseed meal, from 0 g/kg to 160 g/kg in equal increments of 20 g/kg, were fed between day-old and 21 days of age (Table 3). From 22 days to 42 days of age, birds previously fed 0 g/kg, 20 g/kg, 40 g/kg or 60 g/kg rapeseed meal remained on the same concentration, but birds previously fed greater than 80 g/kg were fed none. The relatively low ME value of rapeseed meal limits its inclusion rate in high-energy finisher diets. At concentrations of more than 60 g/kg rapeseed meal, the calculated ME value of the diet was too low, and so these treatments were necessarily discontinued.

Table 3. Dietary concentration of double zero rapeseed meal in the starter and finisher rations (g/kg) tested

| Treatment number | Dietary concentration of rapeseed meal (g/kg) | |
|---|---|---|
| | Starter ration | Finisher ration |
| 1 | 0 | 0 |
| 2 | 20 | 20 |
| 3 | 40 | 40 |
| 4 | 60 | 60 |
| 5 | 80 | 0 |
| 6 | 100 | 0 |
| 7 | 120 | 0 |
| 8 | 140 | 0 |
| 9 | 160 | 0 |

Although it would have been desirable to have fed a higher concentration of rapeseed meal than 60 g/kg between 22 days and 42 days of age, the young birds' responses to higher dietary concentrations of rapeseed meal were tested because young birds are thought to be more sensitive to the antinutritional factors. Furthermore, the withdrawal of rapeseed meal in the finisher ration to birds previously fed high concentrations of rapeseed meal was useful; it provided an indication of whether or not birds might recover from any negative effects of antinutritional factors experienced during early life.

The strategy used for diet formulation was as follows. A soya protein mix was the predominant protein source in the 0 g/kg rapeseed meal diet. The starter ration soya protein mix comprised full fat soya, soya 44 (crude protein content 440 g/kg fresh basis) and soya 50 (crude protein content 500 g/kg fresh basis), whereas the finisher protein mix comprised only full fat soya and soya 50. The proportion of soya protein mix in the diet was increasingly reduced so as to allow a greater proportion of rapeseed meal in the diet. As rapeseed meal did not have the same nutrient contents and ME value as the soya protein mix, other ingredients such as vegetable oils and synthetic amino acids were used to equalise the dietary ME values and nitrogen contents of the rations.

The diet compositions and calculated nutrient analyses are given for the starter and finisher rapeseed meal rations in Tables 4 and 5, respectively.

Table 4. Diet composition and calculated nutrient contents of the starter rapeseed meal rations (g/kg fresh basis) under test

| Ingredient | Quantity (g/kg fresh basis) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rapeseed meal concentration (g/kg) | | | | | | | | |
| | 0 | 20 | 40 | 60 | 80/0 | 100/0 | 120/0 | 140/0 | 160/0 |
| Wheat | 409.2 | 406.4 | 414.9 | 417.4 | 420.1 | 422.8 | 415.8 | 370.8 | 348.1 |
| Maize Germ 10 oil | 172.7 | 158.8 | 154.0 | 159.7 | 165.5 | 171.2 | 185.1 | 204.1 | 230.9 |
| Maize Gluten 60 | 71.5 | 63.7 | 74.3 | 54.7 | 35.1 | 15.5 | 0.0 | 10.9 | 7.8 |
| Vegetable oil | 4.2 | 29.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 34.3 | 33.3 |
| Soya full fat | 122.5 | 16.4 | 141.5 | 142.7 | 143.9 | 145.1 | 145.7 | 0.0 | 0.0 |
| Soya 44 | 177.5 | 263.6 | 118.5 | 97.3 | 76.1 | 54.9 | 34.3 | 89.9 | 29.0 |
| Soya 50 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 70.1 | 111.0 |
| Rapeseed meal | 0.0 | 20.0 | 40.0 | 60.0 | 80.0 | 100.0 | 120.0 | 140.0 | 160.0 |
| Fish meal 66 | 0.0 | 0.0 | 21.3 | 36.7 | 52.0 | 67.4 | 79.3 | 54.2 | 54.9 |
| Synthetic lysine | 3.60 | 3.30 | 2.90 | 2.40 | 1.90 | 1.40 | 1.01 | 1.40 | 1.40 |
| Synthetic methionine | 0.95 | 1.00 | 0.40 | 0.54 | 0.69 | 0.83 | 0.85 | 0.96 | 0.93 |
| Mineral and vitamin premix | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Limestone | 9.8 | 9.7 | 8.8 | 7.9 | 6.9 | 5.9 | 5.15 | 6.3 | 6.1 |
| Dicalcium phosphate | 20.6 | 20.3 | 16.3 | 13.8 | 11.2 | 8.6 | 6.63 | 10.4 | 10.1 |
| Sodium chloride | 2.5 | 2.5 | 2.1 | 1.9 | 1.6 | 1.4 | 1.21 | 1.6 | 1.5 |
| Total | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 |
| | | | | | | | | | |
| Nutrient | Quantity (g/kg fresh basis) | | | | | | | | |
| Crude protein | 221.4 | 240.0 | 239.1 | 236.6 | 234.0 | 231.4 | 229.1 | 227.7 | 228.6 |
| AME (MJ/kg) | 12.6 | 12.6 | 12.6 | 12.6 | 12.6 | 12.6 | 12.6 | 12.6 | 12.6 |
| Arginine | 15.3 | 15.3 | 15.3 | 15.3 | 15.3 | 15.3 | 15.3 | 15.3 | 15.3 |
| Iso-leucine | 9.8 | 10.6 | 10.5 | 10.3 | 10.1 | 9.8 | 9.6 | 9.7 | 9.5 |
| Methionine | 5.2 | 4.8 | 4.8 | 4.9 | 5.1 | 5.2 | 5.2 | 5.2 | 5.2 |
| Methionine + cystine | 9.2 | 9.2 | 9.2 | 9.2 | 9.2 | 9.2 | 9.2 | 9.2 | 9.2 |
| Threonine | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 |
| Tryptophan | 2.5 | 2.6 | 2.6 | 2.6 | 2.6 | 2.7 | 2.7 | 2.7 | 2.7 |
| Lysine | 14.0 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 |
| Calcium | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| Available phosphorus | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Sodium chloride | 3.8 | 3.8 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| Potassium | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 |
| Fibre | 26.3 | 28.8 | 30.2 | 31.4 | 32.7 | 33.9 | 35 | 34.8 | 34.8 |
| Oil | 58.4 | 52.6 | 53.1 | 54.3 | 55.6 | 56.8 | 58.5 | 67.4 | 68.7 |
| Ash | 69.7 | 67.7 | 66.4 | 65.6 | 65.2 | 64.6 | 64.3 | 67.4 | 68.1 |

Table 5. Diet composition and calculated nutrient contents of the finisher rapeseed meal rations (g/kg fresh basis) under test

| Ingredient | Quantity (g/kg fresh basis) | | | |
|---|---|---|---|---|
| | Rapeseed meal concentration (g/kg) | | | |
| | 0 | 20 | 40 | 60 |
| Wheat | 599.5 | 596.9 | 594.5 | 590.7 |
| Maize germ 10 oil | 111.7 | 109.8 | 107.8 | 107.4 |
| Maize gluten 60 | 20.4 | 15.7 | 11.1 | 7.1 |
| Vegetable oil | 44.2 | 44.9 | 45.5 | 44.3 |
| Soya full fat | 0.0 | 0.0 | 0.0 | 8.9 |
| Soya 50 | 180.0 | 160.0 | 140.0 | 111.1 |
| Rapeseed meal | 0.0 | 20.0 | 40.0 | 60.0 |
| Fish meal 66 | 10.8 | 22.8 | 34.9 | 48.2 |
| Synthetic lysine | 1.70 | 1.40 | 1.00 | 0.68 |
| Synthetic methionine | 1.00 | 0.91 | 0.78 | 0.63 |
| Synthetic threonine | 0.42 | 0.25 | 0.08 | 0.00 |
| Mineral and vitamin premix | 5.0 | 5.0 | 5.0 | 5.0 |
| Limestone | 9.2 | 8.4 | 7.6 | 6.8 |
| Dicalcium phosphate | 13.9 | 11.9 | 9.9 | 7.6 |
| Sodium chloride | 2.2 | 2.0 | 1.8 | 1.6 |
| Total | 1000 | 1000 | 1000 | 1000 |
| | | | | |
| Nutrient | Quantity (g/kg fresh basis) | | | |
| | | | | |
| Crude protein | 185.0 | 186.5 | 188.0 | 189.7 |
| AME (MJ/kg) | 13.5 | 13.5 | 13.5 | 13.5 |
| Arginine | 12.1 | 12.1 | 12.1 | 12.1 |
| Iso-leucine | 8.0 | 8.0 | 8.0 | 8.0 |
| Methionine | 4.1 | 4.1 | 4.1 | 4.1 |
| Methionine + cystine | 7.6 | 7.6 | 7.6 | 7.6 |
| Threonine | 6.9 | 6.9 | 6.9 | 7.0 |
| Tryptophan | 2.2 | 2.2 | 2.2 | 2.2 |
| Lysine | 10.5 | 10.5 | 10.5 | 10.5 |
| Calcium | 8.5 | 8.5 | 8.5 | 8.5 |
| Available phosphorus | 4.2 | 4.2 | 4.2 | 4.2 |
| Sodium chloride | 3.2 | 3.2 | 3.2 | 3.2 |
| Potassium | 6.5 | 6.4 | 6.3 | 6.1 |
| Fibre | 22.0 | 23.7 | 25.4 | 27.2 |
| Oil | 67.1 | 68.1 | 69.1 | 70.0 |
| Ash | 57.7 | 57.0 | 56.3 | 55.5 |

Study 1B – Dietary whole rapeseed concentrations

There were six dietary concentrations of double zero whole rapeseed for both the starter and finisher rations, and they ranged from 0 g/kg to 100 g/kg whole rapeseed. Whole rapeseed has a higher ME value than rapeseed meal, and the high ME value of whole rapeseed allowed it to be included at a higher dietary concentration in the finisher rations than rapeseed meal. The dietary concentrations of whole rapeseed used are shown in Table 6.

Table 6. Dietary concentration of double zero whole rapeseed in the starter and finisher rations (g/kg) tested

| Treatment number | Dietary concentration of whole rapeseed (g/kg) | |
|---|---|---|
| | Starter | Finisher |
| 1 | 0 | 0 |
| 10 | 20 | 20 |
| 11 | 40 | 40 |
| 12 | 60 | 60 |
| 13 | 80 | 80 |
| 14 | 100 | 100 |

The strategy used for diet formulation was similar to that used for the formulation of rapeseed meal treatments. A combination of different soya products was used to obtain a soya protein mix which was increasingly replaced in the diet by whole rapeseed, but not on a one for one unit basis because of differences in the ME value and nutrient content of the soya protein mix and whole rapeseed.

There was a common control treatment between the two studies, which contained 0 g/kg rapeseed, the composition of this treatment diet is shown in Table 4 (starter treatment 1). The soya protein mix used in this diet was full fat soya, soya 50 (crude protein 500 g/kg fresh basis) and soya 44 (crude protein 440 g/kg fresh basis). The soya protein mix used at dietary whole rapeseed concentrations of 20 g/kg and above, was full fat soya and soya 44. This was increasingly replaced in the diet by whole rapeseed.

A similar approach was used when formulating the finisher rations, but the soya products used were: i) soya 50 only at 0 g/kg whole rapeseed; ii) a combination of full fat soya and soya 50 at 20 g/kg and 40 g/kg whole rapeseed, and; iii) soya 50 only at 60 g/kg, 80 g/kg and 100 g/kg whole rapeseed.

The diet compositions and calculated nutrient analyses are given for the starter and finisher rapeseed meal rations in Tables 7 and 8.

Table 7. Diet composition and calculated nutrient analyses of the starter whole rapeseed rations (g/kg fresh basis) tested

| Ingredient | Quantity (g/kg fresh basis) | | | | |
|---|---|---|---|---|---|
| | Whole rapeseed concentration (g/kg) | | | | |
| | 20 | 40 | 60 | 80 | 100 |
| Wheat | 390.1 | 427.0 | 441.2 | 455.3 | 470.3 |
| Maize germ 10 oil | 191.5 | 139.2 | 124.8 | 110.3 | 94.2 |
| Maize gluten 60 | 55.5 | 66.2 | 56.5 | 46.8 | 36.2 |
| Soya full fat | 130.3 | 98.0 | 63.6 | 29.3 | 0.0 |
| Soya 44 | 169.7 | 182.0 | 196.4 | 210.7 | 220.0 |
| Whole rapeseed meal | 20.0 | 40.0 | 60.0 | 80.0 | 100.0 |
| Fish meal 66 | 0.0 | 7.4 | 21.3 | 35.2 | 51.1 |
| Synthetic lysine | 3.50 | 3.30 | 2.80 | 2.40 | 1.80 |
| Synthetic methionine | 1.10 | 0.84 | 0.78 | 0.73 | 0.67 |
| Synthetic threonine | 0.64 | 0.39 | 0.3 | 0.22 | 0.13 |
| Mineral and vitamin premix | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Limestone | 9.6 | 9.5 | 8.6 | 7.8 | 6.5 |
| Dicalcium phosphate | 20.6 | 18.8 | 16.6 | 14.4 | 12.4 |
| Salt | 2.5 | 2.4 | 2.1 | 1.9 | 1.7 |
| Total | 1000 | 1000 | 1000 | 1000 | 1000 |
| | | | | | |
| Nutrient | Quantity (g/kg fresh basis) | | | | |
| | | | | | |
| Crude protein | 223.7 | 229.6 | 229.1 | 228.6 | 228.2 |
| AME (MJ) | 12.6 | 12.6 | 12.6 | 12.6 | 12.6 |
| Arginine | 15.3 | 15.1 | 15.1 | 15.1 | 15.1 |
| Iso-leucine | 10.0 | 10.3 | 10.3 | 10.3 | 10.3 |
| Methionine | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 |
| Methionine + cystine | 9.0 | 9.2 | 9.1 | 9.1 | 9.1 |
| Threonine | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 |
| Tryptophan | 2.5 | 2.5 | 2.6 | 2.6 | 2.6 |
| Lysine | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 |
| Calcium | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| Available phosphorus | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Sodium chloride | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| Potassium | 7.2 | 7.2 | 7.2 | 7.2 | 7.2 |
| Fibre | 28.0 | 29.6 | 30.4 | 31.3 | 32.1 |
| Oil | 61.4 | 60.1 | 61.8 | 63.5 | 65.9 |
| Ash | 69.0 | 67.3 | 66.4 | 65.4 | 64.5 |

See Table 4 for the diet composition and nutrient content of the 0 g/kg whole rapeseed starter ration.

Table 8. Diet composition and calculated nutrient analyses of the whole rapeseed finisher rations (g/kg fresh basis) tested

| Ingredient | Quantity (g/kg fresh basis) | | | | |
|---|---|---|---|---|---|
| | Whole rapeseed concentration (g/kg) | | | | |
| | 20 | 40 | 60 | 80 | 100 |
| Wheat | 666.7 | 670.9 | 673.8 | 672.4 | 648.6 |
| Maize Germ 10 oil | 0.0 | 0.0 | 0.0 | 1.5 | 21.9 |
| Maize Gluten 60 | 15.4 | 11.7 | 8.2 | 5.6 | 12.4 |
| Vegetable oil | 48.3 | 39.7 | 31.3 | 23.6 | 15.8 |
| Soya 50 | 129.9 | 150.2 | 160.0 | 140.0 | 120.0 |
| Soya 44 | 70.1 | 29.8 | 0.0 | 0.0 | 0.0 |
| Whole rapeseed meal | 20.0 | 40.0 | 60.0 | 80.0 | 100.0 |
| Fish meal 66 | 19.6 | 31.0 | 43.3 | 57.1 | 63.3 |
| Synthetic lysine | 0.97 | 0.63 | 0.3 | 0.0 | 0.0 |
| Synthetic methionine | 0.81 | 0.70 | 0.59 | 0.46 | 0.31 |
| Synthetic threonine | 0.07 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mineral and vitamin premix | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Limestone | 8.5 | 7.8 | 7 | 6.2 | 5.7 |
| Dicalcium phosphate | 12.6 | 10.7 | 8.8 | 6.6 | 5.6 |
| Sodium chloride | 2.1 | 1.9 | 1.7 | 1.5 | 1.4 |
| Total | 1000 | 1000 | 1000 | 1000 | 1000 |
| | | | | | |
| Nutrient | Quantity (g/kg fresh basis) | | | | |
| | | | | | |
| Crude protein | 190.3 | 192.3 | 194.2 | 195.3 | 197.1 |
| AME (MJ) | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 |
| Arginine | 12.1 | 12.1 | 12.1 | 12.1 | 12.1 |
| Iso-leucine | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 |
| Methionine | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 |
| Methionine + cystine | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 |
| Threonine | 6.9 | 6.9 | 7.0 | 7.1 | 7.2 |
| Tryptophan | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 |
| Lysine | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 |
| Calcium | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 |
| Available phosphorus | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 |
| Sodium chloride | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| Potassium | 7.0 | 7.0 | 7.0 | 6.8 | 6.5 |
| Fibre | 26.2 | 26.8 | 27.1 | 27.9 | 28.3 |
| Oil | 70.1 | 70.5 | 71.1 | 72.6 | 75.3 |
| Ash | 55.7 | 54.9 | 54.2 | 53.3 | 53.2 |

See Table 5 for the diet composition and nutrient content of the 0 g/kg whole rapeseed finisher ration.

Experiment design and statistical analysis of the data

Experiment design

The two studies were run concurrently in House 1 on the poultry unit at ADAS Gleadthorpe. The dietary concentration of rape (meal or whole seed) x sex treatment combinations were fully randomised across the 72 plots available within the house.

There was a common control treatment for the two studies (0 g/kg rapeseed meal or whole rapeseed).

Study 1A – dietary rapeseed meal

8 dietary treatments (not including the control 0 g/kg rapeseed meal) x 2 sexes x 2 replicates = 32 plots.

Study 1B – dietary whole rapeseed

5 dietary treatments (not including the control 0 g/kg whole rapeseed) x 2 sexes x 3 replicates = 30 plots.

Plus, 1 dietary treatment (the control, 0 g/kg rapeseed meal) x 2 sexes x 3 replicates = 6 plots.

This gave a total of 68 plots, where each plot comprised a wood and wire pen, stocked with 22 day-old chicks, either male or female to give a total flock size of 1 496. Thus, there were four random unstocked pens within the house.

Statistical analysis of the data

Study 1A – dietary rapeseed meal

Statistical analysis was by a combination of response curve fitting using 'best fit techniques' and analysis of variance, using GenStat5 software. Response curves were fitted to feed usage and live weight data. All other data were analysed by analysis of variance.

In addition to the statistical analysis of the full data set restricted analyses were made so as to: 1) compare the performance of birds fed 80 g/kg rapeseed meal and above in the starter ration, followed by 0 g/kg rapeseed meal in the finisher ration, with birds fed 0 g/kg rapeseed meal throughout the study, and; 2) compare the performance of birds fed either 0 g/kg, 20 g/kg, 40 g/kg or 60 g/kg rapeseed meal in the starter and finisher rations.

Study 1B – dietary whole rapeseed

Statistical analysis was by the same techniques used in Study 1A.

Materials

Stock

The two studies used a total of 1 496 sexed day-old Ross broiler chicks supplied by P.D.Hook (Hatcheries) Ltd, Cote, Bampton, Oxfordshire.

Diet manufacture

Roslin Nutrition, Roslin, Scotland, manufactured all of the treatment diets. They were supplied to the house in labelled bags detailing the study number and treatment number.

The whole rapeseed was lightly crushed before being incorporated into the diet but care was taken to avoid oil loss and any consequent change in nutritional value.

Methods

Husbandry and management

Chicks were randomly allocated at the stocking rate of 22 males or 22 females per pen at day-old. Each pen measured 1.75 m x 1.55 m and contained four nipple drinkers and one tube feeder. The height of the nipple drinkers was adjusted regularly so as to keep the nipple level with bird eye height. The water pressure was managed so as to minimise the risk of water leakage or water restriction. The height of the tube feeder was adjusted so as to maintain the lip of the tube feeder level with the height of the bird's back.

The treatment diets were supplied in 25 kg bags by Roslin Nutrition. The feed bags were each labelled detailing the study number, dietary treatment number and the weight of the bag plus feed; this was check-weighed before allocation. Each pen of birds was fed by hand and the same quantity of starter ration was given per pen. The finisher ration was fed *ad libitum* from 22 days of age. Each day after feeding, the empty feed bags were checked so as to verify the correct feeding of a dietary treatment.

The house was heated by a warm air brooding system. The house air temperature at day-old was 31°C, which was reduced by 1°C on alternate days until a temperature of 21°C was reached at day 21. The target post-brooding temperature was 21°C.

Minimum ventilation rate was automatically calculated using software within the Farm-Ex Dicam control panel. The minimum ventilation rate was supplied by a 610 mm fan running intermittently at full speed (940 revs /min), providing 1.5 x $10^{-3}$ $m^3$/s per $kg^{0.75}$ live weight.

The light source was tungsten lighting (36, 60-watt bulbs evenly distributed throughout the house). Light intensity was reduced from the maximum attainable at day-old (approximately 30 lux) to an intensity of approximately 10 lux by 10 days of age.

The daylength was 23 hours between day-old and 4 days of age, and between 22 days and 42 days of age, but 16 hours between 5 days and 21 days of age.

Litter was woodshavings to a depth of five cm at day-old.

Measurements

Environment

Records of the house temperature were taken daily, using six maximum/minimum thermometers suspended at bird height at regular intervals throughout the house. The maximum/minimum thermometers were read and recorded within five minutes of each other.

Measurements of house air carbon monoxide and carbon dioxide concentrations were taken using Draeger tubes at day-old and at weekly intervals thereafter for the first three weeks. House air ammonia concentrations were measured using Draeger tubes at day-old and at weekly intervals thereafter throughout the study. House air relative humidity was recorded daily using a TinyTalk humidity probe and logger.

Live weight

All of the birds were weighed on a plot basis at day-old, 14 days, 21 days, 35 days and 42 days of age. At day-old all of the chicks randomly allocated to a plot were weighed together. From 14 days of age this was done by weighing a number of batches of birds and then summing the total weight of birds per plot.

Feed intake

The feed used by each plot of birds was measured for the periods day-old to 21 days of age, 22 days to 35 days of age, and 35 days to 42 days of age by weighing back the amount of feed remaining in the tube feeders and feed bags at the end of the period, and deducting this amount from the quantity of feed allocated.

Litter assessment

A visual assessment of litter friability was made at 20 days and 41 days of age using the scoring system detailed in Table 9.

Table 9. Litter friability deterioration score (1-5)

| Friability score | Guidelines |
|---|---|
| 1 | Free flowing and crumbly either as at day-old or when broken down by bacterial action. No capping visible. |
| 2 | Very slight capping visible, but mostly friable. Any capping easily removed. |
| 3 | Access to friable litter partially reduced by capping but still some friable areas, approximately 50%. |
| 4 | Most areas capped but friable litter still accessible in small areas. |
| 5 | Extensive capping/crusting with access to friable litter negligible. |

A core sample of litter was taken from each pen at 41 days of age and sent to Direct Laboratories, Woodthorne, Wergs Road, Wolverhampton, WV6 8TQ for analysis. The samples were analysed for dry matter, total nitrogen, uric acid-nitrogen and ammonium-nitrogen contents and pH.

Hock burn score

Five birds from each pen were assessed for hock burn damage at 41 days of age. The scoring system detailed in Table 10, was used as a guide.

Table 10. Hock burn scoring guide (1-5)

| Parameter | Score | Guidelines |
|---|---|---|
| Burnt hock | 1 | No discoloration/burning/scalding |
| | 2 | Slight discoloration |
| | 3 | Discoloration with small scab(s) |
| | 4 | Well established scab(s)/burnt area |
| | 5 | Hock well enlarged with large scab/burnt area |

Tissue sampling

Samples of spleen and liver were collected from one bird from each pen for rapeseed meal treatments 1-9 (see Table 4) at 21 days of age and for rapeseed meal treatments 1-4 (see Table 5) at 42 days of age. The samples were sent to Direct Laboratories, Wolverhampton for analyses of dry matter, cobalt, copper, manganese and zinc contents.

Health monitoring and mortality

Twice daily inspections of bird health were carried out. Any birds that were lame or unable to reach their feed and water were humanely culled. All birds that died were weighed and the weight was recorded on the plot record sheet.

Feed sampling

A composite sample of each of the starter and finisher treatment diets was achieved by taking sub-samples from the relevant treatment feed bag at the time of feeding. The composite samples were kept under refrigeration at ADAS Gleadthorpe until all of the starter, or all of the finisher rations had been fed. The composite samples were each then divided into three samples. One sample was kept under refrigeration at ADAS Gleadthorpe (-20°C) and they remain there until after completion of the project. The second sample was sent to Direct Laboratories, Wolverhampton for the determination of dry matter, crude protein, oil, crude fibre, starch, sugar, total ash, calcium, total phosphorus, available phosphorus, sodium, potassium, chloride,

copper, cobalt, zinc and manganese contents. The third sample was sent to Sciantec Analytical Services Ltd, Main site, Dalton, Thirsk, North Yorkshire, YO7 3JA for the determination of amino acid content.

A brief description of the methodology used for the determination of feed amino acid contents has been provided by Sciantec Analytical Services and it is given below, but importantly, the method used measures both natural and synthetic forms of lysine, methionine and threonine.

'The sample is oxidised with a hydrogen peroxide / formic acid / phenol mixture. Excess oxidation reagent is decomposed with sodium metabisulphite. The oxidised sample is hydrolysed with 6 M hydrochloric acid for 24 hours. The hydrolysate is adjusted to pH 2.20, centrifuged and filtered. The amino acids are separated by ion exchange chromatography and the contents determined by reaction with ninhydrin using photometric detection at 570 nm, except for proline, which is detected at 440 nm'.

*Results*

Study 1A Rapeseed meal

Live weight

Feeding increasing concentrations of rapeseed meal linearly reduced male live weight at 14 days ($p<0.01$, Figure 1) and 21 days of age ($p<0.05$) and female live weight at 14 days of age ($p<0.05$, Figure 2), but not at 21 days of age.

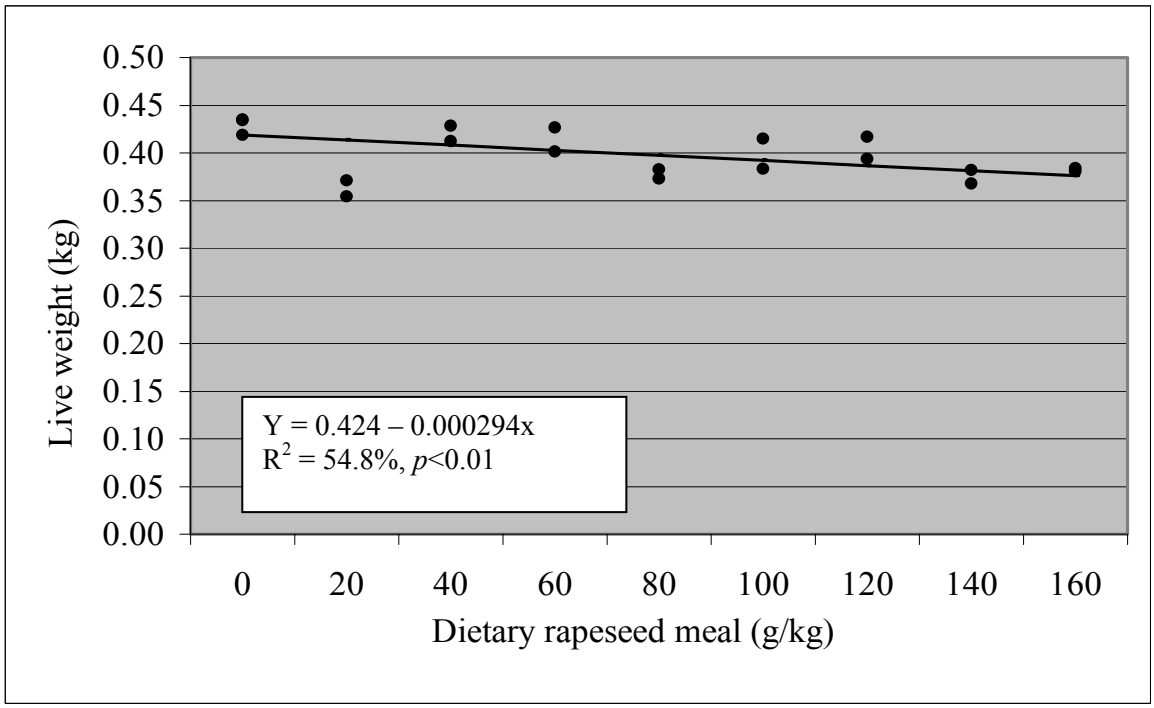


Figure 1. Effect of increasing dietary rapeseed meal concentration on male live weight at 14 days of age (kg/bird)

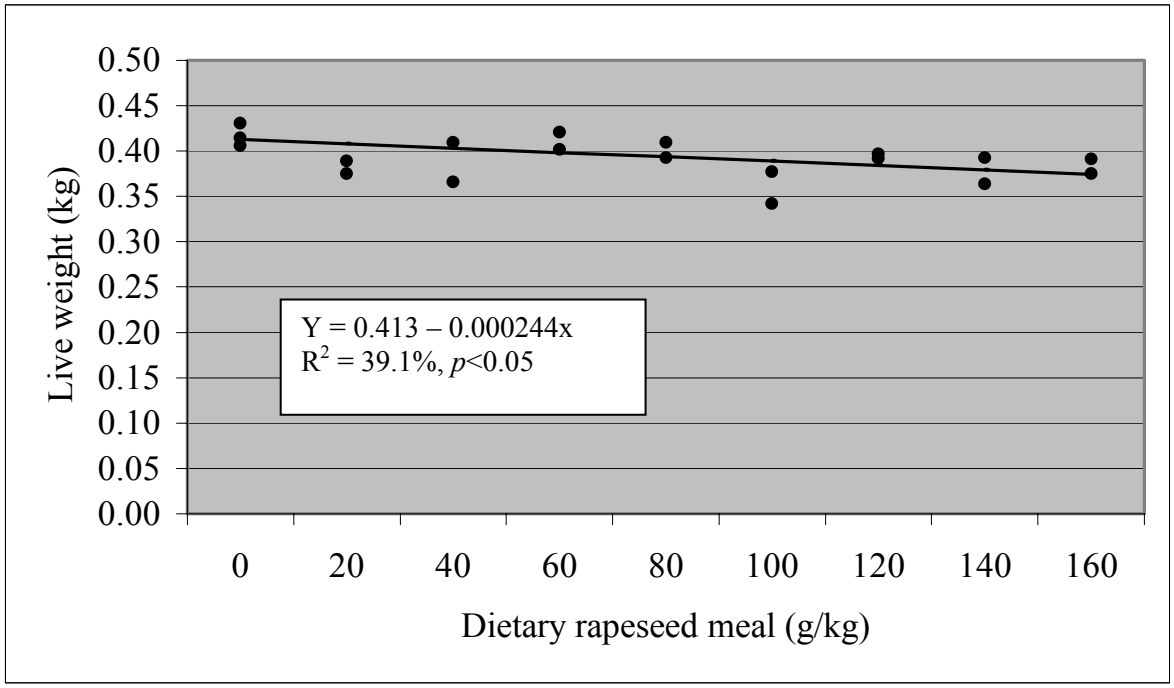


Figure 2. Effect of increasing dietary rapeseed meal concentration on female live weight at 14 days of age (kg/bird)

There were no significant 'best fit' live weight responses to feeding increasing concentrations of rapeseed meal within the range of 0 g/kg to 60 g/kg at either 35 days or 42 days of age.

The effect of dietary rapeseed meal concentration on mean-sex live weight at all ages (day-old, 14 days, 21 days, 35 days and 42 days of age) is shown in Table 11.

Live weight at 14 days and 21 days of age was affected by dietary rapeseed meal concentration ($p<0.01$). Significant differences in live weight between treatments are denoted by superscripts. Live weight at 35 days and 42 days of age was not affected by dietary rapeseed meal concentration ($p>0.05$).

There was no evidence to suggest that the males and females responded differently to increasing dietary concentrations of rapeseed meal. As expected, the males were generally heavier than females ($p<0.01$ at day-old and $p<0.001$ at 21 days, 35 days and 42 days of age).

Birds fed high concentrations of rapeseed meal (80 g/kg to 160 g/kg) between day-old and 21 days of age, followed by 0 g/kg rapeseed meal from 22 days of age, had similar live weights at 35 days and 42 days of age to those fed 0 g/kg throughout the study.

The restricted analysis of variance test on live weight data at 35 days of age for birds fed between 0 g/kg and 60 g/kg rapeseed meal, showed that birds fed 20 g/kg rapeseed meal were smaller than birds fed the other concentrations ($p<0.05$ shown in Table 12 for mean-sex live weight). Birds fed 0 g/kg, 40 g/kg and 60 g/kg rapeseed meal had similar live weights at 35 days of age. At 42 days of age, birds fed 20 g/kg rapeseed meal were numerically smaller than birds fed 0 g/kg, 40 g/kg or 60 g/kg, but this was not significant at $p<0.05$.

The reason why 20 g/kg rapeseed meal was more influential than higher concentrations of rapeseed meal in terms of live weight gain is not known, but it is not thought to be due to rapeseed meal *per se*. Furthermore, the finding cannot be explained in terms of a reduced dietary nutrient content.

Table 11. Live weight (kg/bird)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0 | 14 | 21 | 35 | 42 |
| Factor 1 Dietary rapeseed meal (g/kg) | | | | | |
| 0 | 0.040 | 0.419$^{e}$ | 0.811$^{c}$ | 2.061 | 2.698 |
| 20 | 0.040 | 0.372$^{a}$ | 0.749$^{a}$ | 1.987 | 2.584 |
| 40 | 0.041 | 0.404$^{cde}$ | 0.800$^{bc}$ | 2.098 | 2.711 |
| 60 | 0.040 | 0.412$^{de}$ | 0.801$^{bc}$ | 2.066 | 2.658 |
| 80/0 | 0.041 | 0.389$^{abcd}$ | 0.784$^{bc}$ | 2.041 | 2.633 |
| 100/0 | 0.041 | 0.379$^{abc}$ | 0.774$^{ab}$ | 2.029 | 2.648 |
| 120/0 | 0.041 | 0.400$^{bcde}$ | 0.801$^{bc}$ | 2.054 | 2.699 |
| 140/0 | 0.041 | 0.377$^{ab}$ | 0.741$^{a}$ | 1.995 | 2.615 |
| 160/0 | 0.040 | 0.382$^{abc}$ | 0.784$^{bc}$ | 2.057 | 2.700 |
| Sed ± | 0.00026 | 0.01079 | 0.01487 | 0.03850 | 0.04500 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.141 | 0.003 | 0.002 | 0.170 | 0.114 |
| Sig | NS | ** | ** | NS | NS |
| Factor 2 | | | | | |
| Males | 0.041 | 0.396 | 0.811 | 2.183 | 2.873$^{b}$ |
| Females | 0.040 | 0.390 | 0.754 | 1.903 | 2.448$_{a}$ |
| Sed ± | 0.00012 | 0.00509 | 0.00701 | 0.01815 | 0.02120 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.008 | 0.228 | <0.001 | <0.001 | <0.001 |
| Sig | ** | NS | *** | *** | *** |

Table 12. Live weight (kg/bird) – restricted analysis of treatments containing either 0 g/kg, 20 g/kg, 40 g/kg and 60 g/kg rapeseed meal in both the starter and finisher rations

| Factor | Age (days) | |
|---|---|---|
| | 35 | 42 |
| Factor 1<br>Dietary rapeseed meal (g/kg) | | |
| 0 | 2.061[b] | 2.698 |
| 20 | 1.986[a] | 2.584 |
| 40 | 2.098[b] | 2.711 |
| 60 | 2.066[b] | 2.658 |
| Sed ± | 0.0306 | 0.0490 |
| df | 3 | 3 |
| *P* | 0.034 | 0.117 |
| Sig | * | NS |
| Factor 2<br>Sex | | |
| Males | 2.193 | 2.899 |
| Females | 1.913 | 2.426 |
| Sed ± | 0.0216 | 0.0347 |
| df | 1 | 1 |
| *P* | <0.001 | <0.001 |
| Sig | *** | *** |

There were no significant 'best fit' intake responses to feeding increasing concentrations of rapeseed meal within the range of 0 g/kg to 160 g/kg between day-old and 21 days of age. Neither were there any significant 'best fit' intake responses to feeding rapeseed meal within the range of 0 g/kg to 60 g/kg between 22 days and 42 days of age, nor over the whole growing period.

Feed intake between day-old and 21 days of age was not affected by dietary rapeseed meal concentration (shown on a mean-sex basis in Table 13).

There was an effect of dietary rapeseed meal concentration on feed intake between 22 days and 35 days of age, between 22 days and 42 days of age and between day-old and 42 days of age ($p<0.05$), but not in a consistent manner in terms of increasing dietary rapeseed meal concentration. For example, the lowest feed intakes between 22 days and 42 days of age were in birds fed 20 g/kg rapeseed meal throughout and 80 g/kg rapeseed meal in the starter ration followed by 0 g/kg rapeseed meal in the finisher ration (Table 14). The highest numerical feed intakes over the latter period were in birds fed 40 g/kg and 60 g/kg rapeseed meal throughout, but statistically their intake did not differ from that of birds fed either 0 g/kg rapeseed meal throughout or birds fed 100 g/kg, 120 g/kg, 140 g/kg or 160 g/kg rapeseed meal in the starter ration, followed by 0 g/kg rapeseed meal in the finisher ration.

There was no evidence to suggest that the males and females responded differently to increasing dietary concentrations of rapeseed meal. Males consumed more feed than the females ($p<0.05$ between day-old and 21 days of age and $p<0.001$ for the other periods studied, Table 13).

Birds fed high concentrations of rapeseed meal (80 g/kg to 160 g/kg) between day-old and 21 days of age, followed by 0 g/kg rapeseed meal from 22 days of age, had similar intakes during the latter part of the growing period (22-42 days) and throughout the whole growing period (0-42 days) as those fed 0 g/kg between day-old and 42 days of age.

Birds fed 20 g/kg rapeseed meal throughout the study had lower intakes between 22 days and 35 days of age, and between 22 days and 42 days of age than birds fed either 0 g/kg, 40 g/kg or 60 g/kg rapeseed meal ($p<0.01$). Intakes over these periods were similar between birds fed 0 g/kg, 40 g/kg and 60 g/kg rapeseed meal to 42 days of age. There was trend for intake between day-old and 42 days of age to be lowest when fed 20 g/kg rapeseed meal throughout the study ($p=0.061$). This is shown on a mean-sex basis in Table 15.

Table 13. Feed intake (g/bird.day)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0-21 | 22-35 | 36-42 | 22-42 | 0-42 |
| Factor 1 Dietary rapeseed meal (g/kg) | | | | | |
| 0 | 52 | 160$^{abc}$ | 196 | 172$^{ab}$ | 110$^{abc}$ |
| 20 | 51 | 154$^{a}$ | 188 | 165$^{a}$ | 106$^{ab}$ |
| 40 | 51 | 164$^{bc}$ | 198 | 175$^{b}$ | 111$^{c}$ |
| 60 | 52 | 165$^{c}$ | 193 | 175$^{b}$ | 112$^{c}$ |
| 80/0 | 51 | 154$^{a}$ | 187 | 165$^{a}$ | 106$^{a}$ |
| 100/0 | 53 | 156$^{ab}$ | 193 | 168$^{ab}$ | 109$^{abc}$ |
| 120/0 | 57 | 161$^{abc}$ | 196 | 173$^{ab}$ | 113$^{c}$ |
| 140/0 | 50 | 157$^{ab}$ | 196 | 170$^{ab}$ | 108$^{abc}$ |
| 160/0 | 54 | 160$^{abc}$ | 198 | 172$^{ab}$ | 111$^{bc}$ |
| Sed ± | 2.378 | 3.667 | 3.593 | 3.248 | 2.087 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.221 | 0.046 | 0.054 | 0.037 | 0.040 |
| Sig | NS | * | NS | * | * |
| Factor 2 Sex | | | | | |
| Males | 54 | 170 | 209 | 183 | 116 |
| Females | 51 | 148 | 179 | 158 | 103 |
| Sed ± | 1.121 | 1.728 | 1.694 | 1.531 | 0.984 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.033 | <0.001 | <0.001 | <0.001 | <0.001 |
| Sig | * | *** | *** | *** | *** |

Table 14. Interactions – feed intake (g/bird/day) 22-42 days of age

| Dietary rapeseed meal (g/kg) | Sex | |
|---|---|---|
| | Males | Females |
| 0 | 185 | 159 |
| 20 | 182 | 149 |
| 40 | 193 | 158 |
| 60 | 185 | 164 |
| 80/0 | 170 | 160 |
| 100/0 | 181 | 156 |
| 120/0 | 182 | 163 |
| 140/0 | 182 | 157 |
| 160/0 | 186 | 158 |

df = 8 $P$ <0.034, * Sed ± 4.593

Table 15. Feed intake (g/bird.day) – restricted analysis of treatments containing either 0 g/kg, 20 g/kg, 40 g/kg and 60 g/kg rapeseed meal in both the starter and finisher ration

| Factor | Age (days) | | | |
|---|---|---|---|---|
| | 22-35 | 36-42 | 22-42 | 0-42 |
| Factor 1<br>Dietary rapeseed meal (g/kg) | | | | |
| 0 | 160[ab] | 196 | 172[b] | 110 |
| 20 | 154[a] | 188 | 165[a] | 106 |
| 40 | 164[b] | 198 | 175[b] | 111 |
| 60 | 165[b] | 193 | 175[b] | 112 |
| Sed ± | 2.603 | 3.530 | 2.508 | 1.817 |
| df | 3 | 3 | 3 | 3 |
| *P* | 0.010 | 0.086 | 0.014 | 0.061 |
| Sig | ** | NS | ** | NS |
| Factor 2<br>Sex | | | | |
| Males | 173 | 212 | 186 | 117 |
| Females | 149 | 176 | 158 | 103 |
| Sed ± | 1.840 | 2.500 | 1.774 | 1.285 |
| df | 1 | 1 | 1 | 1 |
| *P* | <0.001 | <0.001 | <0.001 | <0.001 |
| Sig | *** | *** | *** | *** |

The amount of rapeseed meal consumed between day-old and 21 days of age (g/bird.day), between 22 days and 42 days of age (g/bird.day) and between day-old and 42 days of age (g/bird.day and kg/bird) on a mean-sex basis for each dietary treatment is shown in Table 16.

Table 16. Rapeseed meal intake between day-old and 21 days of age (g/bird.day), between 22 days and 42 days of age (g/bird.day) and between day-old and 42 days of age (g/bird.day and kg/bird) on a mean sex basis

| Dietary rapeseed meal (g/kg) | Rapeseed meal intake | | | |
|---|---|---|---|---|
| | Age (days) | | | |
| | 0-21 (g/bird.day) | 22-42 (g/bird.day) | 0-42 (g/bird.day) | 0-42 (kg/bird) |
| 0 | 0 | 0 | 0 | 0.000 |
| 20 | 1 | 3 | 2 | 0.091 |
| 40 | 2 | 7 | 5 | 0.190 |
| 60 | 3 | 10 | 7 | 0.286 |
| 80/0 | 4 | 0 | 2 | 0.086 |
| 100/0 | 5 | 0 | 3 | 0.111 |
| 120/0 | 7 | 0 | 3 | 0.143 |
| 140/0 | 7 | 0 | 3 | 0.146 |
| 160/0 | 9 | 0 | 4 | 0.180 |

Birds fed 60 g/kg rapeseed meal throughout the 42-day study consumed the most rapeseed meal, followed by birds fed 40 g/kg rapeseed meal between day-old and 42 days of age. Birds fed between 80 g/kg and 160 g/kg rapeseed meal between day-old and 21 days of age, followed by 0 g/kg rapeseed meal between 22 days and 42 days of age consumed more rapeseed meal than birds fed 20 g/kg rapeseed meal throughout the study.

Total glucosinolate intake and sinapine intake to 42 days of age is shown on a sex-basis for each dietary treatment in Figures 3 and 4. This has been calculated using rapeseed meal intake data and so the patterns of glucosinolate intake and sinapine intake across the dietary rapeseed meal treatments are as reported for rapeseed meal intake.

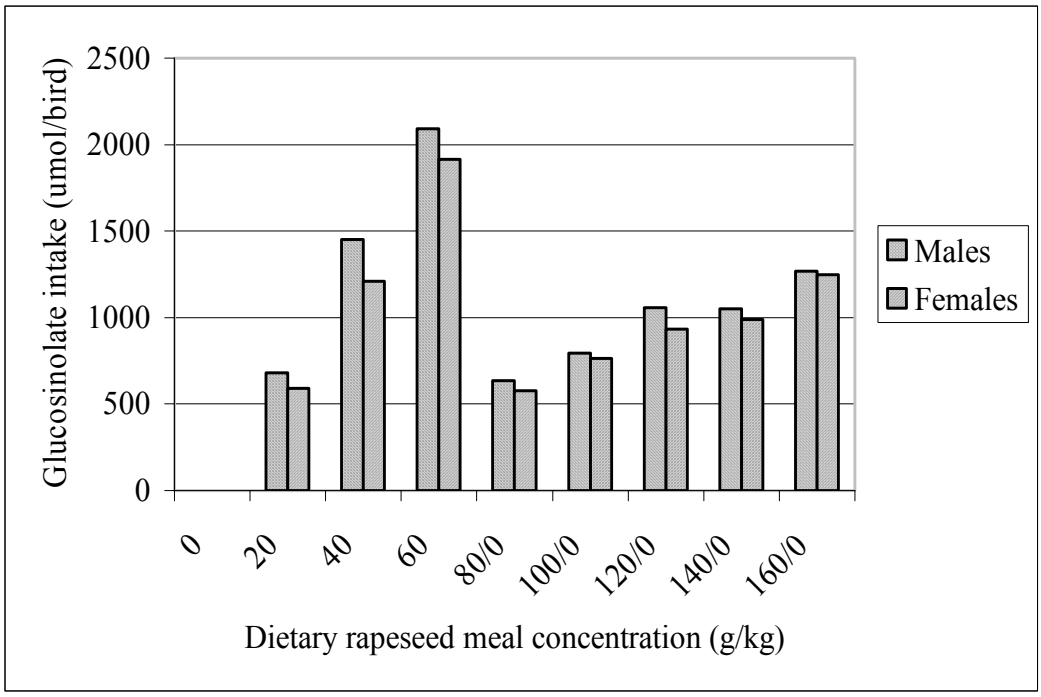


Figure 3. Total glucosinolate intake to 42 days of age (μmol/bird)

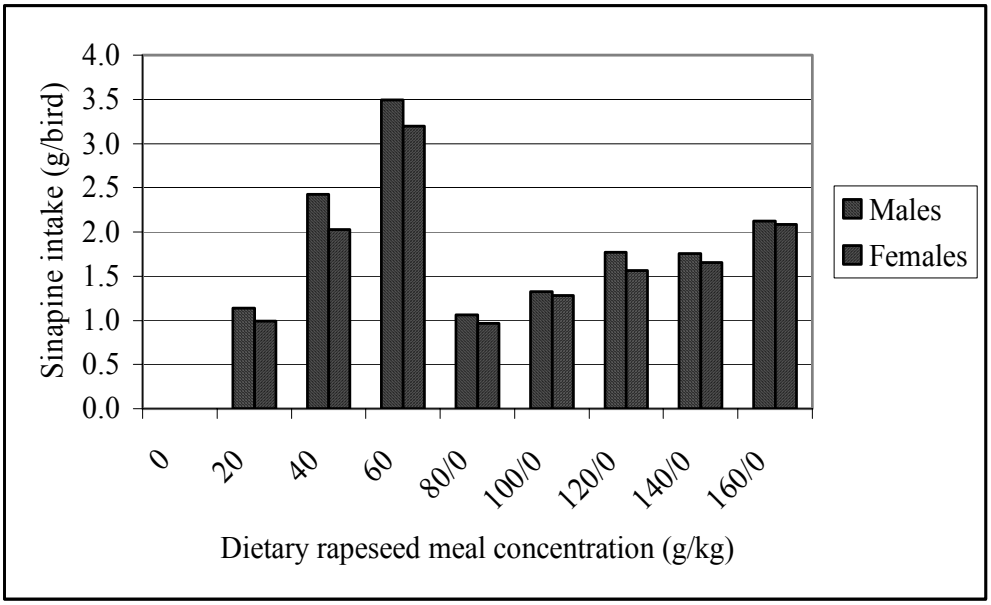


Figure 4. Sinapine intake to 42 days of age

There was no effect of dietary rapeseed meal concentration on FCE between day-old and 21 days of age, between 22 days and 42 days of age and between day-old and 42 days of age. This is shown for all treatments and all periods studied on a mean-sex basis in Table 17.

FCE between day-old and 42 days of age was better in the males than the females ($p<0.001$, Table 17).

Table 17. FCE (0-1)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0-21 | 22-35 | 36-42 | 22-42 | 0-42 |
| Factor 1 Dietary rapeseed meal (g/kg) | | | | | |
| 0 | 0.696 | 0.560[abc] | 0.435 | 0.513 | 0.558 |
| 20 | 0.661 | 0.574[bc] | 0.442 | 0.525 | 0.559 |
| 40 | 0.705 | 0.561[abc] | 0.440 | 0.516 | 0.560 |
| 60 | 0.688 | 0.548[a] | 0.438 | 0.508 | 0.551 |
| 80/0 | 0.684 | 0.573[bc] | 0.444 | 0.525 | 0.565 |
| 100/0 | 0.655 | 0.576[c] | 0.460 | 0.532 | 0.561 |
| 120/0 | 0.635 | 0.554[ab] | 0.468 | 0.522 | 0.551 |
| 140/0 | 0.672 | 0.573[bc] | 0.449 | 0.525 | 0.560 |
| 160/0 | 0.656 | 0.570[bc] | 0.462 | 0.529 | 0.560 |
| Sed ± | 0.02827 | 0.00870 | 0.01458 | 0.00804 | 0.00877 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.310 | 0.043 | 0.289 | 0.118 | 0.809 |
| Sig | NS | * | NS | NS | NS |
| Factor 2 Sex | | | | | |
| Males | 0.680 | 0.575 | 0.463 | 0.533 | 0.568 |
| Females | 0.664 | 0.556 | 0.434 | 0.510 | 0.549 |
| Sed ± | 0.01333 | 0.00410 | 0.00687 | 0.00379 | 0.00414 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.252 | <0.001 | <0.001 | <0.001 | <0.001 |
| Sig | NS | *** | *** | *** | *** |

Mortality and bird health

Mean mortality to 42 days of age was 4.8% and this was similar to commercial broiler mortality rates to 42 days of age as experienced at the time of the study. The causes of mortality were usual in that yolk sac infection due to *E.coli* is often a cause of early mortality and sudden deaths are usually experienced after 21 days of age. The number of birds culled due to leg abnormalities was very low at only two birds out of 748 birds housed.

There was no effect of dietary rapeseed meal concentration on mortality between day-old and 21 days of age, between 22 days and 42 days of age and between day-old and 42 days of age. This is shown for all treatments and all periods studied on a mean-sex basis in Table 18.

Mortality between day-old and 42 days of age was higher in the males than the females ($p<0.05$, Table 18), and this was due to more males dying than females between 22 days and 42 days of age ( $p<0.01$, $p<0.05$ and $p<0.05$, respectively).

Table 18. Mortality (%)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0-21 | 22-35 | 36-42 | 22-42 | 0-42 |
| Factor 1 Dietary rapeseed meal (g/kg) | | | | | |
| 0 | 3.4 | 1.1 | 2.3 | 3.4 | 6.8 |
| 20 | 2.3 | 0.0 | 3.4 | 3.4 | 5.7 |
| 40 | 3.4 | 1.1 | 0.0 | 1.1 | 4.6 |
| 60 | 2.3 | 1.1 | 0.0 | 1.1 | 3.4 |
| 80/0 | 3.4 | 2.3 | 1.1 | 3.4 | 6.8 |
| 100/0 | 4.6 | 0.0 | 1.1 | 1.1 | 5.7 |
| 120/0 | 3.4 | 1.1 | 1.1 | 2.3 | 5.7 |
| 140/0 | 1.4 | 0.0 | 0.0 | 0.0 | 1.1 |
| 160/0 | 3.5 | 0.0 | 0.0 | 0.0 | 3.5 |
| Sed ± | 3.319 | 1.515 | 1.515 | 2.004 | 4.163 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.991 | 0.795 | 0.328 | 0.481 | 0.908 |
| Sig | NS | NS | NS | NS | NS |
| Factor 2 Sex | | | | | |
| Males | 3.6 | 1.5 | 1.8 | 3.3 | 6.8 |
| Females | 2.5 | 0.0 | 0.3 | 0.3 | 2.8 |
| Sed ± | 1.565 | 0.714 | 0.714 | 0.945 | 1.962 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.517 | 0.048 | 0.048 | 0.005 | 0.053 |
| Sig | NS | * | * | ** | NS |

Litter quality and hock burn damage

Litter friability was good throughout the study and birds were free from hock burn damage. There were no effects of dietary rapeseed meal concentration or sex of bird on either of these parameters or on litter dry matter, total nitrogen, uric acid-nitrogen and ammonium-nitrogen contents and pH at 41 days of age (Table 19).

Table 19. Litter dry matter, total nitrogen, uric acid-nitrogen and ammonium-nitrogen contents (g/kg fresh basis) and pH at 41 days of age

| Factor | Litter quality variable | | | | |
|---|---|---|---|---|---|
| | Dry matter (g/kg) | Total nitrogen (g/kg fresh basis) | Uric acid-nitrogen (g/kg fresh basis) | Ammonium-nitrogen (g/kg basis) | pH |
| Factor 1 Dietary rapeseed meal (g/kg) | | | | | |
| 0 | 595 | 43 | 7.9 | 6.5 | 7.5 |
| 20 | 646 | 37 | 7.8 | 5.3 | 8.3 |
| 40 | 580 | 42 | 6.7 | 5.8 | 7.5 |
| 60 | 662 | 39 | 8.0 | 5.0 | 7.2 |
| 80/0 | 642 | 37 | 7.4 | 5.7 | 7.8 |
| 100/0 | 581 | 39 | 7.8 | 5.9 | 7.3 |
| 120/0 | 621 | 37 | 7.1 | 6.2 | 7.2 |
| 140/0 | 601 | 38 | 7.8 | 5.5 | 7.2 |
| 160/0 | 591 | 38 | 6.5 | 5.9 | 8.0 |
| Sed ± | 32.54 | 4.72 | 1.210 | 0.773 | 0.477 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.149 | 0.876 | 0.881 | 0.701 | 0.287 |
| Sig | NS | NS | NS | NS | NS |
| Factor 2 Sex | | | | | |
| Males | 615 | 38 | 7.3 | 5.6 | 7.5 |
| Females | 611 | 40 | 7.6 | 5.9 | 7.6 |
| Sed ± | 15.34 | 2.23 | 0.571 | 0.364 | 0.225 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.833 | 0.314 | 0.687 | 0.514 | 0.827 |
| Sig | NS | NS | NS | NS | NS |

Liver and spleen trace element concentrations

Except for manganese, the trace element content of the liver and spleen at 21 days of age was not affected by dietary rapeseed meal concentration (shown on a mean-sex basis in Table 20). There was an interactive effect of dietary rapeseed meal concentration and sex of bird on the manganese content of the liver and spleen, the values being higher in the females than the males when fed either 40 g/kg or 100 g/kg rapeseed meal to 21 days of age ($p<0.05$). Although statistically significant, there is no explanation for why this occurred.

The moisture content of the liver and spleen at 21 days of age was higher in the males than the females ($p<0.05$, Table 20), whereas the concentration of copper in the liver and spleen was higher in the females than the males ($p<0.01$).

There were no effects of feeding rapeseed meal within the range of 0 g/kg to 40 g/kg between day-old and 42 days of age on liver and spleen trace element contents at 42 days of age.

Table 20. Liver and spleen moisture (g/kg) and trace element concentrations (mg/kg fresh basis) at 21 days

| Factor | Concentrations | | | | |
|---|---|---|---|---|---|
| | Moisture (g/kg) | Cobalt (mg/kg fresh basis) | Copper (mg/kg fresh basis) | Manganese (mg/kg fresh basis) | Zinc (mg/kg fresh basis) |
| Factor 1 Dietary rapeseed meal (g/kg) | | | | | |
| 0 | 744 | 0.03 | 3.7 | 3.5 | 21.9 |
| 20 | 742 | 0.03 | 4.1 | 3.7 | 22.7 |
| 40 | 747 | 0.03 | 4.1 | 3.5 | 23.5 |
| 60 | 744 | 0.03 | 4.0 | 3.4 | 22.2 |
| 80/0 | 751 | 0.03 | 3.7 | 3.3 | 21.6 |
| 100/0 | 753 | 0.03 | 3.5 | 3.1 | 20.8 |
| 120/0 | 742 | 0.03 | 4.0 | 3.4 | 22.8 |
| 140/0 | 748 | 0.03 | 3.6 | 3.1 | 21.2 |
| 160/0 | 750 | 0.03 | 3.6 | 2.9 | 22.9 |
| Sed ± | 6.59 | 0.0000 | 0.253 | 0.263 | 1.055 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.712 | - | 0.119 | 0.119 | 0.265 |
| Sig | NS | NS | NS | NS | NS |
| Factor 2 Sex | | | | | |
| Male | 750 | 0.03 | 3.6 | 3.1 | 21.2 |
| Female | 740 | 0.03 | 4.0 | 3.6 | 23.1 |
| Sed ± | 3.11 | 0.0000 | 0.119 | 0.124 | 0.497 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.038 | - | 0.008 | 0.001 | 0.001 |
| Sig | * | NS | NS | ** | ** |

Diet costs and gross margins of live weight sales minus feed costs

Using the ingredient prices shown in Table 21, the costs of the treatment diets have been calculated and the results are given in Table 22. In both the starter and finisher rations, the diets became more expensive as the concentration of rapeseed meal increased.

Table 21. Ingredient cost (£/tonne)

| Ingredient | Cost (£/tonne) |
|---|---|
| Wheat | 95.00 |
| Maize germ meal | 170.00 |
| Maize gluten 60 | 92.00 |
| Vegetable oil | 545.00 |
| Soya full fat | 299.00 |
| Soya 44 | 197.00 |
| Soya 50 | 240.00 |
| Rapeseed meal | 215.00 |
| Whole rapeseed | 340.00 |
| Fishmeal 66 | 440.00 |
| Synthetic lysine | 1750.00 |
| Synthetic methionine | 2000.00 |
| Synthetic threonine | 5500.00 |
| Premix starter | 2280.00 |
| Premix finisher | 1480.00 |
| Limestone | 54.65 |
| Dicalcium phosphate | 275.00 |
| Salt | 90.00 |

Table 22. Treatment diet cost (£/tonne)

| Dietary rapeseed meal (g/kg) | Cost of starter ration (£/tonne) | Cost of finisher ration (£/tonne) |
|---|---|---|
| 0 | 174.80 | 169.07 |
| 20 | 174.21 | 170.98 |
| 40 | 178.54 | 172.63 |
| 60 | 183.84 | 175.06 |
| 80/0 | 189.12 | - |
| 100/0 | 194.40 | - |
| 120/0 | 199.05 | - |
| 140/0 | 197.27 | - |
| 160/0 | 201.07 | - |

Gross margins of live weight sales minus feed costs have been calculated (Table 23) using:

- starter feed intake and finisher feed intake data to 42 days of age;
- diet costs (£/tonne);
- total live weight produced at 42 days of age (based on mean live weight data at 42 days of age and mortality to 42 days of age), and;
- a value of £0.46/kg of live weight sold.

Table 23. Gross margins of live weight sales minus feed costs

| Dietary rapeseed meal (g/kg) | Gross margin (£/bird) |
|---|---|
| | |
| 0 | 0.40 |
| 20 | 0.37 |
| 40 | 0.40 |
| 60 | 0.36 |
| 80/0 | 0.38 |
| 100/0 | 0.38 |
| 120/0 | 0.36 |
| 140/0 | 0.38 |
| 160/0 | 0.39 |

There was not an increasing financial penalty associated with feeding more rapeseed meal (Table 24). Although one of the highest gross margins of live weight sales minus feed costs was achieved by feeding 0 g/kg rapeseed meal to 42 days of age, the same return was achieved by feeding 40 g/kg rapeseed meal throughout the whole growing period. Furthermore, feeding 160 g/kg rapeseed meal between day-old and 21 days of age, followed by 0 g/kg rapeseed meal from 22 days to 42 days of age gave only a slight reduction in gross margin.

This is encouraging as the diets were formulated to be iso-energetic and iso-nitrogenous and not on the basis of 'least cost formulation'. Thus, there is scope for commercial feeds including rapeseed meal to be less costly than the treatment diets.

Study 1B Whole rapeseed

Feeding increasing concentrations, up to 100 g/kg, of whole rapeseed linearly reduced male live weight at 42 days ($p<0.01$, Figure 5) and female live weight at 14 days ($p<0.01$), 21 days ($p<0.05$), 35 days ($p<0.01$) and 42 days of age ($p<0.01$, Figure 5). The linear response equations describing the effects of increasing dietary whole rapeseed concentration on female live weight at 14 days, 21 days and 35 days of age and the respective $R^2$ values are given in Table 24.

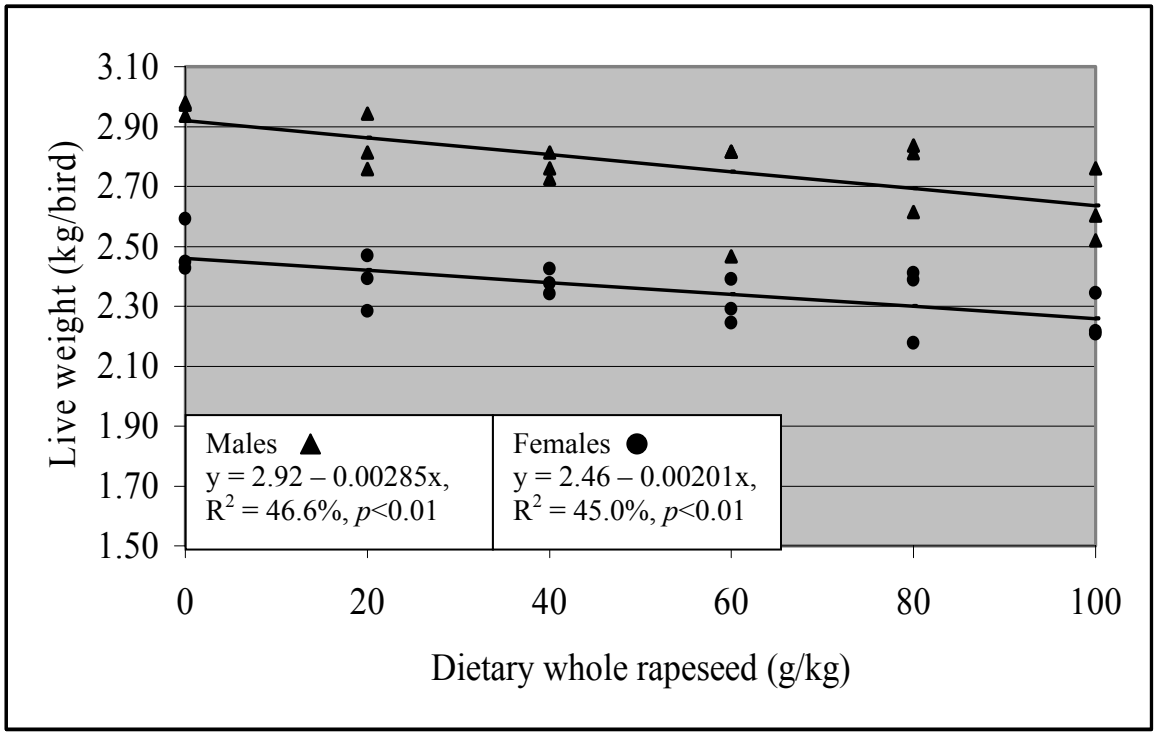


Figure 5. Effect of increasing dietary whole rapeseed concentrations on male and female live weight at 42 days of age (kg/bird)

Table 24. Linear response equations describing the effects of increasing dietary concentrations of whole rapeseed on female live weight at 14 days, 21 days and 35 days of age (kg/bird)

| Age | Equation | $R^2$ value (%) | Significance |
|---|---|---|---|
| 14 | y = 0.409 – 0.000382x | 44.5 | $p<0.01$ |
| 21 | y = 0.773 – 0.000475x | 27.0 | $p<0.05$ |
| 35 | y = 1.930 – 0.001780x | 44.8 | $p<0.01$ |

where:

y = live weight (kg/bird), and;

x = dietary concentration of whole rapeseed (g/kg)

There was no indication that males and females responded differently to increasing dietary concentrations of whole rapeseed. Regressions of live weight at 42 days of age against dietary concentration of whole rapeseed were significant for males and females ($p<0.001$) when the slope of the response was constant (i.e. parallel linear responses):

Male live weight at 42 days of age (kg/bird)

y = 2.8962 – 0.002431x, $p<0.001$

Female live weight at 42 days of age (kg/bird)

y = 2.4784 – 0.002431x, $p<0.001$

Feeding increasing dietary concentrations of whole rapeseed within the range of 0 g/kg to 100 g/kg reduced mean-sex live weight at 14 days ($p<0.01$), 21 days ($p<0.05$), 35 days ($p<0.01$) and 42 days of age ($p<0.01$) (Table 25). Significant differences between treatments are denoted by the use of superscripts.

There was no evidence to suggest that the males and females responded differently to increasing dietary concentrations of whole rapeseed. As expected, the males were heavier than females ($p<0.05$ at day-old and $p<0.001$ at 21 days, 35 days and 42 days of age, Table 25).

Table 25. Live weight (kg)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0 | 14 | 21 | 35 | 42 |
| Factor 1 Dietary whole rapeseed (g/kg) | | | | | |
| 0 | 0.040 | 0.423[c] | 0.817 | 2.097[b] | 2.726[c] |
| 20 | 0.041 | 0.399[ab] | 0.780 | 2.008[ab] | 2.610[bc] |
| 40 | 0.041 | 0.407[bc] | 0.810 | 2.026[b] | 2.573[ab] |
| 60 | 0.040 | 0.390[ab] | 0.782 | 1.932[ab] | 2.504[ab] |
| 80 | 0.041 | 0.409[bc] | 0.813 | 1.990[b] | 2.540[ab] |
| 100 | 0.040 | 0.380[a] | 0.758 | 1.937[a] | 2.441[a] |
| Sed ± | 0.00039 | 0.00982 | 0.01819 | 0.04070 | 0.05970 |
| df | 5 | 5 | 5 | 5 | 5 |
| *P* | 0.439 | 0.004 | 0.019 | 0.005 | 0.002 |
| Sig | NS | ** | * | ** | ** |
| Factor 2 Sex | | | | | |
| Males | 0.041 | 0.413 | 0.837 | 2.161 | 2.775 |
| Females | 0.040 | 0.390 | 0.749 | 1.836 | 2.357 |
| Sed ± | 0.00022 | 0.00567 | 0.01050 | 0.02350 | 0.03450 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.027 | <0.001 | <0.001 | <0.001 | <0.001 |
| Sig | * | *** | *** | *** | *** |

Feed intake

Feed intake between day-old and 21 days of age in the males was not affected by dietary whole rapeseed concentration, but feed intake between 22 days and 42 days of age and between day-old and 42 days of age was reduced linearly as the concentration of whole rapeseed increased ($p<0.01$ and $p<0.05$, respectively). In the females, increasing the dietary concentration of whole rapeseed reduced feed intake linearly between day-old and 21 days of age ($p<0.05$), between 22 days and 42 days of age ($p<0.001$) and between day-old and 42 days of age ($p<0.001$). The effects of dietary whole rapeseed concentration on feed intake between day-old and 42 days of age are shown for each sex in Figure 6.

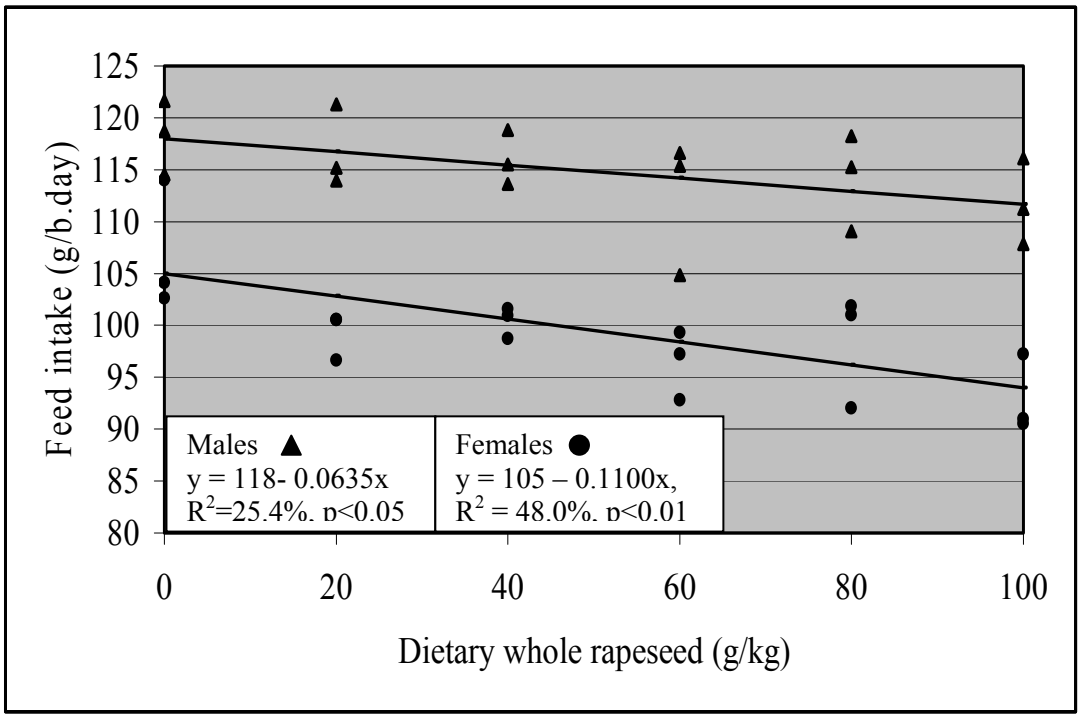


Figure 6. Effect of dietary whole rapeseed concentration on feed intake (g/bird.day) between day-old and 42 days of age

The linear response equations describing the effects of increasing dietary whole rapeseed concentration on feed intake between day-old and 21 days of age (females only) and between 22 days and 42 days of age, and the respective $R^2$ values are given in Table 26.

Table 26. Linear response equations describing the effects of increasing dietary concentrations of whole rapeseed on feed intake between day-old and 14 days of age (females only) and between 22 days and 42 days of age (males and females) (g/bird.day)

| Sex | Age (days) | Equation | $R^2$ value (%) | Significance |
|---|---|---|---|---|
| Male | 22–42 | y = 186.0 – 0.172x | 45.8 | $p<0.01$ |
| Female | 0-21 | y = 51.7 – 0.0401x | 25.3 | $p<0.05$ |
| Female | 22-42 | y = 159.0 – 0.1960x | 52.6 | $p<0.01$ |

where:

y = feed intake (g/bird.day), and;

x = dietary concentration of whole rapeseed (g/kg)

There was no indication that males and females responded differently to increasing dietary concentrations of whole rapeseed. Regressions of feed intake to 42 days of age against dietary concentration of whole rapeseed were significant for males and females ($p<0.001$) when the slope of the responses was constant (i.e. parallel linear responses):

Male feed intake 0-42 days of age (g/bird.day)

y = 119.20 – 0.0866x, $p<0.001$

Female feed intake 0-42 days of age (g/bird.day)

y = 103.36 – 0.0866x, $p<0.001$

Feed intake on a mean-sex basis was reduced between 22 days and 35 days of age ($p<0.01$), between 36 days and 42 days of age ($p<0.01$), between 22 days and 42 days of age ($p<0.001$) and between day-old and 42 days of age ($p<0.01$) (Table 27).

Table 27. Feed intake (g/bird/day)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0-21 | 22-35 | 36-42 | 22-42 | 0-42 |
| Factor 1 Dietary whole rapeseed (g/kg) | | | | | |
| 0 | 54 | 164[c] | 199[c] | 175[c] | 113[c] |
| 20 | 51 | 156[bc] | 187[bc] | 166[b] | 108[bc] |
| 40 | 53 | 156[bc] | 182[ab] | 165[b] | 108[bc] |
| 60 | 50 | 150[ab] | 176[ab] | 159[ab] | 104[ab] |
| 80 | 52 | 151[ab] | 178[ab] | 160[ab] | 106[ab] |
| 100 | 51 | 147[a] | 169[a] | 155[a] | 102[a] |
| Sed ± | 1.36 | 3.87 | 6.47 | 4.17 | 2.45 |
| df | 5 | 5 | 5 | 5 | 5 |
| *P* | 0.160 | 0.004 | 0.003 | <0.001 | 0.007 |
| Sig | NS | ** | ** | *** | ** |
| Factor 2 Sex | | | | | |
| Males | 54 | 167 | 197 | 177 | 115 |
| Females | 50 | 141 | 167 | 150 | 99 |
| Sed ± | 0.79 | 2.23 | 3.74 | 2.41 | 1.42 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Sig | *** | *** | *** | *** | *** |

The amount of whole rapeseed consumed between day-old and 42 days of age (kg/bird) on a mean-sex basis for each dietary treatment is shown in Figure 7.

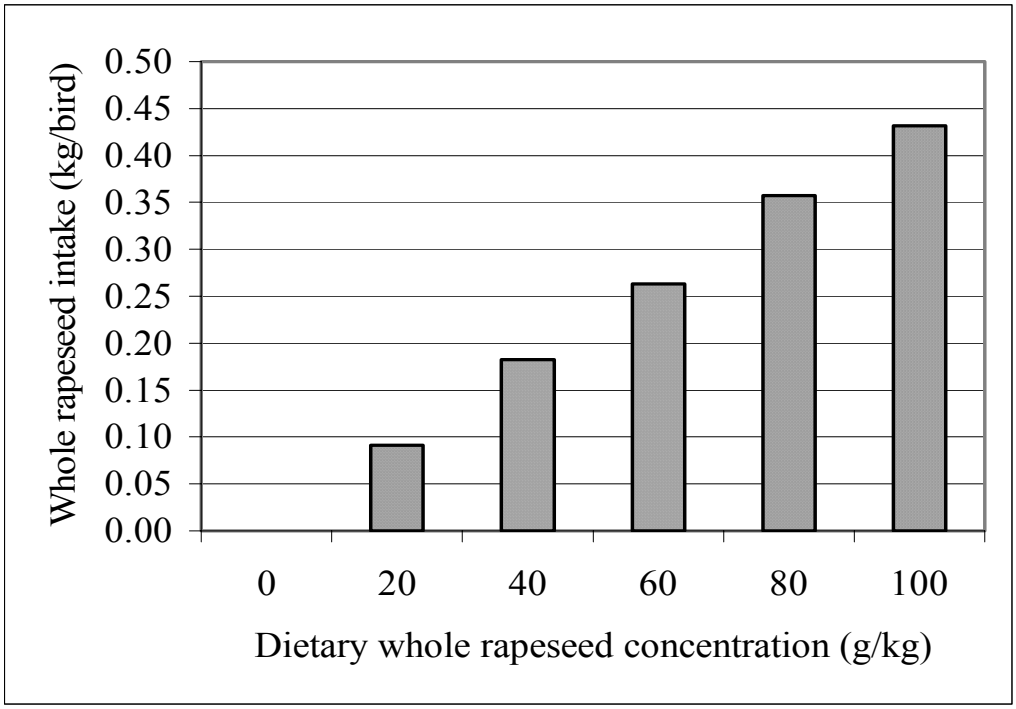


Figure 7. Dietary whole rapeseed intake (kg/bird) to 42 days of age on a mean-sex basis

Whole rapeseed intake increased with increasing dietary concentrations of whole rapeseed. The highest whole rapeseed intake to 42 days of age was achieved when feeding 100 g/kg whole rapeseed between day-old and 42 days of age.

Total glucosinolate intake and sinapine intake to 42 days of age is shown on a sexed-basis for each dietary treatment in Figures 8 and 9, respectively. This has been calculated using whole rapeseed intake data and so the patterns of both glucosinolate intake and sinapine intake across the dietary whole rapeseed treatments are as reported for whole rapeseed intake.

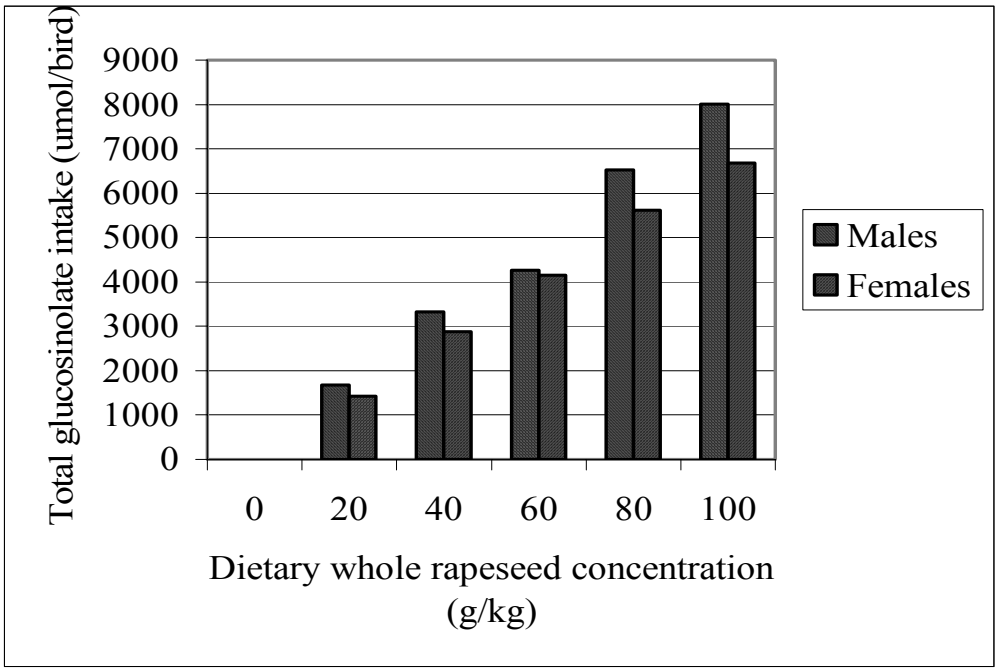


Figure 8. Total glucosinolate intake to 42 days of age (µmol/bird)

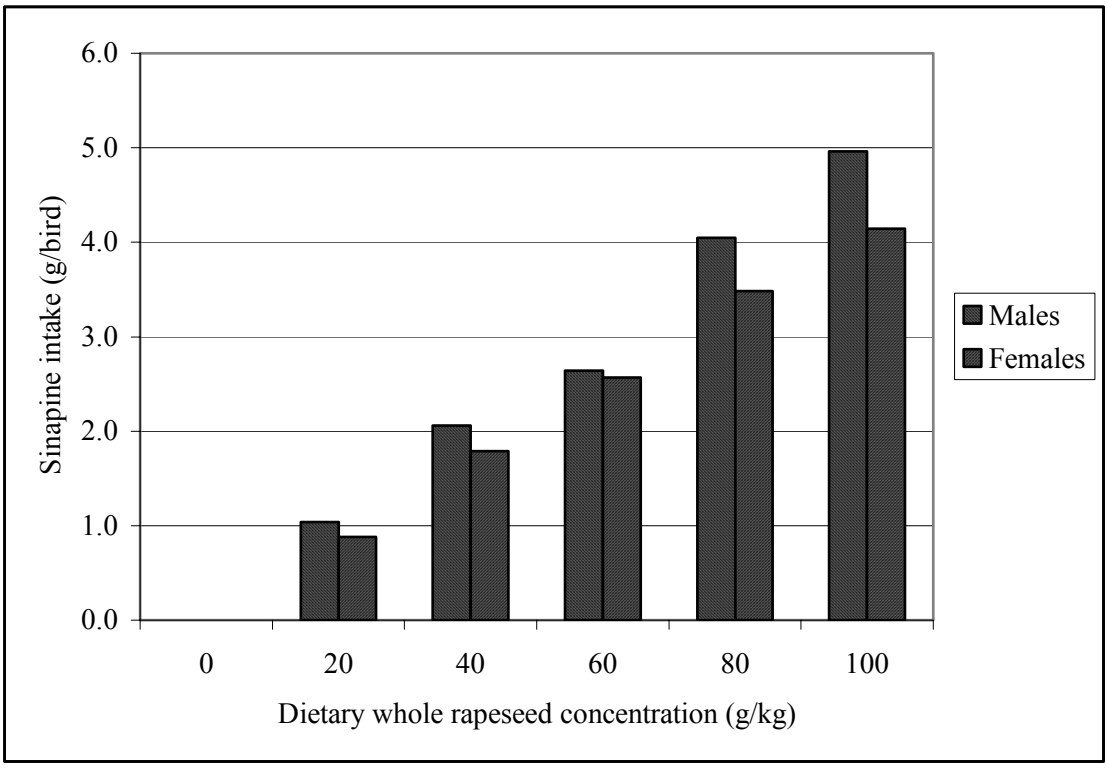


Figure 9. Sinapine intake to 42 days of age (mg/bird)

FCE

There was an interaction between dietary whole rapeseed concentration and sex of bird on FCE between day-old and 42 days of age ($p$<0.001). The poorest male FCE to 42 days of age was achieved by feeding 100 g/kg whole rapeseed, whereas in the females, FCE was best at this dietary concentration. The converse was also true. In the males, FCE to 42 days of age was best when feeding 0 g/kg whole rapeseed, whereas in the females, FCE was poorest at this concentration.

However, these findings should be treated with some caution as the interactive effect of dietary whole rapeseed concentration and sex occurred in the absence of a significant effect of dietary whole rapeseed concentration (p=0.595, Table 28). A poorer than expected FCE for one replicate of males fed 120 g/kg whole rapeseed was responsible for the significant interaction between dietary whole rapeseed and sex. Furthermore, as reported earlier significant parallel sex responses for live weight and feed intake to 42 days of age to increasing dietary concentrations of whole rapeseed were identified ($p$<0.001).

There were no other periods were interactive effects of dietary whole rapeseed and sex were found. FCE between day-old and 21 days of age, 22 days and 35 days of age, 36 days and 42 days of age and between 22 days and 42 days of age was not affected by dietary whole rapeseed concentration (Table 28).

FCE between day-old and 42 days of age was better in the males than the females ($p$<0.01, Table 28).

Table 28. FCE (0-1)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0-21 | 22-35 | 36-42 | 22-42 | 0-42 |
| Factor 1 Dietary whole rapeseed (g/kg) | | | | | |
| 0 | 0.684 | 0.560 | 0.433 | 0.512 | 0.554 |
| 20 | 0.682 | 0.560 | 0.455 | 0.521 | 0.560 |
| 40 | 0.694 | 0.556 | 0.430 | 0.510 | 0.555 |
| 60 | 0.698 | 0.546 | 0.458 | 0.514 | 0.559 |
| 80 | 0.701 | 0.555 | 0.441 | 0.513 | 0.559 |
| 100 | 0.670 | 0.568 | 0.426 | 0.517 | 0.556 |
| Sed ± | 0.01330 | 0.00763 | 0.01600 | 0.00618 | 0.00407 |
| df | 5 | 5 | 5 | 5 | 5 |
| *P* | 0.221 | 0.155 | 0.253 | 0.486 | 0.595 |
| Sig | NS | NS | NS | NS | NS |
| Factor 2 Sex | | | | | |
| Males | 0.699 | 0.565 | 0.436 | 0.518 | 0.561 |
| Females | 0.677 | 0.551 | 0.445 | 0.511 | 0.553 |
| Sed ± | 0.00768 | 0.00441 | 0.00924 | 0.00357 | 0.00235 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.008 | 0.004 | 0.344 | 0.094 | 0.004 |
| Sig | ** | ** | NS | NS | ** |

Mortality and bird health

Mortality between day-old and 42 days of age, or during any of the intermediate periods studied, was not affected by dietary whole rapeseed concentration or sex (Table 29). Mean mortality to 42 days of age was low at only 3.3%. Only three birds out of 748 housed at day-old were culled due to leg abnormalities.

Table 29. Mortality (%)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0-21 | 22-35 | 36-42 | 22-42 | 0-42 |
| Factor 1 Dietary whole rapeseed (g/kg) | | | | | |
| 0 | 3.0 | 0.8 | 1.5 | 2.3 | 5.3 |
| 20 | 4.6 | 0.0 | 0.8 | 0.8 | 5.3 |
| 40 | 1.5 | 1.5 | 0.0 | 1.5 | 3.0 |
| 60 | 1.5 | 0.0 | 0.8 | 0.8 | 2.3 |
| 80 | 0.8 | 0.0 | 0.0 | 0.0 | 0.8 |
| 100 | 0.0 | 2.2 | 0.8 | 3.0 | 3.0 |
| Sed ± | 1.750 | 0.974 | 1.157 | 1.309 | 2.228 |
| df | 5 | 5 | 5 | 5 | 5 |
| *P* | 0.159 | 0.133 | 0.783 | 0.251 | 0.311 |
| Sig | NS | NS | NS | NS | NS |
| Factor 2 Sex | | | | | |
| Males | 2.3 | 0.8 | 1.0 | 1.8 | 4.0 |
| Females | 1.5 | 0.8 | 0.3 | 1.0 | 2.5 |
| Sed ± | 1.010 | 0.562 | 0.668 | 0.756 | 1.287 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.461 | 0.985 | 0.268 | 0.319 | 0.247 |
| Sig | NS | NS | NS | NS | NS |

Litter quality and hock burn damage

Litter friability was extremely good at 20 days of age, and although there were differences in litter friability deterioration score at 41 days of age ($p<0.01$) between dietary whole rapeseed concentrations even at the highest score of 1.5, the litter was mostly friable and free flowing (Table 30). Litter friability deterioration score was highest in birds fed 0 g/kg whole rapeseed, and lowest in birds fed 20 g/kg, 60 g/kg, 80 g/kg and 100 g/kg whole rapeseed. Birds fed 40 g/kg whole rapeseed had an intermediate litter friability deterioration score.

Litter friability deterioration score was similar between males and females at 20 days and 41 days of age.

Table 30. Litter friability deterioration score (1-5)

| Factor | Age (days) | |
|---|---|---|
| | 20 | 41 |
| Factor 1<br>Dietary whole rapeseed<br>(g/kg) | | |
| 0 | 1.0 | 1.5 |
| 20 | 1.0 | 1.0 |
| 40 | 1.0 | 1.3 |
| 60 | 1.0 | 1.0 |
| 80 | 1.0 | 1.1 |
| 100 | 1.0 | 1.1 |
| Sed ± | 0.000 | 0.1434 |
| df | 5 | 5 |
| *P* | - | 0.010 |
| Sig | NS | ** |
| Factor 2<br>Sex | | |
| Males | 1.0 | 1.2 |
| Females | 1.0 | 1.1 |
| Sed ± | 0.000 | 0.0828 |
| df | 1 | 1 |
| *P* | - | 0.659 |
| Sig | NS | NS |

There were no effects of dietary whole rapeseed concentration on litter dry matter, total nitrogen and uric acid-nitrogen contents, and pH at 41 days of age (Table 31). Ammonium-nitrogen concentrations were affected by dietary whole rapeseed concentration and sex ($p<0.01$, Table 31) but not in a consistent manner.

Table 31. Litter dry matter, total nitrogen, uric acid-nitrogen and ammonium-nitrogen contents (g/kg fresh basis) and pH at 41 days of age

| Factor | Litter quality variable | | | | |
|---|---|---|---|---|---|
| | Dry matter (g/kg) | Total nitrogen (g/kg fresh basis) | Uric acid-nitrogen (g/kg fresh basis) | Ammonium-nitrogen (g/kg basis) | pH |
| Factor 1 Dietary whole rapeseed (g/kg) | | | | | |
| 0 | 587 | 43 | 7.9 | 7.1[c] | 7.2 |
| 20 | 650 | 39 | 8.5 | 4.6[ab] | 7.4 |
| 40 | 642 | 43 | 7.9 | 5.6[b] | 8.0 |
| 60 | 680 | 38 | 8.2 | 4.4[a] | 8.0 |
| 80 | 684 | 38 | 8.6 | 4.6[ab] | 7.7 |
| 100 | 673 | 39 | 7.2 | 4.8[ab] | 7.8 |
| Sed ± | 34.01 | 3.94 | 0.798 | 0.471 | 0.416 |
| df | 5 | 5 | 5 | 5 | 5 |
| *P* | 0.079 | 0.624 | 0.534 | <0.001 | 0.371 |
| Sig | NS | NS | NS | *** | NS |
| Factor 2 Sex | | | | | |
| Males | 662 | 38 | 8.0 | 4.9 | 7.7 |
| Females | 644 | 42 | 8.0 | 5.5 | 7.6 |
| Sed ± | 19.63 | 2.27 | 0.461 | 0.272 | 0.240 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.371 | 0.054 | 0.990 | 0.037 | 0.600 |
| Sig | NS | NS | NS | NS | NS |

There was minimal hock burn damage at 41 days of age and there were no differences between males and females (Table 32). Hock burn damage was highest in birds fed 0 g/kg whole rapeseed and lowest in birds fed 60 g/kg whole rapeseed.

Table 32. Hock burn score at 41 days of age

| Factor | Age (days)<br>41 |
|---|---|
| Factor 1<br>Dietary whole rapeseed (g/kg)<br>0 | 1.4 |
| 20 | 1.3 |
| 40 | 1.3 |
| 60 | 1.0 |
| 80 | 1.1 |
| 100 | 1.1 |
| Sed ± | 0.119 |
| df | 5 |
| *P* | 0.019 |
| Sig | * |
| Factor 2<br>Sex<br>Males | 1.2 |
| Females | 1.2 |
| Sed ± | 0.069 |
| df | 1 |
| *P* | 0.425 |
| Sig | NS |

Diet costs and gross margins of live weight sales minus feed costs

Using the ingredient prices shown in Table 21, the cost of the treatment diets have been calculated and the results are given in Table 33. The cheapest starter ration contained 0 g/kg whole rapeseed, whereas the most expensive starter ration contained the highest concentration of whole rapeseed (100 g/kg), the difference between the two diets being about £10/tonne. There was a smaller price differential between the cheapest and most expensive finisher diets (about £7/tonne), but again the most expensive diet was the finisher ration containing 100 g/kg whole rapeseed. The cheaper finisher rations contained the lower concentrations of whole rapeseed.

Table 33. Treatment diet cost (£/tonne)

| Dietary whole rapeseed (g/kg) | Cost of starter ration (£/tonne) | Cost of finisher ration (£/tonne) |
|---|---|---|
| 0 | 174.80 | 169.07 |
| 20 | 183.65 | 166.74 |
| 40 | 179.32 | 169.06 |
| 60 | 180.64 | 171.74 |
| 80 | 182.19 | 174.05 |
| 100 | 184.48 | 175.74 |

Gross margins of live weight sales minus feed costs have been calculated (Table 34) using:

- starter feed intake and finisher feed intake data to 42 days of age;
- diet costs (£/tonne);
- total live weight produced at 42 days of age (based on mean live weight data at 42 days of age and mortality to 42 days of age), and;
- a value of £0.46/kg of live weight sold.

Table 34. Gross margins of live weight sales minus feed costs

| Dietary whole rapeseed (g/kg) | Gross margin (£/bird) |
|---|---|
| | |
| 0 | 0.40 |
| 20 | 0.41 |
| 40 | 0.40 |
| 60 | 0.38 |
| 80 | 0.38 |
| 100 | 0.34 |

Gross margins of live weight sales minus feed costs at 42 days of age were similar when feeding 0 g/kg, 20 g/kg and 40 g/kg whole rapeseed to 42 days of age. At concentrations of greater than 40 g/kg whole rapeseed, the gross margins of live weight sales minus feed costs were reduced.

It is important to note that these financial findings are not definitive: they will change with changing ingredient prices.

*Discussion*

The blend of whole seeds used was sourced separately from the blend of rapeseed meal. Thus, in addition to differences in nutrient content between meal and whole seeds, which were accounted for in the diet formulation processes, the two sources differed in their content of antinutritional factors; the most important of which were glucosinolates, erucic acid and sinapine. In both cases, UK blends of double zero rapeseed varieties were sought. These varieties have low glucosinolate and low erucic acid contents and so they offer better potential as feed ingredients for poultry.

The glucosinolate content of the rapeseed meal used (7 μmol/g) confirms that the aim of sourcing double zero rapeseed varieties was achieved. Larbier and Leclercq (1994) wrote that glucosinolate contents were less than 50 μmol/g in double zero rapeseed meal varieties. van Kempen and Jansmen (1994) reported glucosinolate contents of between 20 μmol/g and 30 μmol/g in the oil free dry matter of rapeseed meals comprising double zero varieties. More recently, Slominski et al., (1999) reported glucosinolate contents of between 11.4 μmol/g and 21.7 μmol/g in the oil free meal when using varieties of yellow seeded canola.

The glucosinolate content of the blended whole seeds at 17 μmol/g was greater than reported for the blended meal, but the glucosinolate content of the whole seeds was still commensurate with having sourced double zero varieties.

Erucic acid contents in the oil were low at less than 0.29% and 10% in the meal and whole seed, respectively.

The sinapine content of the whole rapeseed blend was less than the sinapine content of the rapeseed meal blend (10.5 g/kg versus 11.7 g/kg, respectively). In both cases, however, the sinapine contents were towards the lower end of the published range for double zero rapeseed; this being from 6 g/kg to 30 g/kg depending on cultivar, growing conditions and location (Krygier et al., 1982 and Lacki and Duvnjak, 1996 cited by Qaio and Classen, 2003).

Although the study was not designed in this manner, there were differences in the maximum intakes of total glucosinolates between birds fed rapeseed meal and birds fed whole rapeseed. The maximum intake of total glucosinolates to 42 days of age was considerably higher when feeding whole rapeseed, compared with feeding rapeseed meal (about 8 000 μmol/male bird, *versus* about 2 050 μmol/male bird respectively). This reflected the higher total glucosinolate content of whole rapeseed (17 μmol/g) compared with rapeseed meal (7 μmol/g), and the higher maximum concentration of whole rapeseed fed between day-old and 42 days of

age (100 mg/kg, *versus* 60 g/kg rapeseed meal). The inability to feed high concentrations of rapeseed meal in finisher rations, owing the low ME value of the meal limited the intake of total glucosinolates.

There was a similar story for differences between rapeseed meal and whole rapeseed in sinapine intake to 42 days of age. The maximum intake of sinapine between day-old and 42 days of age was also achieved by feeding whole rapeseed (about 5.0 g/male bird, *versus* about 3.5 g/male bird with rapeseed meal).

The differences in the antinutritional contents of whole seeds and rapeseed meal are likely to be important, whereas theoretically, differences in the nutritive value of the seed and meal can be balanced during diet formulation.

Both glucosinolates and sinapine are metabolised by poultry. Glucosinolates are metabolised by the bird and excreted in the faeces, but the site in the body where metabolism occurs is not clear (Frieg *et al.,* 1986). Qaio and Classen (2003) reported that the hind-gut is probably an important metabolic site for sinapine and that hydrolysis is by gut micro-organisms.

Modern UK broiler hybrids have a very fast growth rate, and they are capable of achieving market live weights of about 2.2 kg or above by 40 days of age. Their rapid growth rates make them particularly sensitive to inadequacies in protein supply, either through low dietary concentrations of nitrogen and amino acids or imbalanced supplies of essential amino acids. They are also sensitive to ingredient antinutritional factors, which either interfere with metabolism or reduce nutrient availability for absorption and metabolism.

Rapeseed, either as a meal or whole seed, reduced live weight gain during early life (0-21 days of age), but in the case of rapeseed meal this did not appear to be the result of lower feed intakes. Neither were there dietary effects on FCE during this period.

Lower live weight gains to 21 days of age in birds fed whole rapeseed did appear to be accounted for by lower feed intakes, although this was only significant for the females.

There was an effect of dietary rapeseed meal concentration on feed intake during the latter part of the growing period (22-42 days of age), but this was not in a consistent manner with regards to dietary rapeseed meal concentration. By comparison there was a linear reduction in feed intake between 22 days and 42 days of age, and throughout the whole growing period (0-42 days of age) in birds fed whole rapeseed.

Live weight at 42 days of age was linearly reduced with increasing dietary concentrations of whole rapeseed, whereas dietary rapeseed meal concentration did not affect live weight at 42 days of age. FCE to 42 days of

age was similar irrespective of dietary rapeseed meal concentration, and it is thought that there was no real effect of dietary whole rapeseed concentration on FCE over this period.

Salmon *et al.,* (1981) reported similar live weight gains to 56 days of age between broilers fed 0 g/kg canola meal throughout, and birds fed increasing concentrations of canola meal up to 281 g/kg in the starter rations and up to 121 g/kg in the finisher rations. FCE to 56 days of age was not affected by canola meal when the nutrient density of the diets was maintained by added fat (*loc. sit*.).

It seems that if there is an effect of rapeseed on broiler performance it is through feed intake responses to dietary rapeseed, whereby a reduced feed intake, and therefore reduced nutrient intake, mostly accounts for any reduction in live weight gain to 42 days of age when the diets are iso-energetic and iso-nitrogenous.

Other workers have reported similar findings for the effects of rapeseed meal on broiler performance. McNeill *et al.,* (2004) found lower feed intakes and live weight gains in broilers grown to 42 days of age when fed either 100 g/kg or 200 g/kg low glucosinolate, low erucic acid rapeseed meal, compared with 0 g/kg rapeseed meal. All diets were iso-energetic and iso-nitrogenous. Performance was similar between birds fed 100 g/kg and 200 g/kg rapeseed meal. FCE to 42 days of age was not affected by dietary rapeseed meal concentration.

The array and concentrations of antinutritional factors in the UK-grown blends of rapeseed used in these studies may have been responsible for the depression in feed intake. They do not appear however, to be at such high concentrations as to impact on the digestion and absorption of nutrients, this being surmised from the lack of an effect on FCE.

Whether chickens perceive diets rich in rapeseed as tasting bitter or astringent is not known. In a review by Picard *et al.,* (2002), it was noted that young chickens perceive tastes (citing work by Ganchrow *et al.,* 1990), but the lack of mastication and the mode of deglutition limits the practical importance of taste in feeding birds. Furthermore, the effect of dietary rapeseed meal concentration on feed intake in the growth study by McNeill *et al.,* (2004), was not reflected in their study on food preference (*loc. sit*.). Broilers up to 14 days of age were allowed the free choice between a diet containing 0 g/kg rapeseed meal and a diet containing 20 g/kg rapeseed meal. Selection to this age between the two diets was similar.

Thus, it is perhaps unlikely that the reduction in feed intake in the growth study was due to poor palatability associated with rapeseed meal. A metabolic or physiological effect of rapeseed antinutritional factors on feed intake might be the reason.

As discussed above there were large discrepancies between glucosinolate intake to 42 days of age in birds fed rapeseed meal and birds fed whole rapeseed (max. about 2 050 µmol/male bird, *versus* 8 000 µmol/male bird, respectively).

A comparison of live weight at 42 days and feed intake to 42 days of age between birds fed either rapeseed meal or whole rapeseed at dietary concentrations of 20 g/kg, 40 g/kg and 60 g/kg, found that birds fed whole rapeseed had significantly lower intakes (mean intake 107 g/bird.day for birds fed whole rapeseed *versus* 110 g/bird.day for birds fed rapeseed meal) and lower live weights (2.562 kg/bird when fed whole rapeseed *versus* 2.651 kg/bird when fed rapeseed meal) (both $p<0.05$). This was despite there being only small discrepancies in ME values and contents of crude protein, lysine, methionine cystine between the meal and whole seed diets. FCE to 42 days of age was similar for birds fed either whole rapeseed or rapeseed meal at concentrations of between 20 g/kg and 60 g/kg.

Other workers (Slominski *et al.,* 1999) reported that rapeseed glucosinolates might be important in reducing feed intake and live weight gain during early life. In the work of Slominski *et al.,* (1999) 301 g/kg meal of *Brassica juncea* 'yellow' cultivar J4316 was fed between four days and 18 days of age. The glucosinolate content of the meal was higher than that of other cultivars studied at 21.7 µmol/g DM. The protein quality was similar across the treatment diets (cultivars), and so the authors attributed poorer live weight gains to 18 days of age with the aforementioned cultivars' higher glucosinolate content.

The study was not designed to test the effects of feeding glucosinolates on broiler feed intakes and live weight gains. There is the suggestion however, that dietary glucosinolate content might have influenced feed intake and live weight gain, and this merits further investigation.

Qaio and Classen (2003) reported that sinapine (sinapine bisulphate trihydrate or sinapine ethanol extract) included at concentrations approximately equivalent to that found in diets containing 300 g/kg rapeseed meal did not cause toxicity or an antinutritional effect in broilers grown to 18 days of age. Qaio and Classen (2003) determined the sinapine content of commercial rapeseed meals prior to diet formulation and reported them as being about 10.0 g sinapine /kg. This was similar to the sinapine content of the whole rapeseed (10.5 g/kg) and slightly less than the sinapine content of the rapeseed meal (11.7 g/kg) used in this study.

However, Qaio and Classen (2003) only fed broiler chicks rapeseed meal or sinapine (sinapine bisulphate trihydrate or sinapine ethanol extract) to 18 days of age. Thus, the total sinapine intake to 18 days of age was less than the total sinapine intake achieved in this study, where birds were grown to 42 days of age. Based on the data of Qaio and Classen (2003) the mean sinapine intake to 18 days of age at a corresponding dietary rapeseed meal concentration of 300 g/kg was calculated to be 1.9 g/bird.

It is the findings of Qaio and Classen (2003) however, and the differences in performance between birds fed whole rapeseed and rapeseed meal in this study, which suggest that sinapine is perhaps not the main factor responsible for poor feed intakes and live weight gains when feeding whole rapeseed.

In this study, feed intake and live weight at 42 days of age were not affected by feeding 60 g/kg rapeseed meal throughout, which gave the maximum sinapine intake as associated with feeding rapeseed meal (about 3.5 g sinapine intake/male bird). Feeding 60 g/kg whole rapeseed to 42 days of age gave a sinapine intake of about 2.8 g/male bird, this being less than the maximum sinapine intake achieved when feeding 60 g/kg rapeseed meal. Thus, if sinapine was responsible for the poor feed intakes and live weight gains found when feeding 60 g/kg whole rapeseed then similar poor performances would have been found for feeding 60 g/kg rapeseed meal.

There is the possibility however, that at the higher concentrations of whole rapeseed (80 g/kg and 100 g/kg) sinapine intake might have been influenced feed intakes and live weight gains.

Further research is needed to clarify the effects of glucosinolate and sinapine intakes on feed intake and live weight gain in broilers grown to market age.

It is worth noting that neither feed intake nor live weight data have been expressed in terms of responses to increasing dietary concentrations or intakes of glucosinolates or sinapine as this is effectively a re-iteration of the results for dietary rapeseed (meal or whole seed) concentration. Furthermore, this would be less accurate than expressing the findings in terms of dietary rapeseed concentration (either meal or seed) as the concentrations of other ingredients, some nutrients and both known and unknown antinutritional factors changed with increasing rapeseed concentration.

If the use of UK rapeseed meal as an ingredient in broiler diets is to be encouraged then perhaps more information is needed on the quality of blended rapeseed meals produced in the UK (protein, amino acid availability and concentrations of antinutritional factors). In addition to varietal and agronomic effects on rapeseed quality, processing is a variable, which influences quality. Over-processing (toasting) reduces protein quality and amino acid availability, and particularly lysine content and availability (Anderson-Hafermann *et al.,* 1993; Newkirk *et al.,* 2003). Naczk *et al.,* (1998) in a review on rapeseed meal cited work by Dabrowski and Sosulski (1983) which showed a reduction in rapeseed phenolic acid content (including sinapine) after solvent extraction.

The ability to dehull rapeseed prior to commercial processing would undoubtedly improve the feeding value of rapeseed meal to broilers. The content of the hulls varies from 10.5 to 20% of the seed weight and 20 to 30% of the defatted meal on a dry weight basis (Naczk *et al.,* 1998 citing work by Applequist and Ohlson,

1972, Theander *et al.,* 1977, Bell, 1993 and Jensen *et al.,* 1995). Hulls consist of low molecular weight carbohydrates, polysaccharides, pectins, cellulose and lignin, as well as proteins, polyphenolics, glucosinolates and minerals (Naczk *et al.,* 1998).

Naczk *et al.,* (1998) reported that mechanical methods for separation of hulls from rapeseed are still inefficient and therefore dehulling is not a standard practice in oil extraction plants.

There was no effect of rapeseed meal or whole rapeseed on mortality to 42 days of age and there was no indication that bird health was adversely affected by dietary rapeseed treatment. Recent work by McNeil *et al.,* (2004), which examined the performance of broilers fed a low glucosinolate, low erucic acid rapeseed meal at concentrations up to 200 g/kg made no mention of an effect on mortality. Information on mortality levels has been omitted from studies, which have been reviewed whilst writing this discussion. It is suggested that this is a positive finding, as an adverse effect of feeding rapeseed meal on the incidence of mortality to market age would most probably have been reported.

Although Timms (1983) reported a high incidence of leg abnormalities (19.4% of 216 birds) in male broilers fed a diet containing 125 g/kg rapeseed meal to ten weeks of age there was no indication in these studies that feeding rapeseed caused leg health problems. Only two birds out of 748 birds fed rapeseed meal and three birds out of 748 birds fed whole rapeseed, were necessarily culled due to leg abnormalities.

Timms (1983) accepted that the incidence of leg abnormalities might have been higher than normal for contemporaneous commercial flocks because of the longer than typical growing period (10 weeks rather than 6 weeks to slaughter), and the sole use of males, which are heavier and more prone to leg abnormalities than females. The mechanism by which rapeseed meal affected leg health was not identified. Previous studies of rapeseed constituents eliminated goitrogenic substances (Timms, 1983 citing Holmes and Roberts, 1963) and low availabilities of manganese (Seth and Clandinin, 1973 cited by Timms, 1983) or zinc (Motzok, 1976 cited by Timms, 1983) as being possible causative factors of leg weakness.

Griffiths *et al.,* (1980) in a study of high glucosinolate rapeseed meal and its effects on meat flavour in three UK broiler hybrids reported that 19 out of 120 birds developed leg abnormalities. There was no effect of diet on the incidence of leg abnormalities but the incidence was highest in the heavier hybrid.

Leg weakness was a particular welfare problem in the 1980s and since then there have been improvements in the leg health of broilers through selection against tibial dyschondroplasia, better management practices and improved nutrition. Dyschondroplasia, valgus and varus deformities, slipped gastrocneumius tendons and rotational deformities as reported by Timms (1983), where more commonly found in commercial broiler

flocks in the 1980s than they are today. This might reduce the likelihood of rapeseed causing leg health problems in commercial broiler flocks but any incidences should be thoroughly examined.

Summers (1995) warned of the possibility of high dietary sulphur contents increasing the incidence of leg abnormalities when feeding canola to broilers. He suggested that this might be partially alleviated by feeding supplementary calcium.

The litter remained mostly friable throughout the growing period and hock burn damage at 41 days of age was minimal. The potassium contents of the rapeseed meal starter rations and of the whole rapeseed starter and finisher rations were high, and this might have been expected to impact on water intake and litter moisture contents. Tucker and Walker (1992) in a review of hock burn damage in broilers highlighted the risk of wet litter and hock burn damage when feeding soya-rich high potassium diets. Perhaps, the use of an exogenous β-gluconase enzyme in the diet helped to alleviate litter problems through improved wheat starch digestibility. Often serious litter quality problems are multifactorial.

Neither litter dry matter content nor litter total nitrogen content at 41 days of age was affected by dietary rapeseed concentration (meal or seed). Litter uric-acid nitrogen and ammonium contents and pH at 41 days of age were similar between dietary rapeseed meal concentrations and except for ammonium-nitrogen contents this was the case for whole rapeseed. Ammonium-nitrogen content at 41 days of age was affected by dietary whole rapeseed and sex, but in an inconsistent manner. Although this is difficult to explain it is likely that the feeding of rapeseed influences gut bacterial populations and this might impact on the availability of nitrogen in the droppings.

Despite concern about phytate complexes reducing the bioavailability of zinc and other divalent metal ions (Erdman, 1979; Jones, 1979; Cheryan, 1980; Maga, 1982), liver and spleen stores of zinc at 21 days and 42 days of age were unaffected by dietary rapeseed concentration.

Although the eating quality of broilers fed rapeseed meal or whole rapeseed was not examined in this study, it is an important issue and so the potential for ‘off’ or ‘fishy’ taint in rapeseed fed broiler meat is briefly discussed.

High glucosinolate rapeseed meal has been found to adversely affect the flavour of broiler meat (Yule and McBride, 1976, 1978; Steedman *et al.,* 1979) although Griffiths *et al.,* (1980) reported that high glucosinolate rapeseed meal (glucosinolate content 49.9 g/kg in the seed) fed at 100 g/kg to 42 days of age did not affect meat flavour.

In general however, the meal from low glucosinolate varieties seems to produce fewer meat flavour problems, although this is dependent on the specifics of the meal and the concentration fed.

Hawrysh *et al.,* (1980a and 1982) reported that the eating quality of broiler meat assessed by a trained taste panel was similar between birds fed a soya bean-based diet and birds fed a diet containing 200 g/kg low glucosinolate rapeseed meal. Other work by Hawrysh *et al.,* (1980b and c) using a trained taste panel or a consumer-based panel found similar eating qualities between birds fed a soya-based diet and birds fed a diet containing 100 g/kg low glucosinolate rapeseed meal. Supplementing diets containing 200 g/kg canola meal with methionine or choline had no adverse effect on eating quality. Methyl containing compounds and choline are produced during the metabolism of sinapine, and 'fishy' taint in brown eggs from susceptible hens fed rapeseed meal has been attributed to the deposition of trimethylamine in the egg.

Salmon *et al.,* (1981) found that the intensity of chicken flavour decreased and the frequency of 'off' flavours increased when diets contained 281 g/kg canola meal in the starter and 121 g/kg canola meal in the finisher were fed. There were no adverse effects on eating quality when the diet contained canola meal up to 210 g/kg in the starter and 90 g/kg canola meal in the finisher. Later work by Salmon *et al.,* (1984) found that canola meal could be fed at concentrations as high as 300 g/kg to 52 days of age without adversely affecting broiler meat flavour, juiciness or tenderness. They also found no adverse effects of supplementing canola-based diets with methionine (1 g DL methionine/kg) and choline (0.5 g choline chloride) on eating quality. However, when high concentrations of canola meal were fed in combination with herring meal (50 g/kg) and supplementary methionine and choline there was an increased incidence of 'off' flavours. Hawrysh *et al.,* (1980a) had previously reported that 200 g/kg canola meal fed together with 50 g herring meal and supplementary methionine (1 g DL methionine/kg) and choline (0.5 g choline chloride) reduced the palatability of broiler meat. They suggested that this combination of ingredients might lead to an accumulation of trimethylamine in the tissues, causing undesirable odours and flavours in the meat. However, an increase in the tissue concentration of omega-3 fatty acids might be a contributing factor (reviewed by Gordon, 2001).

Recent work by McNeill *et al.,* (2004) found that the breast meat from broilers fed 200 g/kg double zero rapeseed meal (solvent extracted) was identified as tasting different when compared with birds fed 0 g/kg rapeseed meal, but there was no strong aversion to the meat. It was not possible to identify differences in meat flavour between birds fed 0 g/kg rapeseed meal and birds fed 100 g/kg rapeseed meal.

Thus, it seems that rapeseed meal at practical commercial concentrations of about 100 g/kg is unlikely to adversely affect broiler meat flavour, but caution is warranted if higher concentrations are used and the diets contain fishmeal and supplementary methionine and choline.

Literature reporting the effects of feeding whole rapeseed on broiler meat flavour has not been found. If whole rapeseed generally has a similar concentration of sinapine to that of rapeseed meal there is perhaps a similar risk of 'off' or 'fishy' flavours at similar dietary concentrations. Research is needed to examine the effects of feeding increasing concentrations of whole rapeseed on broiler meat flavour. This should take into account the interactive effects of feeding whole rapeseed and supplementary methionine and choline on meat flavour, and perhaps also fishmeal.

Another perhaps adverse effect of feeding whole rapeseed on quality is the potential for yellow skin pigmentation. Khattack *et al.,* (1995) reported that whole rapeseed fed at either 100 g/kg or 300 g/kg to broilers aged between seven days and 35 days of age produced yellow pigmented skin on the legs and feet. Yellow pigmentation was greater at the higher dietary concentration of whole rapeseed. It was attributed to undefined carotenoid products in rapeseed (Khattack *et al.,* 1995 citing work by Cmolik *et al.,* 1991).

Yellow skin pigmentation might lead to the birds being downgraded because of poor consumer acceptance. Yellow skin pigmentation is associated with feeding maize and maize fed birds are niche products. However, yellow skin pigmentation was not seen in this study even though broilers were fed up to 100 g/kg whole rapeseed between day-old and 42 days of age.

The finding that gross margins were not affected by feeding rapeseed meal was encouraging, as this is the ultimate factor affecting the use of an ingredient. The financial viability of feeding rapeseed meal will depend however on the price of other proteinaceous raw ingredients and the value of the broiler at market age.

*Conclusions*

1. There was a linear reduction in feed intake and live weight up to 21 days of age when feeding rapeseed meal within the range of 0 g/kg to 160 g/kg. At 42 days of age, there was an effect of rapeseed meal concentration (0 g/kg, 20 g/kg, 40 g/kg, 60 g/kg, 80/0 g/kg, 100/0 g/kg, 120/0 g/kg, 140/0 g/kg and 160/0 g/kg) on feed intake, but not in a consistent manner. Neither live weight nor FCE to 42 days of age were significantly affected by dietary rapeseed meal concentration.
2. There was a linear reduction in feed intake and live weight up to 42 days of age in females fed whole rapeseed within the range of 0 g/kg to 100 g/kg, and in the males at 42 days of age. FCE to 42 days of age was not affected and so the depression in feed intake with increasing whole rapeseed concentration accounted for the reduction in live weight gain.
3. The use of 'best fit' analysis identified a linear relationship between dietary rapeseed concentration (meal or whole seed) and feed intake or live weight as being the most appropriate descriptor. The equations cited in this report describe the bird's responses to the range of dietary rapeseed concentrations studied and they should not be extrapolated to wider ranges of dietary concentrations. Linearality is not expected across a wider range of dietary rapeseed concentrations. However, within the constraints of formulating treatment diets to be iso-energetic and iso-nitrogenous, the maximum range of dietary rapeseed concentrations were studied.
4. Birds fed 20 g/kg, 40 g/kg or 60 g/kg whole rapeseed had lower feed intakes and live weight gains to 42 days of age than birds fed corresponding concentrations of rapeseed meal. The differences in feed intakes and live weight gains between birds fed the two different categories of rapeseed could not be explained by differences in the nutrient content and ME value of the diets. There were however, large differences in total glucosinolate intake to 42 days of age between birds fed whole rapeseed and birds fed rapeseed meal. Birds fed whole rapeseed had much high intakes of total glucosinolates to 42 days of age than birds fed rapeseed meal. Thus, an antinutritional effect of glucosinolates in birds fed whole rapeseed cannot be ruled out.
5. Except at the higher concentrations of whole rapeseed (80 g/kg and 100 g/kg), sinapine was not thought to have been an important antinutritional factor. Whether at the higher concentrations of whole rapeseed, sinapine depressed feed intake and live weight gain is not known.
6. Mortality to 42 days of age was not affected by feeding rapeseed meal up to 160 g/kg in the starter ration and up to 60 g/kg in the finisher ration, or by feeding whole rapeseed up to 100 g/kg in both the starter and finisher rations.
7. The incidence of birds culled due to leg abnormalities was very low and there was no effect of diet on this.
8. The litter remained mostly friable to 42 days of age irrespective of dietary rapeseed meal or whole rapeseed concentration. Neither litter moisture nor total litter nitrogen content was affected by dietary rapeseed concentration (meal or whole seed). There was an indication that the form and availability of

nitrogen in the droppings and litter manure might be affected by dietary protein source. This is not surprising as ingredient intake influences the gut bacterial population and this will impact on the digestion and excretion of nutrients.

9. Hock burn damage was minimal at 42 days of age across all concentrations of dietary rapeseed meal or whole seed.
10. Dietary rapeseed meal concentration did not affect the storage of zinc, copper and cobalt in the liver and spleen at 21 days and 42 days of age, and although there was an interactive effect of dietary rapeseed meal concentration and sex on liver and spleen manganese content at 21 days of age this was in an inconsistent manner. There was no effect of dietary rapeseed meal concentration on liver and spleen manganese content at 42 days of age. The findings suggest that despite rapeseed having a high phytic acid concentration this does not impact on the bird's storage and therefore availability of trace elements for physiological and metabolical processes.

Study 2 Peas and beans

*Introduction*

This study investigated the use of field peas and field beans as protein sources for broilers.

Peas are an increasingly important raw material in some European countries, in particular in France where they represent 11% of all raw materials used by the feed industry (UNIP-ITCF, 1995). The "protein crop" regulation introduced in 1978 stimulated an increase in dry pea production in the EU12 during the 1980s. Total production rapidly increased from less than 400 Mt in the early 1980s to approximately 4 500 Mt in 1994 (*loc. sit*.). Of the EU12 countries France is the most important in terms of pea production, accounting for approximately 79% of total production in 1994. In the same year, Denmark accounted for 8.5% of total production, England accounted for 6.2% of total production and Germany accounted for 3.5% of total production. The area used for dry pea production was 661 000 ha in France, 104 000 ha in Denmark, 80 000 ha in England and 45 000 ha in Germany. The total area used for dry pea production in the EU12 was 981 000 ha. This is a small area compared with that down to cereals. In 2003 3.06 million ha of cereals were grown in UK alone (Defra, 2004).

The majority of dry peas destined for use in animal feeding are round-seeded, free from tannins and with low trypsin inhibitor activity. White flower coloured peas do not contain tannins unlike the coloured flowered varieties (Larbier and Leclercq, 1994). Spring varieties sown between January and April are favoured because of their lower trypsin inhibitor activity and fibre contents than winter sown varieties (*loc. sit*.). Other antinutritional factors present in peas are lectins, saponins and phytic acid, but either they have mild effects or they have received little attention (McNeil *et al.,* 2004).

The crude protein content of peas is variable. Between 1987 and 1994 the crude protein content was 241 ± 12 g/kg DM with the maximum range in one year approaching 70g/kg DM (UNIP-ITCF, 1995). The causes of variability are genetic, cultural and environmental in origin. However, the crude protein content of a variety may be established and reproduced when adopting similar cultural and environmental conditions. UNIP-ITCF (1995) cited work by Carrouree and Duchene (1993) which identified techniques and climatic conditions having a large effect on crude protein content. They found that early drought at the beginning of flowering followed by a period of high moisture generally led to low protein contents. Pea weevil attack or soil compaction below the seed bed, which reduce nitrogen fixation, are likely to lead to lower protein contents. Very early sowing dates will generally lead to higher protein concentrations.

The apparent nitrogen digestibility of raw peas in the adult fowl is estimated as being 75-80% (UNIP-ITCF, 1995 citing the work of Carre *et al.,* 1991). The true digestibility of nitrogen is 88% according to RPAN

(1993). Pea proteins are predominantly water soluble (UNIP-ITCF, 1995). The water soluble proteins are principally globulins (approximately 60% of the total protein content) and albumins (approximately 25% of the total protein content). Ratios of globulins to albumins may vary and the variability is primarily of genetic origin rather than environmental (Baniel *et al.,* 1992). Both globulins and albumins are fairly rich in lysine. As a consequence the ratio of lysine:crude protein content is high. However, the crude protein and lysine contents of peas are less than those of soya bean meal but higher than those of cereals. Lysine is the first limiting amino acid in growth and egg production. Peas have low sulphur amino acid contents and a low tryptophan content compared with soya bean meal.

The amino acid composition of peas varies linearly with crude protein content according to work reviewed by UNIP-ITCF (1995).

Digestibility of pea proteins is improved by pelleting (Carre *et al.,* 1987 and Conan *et al.,* 1992). Autoclaving has less effect on the digestibility of crude protein (Conan and Carre, 1989). Extrusion and fine grinding have very little effect according to Lacassagne (1988) and Conan *et al.,* (1992) respectively.

The dietary energy value of peas is compatible with the majority of diets employed in conventional poultry production. UNIP-ITCF (1995) published an average metabolisable energy value for feed peas of 12.1 MJ/kg DM, which was determined using diets fed as meal to adult cockerels. They noted that the value of pea metabolisable energy in diets after pelleting was higher, being approximately 13.0 MJ/kg DM in the case of steam pelleting. This was said to be due to an improvement in the digestibility of starch from approximately 75-90% in raw peas to as high as 95% following heat treatment (Larbier and Leclercq, 1992). Starch is the predominant component of peas. Samples taken between 1987 and 1994 identified a concentration of 514 ± 15 g/kg DM (UNIP-ITCF, 1995). However, even after heat treatment pea starch is less digestible than cereal starch (Larbier and Leclercq, 1992). Digestibility of fibre is low (Longstaff and McNab, 1989), hence the improvement in metabolisable energy value of peas following dehulling. Lacassagne (1988) reported that extrusion had little effect on the metabolisable energy value of peas. Grinding through a screen size of 0.8 mm increased the metabolisable energy value of peas by 9.6% compared with a screen size of 4 mm (Conan *et al.,* 1992).

The metabolisable energy value of peas is lower in young chicks than in adult cockerels. The greatest difference is seen in meal diets, the reduction being 8.2% compared with only 0.5% in pelleted diets (Barrier-Guillot *et al.,* 1995). Askbrant (1988) reported that the metabolisable energy value of peas in laying hens fed meal was 7.4% lower than in adult cockerels. Work reported by UNIP-ITCF (1995) identified reductions between 2% and 5% in the metabolisable energy value of diets containing 18% peas in the laying hen.

Peas contain small amounts of oligosaccharides, these being between 63-75 g/kg DM according to UNIP-ITCF (1995). The major example is sucrose, representing between 30 and 40% of total soluble carbohydrates in peas, but there are also α-galactosides.

Huisman and Tolman (1992) reviewed the literature on the presence of antinutritional factors in beans. Tannins were of particular concern, but trypsin inhibitors, lectins, phenolics, vicine and covicine might also be problematic for poultry. Vicine and covicine are of more relevance to laying hens however, as they depress egg weight. Recent work has been aimed at examining the effect of tannin-binding agents on digestibility (Lamb and Acamovic, 1998).

Beans have a much lower crude protein content (approximately 291 g /kg DM) than soya bean meal (Larbier and Leclercq, 1994), and beans are much less rich in lysine and tryptophan, and slightly less rich in methionine than soya (see Gordon and Charles, 2002).

Gordon and Charles (2002), in a review of protein sources for organic poultry, recognised that there were considerable differences in published recommended maximum dietary concentrations. This might have been due to differences in nutrient content and contents of antinutritional factors of field peas and field beans between studies. Variety was found to be important in influencing feeding value.

The use of UK-blends of peas and UK-blends of beans, fed at a range of dietary concentrations, which allow for the testing of broiler intake and growth responses, was thought to be worthwhile. This approach was the basis of the study and importantly within the range of concentrations tested the diets were formulated to be iso-energetic and iso-nitrogenous.

*Materials and methods*

The experimental housing and pen facilities used for Studies 2A and 2B were the same as for Study 1, and so were the physical environmental factors, such as room temperature and ventilation rate control. The bird genetic material and the husbandry were the same, and so were the main factors measured and recorded.

UK-grown blends of field peas and field beans were used in this study. The determined nutrient contents and the contents of some of the known antinutritional factors present in field peas and field beans are given in Tables 35 and 36.

Table 35. Determined nutrient content of UK-grown field peas and UK-grown field beans (g/kg fresh basis) under test

| Nutrient (g/kg) | Field peas | Field beans |
|---|---|---|
| Dry matter | 837.0 | 897.5 |
| Crude protein[1] | 202.5 | 267.5 |
| Oil[2] | 19.5 | 15.0 |
| Sugar[3] | N/A | N/A |
| Starch[4] | 405.5 | 386.5 |
| Available lysine | 13.0 | 17.3 |
| Methionine | 2.3 | 1.8 |
| Threonine | 8.6 | 9.6 |
| Estimated ME (MJ/kg) | 11.6 | 11.2 |

[1]Dumas

[2]Acid hydrolysed

[3]Luff Schoorl

[4]Polarimetric

Table 36. Determined contents of some antinutritional factors present in UK-grown field peas and UK-grown field beans (unit fresh weight) under test

| Antinutritional factor | Field peas | Field beans |
|---|---|---|
| Tannins[1] (mg/kg) | 17150 | 24150 |
| Trypsin inhibitor activity (mg/g) | 1.65 | - |
| Erucic acid (% of oil extracted) | 0.13 | 0.10 |
| Glucosinolates[2] (μmol/g) | <2 | <2 |
| Chlorogenic acid (mg/kg) | <1000 | <1000 |
| Sinapine[3] (mg/kg) | <100 | <100 |
| Dry matter | 837.0 | 897.5 |

[1]Tannins are polyphenolic compounds with medium to high molecular weights extracted from oil-free feed/plant material with hot water. The tannin in the extract is defined as that which can reduce cold standard potassium permanganate solution with indigo carmine indicator expressed as quercitannic acid.

[2]Total glucosinolates determined by HPLC

[3]Sinapine determined as sinapine hydrogen sulphide and corrected for recovery.

Study 2A – Dietary field pea concentrations

Nine concentrations of field peas, from 0 to 200 g/kg in equal increments of 25 g/kg, were fed between day-old and 42 days of age (Table 37).

Table 37. Dietary concentration of field peas in the starter and finisher rations (g/kg) tested

| Treatment number | Dietary concentration of field peas (g/kg) | |
|---|---|---|
| | Starter ration | Finisher ration |
| 1 | 0 | 0 |
| 2 | 20 | 20 |
| 3 | 40 | 40 |
| 4 | 60 | 60 |
| 5 | 80 | 0 |
| 6 | 100 | 0 |
| 7 | 120 | 0 |
| 8 | 140 | 0 |
| 9 | 160 | 0 |

The strategy for feed formulation was as follows. A soya protein mix was used as the predominant protein source in the 0 g/kg field pea diet. The starter ration soya protein mix comprised full fat soya and soya 50 (crude protein content 500 g/kg fresh basis), whereas the finisher protein mix comprised only full fat soya. The proportion of soya protein mix in the diet was increasingly reduced so as to allow a greater proportion of field peas in the diet. As field peas did not have the same nutrient contents and ME value as the soya protein mix, other ingredients such as vegetable oils, fishmeal and synthetic amino acids were used to equalise the dietary ME values and nitrogen contents of the rations.

The diet compositions and calculated nutrient analyses are given for the starter and finisher field pea rations in Tables 38 and 39.

Table 38. Diet composition and calculated nutrient contents of the starter field pea rations (g/kg fresh basis) tested

| Ingredient | Quantity (g/kg fresh basis) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Dietary pea concentration (g/kg) | | | | | | | | |
| | 0 | 25 | 50 | 75 | 100 | 125 | 150 | 175 | 200 |
| Wheat | 410.20 | 400.01 | 389.92 | 391.27 | 412.28 | 433.50 | 443.84 | 402.02 | 388.40 |
| Maize germ 10 oil | 212.10 | 200.00 | 187.90 | 169 | 138.30 | 107.50 | 74.20 | 88.70 | 78.70 |
| Maize gluten 60 | 89.80 | 93.40 | 97.00 | 96.20 | 87.80 | 79.30 | 73.90 | 80.00 | 84.90 |
| Salt | 2.40 | 2.40 | 2.40 | 2.30 | 2.00 | 1.80 | 1.80 | 1.90 | 1.90 |
| Soya full fat | 63.30 | 73.20 | 83.10 | 87.80 | 83.50 | 79.20 | 97.50 | 110.80 | 122.30 |
| Soya 50 | 181.20 | 164.80 | 148.50 | 132.30 | 116.70 | 101.00 | 82.90 | 71.60 | 55.10 |
| Field peas | 0.00 | 25.00 | 50.00 | 75.00 | 100.00 | 125.00 | 150.00 | 175.00 | 200.00 |
| Fish meal 66 | 0.00 | 0.00 | 0.00 | 6.40 | 23.80 | 41.30 | 45.40 | 37.90 | 36.00 |
| Synthetic lysine | 3.80 | 3.80 | 3.80 | 3.70 | 3.20 | 2.70 | 2.50 | 2.50 | 2.60 |
| Synthetic methionine | 0.67 | 0.67 | 0.67 | 0.65 | 0.60 | 0.54 | 0.59 | 0.62 | 0.64 |
| Synthetic threonine | 0.53 | 0.52 | 0.51 | 0.48 | 0.42 | 0.36 | 0.37 | 0.36 | 0.36 |
| Mineral and vitamin premix | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Limestone | 10.50 | 10.60 | 10.60 | 10.30 | 9.50 | 8.70 | 8.50 | 8.80 | 9.00 |
| Dicalcium phosphate | 19.80 | 19.90 | 19.90 | 18.90 | 16.20 | 13.40 | 12.80 | 14.10 | 14.40 |
| Sodium bicarbonate | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 |
| Total | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 |
| | | | | | | | | | |
| Nutrient | Quantity (g/kg fresh basis) | | | | | | | | |
| Crude protein | 237.3 | 237.8 | 238.4 | 238.7 | 238.9 | 239.1 | 238.8 | 239.4 | 240.0 |
| AME (MJ/kg) | 12.6 | 12.6 | 12.6 | 12.6 | 12.6 | 12.6 | 12.6 | 12.6 | 12.6 |
| Arginine | 15.1 | 15.1 | 15.1 | 15.1 | 15.1 | 15.1 | 15.1 | 15.3 | 15.3 |
| Iso-leucine | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 |
| Methionine | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 |
| Methionine + cystine | 9.3 | 9.3 | 9.2 | 9.2 | 9.1 | 9.1 | 9.0 | 9.0 | 9.0 |
| Threonine | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 |
| Tryptophan | 2.5 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.3 |
| Lysine | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 |
| Calcium | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| Available phosphorus | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Sodium | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| Potassium | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.2 | 7.2 | 7.2 |
| Fibre | 21.6 | 22.6 | 23.6 | 24.6 | 25.7 | 26.7 | 28.4 | 29.0 | 30.0 |
| Oil | 43.7 | 44.4 | 45.2 | 44.7 | 42.1 | 39.5 | 40 | 43.2 | 44.3 |
| Ash | 68.0 | 67.8 | 67.5 | 66.6 | 64.7 | 62.8 | 62.0 | 63.0 | 62.9 |

Table 39. Diet composition and calculated nutrient contents of the finisher field pea rations (g/kg fresh basis) tested

| Ingredient | Quantity (g/kg fresh basis) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Dietary pea concentration (g/kg) | | | | | | | | |
| | 0 | 25 | 50 | 75 | 100 | 125 | 150 | 175 | 200 |
| Wheat | 492.16 | 474.82 | 457.38 | 439.74 | 422.20 | 404.86 | 413.63 | 423.01 | 432.67 |
| Maize germ 10 oil | 200.00 | 200.00 | 200.00 | 200.00 | 200.00 | 200.00 | 167.30 | 133.70 | 100.00 |
| Maize gluten 60 | 65.00 | 72.40 | 79.70 | 87.10 | 94.40 | 101.80 | 96.90 | 91.70 | 86.50 |
| Salt | 2.40 | 2.40 | 2.30 | 2.40 | 2.40 | 2.40 | 2.40 | 2.50 | 2.50 |
| Soya full fat | 199.30 | 181.30 | 163.30 | 145.30 | 127.30 | 109.20 | 109.20 | 109.70 | 110.20 |
| Vegetable oil | 6.00 | 9.00 | 12.10 | 15.10 | 18.20 | 21.20 | 25.00 | 28.80 | 32.60 |
| Field peas | 0.00 | 25.00 | 50.00 | 75.00 | 100.00 | 125.00 | 150.00 | 175.00 | 200.00 |
| Synthetic lysine | 3.00 | 3.00 | 3.10 | 3.20 | 3.30 | 3.30 | 3.20 | 3.00 | 2.80 |
| Synthetic methionine | 0.67 | 0.63 | 0.59 | 0.56 | 0.52 | 0.48 | 0.57 | 0.65 | 0.74 |
| Synthetic threonine | 0.17 | 0.15 | 0.13 | 0.10 | 0.08 | 0.06 | 0.10 | 0.14 | 0.19 |
| Mineral and vitamin premix | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Limestone | 9.60 | 9.60 | 9.70 | 9.80 | 9.90 | 10.00 | 10.00 | 10.00 | 10.00 |
| Dicalcium phosphate | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 | 16.10 | 16.10 |
| Sodium bicarbonate | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 |
| Total | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 |
| | | | | | | | | | |
| Nutrient | Quantity (g/kg fresh basis) | | | | | | | | |
| Crude protein | 191.0 | 191.8 | 192.7 | 193.6 | 194.5 | 195.4 | 194.8 | 194.2 | 193.5 |
| AME (MJ/kg) | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 |
| Arginine | 12.1 | 12.1 | 12.1 | 12.1 | 12.1 | 12.1 | 12.1 | 12.1 | 12.1 |
| Iso-leucine | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| Methionine | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 |
| Methionine + cystine | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.7 |
| Threonine | 6.9 | 6.9 | 6.9 | 6.9 | 6.9 | 6.9 | 6.9 | 6.9 | 6.9 |
| Tryptophan | 2.0 | 2.0 | 1.9 | 1.9 | 1.9 | 1.8 | 1.8 | 1.8 | 1.8 |
| Lysine | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 |
| Calcium | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 |
| Available phosphorus | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 |
| Sodium | 3.2 | 3.2 | 3.2 | 5.3 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| Potassium | 5.5 | 5.4 | 5.3 | 5.7 | 5.1 | 5.0 | 5.2 | 5.5 | 5.7 |
| Fibre | 23.5 | 23.6 | 23.8 | 24.0 | 24.1 | 24.3 | 25.6 | 27.0 | 28.4 |
| Oil | 71.6 | 71.6 | 71.6 | 71.5 | 71.5 | 71.5 | 72.4 | 73.3 | 74.2 |
| Ash | 58.8 | 58.7 | 58.6 | 58.5 | 58.3 | 58.2 | 57.8 | 57.4 | 57.0 |

Study 2B – Dietary field bean concentrations

For the field bean study, the range of concentrations used was between 0 g and 160 g field beans/kg in the starter ration and between 0 g and 120 g field beans/kg in the finisher ration. The lower maximal concentration of field beans in the finisher ration was because of its low dietary energy content limiting its acceptability when formulating diets that were iso-energetic and iso-nitrogenous. There were nine dietary treatments and equal increments in field bean concentrations were used (increments of 20 g/kg field beans in the starter ration and of 15 g/kg field beans in the finisher ration).

The dietary concentrations of field beans used are shown in Table 40.

Table 40. Dietary concentrations of field beans in the starter and finisher rations (g/kg) tested

| Treatment number | Dietary concentration of field beans (g/kg) | |
|---|---|---|
| | Starter | Finisher |
| 10 | 0 | 0 |
| 11 | 20 | 15 |
| 12 | 40 | 30 |
| 13 | 60 | 45 |
| 14 | 80 | 60 |
| 15 | 100 | 75 |
| 16 | 120 | 90 |
| 17 | 140 | 105 |
| 18 | 160 | 120 |

The strategy for diet formulation was similar to that used for the field pea treatments. A combination of different soya products was used to obtain a soya protein mix, which was increasingly replaced in the diet by field beans.

The diet compositions and calculated nutrient analyses are given for the starter and finisher field beans rations in Tables 41 and 42.

Table 41. Diet composition and calculated nutrient analyses of the starter field bean rations (g/kg fresh basis) tested

| Ingredient | Quantity (g/kg fresh basis) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Dietary bean concentration (g/kg) | | | | | | | | |
| | 0/0 | 20/15 | 40/30 | 60/45 | 80/60 | 100/75 | 120/90 | 140/105 | 160/120 |
| Wheat | 410.20 | 409.98 | 409.46 | 409.33 | 409.10 | 408.78 | 408.66 | 408.44 | 408.01 |
| Maize germ 10 oil | 212.10 | 198.60 | 185.10 | 171.50 | 158.00 | 144.50 | 130.90 | 117.40 | 103.90 |
| Maize gluten 60 | 89.80 | 91.40 | 93.00 | 94.70 | 96.30 | 97.90 | 99.50 | 101.10 | 102.80 |
| Salt | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 |
| Soya full fat | 63.30 | 69.80 | 76.40 | 82.90 | 89.50 | 96.00 | 102.60 | 109.10 | 115.70 |
| Soya 50 | 181.20 | 166.70 | 152.30 | 137.80 | 123.30 | 108.90 | 94.40 | 79.90 | 65.40 |
| Field beans | 0.00 | 20.00 | 40.00 | 60.00 | 80.00 | 100.00 | 120.00 | 140.00 | 160.00 |
| Synthetic lysine | 3.80 | 3.80 | 3.90 | 3.90 | 3.90 | 3.90 | 3.90 | 4.00 | 4.00 |
| Synthetic methionine | 0.67 | 0.70 | 0.72 | 0.75 | 0.78 | 0.80 | 0.83 | 0.85 | 0.88 |
| Synthetic threonine | 0.53 | 0.52 | 0.52 | 0.52 | 0.52 | 0.52 | 0.52 | 0.51 | 0.51 |
| Mineral and vitamin premix | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Limestone | 10.50 | 10.60 | 10.60 | 10.60 | 10.60 | 10.60 | 10.60 | 10.60 | 10.60 |
| Dicalcium phosphate | 19.80 | 19.80 | 19.90 | 19.90 | 19.90 | 20.00 | 20.00 | 20.00 | 20.10 |
| Sodium bicarbonate | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 |
| Total | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 |
| | | | | | | | | | |
| Nutrient | Quantity (g/kg fresh basis) | | | | | | | | |
| Crude protein | 237.3 | 237.49 | 237.7 | 237.9 | 238.1 | 238.3 | 238.5 | 238.7 | 238.9 |
| AME (MJ/kg) | 12.6 | 12.6 | 12.6 | 12.6 | 12.6 | 12.6 | 12.6 | 12.6 | 12.6 |
| Arginine | 15.1 | 15.1 | 15.1 | 15.1 | 15.1 | 15.1 | 15.1 | 15.1 | 15.1 |
| Iso-leucine | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 | 10.3 |
| Methionine | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 | 8.9 | 4.9 |
| Methionine + cystine | 9.3 | 9.2 | 9.2 | 9.2 | 9.1 | 9.1 | 9.1 | 9 | 9 |
| Threonine | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 |
| Tryptophan | 2.5 | 2.5 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.3 | 2.3 |
| Lysine | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 |
| Calcium | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 |
| Available phosphorus | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Sodium | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| Potassium | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 |
| Fibre | 21.6 | 22.8 | 24 | 25.3 | 26.5 | 27.7 | 28.9 | 10.1 | 31.4 |
| Oil | 43.7 | 43.7 | 43.6 | 43.6 | 43.5 | 43.4 | 43.4 | 43.4 | 43.4 |
| Ash | 68.0 | 67.7 | 67.3 | 67.0 | 66.6 | 66.3 | 66.0 | 65.6 | 65.3 |

Table 42. Diet composition and calculated nutrient analyses of the field bean finisher rations (g/kg fresh basis) tested

| Ingredient | Quantity (g/kg fresh basis) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Dietary bean concentration (g/kg) | | | | | | | | |
| | 0/0 | 20/15 | 40/30 | 60/45 | 80/60 | 100/75 | 120/90 | 140/105 | 160/120 |
| Wheat | 492.16 | 485.48 | 478.62 | 471.74 | 464.96 | 458.29 | 451.51 | 44453 | 437.86 |
| Maize germ 10 oil | 200.00 | 200.00 | 200.00 | 200.00 | 200.00 | 200.00 | 200.00 | 200.00 | 200.00 |
| Maize gluten 60 | 65.00 | 69.50 | 74.00 | 78.50 | 83.00 | 87.50 | 91.90 | 96.40 | 100.90 |
| Salt | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 |
| Soya full fat | 199.30 | 184.60 | 169.80 | 155.10 | 140.30 | 125.60 | 110.80 | 96.10 | 81.40 |
| Field beans | 0.00 | 15.00 | 30.00 | 45.00 | 60.00 | 75.00 | 90.00 | 105.00 | 120.00 |
| Vegetable oil | 6.00 | 7.90 | 9.90 | 11.90 | 13.90 | 15.80 | 17.80 | 19.90 | 21.70 |
| Synthetic lysine | 3.00 | 3.00 | 3.10 | 3.20 | 3.20 | 3.30 | 3.40 | 3.50 | 3.50 |
| Synthetic methionine | 0.67 | 0.66 | 0.64 | 0.63 | 0.62 | 0.61 | 0.60 | 0.59 | 0.58 |
| Synthetic threonine | 0.17 | 0.16 | 0.14 | 0.13 | 0.12 | 0.10 | 0.09 | 0.08 | 0.06 |
| Mineral and vitamin premix | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Limestone | 9.60 | 9.60 | 9.70 | 9.70 | 9.80 | 9.80 | 9.90 | 9.90 | 10.00 |
| Dicalcium phosphate | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 | 15.90 | 15.90 | 15.90 | 15.90 |
| Sodium bicarbonate | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 |
| Total | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 |
| | | | | | | | | | |
| Nutrient | Quantity (g/kg fresh basis) | | | | | | | | |
| Crude protein | 191.0 | 191.4 | 191.9 | 192.4 | 192.9 | 193.4 | 193.9 | 194.4 | 195 |
| AME (MJ/kg) | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 |
| Arginine | 12.1 | 12.1 | 12.1 | 12.1 | 12.1 | 12.1 | 12.1 | 12.1 | 12.1 |
| Iso-leucine | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| Methionine | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 |
| Methionine + cystine | 7.8 | 7.8 | 7.8 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 |
| Threonine | 6.9 | 6.9 | 6.9 | 6.9 | 6.9 | 6.9 | 6.9 | 6.9 | 6.9 |
| Tryptophan | 2.0 | 2.0 | 2.0 | 2.0 | 1.9 | 1.9 | 1.9 | 1.8 | 1.8 |
| Lysine | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 |
| Calcium | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 |
| Available phosphorus | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 |
| Sodium | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| Potassium | 5.5 | 5.4 | 5.3 | 5.3 | 5.2 | 5.1 | 5.0 | 4.9 | 4.8 |
| Fibre | 23.5 | 23.8 | 24.0 | 24.3 | 24.6 | 24.9 | 25.2 | 25.5 | 25.7 |
| Oil | 71.6 | 71.0 | 70.4 | 69.8 | 69.2 | 68.6 | 68.0 | 67.5 | 66.9 |
| Ash | 58.8 | 58.6 | 58.5 | 58.4 | 58.3 | 58.1 | 58.0 | 57.9 | 57.8 |

## Experiment design and statistical analysis of the data

### Experiment design

The two studies were run concurrently in House 1 on the poultry unit at ADAS Gleadthorpe. The dietary concentration of field peas or field beans x sex treatment combinations was fully randomised across the 72 plots available within the house.

There was a separate control treatment (0 g/kg field peas and 0 g/kg field beans) for the two studies.

Study 2A – Dietary field peas
9 dietary treatments x 2 sexes x 2 replicates = 36 plots.

Study 2B – Dietary field beans
9 dietary treatments x 2 sexes x 2 replicates = 36 plots.

This gave a total of 72 plots, were each plot comprised a wood and wire pen, which was stocked with 22 day-old chicks, either male or female to give a total flock size of 1 584.

### Statistical analysis of the data

The data were analysed using a number of statistical techniques (response curve fitting, ANOVA, covariate analysis, Duncan's multiple range test, Kruksal-Wallis test and Freidman's test) using the software packages GenStat 5 (release 4.1) and Statistica (version 5.5A).

*Results*

Study 2A Field peas

Live weight

For the males, neither linear nor curvilinear responses were identified as being suitable descriptors of the live weight results across the range of dietary pea concentrations studied. In addition to an inconsistency for the effect of increasing dietary field pea concentration on male live weight, there was considerable variation in live weight at a given age and within the same dietary concentration of field peas. For example, mean male live weight at 42 days of age when fed either 0 g /kg, 75 g/kg or 100 g/kg field peas varied by more than 100 g/bird between replicate groups and by more than 150 g/bird at 75 g/kg field peas. This amount of variation in male live weight was large and it would not be acceptable in commercial broiler production. The reason for the variability is not fully understood and cannot be attributed to feeding peas as it occurred in males fed 0 g/kg field peas. This issue is addressed again later in the live weight results section and is considered more fully in the discussion.

There was a curvilinear response to increasing dietary concentrations of field peas on female live weight at 14 days, 21 days and 35 days of age ($p<0.01$), but not at 42 days of age. The form of the response was quadratic and the equations and respective $R^2$ values are given in Table 43 for female live weight at 14 days and 35 days of age, and illustrated in Figure 10 for female live weight at 21 days of age.

Table 43. Quadratic response equations describing the effects of increasing dietary concentrations of whole peas on female live weight at 14 days, 21 days and 35 days of age (kg/bird)

| Age | Equation | $R^2$ value (%) | Significance |
|---|---|---|---|
| 14 | $Y = 0.364 + 4.874e^{-4}x - 1.484e^{-6}x^2$ | 54.9 | $p<0.01$ |
| 35 | $Y = 1.748 + 0.001x - 1.883e^{-6}x^2$ | 49.3 | $p<0.01$ |

where:

y = live weight (kg/bird), and;

x = dietary concentration of field peas (g/kg)

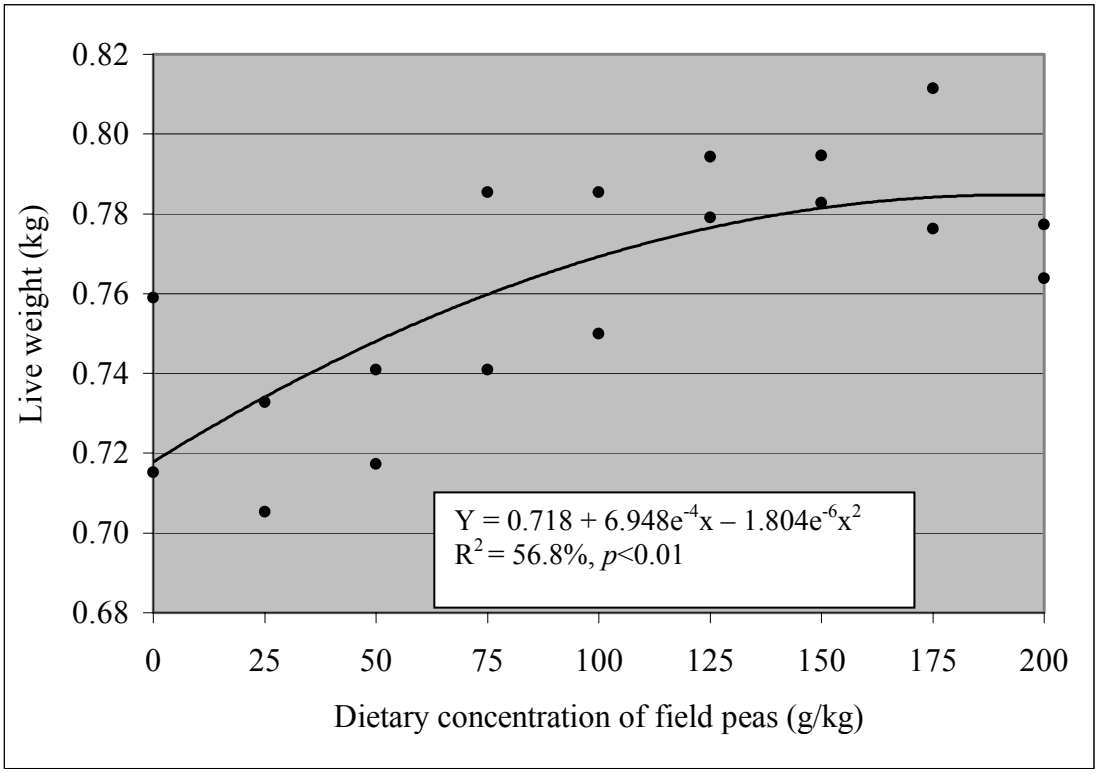


Figure 10. Effect of increasing dietary concentration of field peas on female live weight at 21 days of age (kg/bird)

Analysis of variance of the live weight data was undertaken so as to improve the understanding of the results. There were limitations however, as there were only two replicates of each dietary pea concentration x sex combination, but the low level of replication was a trade-off which was considered to be worthwhile as it allowed a large number of dietary pea concentrations to be studied. The aim was to establish the broilers' performance responses to increasing dietary concentrations of peas.

The following is a description of the actual live weight results and the statistical findings for birds fed increasing dietary concentrations of field peas. It should be noted however, that there was a significant block effect on day-old live weight ($p<0.001$) and so covariate analysis of the live weight data has been undertaken and the findings are reported later. Covariate analysis was also applied to feed intake and FCE data as differences in day-old live weight were likely to influence feed intake, and possibly FCE.

There were interactions between dietary field pea concentration and sex on live weight at 14 days and 42 days of age ($p<0.05$ and $p<0.01$, respectively), but not at 21 days and 35 days of age. The interactions were inconsistent however. For example, at 42 days of age male live weight was highest when fed 175 g/kg field peas, and lowest when fed 200 g/kg field peas (Table 45). Female live weight at 42 days of age was highest

when fed 125 g/kg or 150 g/kg field peas and poorest when fed either 50 g/kg or 100 g/kg field peas. However, the mean female live weight at 42 days of age when fed 75 g/kg field peas was only 30 g less than the maximum mean female live weight, which was achieved by feeding 125 g/kg field peas.

At 21 days and 35 days of age, the lowest mean sex live weights were achieved by feeding 25 g/kg field peas ($p<0.01$) (Table 44). Live weight at 21 days of age did not differ statistically however, between birds fed 0 g/kg, 25 g/kg, 50 g/kg, 75 g/kg, 100 g/kg and 200 g/kg field peas. This was also the case at 35 days of age, except for birds fed 75 g/kg field peas whose mean sex live weights were heavier than for birds fed the aforementioned dietary concentrations.

Feeding 175 g/kg field peas gave the highest mean sex live weights at 21 days and 35 days of age ($p<0.01$). However, mean sex live weight at 21 days of age was statistically similar between birds fed 125 g/kg, 150 g/kg, 175 g/kg and 200 g/kg field peas. This was also the case at 35 days of age, but in addition birds fed 75 g/kg field peas were of similar live weight.

Male live weights were heavier at 21 days and 35 days of age than female live weights ($p<0.001$) (Table 44).

Table 45. Live weight (kg/bird)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0 | 14 | 21 | 35 | 42 |
| Factor 1 Dietary pea concentration (g/kg) | | | | | |
| 0 | 0.045 | 0.395$^{ab}$ | 0.790$^{ab}$ | 1.936$^{ab}$ | 2.634$^{ab}$ |
| 25 | 0.044 | 0.382$^{a}$ | 0.774$^{a}$ | 1.923$^{a}$ | 2.588$^{ab}$ |
| 50 | 0.046 | 0.400$^{ab}$ | 0.794$^{abc}$ | 1.955$^{ab}$ | 2.565$^{a}$ |
| 75 | 0.045 | 0.399$^{ab}$ | 0.797$^{abc}$ | 2.016$^{bcd}$ | 2.560$^{a}$ |
| 100 | 0.045 | 0.409$^{b}$ | 0.804$^{abc}$ | 1.980$^{abc}$ | 2.556$^{a}$ |
| 125 | 0.045 | 0.412$^{bc}$ | 0.823$^{bcd}$ | 1.993$^{abcd}$ | 2.647$^{ab}$ |
| 150 | 0.045 | 0.431$^{c}$ | 0.834$^{cd}$ | 2.057$^{cd}$ | 2.688$^{b}$ |
| 175 | 0.046 | 0.430$^{c}$ | 0.849$^{d}$ | 2.065$^{d}$ | 2.683$^{b}$ |
| 200 | 0.045 | 0.406$^{b}$ | 0.812$^{abcd}$ | 2.002$^{abcd}$ | 2.629$^{ab}$ |
| Sed ± | 0.00041 | 0.00839 | 0.01677 | 0.03431 | 0.04390 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.114 | < 0.001 | 0.009 | 0.006 | 0.038 |
| Sig | NS | *** | ** | ** | * |
| Factor 2 | | | | | |
| Males | 0.045 | 0.423 | 0.855 | 2.157 | 2.840 |
| Females | 0.045 | 0.391 | 0.762 | 1.827 | 2.393 |
| Sed ± | 0.00019 | 0.00396 | 0.00791 | 0.01617 | 0.02070 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.014 | < 0.001 | < 0.001 | < 0.001 | < 0.001 |
| Sig | * | *** | *** | *** | *** |

Table 45. Interactions – live weight (kg/bird) at 42 days of age

| Dietary pea concentration (g/kg) | Sex | |
|---|---|---|
| | Males | Females |
| 0 | 2.861 | 2.407 |
| 25 | 2.831 | 2.344 |
| 50 | 2.856 | 2.274 |
| 75 | 2.675 | 2.445 |
| 100 | 2.855 | 2.257 |
| 125 | 2.820 | 2.475 |
| 150 | 2.905 | 2.471 |
| 175 | 2.964 | 2.402 |
| 200 | 2.796 | 2.462 |

df = 8 $P = 0.007$, ** Sed ± 0.06210

Covariate analysis of the live weight data

The results of covariate analysis of mean sex live weight data at 21 days and 42 days of age are presented in Tables 46 and 47. There were significant effects of dietary field pea concentration on mean sex`live weight at 21 days of age ($p<0.01$). At 21 days of age, live weights were lowest when fed 25 g/kg field peas and highest when fed 175 g/k field peas. Live weight at 21 days of age did not differ statistically however, between birds fed 0 g/kg, 25 g/kg, 50 g/kg, 75 g/kg, 100 g/kg, 125 g/kg and 200 g/kg field peas.

The heaviest birds at 21 days of age were those fed 175 g/kg field peas, but their live weight did not differ statistically from birds fed 0 g/kg, 25 g/kg, 125 g/kg, 150 g/kg and 200 g/kg field peas.

At 42 days of age, there was an interaction between dietary field pea concentration and sex on live weight ($p<0.01$). The interactions were inconsistent and as described earlier.

Covariate analysis of the data produced only subtle differences in the statistical findings and so whilst there was a significant effect of block on day-old live weight, this did not greatly affect the birds responses to dietary pea concentration at later ages.

Table 46. Live weight (kg/bird) – covariate analysis

| Factor | Age (days) | |
|---|---|---|
| | 21 | 42 |
| Factor 1 Dietary pea concentration (g/kg) | | |
| 0 | 0.792[a] | 2.646[ab] |
| 25 | 0.780[a] | 2.619[ab] |
| 50 | 0.791[a] | 2.548[a] |
| 75 | 0.796[ab] | 2.556[a] |
| 100 | 0.803[ab] | 2.550[a] |
| 125 | 0.822[abc] | 2.641[ab] |
| 150 | 0.837[bc] | 2.707[b] |
| 175 | 0.845[c] | 2.665[b] |
| 200 | 0.810[abc] | 2.618[ab] |
| Sed ± | 0.01791 | 0.04399 |
| df | 8 | 8 |
| *P* | 0.019 | < 0.001 |
| Sig | * | *** |
| Factor 2 Males | 0.853 | 2.829 |
| Females | 0.764 | 2.404 |
| Sed ± | 0.00961 | 0.02361 |
| df | 1 | 1 |
| *P* | < 0.001 | < 0.001 |
| Sig | *** | *** |

Table 47. Covariate analysis interactions – live weight (kg/bird) at 42 days of age

| Dietary pea concentration (g/kg) | Sex | |
|---|---|---|
| | Males | Females |
| 0 | 2.837 | 2.455 |
| 25 | 2.868 | 2.371 |
| 50 | 2.825 | 2.271 |
| 75 | 2.656 | 2.455 |
| 100 | 2.828 | 2.272 |
| 125 | 2.798 | 2.484 |
| 150 | 2.912 | 2.502 |
| 175 | 2.951 | 2.379 |
| 200 | 2.789 | 2.448 |

df = 8 $P = 0.004$, ** Sed ± 0.06219

Feed intake

There were no significant intake responses to feeding increasing concentrations of field peas within the range of 0 g/kg to 200 g/kg between day-old and 21 days of age, between 22 days and 42 days of age, or between day-old and 42 days of age. Neither were there any significant effects of dietary field pea concentration on male, female or mean-sex actual feed intakes for the periods studied ($p>0.05$, shown on a mean-sex basis in Table 48).

There was considerable variation between replicate groups of the same sex in feed intake over the whole growing period. For example, male feed intakes differed by up to 11 g/bird.day (maximum at 25 g/kg field peas) and female intake differed by up to 9 g/bird.day (maximum at 150 g/kg field peas) between replicate groups of the same dietary field pea concentration.

As expected males had the highest feed intakes for all periods studied ($p<0.001$) (Table 48).

Table 48. Feed intake (g/bird.day)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0-21 | 22-35 | 36-42 | 22-42 | 0-42 |
| Factor 1 Dietary pea concentration (g/kg) | | | | | |
| 0 | 55 | 161 | 213 | 178 | 116 |
| 25 | 56 | 157 | 204 | 173 | 114 |
| 50 | 55 | 160 | 201 | 173 | 114 |
| 75 | 54 | 161 | 204 | 176 | 114 |
| 100 | 56 | 159 | 192 | 169 | 112 |
| 125 | 54 | 160 | 204 | 174 | 114 |
| 150 | 56 | 163 | 209 | 178 | 117 |
| 175 | 56 | 163 | 210 | 179 | 117 |
| 200 | 52 | 158 | 204 | 173 | 112 |
| Sed ± | 2.67 | 3.10 | 6.01 | 3.80 | 2.69 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.669 | 0.523 | 0.109 | 0.316 | 0.536 |
| Sig | NS | NS | NS | NS | NS |
| Factor 2 Sex | | | | | |
| Males | 58 | 173 | 222 | 189 | 123 |
| Females | 52 | 147 | 187 | 160 | 106 |
| Sed ± | 1.26 | 1.46 | 2.83 | 1.79 | 1.27 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | < 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 |
| Sig | *** | *** | *** | *** | *** |

Covariate analysis of feed intake data

There were no effects of dietary field pea concentration on feed intake between day-old and 21 days of age, but there were effects on pea concentration on feed intake between 22 days and 42 days of age and between day-old and 42 days of age ($p<0.05$, Table 49).

Table 49. Feed intake (g/bird.day) – covariate analysis

| Factor | Age (days) | | |
|---|---|---|---|
| | 0-21 | 22-42 | 0-42 |
| Factor 1 Dietary pea concentration (g/kg) | | | |
| 0 | 55 | 179[a] | 116[a] |
| 25 | 55 | 174[a] | 114[a] |
| 50 | 55 | 173[a] | 114[a] |
| 75 | 54 | 175[a] | 114[a] |
| 100 | 57 | 169[a] | 112[a] |
| 125 | 54 | 174[a] | 114[a] |
| 150 | 55 | 178[a] | 117[a] |
| 175 | 57 | 178[a] | 117[a] |
| 200 | 52 | 173[a] | 112[a] |
| Sed ± | 2.81 | 4.12 | 2.92 |
| df | 8 | 8 | 8 |
| *P* | 0.539 | 0.010 | 0.038 |
| Sig | NS | * | * |
| Factor 2 Sex | | | |
| Males | 58 | 189 | 123 |
| Females | 52 | 161 | 106 |
| Sed ± | 1.51 | 2.21 | 1.57 |
| df | 1 | 1 | 1 |
| *P* | < 0.001 | < 0.001 | < 0.001 |
| Sig | *** | *** | *** |

The amount of field peas consumed between day-old and 21 days of age (g/bird.day), between 22 days and 42 days of age (g/bird.day) and between day-old and 42 days of age (g/bird.day and kg/bird) on a mean sex basis for each dietary treatment is shown in Table 50.

Table 50. Field pea intake between day-old and 21 days of age (g/bird.day), between 22 days and 42 days of age (g/bird.day) and between day-old and 42 days of age (g/bird.day and kg/bird) on a mean sex basis

| Dietary pea concentration (g/kg) | Field pea intake | | | |
|---|---|---|---|---|
| | Age (days) | | | |
| | 0-21 (g/bird.day) | 22-42 (g/bird.day) | 0-42 (g/bird.day) | 0-42 (kg/bird) |
| 0 | 0 | 0 | 0 | 0.000 |
| 25 | 1 | 4 | 3 | 0.120 |
| 50 | 3 | 9 | 6 | 0.239 |
| 75 | 4 | 13 | 9 | 0.359 |
| 100 | 6 | 17 | 11 | 0.470 |
| 125 | 7 | 22 | 14 | 0.599 |
| 150 | 8 | 27 | 18 | 0.737 |
| 175 | 10 | 31 | 20 | 0.860 |
| 200 | 10 | 35 | 22 | 0.941 |

Field pea intake to 42 days of age increased with increasing dietary concentrations. Thus, the highest intake of field peas between day-old and 42 days of age was achieved by feeding 200 g/kg field peas.

FCE

There was a curvilinear relationship between dietary field pea concentration and male and female FCEs between day-old and 21 days of age, and for the females between day-old and 42 days of age ($p<0.05$). The form of the response was quadratic, and the equations and the respective $R^2$ values are given in Table 51 for

male and female FCEs between day-old and 21 days of age, and illustrated in Figure 11 for female FCE between day-old and 42 days of age.

Table 51. Quadratic response equations describing the effects of increasing dietary concentrations of whole peas on male and female FCE between day-old and 21 days of age (0-1)

| Sex | Equation | $R^2$ value (%) | Significance |
|---|---|---|---|
| Males | $Y = 0.628 + 2.904e^{-4}x + 6.508e^{-7}x^2$ | 36.0 | $p<0.05$ |
| Females | $Y = 0.626 + 3.15e^{-4}x - 3.076e^{-7}x^2$ | 34.6 | $p<0.05$ |

where:

y = FCE (0-1), and;

x = dietary concentration of field peas (g/kg)

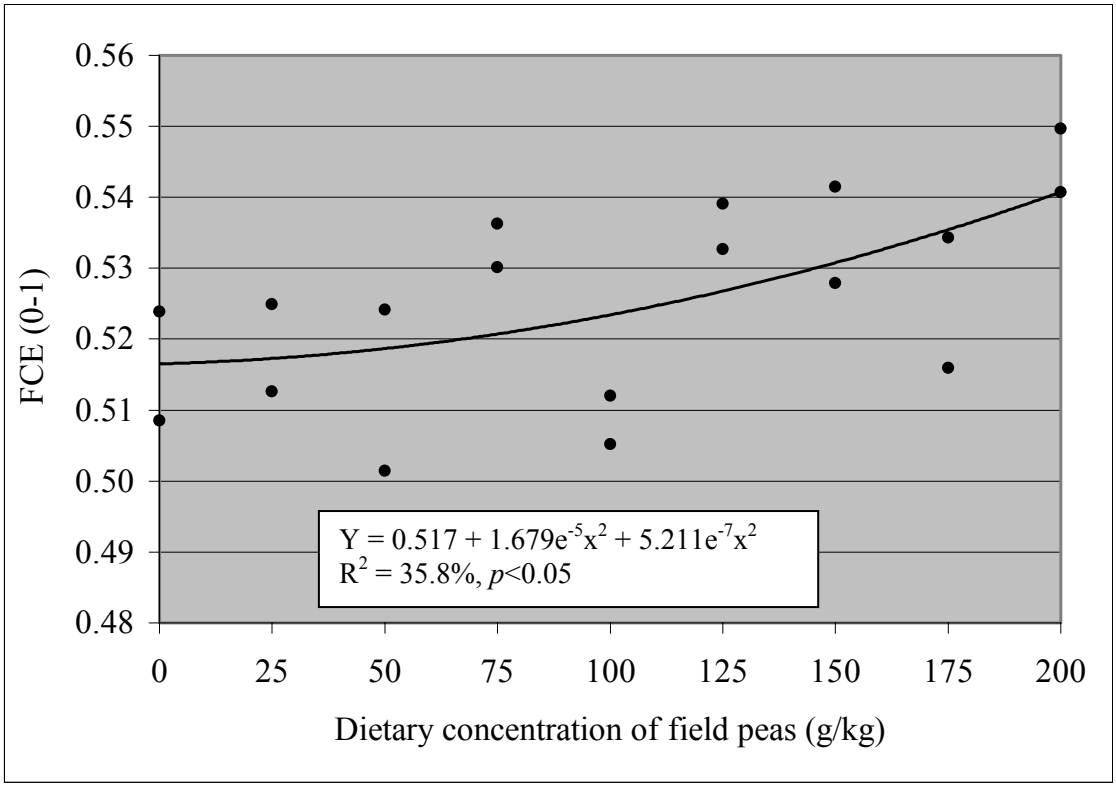


Figure 11. Effect of dietary field pea concentration on female FCE between day-old and 42 days of age (0-1)

It should be noted that the low $R^2$values given in Table 51 and Figure 11 suggest that the quadratic response is perhaps not a good descriptor of the relationship between dietary field pea concentration and FCE between day-old and 42 days of age. Variable performance in birds fed the same dietary field pea concentration and inconsistencies in the effects of increasing dietary field pea concentration on FCE to 42 days of age affected the 'goodness of fit'. Other forms of descriptive curves could be considered, but they will also be affected by variability in bird performance, and their biological meaning might be poor.

FCEs between day-old and 21 days of age and between day-old and 42 days of age were not affected by dietary field pea concentration (Table 52).

There was an interaction between dietary field pea concentration and sex on FCE between 22 days and 42 days of age ($p<0.05$, Table 53) but it was inconsistent. For example, male FCE between 22 days and 42 days of age was highest when fed 25 g/kg or 100 g/kg field peas, and lowest when fed 75 g/kg field peas. Males fed 50 g/kg field peas however, had a reasonable FCE between 22 days and 42 days of age, as did birds fed 0 g/kg, 125 g/kg or 175 g/kg field peas. Female FCE between 22 days and 42 days of age was highest when fed 75 g/kg or 150 g/kg field peas and poorest when fed either 50 g/kg or 100 g/kg field peas. It is suggested that the finding of an interaction between dietary field pea concentration and sex on FCE between 22 days and 42 days of age is treated with some caution as this occurred in the absence of a significant effect of dietary field pea concentration ($p=0.693$, Table 53).

Males had a better FCE between day-old and 42 days of age than females ($p<0.05$) (Table 52).

Table 52. FCE (0-1)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0-21 | 22-35 | 36-42 | 22-42 | 0-42 |
| Factor 1 Dietary pea concentration (g/kg) | | | | | |
| 0 | 0.633 | 0.508[a] | 0.463 | 0.490 | 0.525 |
| 25 | 0.616 | 0.521[ab] | 0.466 | 0.499 | 0.527 |
| 50 | 0.655 | 0.519[ab] | 0.434 | 0.486 | 0.527 |
| 75 | 0.658 | 0.538[c] | 0.391 | 0.482 | 0.524 |
| 100 | 0.641 | 0.526[bc] | 0.428 | 0.490 | 0.528 |
| 125 | 0.688 | 0.534[bc] | 0.434 | 0.495 | 0.541 |
| 150 | 0.669 | 0.533[bc] | 0.437 | 0.496 | 0.538 |
| 175 | 0.675 | 0.531[bc] | 0.425 | 0.490 | 0.535 |
| 200 | 0.701 | 0.538[c] | 0.43 | 0.496 | 0.544 |
| Sed ± | 0.02736 | 0.00668 | 0.02269 | 0.00929 | 0.01025 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.119 | 0.004 | 0.131 | 0.693 | 0.421 |
| Sig | NS | ** | NS | NS | NS |
| Factor 2 Sex | | | | | |
| Males | 0.666 | 0.539 | 0.437 | 0.500 | 0.539 |
| Females | 0.653 | 0.516 | 0.432 | 0.484 | 0.526 |
| Sed ± | 0.01290 | 0.00315 | 0.01070 | 0.00438 | 0.00483 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.334 | < 0.001 | 0.616 | 0.002 | 0.016 |
| Sig | NS | *** | NS | ** | * |

Table 53. Interactions – FCE (0-1) 22-42 days of age

| Dietary pea concentration (g/kg) | Sex | |
|---|---|---|
| | Males | Females |
| 0 | 0.500 | 0.481 |
| 25 | 0.513 | 0.486 |
| 50 | 0.505 | 0.467 |
| 75 | 0.472 | 0.492 |
| 100 | 0.514 | 0.466 |
| 125 | 0.500 | 0.490 |
| 150 | 0.498 | 0.493 |
| 175 | 0.503 | 0.478 |
| 200 | 0.491 | 0.501 |

df = 8 $P = 0.037$, * Sed ± 0.01313

Covariate analysis of FCE data

There were no interactions between dietary field pea concentration and sex on FCE between day-old and 42 days of age, and FCE over the whole growing period was not affected by dietary field pea concentration (Table 54).

Table 54. FCE (0-1) – covariate analysis

| Factor | Age (days)<br>0-42 |
|---|---|
| Factor 1<br>Dietary pea concentration (g/kg)<br>0 | 0.528 |
| 25 | 0.536 |
| 50 | 0.522 |
| 75 | 0.522 |
| 100 | 0.526 |
| 125 | 0.540 |
| 150 | 0.543 |
| 175 | 0.531 |
| 200 | 0.541 |
| Sed ± | 0.00997 |
| df | 8 |
| *P* | 0.277 |
| Sig | NS |
| Factor 2<br>Sex<br>Males | 0.536 |
| Females | 0.529 |
| Sed ± | 0.00535 |
| df | 1 |
| *P* | 0.119 |
| Sig | NS |

Mortality and bird health

Mean mortality to 42 days of age was low at only 3.3%. The causes of mortality were usual in that yolk sac infection due to *E.coli* is often a cause of early mortality and sudden deaths are usually experienced after 21 days of age. The number of birds culled due to leg abnormalities was very low at only one bird out of 792 birds housed.

There was no effect of dietary field concentration on mortality between day-old and 21 days of age, between 22 days and 42 days of age and between day-old and 42 days of age. This is shown on a mean sex basis in Table 55.

Table 55. Estimated median mortality (%) for both sexes

| Factor | Age (days) 0-21 | 22-42 | 0-42 |
|---|---|---|---|
| Factor 1 Dietary pea concentration (g/kg) | | | |
| 0 | 6.8 | 1.1 | 8.0 |
| 25 | 2.3 | 0.0 | 2.3 |
| 50 | 0.0 | 1.1 | 1.1 |
| 75 | 2.3 | 0.0 | 2.3 |
| 100 | 0.0 | 3.4 | 3.4 |
| 125 | 0.0 | 2.3 | 2.3 |
| 150 | 0.0 | 3.4 | 3.4 |
| 175 | 2.3 | 2.3 | 4.6 |
| 200 | 1.1 | 1.1 | 2.3 |
| df | 8 | 8 | 8 |
| S | 11.81 | 6.98 | 8.51 |
| *P* | 0.160 | 0.539 | 0.385 |
| Sig | NS | NS | NS |

Litter quality and hock burn damage

Litter friability was good throughout the study and birds were free from hock burn damage. There were no effects of field pea concentration or sex of bird on either of these parameters (Tables 56 to 58) or on litter dry matter, total nitrogen, uric acid-nitrogen and ammonium-nitrogen contents at 41 days of age (Table 59).

Litter pH at 41 days of age was affected by dietary field pea concentration ($p<0.05$) (Table 59). Litter pH at 41 days of age was lowest when fed 25 g/kg and 100 g/kg field peas and highest when fed 200 g/kg field peas. Litter pH at this age did not differ statistically ($p<0.05$) however, between birds fed 0 g/kg, 25 g/kg, 50 g/kg, 75 g/kg 100 g/kg, 125 g/kg and 150 g/kg field peas. In addition, litter pH at 41 days of age was statistically similar between birds fed 50 g/kg, 75 g/kg, 125 g/kg, 150 g/kg, 175 g/kg and 200 g/kg field peas.

There was no difference in litter pH at 41 days of age between the males and females (Table 59).

Table 56. Median litter friability deterioration score (1-5) for males

| Factor | Age (days) | |
|---|---|---|
| | 20 | 41 |
| Factor 1 Dietary pea concentration (g/kg) | | |
| 0 | 1.0 | 1.2 |
| 25 | 1.0 | 1.5 |
| 50 | 1.0 | 1.8 |
| 75 | 1.0 | 2.3 |
| 100 | 1.0 | 3.3 |
| 125 | 1.0 | 1.7 |
| 150 | 1.0 | 2.7 |
| 175 | 1.0 | 2.3 |
| 200 | 1.0 | 2.0 |
| df | 8 | 8 |
| H | 0.00 | 11.06 |
| *P* | 1.000 | 0.198 |
| Sig | NS | NS |

Table 57. Median litter friability deterioration score (1-5) for females

| Factor | Age (days) | |
|---|---|---|
| | 20 | 41 |
| Factor 1 Dietary pea concentration (g/kg) | | |
| 0 | 1.0 | 2.0 |
| 25 | 1.0 | 2.3 |
| 50 | 1.0 | 1.2 |
| 75 | 1.0 | 2.0 |
| 100 | 1.0 | 1.7 |
| 125 | 1.0 | 1.3 |
| 150 | 1.0 | 2.0 |
| 175 | 1.0 | 1.2 |
| 200 | 1.0 | 1.0 |
| df | 8 | 8 |
| H | 0.00 | 10.93 |
| *P* | 1.000 | 0.206 |
| Sig | NS | NS |

Table 58. Median hock burn score (1-5) at 41 days

| Factor | Sex | |
|---|---|---|
| | Male | Female |
| Factor 1 Dietary pea concentration (g/kg) | | |
| 0 | 1.8 | 1.5 |
| 25 | 1.4 | 1.5 |
| 50 | 2.0 | 1.5 |
| 75 | 1.4 | 1.8 |
| 100 | 1.8 | 1.2 |
| 125 | 1.6 | 1.5 |
| 150 | 2.0 | 1.7 |
| 175 | 2.3 | 1.5 |
| 200 | 1.7 | 1.7 |
| df | 8 | 8 |
| H | 8.57 | 5.27 |
| *P* | 0.380 | 0.729 |
| Sig | NS | NS |

Table 59. Litter dry matter, total nitrogen, uric acid-nitrogen and ammonium-nitrogen contents (g/kg) and pH at 41 days of age

| Factor | Litter quality variable | | | | |
|---|---|---|---|---|---|
| | Dry matter (g/kg) | Total nitrogen (g/kg DM basis) | Uric acid-nitrogen (g/kg fresh basis) | Ammonium-nitrogen (g/kg DM basis) | pH |
| Factor 1 Dietary pea concentration (g/kg) | | | | | |
| 0 | 599.0 | 47.4 | 20.2 | 6.9 | 6.7[ab] |
| 25 | 646.0 | 40.8 | 18.5 | 7.6 | 6.6[a] |
| 50 | 633.0 | 56.7 | 20.2 | 7.2 | 6.8[abc] |
| 75 | 656.0 | 43.1 | 21.2 | 8.2 | 7.2[abc] |
| 100 | 648.0 | 49.5 | 26.2 | 8.4 | 6.7[a] |
| 125 | 678.0 | 39.9 | 22.0 | 7.7 | 7.3[abc] |
| 150 | 607.0 | 46.4 | 22.5 | 10.6 | 7.4[abc] |
| 175 | 640.0 | 38.5 | 22.5 | 7.4 | 7.4[bc] |
| 200 | 708.0 | 41.2 | 24.7 | 6.6 | 7.6[c] |
| Sed ± | 48.200 | 5.350 | 4.370 | 1.579 | 0.320 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.499 | 0.062 | 0.774 | 0.410 | 0.043 |
| Sig | NS | NS | NS | NS | * |
| Factor 2 Sex | | | | | |
| Males | 643.0 | 47.1 | 20.5 | 8.3 | 7.2 |
| Females | 649.0 | 42.6 | 23.6 | 7.3 | 7.0 |
| Sed ± | 22.700 | 2.520 | 2.060 | 0.744 | 0.151 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.791 | 0.087 | 0.156 | 0.199 | 0.139 |
| Sig | NS | NS | NS | NS | NS |

Liver and spleen trace element concentrations

Liver and spleen moisture and trace element contents were not affected by dietary field pea concentration (Table 60). There were no differences between males and females in the trace element content of the liver and spleen but the males had a higher liver and spleen moisture content than the females ($p<0.05$) (Table 60).

Table 60. Liver and spleen moisture (g/kg) and trace element concentrations (mg/kg fresh basis) at 42 days

| Factor | Concentrations | | | | |
|---|---|---|---|---|---|
| | Moisture (g/kg) | Cobalt (mg/kg fresh basis) | Copper (mg/kg fresh basis) | Manganese (mg/kg fresh basis) | Zinc (mg/kg fresh basis) |
| Factor 1 Dietary pea concentration (g/kg) | | | | | |
| 0 | 701 | 0.1 | 3.6 | 2.6 | 23.5 |
| 25 | 759 | 0.1 | 3.4 | 2.9 | 23.5 |
| 50 | 704 | 0.1 | 3.8 | 2.8 | 23.2 |
| 75 | 750 | 0.1 | 3.4 | 2.7 | 21.9 |
| 100 | 702 | 0.1 | 3.5 | 2.5 | 23.0 |
| 125 | 677 | 0.2 | 3.6 | 2.5 | 22.4 |
| 150 | 680 | 0.1 | 3.4 | 2.8 | 22.0 |
| 175 | 722 | 0.2 | 3.4 | 2.6 | 23.1 |
| 200 | 709 | 0.1 | 3.4 | 2.7 | 22.8 |
| Sed ± | 29.54 | 0.100 | 0.360 | 0.321 | 1.769 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.141 | 0.901 | 0.981 | 0.969 | 0.980 |
| Sig | NS | NS | NS | NS | NS |
| Factor 2 Sex | | | | | |
| Male | 727 | 0.1 | 3.4 | 2.6 | 22.7 |
| Female | 696 | 0.1 | 3.5 | 2.7 | 22.9 |
| Sed ± | 13.92 | 0.047 | 0.170 | 0.151 | 0.834 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.036 | 0.635 | 0.575 | 0.472 | 0.828 |
| Sig | * | NS | NS | NS | NS |

Diet costs and gross margins of live weight sales minus feed costs

Using the ingredient prices shown in Table 61, the cost of the treatment diets have been calculated and the results are given in Table 62. In both the starter and finisher rations, the diets became more expensive as the concentration of field peas increased.

Table 61. Ingredient cost (£/tonne)

| Ingredient | Cost (£/tonne) |
|---|---|
| Wheat | 95.00 |
| Maize germ meal | 175.00 |
| Maize gluten 60 | 92.00 |
| Vegetable oil | 545.00 |
| Soya full fat | 231.00 |
| Soya 50 | 197.50 |
| Peas | 260.00 |
| Beans | 270.00 |
| Fishmeal 66 | 440.00 |
| Synthetic lysine | 1750.00 |
| Synthetic methionine | 2000.00 |
| Synthetic threonine | 5500.00 |
| Premix starter | 2280.00 |
| Premix finisher | 1480.00 |
| Limestone | 54.65 |
| Dicalcium phosphate | 275.00 |
| Sodium bicarbonate | 210.00 |
| Salt | 90.00 |

Table 62. Treatment diet cost (£/tonne)

| Dietary pea concentration (g/kg) | Cost of starter ration (£/tonne) | Cost of finisher ration (£/tonne) |
|---|---|---|
| 0 | 162.38 | 156.26 |
| 25 | 165.22 | 159.08 |
| 50 | 168.04 | 162.10 |
| 75 | 171.41 | 165.05 |
| 100 | 175.38 | 168.08 |
| 125 | 179.32 | 170.88 |
| 150 | 182.73 | 174.50 |
| 175 | 186.21 | 177.95 |
| 200 | 189.04 | 181.46 |

Gross margins of live weight sales minus feed costs have been calculated (Table 63) using:

- starter feed intake and finisher feed intake data to 42 days of age (Table 48);
- diet costs (£/tonne, Table 62);
- total live weight produced at 42 days of age (based on mean live weight data at 42 days of age and mortality to 42 days of age, and;
- a value of £0.47/kg of live weight sold.

Table 63. Gross margins of live weight sales minus feed costs

| Dietary pea concentration (g/kg) | Gross margin (£/bird) |
|---|---|
| 0 | 0.41 |
| 25 | 0.40 |
| 50 | 0.38 |
| 75 | 0.36 |
| 100 | 0.34 |
| 125 | 0.36 |
| 150 | 0.33 |
| 175 | 0.32 |
| 200 | 0.32 |

In general, there was an increasing financial penalty associated with feeding more field peas (Table 63), which was due to the higher diet costs with increasing pea concentration (Table 62) rather than poorer FCEs to 42 days of age. As the diets were formulated to be iso-energetic and iso-nitrogenous within the range of field pea concentrations studied, there might be more scope in commercial diet formulations to reduce the cost of diets including peas. This will depend however, on the price of ingredients at any given time.

Study 2B Field beans

Live weights

There was a curvilinear response to increasing dietary concentrations of field beans on male live weight at 14 days ($p<0.05$, Figure 12), but not on female live weight at 14 days and for neither the males or females at 21 days, 35 days nor 42 days of age.

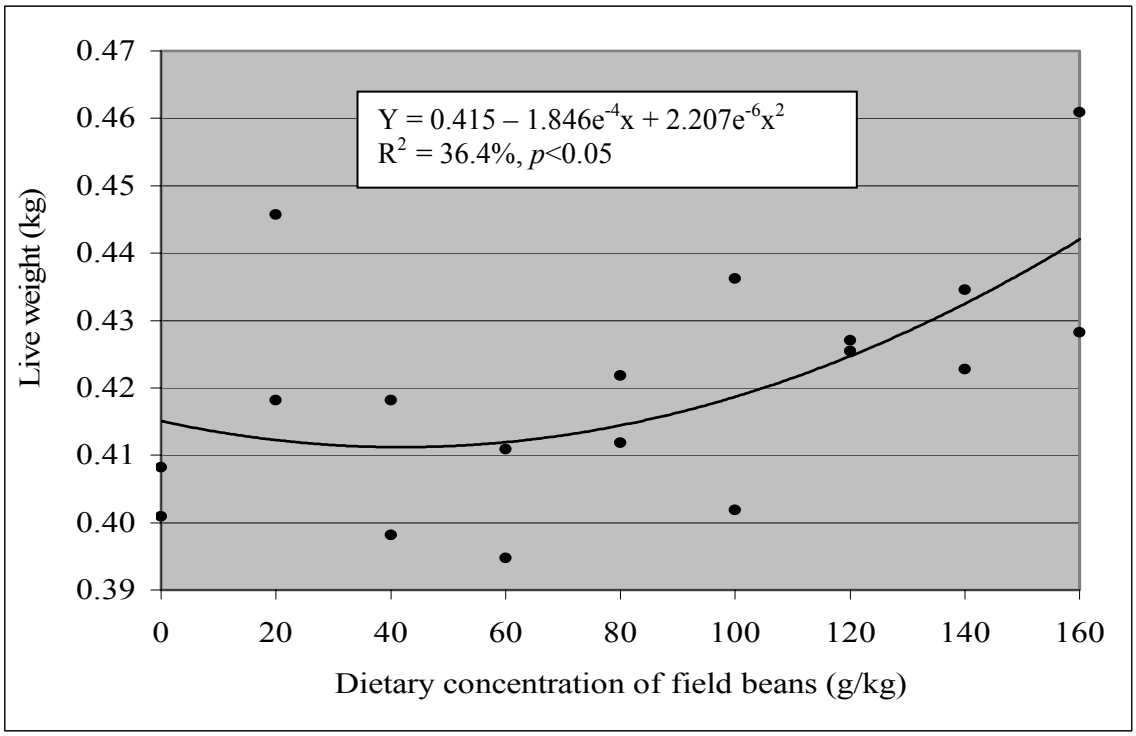


Figure 12. Effect of dietary field bean concentration on male live weight at 14 days of age (kg/bird)

There were no statistically significant effects of dietary field bean concentration on live weight at 14 days, 21 days, 35 days or 42 days of age ($p>0.05$). This is shown on a mean sex-basis in Table 64. There was however, quite a range in mean-sex live weights at 42 days of age; from 2.552 kg/bird in birds fed 40/30 g/kg field beans to 2.645 kg/bird in birds fed 140/105 g/kg field beans. This was a difference of 93 g/bird, which would be important in commercial broiler production.

There was also considerable variation between replicate groups fed the same dietary concentration of field beans. For example, male live weight at 42 days of age differed by more than 200 g/bird when fed 0 g/kg

field beans and by more than 100 g/bird when fed 40/30 g/kg, 60/45 g/kg or 100/75 g/kg field beans. This level of variability in replicate group live weights was very large and as reported in the results for field peas, is atypical of the performance usually achieved in small pen broiler studies at Gleadthorpe. Unlike for field peas, there was not a significant block effect on live weight at day-old ($p>0.05$). Thus, covariate analysis of the performance results was not undertaken.

Male live weight at 14 days, 21 days, 35 days and 42 days of age was greater than for female live weights ($p<0.001$).

Table 64. Live weight (kg/bird)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0 | 14 | 21 | 35 | 42 |
| Factor 1 Dietary bean concentration (g/kg) | | | | | |
| 0 | 0.045 | 0.406 | 0.803 | 2.003 | 2.623 |
| 20/15 | 0.045 | 0.410 | 0.806 | 1.999 | 2.570 |
| 40/30 | 0.045 | 0.402 | 0.791 | 1.967 | 2.552 |
| 60/45 | 0.045 | 0.403 | 0.797 | 1.955 | 2.614 |
| 80/60 | 0.045 | 0.402 | 0.797 | 2.001 | 2.592 |
| 100/75 | 0.045 | 0.408 | 0.800 | 1.940 | 2.607 |
| 120/90 | 0.044 | 0.412 | 0.793 | 1.940 | 2.591 |
| 140/105 | 0.046 | 0.412 | 0.803 | 1.948 | 2.645 |
| 160/120 | 0.045 | 0.419 | 0.811 | 1.970 | 2.624 |
| Sed ± | 0.00053 | 0.00899 | 0.01550 | 0.04042 | 0.05180 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.456 | 0.622 | 0.942 | 0.591 | 0.743 |
| Sig | NS | NS | NS | NS | NS |
| Factor 2 | | | | | |
| Males | 0.045 | 0.420 | 0.841 | 2.118 | 2.833 |
| Females | 0.045 | 0.396 | 0.760 | 1.820 | 2.371 |
| Sed ± | 0.00025 | 0.00424 | 0.00731 | 0.01905 | 0.02440 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.066 | <0.001 | <0.001 | <0.001 | <0.001 |
| Sig | NS | *** | *** | *** | *** |

Feed intake

There were no effects of dietary field bean concentration on feed intake for any of the periods studied (Table 65). The males had consistently higher feed intakes throughout the 42-day growing period than the females ($p$<0.001, Table 65).

Table 65. Feed intake (g/bird.day)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0-21 | 22-35 | 36-42 | 22-42 | 0-42 |
| Factor 1 Dietary bean concentration (g/kg) | | | | | |
| 0 | 54 | 160 | 206 | 175 | 114 |
| 20/15 | 58 | 162 | 205 | 176 | 117 |
| 40/30 | 56 | 161 | 209 | 177 | 117 |
| 60/45 | 57 | 156 | 200 | 170 | 112 |
| 80/60 | 53 | 160 | 207 | 176 | 114 |
| 100/75 | 54 | 156 | 200 | 171 | 112 |
| 120/90 | 52 | 160 | 204 | 174 | 113 |
| 140/105 | 56 | 155 | 202 | 170 | 113 |
| 160/120 | 56 | 158 | 199 | 171 | 113 |
| Sed ± | 2.77 | 3.24 | 6.87 | 4.04 | 2.89 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.546 | 0.374 | 0.824 | 0.537 | 0.710 |
| Sig | NS | NS | NS | NS | NS |
| Factor 2 Sex | | | | | |
| Males | 59 | 172 | 224 | 189 | 124 |
| Females | 52 | 145 | 183 | 158 | 104 |
| Sed ± | 1.30 | 1.53 | 3.24 | 1.91 | 1.36 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | < 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 |
| Sig | *** | *** | *** | *** | *** |

The amount of field beans consumed between day-old and 21 days of age (g/bird.day), between 22 days and 42 days of age (g/bird.day) and between day-old and 42 days of age (g/bird.day and kg/bird) on a mean sex basis per dietary field bean treatment is shown in Table 66.

Table 66. Field bean intake between day-old and 21 days of age (g/bird.day), between 22 days and 42 days of age (g/bird.day) and between day-old and 42 days of age (g/bird.day and kg/bird) on a mean sex basis

| Dietary field bean Concentration (g/kg) | Field bean intake Age (days) 0-21 (g/bird.day) | 22-42 (g/bird.day) | 0-42 (g/bird.day) | 0-42 (kg/bird) |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0.000 |
| 20/15 | 1 | 3 | 2 | 0.080 |
| 40/30 | 2 | 5 | 4 | 0.159 |
| 60/45 | 3 | 8 | 6 | 0.232 |
| 80/60 | 4 | 11 | 7 | 0.311 |
| 100/75 | 5 | 13 | 9 | 0.383 |
| 120/90 | 6 | 16 | 11 | 0.460 |
| 140/105 | 8 | 18 | 13 | 0.539 |
| 160/120 | 9 | 21 | 15 | 0.619 |

FCE

FCE between day-old and 21 days of age was not affected by dietary field bean concentration, but there was an effect of bean concentration on FCE between 22 days and 42 days of age and between day-old and 42 days of age ($p<0.05$, Table 67). FCE between 22 days and 42 days of age was highest when feeding 105 g/kg field beans over this period, the birds having previously been fed 140 g/kg field beans. This treatment also produced the highest FCE between day-old and 42 days of age. FCE between 22 days and 42 days of age and between day-old and 42 days of age was similar however, between birds fed the following field bean concentrations 0 g/kg, 60/45 g/kg, 80/60 g/kg, 100/75 g/kg, 120/90 g/kg, 140/105 g/kg and 160/120 g/kg.

The lowest FCE between 22 days and 42 days of age and between day-old and 42 days of age was in birds fed 20/15 g/kg field beans ($p<0.05$). However, FCEs for these periods did not differ between birds fed 0 g/kg, 20/15 g/kg, 40/30 g/kg and 80/60 g/kg field beans, and for the period day-old to 42 days of age this included birds fed 60/45 g/kg field beans.

FCE between 22 days and 42 days of age was better in the males than females ($p<0.05$) (Table 67). Although there were no statistically significant effects of sex on FCE between day-old and 42 days of age the males had a numerically higher FCE (Table 67).

The findings on FCE between day-old and 42 days of age should however, be treated with caution as this is a ratio of two measured variables which were subject to a great deal of variability.

Table 67. FCE (0-1)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0-21 | 22-35 | 36-42 | 22-42 | 0-42 |
| Factor 1 Dietary bean concentration (g/kg) | | | | | |
| 0 | 0.665 | 0.526 | 0.433$^{abc}$ | 0.490$^{ab}$ | 0.532$^{ab}$ |
| 20/15 | 0.624 | 0.524 | 0.401$^{a}$ | 0.476$^{a}$ | 0.513$^{a}$ |
| 40/30 | 0.632 | 0.522 | 0.406$^{a}$ | 0.477$^{a}$ | 0.515$^{a}$ |
| 60/45 | 0.625 | 0.522 | 0.464$^{c}$ | 0.499$^{b}$ | 0.531$^{ab}$ |
| 80/60 | 0.673 | 0.535 | 0.412$^{ab}$ | 0.487$^{ab}$ | 0.530$^{ab}$ |
| 100/75 | 0.655 | 0.518 | 0.473$^{c}$ | 0.501$^{b}$ | 0.539$^{b}$ |
| 120/90 | 0.679 | 0.514 | 0.456$^{c}$ | 0.491$^{ab}$ | 0.535$^{b}$ |
| 140/105 | 0.648 | 0.525 | 0.480$^{bc}$ | 0.508$^{b}$ | 0.542$^{b}$ |
| 160/120 | 0.649 | 0.525 | 0.468$^{c}$ | 0.503$^{b}$ | 0.539$^{b}$ |
| Sed ± | 0.02392 | 0.01359 | 0.02188 | 0.00898 | 0.00876 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.267 | 0.920 | 0.007 | 0.024 | 0.032 |
| Sig | NS | NS | ** | * | * |
| Factor 2 Sex | | | | | |
| Males | 0.643 | 0.527 | 0.454 | 0.499 | 0.533 |
| Females | 0.657 | 0.519 | 0.434 | 0.487 | 0.529 |
| Sed ± | 0.01128 | 0.00640 | 0.01032 | 0.00423 | 0.00413 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.241 | 0.247 | 0.065 | 0.011 | 0.367 |
| Sig | NS | NS | NS | * | NS |

Mortality and bird health

Mortality between day-old and 42 days of age was not affected by dietary field bean concentration (Tables 68 to 70?). Mean mortality to 42 days of age was low at only 3.8%. Only four birds out of 792 birds housed at day-old were culled due to leg abnormalities.

Table 68. Estimated median mortality (%) for both sexes

| Factor | Age (days) 0-21 | 22-42 | 0-42 |
|---|---|---|---|
| Factor 1 Dietary bean concentration (g/kg) | | | |
| 0 | 2.3 | 3.4 | 5.7 |
| 20/15 | 1.1 | 1.1 | 2.3 |
| 40/30 | 1.1 | 0.0 | 1.1 |
| 60/45 | 5.7 | 2.3 | 8.0 |
| 80/60 | 1.1 | 0.0 | 1.1 |
| 100/75 | 5.7 | 1.1 | 6.8 |
| 120/90 | 2.3 | 0.0 | 2.3 |
| 140/105 | 0.0 | 2.3 | 2.3 |
| 160/120 | 3.4 | 1.1 | 4.5 |
| df | 8 | 8 | 8 |
| S | 13.96 | 11.43 | 15.25 |
| *P* | 0.083 | 0.178 | 0.054 |
| Sig | NS | NS | NS |

Table 69. Estimated median mortality (%) for the males

| Factor | Age (days) | | |
|---|---|---|---|
| | 0-21 | 22-42 | 0-42 |
| Factor 1 Dietary bean concentration (g/kg) | | | |
| 0 | 2.3 | 2.3 | 4.5 |
| 20/15 | 2.3 | 2.3 | 4.5 |
| 40/30 | 0.0 | 0.0 | 0.0 |
| 60/45 | 9.1 | 4.5 | 13.6 |
| 80/60 | 0.0 | 0.0 | 0.0 |
| 100/75 | 4.5 | 0.0 | 4.5 |
| 120/90 | 4.5 | 0.0 | 4.5 |
| 140/105 | 0.0 | 4.5 | 4.5 |
| 160/120 | 0.0 | 2.3 | 2.3 |
| df | 8 | 8 | 8 |
| S | 9.01 | 9.59 | 10.11 |
| *P* | 0.341 | 0.295 | 0.258 |
| Sig | NS | NS | NS |

Table 70. Estimated median mortality (%) for the females

| Factor | Age (days) | | |
|---|---|---|---|
| | 0-21 | 22-42 | 0-42 |
| Factor 1 Dietary bean concentration (g/kg) | | | |
| 0 | 2.3 | 4.5 | 6.8 |
| 20/15 | 0.0 | 0.0 | 0.0 |
| 40/30 | 2.3 | 0.0 | 2.3 |
| 60/45 | 2.3 | 0.0 | 2.3 |
| 80/60 | 2.3 | 0.0 | 2.3 |
| 100/75 | 6.8 | 2.3 | 9.1 |
| 120/90 | 0.0 | 0.0 | 0.0 |
| 140/105 | 0.0 | 0.0 | 0.0 |
| 160/120 | 6.8 | 0.0 | 6.8 |
| df | 8 | 8 | 8 |
| S | 11.48 | 13.09 | 12.73 |
| *P* | 0.176 | 0.109 | 0.122 |
| Sig | NS | NS | NS |

Litter quality and hock burn damage

Litter friability was good throughout the study and birds were free from hock burn damage. There were no effects of field bean concentration or sex of bird on either of these parameters (Tables 71 to 73 and Table 74) or on litter dry matter, total nitrogen, uric acid-nitrogen and ammonium-nitrogen contents and pH at 41 days of age (Tables 74).

There were differences between the males and females in litter dry matter, total nitrogen and ammonium-nitrogen contents at 41 days of age ($p<0.05$, $p<0.01$ and $p<0.05$, respectively, Table 74). Litter dry matter content was lower in the males than females, but litter total nitrogen and ammonium-nitrogen contents were higher in the males.

Table 71. Median litter friability deterioration score (1-5) for males

| Factor | Age (days) | |
|---|---|---|
| | 20 | 41 |
| Factor 1 Dietary bean concentration (g/kg) | | |
| 0 | 1.0 | 1.8 |
| 20/15 | 1.0 | 2.0 |
| 40/30 | 1.2 | 2.7 |
| 60/45 | 1.0 | 1.5 |
| 80/60 | 1.0 | 2.5 |
| 100/75 | 1.0 | 2.8 |
| 120/90 | 1.0 | 1.7 |
| 140/105 | 1.0 | 1.8 |
| 160/120 | 1.0 | 1.3 |
| df | 8 | 8 |
| H | 8.00 | 6.85 |
| *P* | 0.433 | 0.553 |
| Sig | NS | NS |

Table 72. Median litter friability deterioration score (1-5) for females

| Factor | Age (days) | |
|---|---|---|
| | 20 | 41 |
| Factor 1 Dietary bean concentration (g/kg) | | |
| 0 | 1.0 | 1.2 |
| 20/15 | 1.0 | 2.3 |
| 40/30 | 1.0 | 1.5 |
| 60/45 | 1.0 | 1.5 |
| 80/60 | 1.0 | 1.0 |
| 100/75 | 1.0 | 1.3 |
| 120/90 | 1.0 | 1.2 |
| 140/105 | 1.0 | 1.8 |
| 160/120 | 1.0 | 1.2 |
| df | 8 | 8 |
| H | 0.00 | 10.35 |
| *P* | 1.000 | 0.241 |
| Sig | NS | NS |

Table 73. Median hock burn score (1-5) at 41 days

| Factor | Sex | |
|---|---|---|
| | Male | Female |
| Factor 1 Dietary bean concentration (g/kg) | | |
| 0 | 1.6 | 1.6 |
| 20/15 | 1.6 | 1.4 |
| 40/30 | 2.1 | 1.1 |
| 60/45 | 1.7 | 1.4 |
| 80/60 | 1.8 | 1.5 |
| 100/75 | 1.7 | 1.5 |
| 120/90 | 1.5 | 1.1 |
| 140/105 | 1.4 | 1.3 |
| 160/120 | 1.9 | 1.5 |
| df | 8 | 8 |
| H | 5.63 | 5.76 |
| *P* | 0.688 | 0.674 |
| Sig | NS | NS |

Table 74. Litter dry matter, total nitrogen, uric acid-nitrogen and ammonium-nitrogen contents (g/kg) and pH at 41 days of age

| Factor | Litter quality variable | | | | |
|---|---|---|---|---|---|
| | Dry matter (g/kg) | Total nitrogen (g/kg DM basis) | Uric acid-nitrogen (g/kg fresh basis) | Ammonium-nitrogen (g/kg DM basis) | pH |
| Factor 1 Dietary bean concentration (g/kg) | | | | | |
| 0 | 652.0 | 46.6 | 20.0 | 8.0 | 7.2 |
| 20/15 | 694.0 | 39.4 | 24.0 | 6.4 | 7.1 |
| 40/30 | 643.0 | 49.3 | 23.7 | 7.2 | 7.2 |
| 60/45 | 638.0 | 45.4 | 19.2 | 7.6 | 6.8 |
| 80/60 | 680.0 | 41.9 | 25.0 | 6.7 | 7.2 |
| 100/75 | 609.0 | 42.7 | 21.2 | 8.8 | 6.9 |
| 120/90 | 663.0 | 41.4 | 22.0 | 8.0 | 6.9 |
| 140/105 | 652.0 | 40.2 | 20.0 | 8.2 | 7.1 |
| 160/120 | 681.0 | 35.8 | 19.5 | 7.4 | 7.2 |
| Sed ± | 44.200 | 3.974 | 4.270 | 0.981 | 0.336 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.689 | 0.090 | 0.833 | 0.365 | 0.765 |
| Sig | NS | NS | NS | NS | NS |
| Factor 2 Sex | | | | | |
| Males | 633.0 | 45.6 | 20.6 | 8.1 | 7.0 |
| Females | 680.0 | 39.4 | 22.7 | 7.1 | 7.0 |
| Sed ± | 20.800 | 1.874 | 2.010 | 0.463 | 0.158 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.039 | 0.004 | 0.296 | 0.032 | 0.972 |
| Sig | * | ** | NS | * | NS |

Liver and spleen trace element concentrations

There was no effect of dietary field bean concentration on liver and spleen moisture or trace element content at 42 days of age (Table 75). The only difference between the males and females was that the liver and spleen moisture content was higher in the males ($p<0.05$).

Table 75. Liver and spleen moisture (g/kg) and trace element concentrations (mg/kg fresh basis) at 42 days

| Factor | Concentrations | | | | |
|---|---|---|---|---|---|
| | Moisture (g/kg) | Cobalt (mg/kg fresh basis) | Copper (mg/kg fresh basis) | Manganese (mg/kg fresh basis) | Zinc (mg/kg fresh basis) |
| Factor 1 Dietary bean concentration (g/kg) | | | | | |
| 0 | 696 | 0.1 | 3.6 | 2.5 | 23.5 |
| 20/15 | 720 | 0.3 | 3.3 | 2.7 | 23.7 |
| 40/30 | 713 | 0.1 | 3.5 | 2.9 | 24.7 |
| 60/45 | 719 | 0.1 | 3.3 | 2.6 | 31.0 |
| 80/60 | 704 | 0.1 | 3.5 | 2.7 | 22.9 |
| 100/75 | 701 | 0.1 | 3.5 | 2.7 | 22.8 |
| 120/90 | 749 | 0.1 | 3.2 | 2.5 | 23.8 |
| 140/105 | 731 | 0.1 | 3.2 | 2.9 | 22.5 |
| 160/120 | 726 | 0.2 | 3.4 | 2.5 | 23.2 |
| Sed ± | 2.957 | 0.121 | 0.218 | 0.231 | 3.767 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 7.43 | 0.677 | 0.529 | 0.546 | 0.488 |
| Sig | NS | NS | NS | NS | NS |
| Factor 2 Sex | | | | | |
| Male | 733 | 0.1 | 3.4 | 2.6 | 24.9 |
| Female | 702 | 0.1 | 3.4 | 2.7 | 23.6 |
| Sed ± | 13.94 | 0.057 | 0.103 | 0.109 | 1.776 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.039 | 0.434 | 0.741 | 0.396 | 0.479 |
| Sig | * | NS | NS | NS | NS |

Diet costs and gross margins of live weight sales minus feed costs

Using the ingredient prices shown in Table 61, the cost of the treatment diets have been calculated and the results are given in Table 76. The cheapest starter ration contained 0 g/kg field beans, whereas the most expensive starter ration contained the highest concentration of field beans (160 g/kg), the difference between the two diets being about £16/tonne. There was a smaller price differential between the cheapest and most expensive finisher diets (about £12/tonne), but again the most expensive diet was the finisher ration containing the highest concentration of field beans (120 g/kg field beans). The cheaper finisher rations contained the lower concentrations of field beans.

Table 76. Treatment diet cost (£/tonne)

| Dietary field bean concentration (g/kg) | Cost of starter ration (£/tonne) | Cost of finisher ration (£/tonne) |
|---|---|---|
| 0/0 | 162.38 | 156.26 |
| 20/15 | 164.26 | 157.65 |
| 40/30 | 166.39 | 159.16 |
| 60/45 | 168.32 | 160.77 |
| 80/60 | 170.27 | 162.19 |
| 100/75 | 172.22 | 163.68 |
| 120/90 | 174.16 | 165.27 |
| 140/105 | 176.19 | 166.92 |
| 160/120 | 178.16 | 168.21 |

Gross margins of live weight sales minus feed costs have been calculated (Table 77) using:

- starter feed intake and finisher feed intake data to 42 days of age (Table 65);
- diet costs (£/tonne, Table 76);
- total live weight produced at 42 days of age (based on mean live weight data at 42 days of age and mortality to 42 days of age), and;
- a value of £0.47/kg of live weight sold.

Table 77. Gross margins of live weight sales minus feed costs

| Dietary field bean concentration (g/kg) | Gross margin (£/bird) |
|---|---|
| 0/0 | 0.42 |
| 20/15 | 0.38 |
| 40/30 | 0.37 |
| 60/45 | 0.39 |
| 80/60 | 0.39 |
| 100/75 | 0.40 |
| 120/90 | 0.38 |
| 140/105 | 0.38 |
| 160/120 | 0.37 |

Gross margins of live weight sales minus feed costs at 42 days of age were reduced by feeding field beans, but to a lesser extent than when feeding field peas. In addition, there was not a progressive decline in gross margins of live weight sales minus feed costs with increasing dietary field bean concentration. The reason for this is that although the feed was more expensive with increasing field bean concentration, the FCEs between day-old and 42 days of age were better in birds fed the higher concentrations of field beans. Whether the latter was real effect or a statistically significant effect that occurred by chance due to high levels of variability in live weight gain and feed intake is not clear.

It is important to note however, that these findings are not definitive: they will change with changing ingredient prices.

*Discussion*

UK blends of field peas and field beans were sourced for use in this study. Although feed grade peas were specified at the point of purchase, the determined tannin content of the UK blend of peas was not insignificant at 17 150 mg/kg. Thus, protein and starch digestibility is expected to have been poorer than for blends of white flowered peas, which do not contain tannins.

The UK blend of field beans had a higher tannin content than the peas (at 24 150 mg/kg field beans), and again the value suggests that the preferred white flowered varieties, which have relatively low tannin contents (Larbier and Leclercq, 1994) were not used.

The level of trypsin inhibitor activity in the peas was 1.65 mg/g but it is likely that the activity was destroyed by steam pelleting. Larbier and Leclercq (1994) wrote that steam pelleting at 80°C destroys antinutritional factors having trypsin inhibitor activity. Even if they were not, there is some doubt about the effect pea trypsin inhibitors on poultry performance (McNeil *et al.,* 2004). McNeil *et al.,* (2004) cited work by Carre and Conan (1989), which found that protein digestibility was not correlated with reduced trypsin inhibitor activity.

Although there were some effects of dietary field pea or field bean concentration on performance during the 42-day growing period there tended to be no consistent effects on live weight at 42 days of age or feed intake to 42 days of age.

The most notable finding was the high level of variability in broiler performance to 42 days of age even when fed the control diet (0g/kg field peas or field beans). This is extremely unusual for Gleadthorpe small pen broiler studies as care is taken to control factors (e.g. temperature, background disease levels) which are likely to increase variability. The premise of the experiment design and level of replication used was that variability in broiler performance in small pen Gleadthorpe studies is low. However, differences between replicate groups of the same dietary concentration of peas or beans in broiler live weight at 42 days and feed intake to 42 days of age of greater than 100 g/bird and 10 g/bird.day, respectively were found.

The reason for such variability is not known, and cannot be explained in terms of pea or bean fed birds. Birds fed the control diet, which contained no peas or beans, and which were not atypical of commercial diets in terms of ingredients and ME values and nutrient content, were also variable in live weight and feed intake to 42 days of age. Furthermore, there were two replicate groups of males or females fed 0 g/kg peas or beans as a common control group was not used and in both of the replicate groups live weight and feed intake to 42 days of age was variable.

Disease did not appear to have been an issue as mortality to 42 days of age was low (mean 3.3% in pea fed birds and 3.8% bean fed birds). Litter friability was good throughout most of the growing period and litter dry matter contents at 41 days of age were acceptable, although tending to be perhaps a little low in birds fed 0 g/kg peas. Nicholson *et al.,* (1996) published a mean litter dry matter content of 642 g/kg when surveying and determining the nutrient contents of commercial broiler litters. However, scouring was not evident in any of the treatment or replicate groups.

The control of temperature within the house was good and so this was not a factor, which contributed to the variable performance.

It is noted that day-old live weights were unusually high at a mean of 45 g/bird. This suggests that the chicks were from an old breeder flock as egg weights increase with age and there is a positive correlation between egg weight and day-old chick weight (Raju *et al.,* 1997).

Importantly, there was a significant block effect on day-old chick weight in the field pea study and this was taken into account by applying covariate analysis to the performance data. There were no significant block differences in live weight at day-old in the field bean study.

It was unfortunate that there were differences in day-old chick live weight between the two replicate blocks in the field pea study, and this occurred despite randomly allocating chicks to the plots. It is possible that the chicks came from more than one breeder flock, with the flocks being of different ages and therefore producing different sized eggs. This would account for the variability in day-old chick weight. It is standard practice in Gleadthorpe studies to specify at purchase that chicks should be sourced by the hatchery from only one breeder flock and that the flock should be in mid-lay.

Variability in day-old chick live weight does influence subsequent performance. Other workers have reported increased variability in live weight and feed intake to 42 days of age when growing chicks of different day-old weights in the same pen (Raju *et al.,* 1997). There was less variability in performance to 42 days of age when chicks were group-reared according to day-old live weight. However, in the field pea study there was only about 1 g/bird difference in mean live weight at day-old between the two replicate groups and this is unlikely to have fully accounted for the variability in live weight between replicate groups at 42 days of age. Thus, it is not possible to fully account for the large variability in performance at 42 days of age between replicate groups.

As performance was variable in the control fed birds (0 g/kg field peas and 0 g/kg field beans) the findings cannot be explained in terms of the potential effects of antinutritional factors present in either peas or beans. Furthermore, the dietary concentration of tannins and other antinutritional factors would have increased with

dietary field pea or field bean content and there was no evidence of either a linear depression in performance or increasing variability in performance with increasing dietary concentrations of peas or beans.

There is recent evidence that choice fed broilers select against diets containing high concentrations of pea meal (200 g/kg, McNeil *et al.,* 2004), and this might be expected to increase the variability in feed intake of broilers fed peas but again it does not account for variable feed intakes in control fed birds.

The findings of this study suggest that in broilers having atypically variable performance, feeding peas up to 200 g/kg between day-old and 42 days of age, or feeding field beans up to 160 g/kg between day-old and 21 days of age, followed by up to 120 g/kg field beans from 22 days to 42 days of age did not generally reduce broiler performance. As the dietary concentrations of field peas or field beans increased the costs of the diets increased and this impacted on the gross margins of live weight sales minus feed costs. It is important to note however, that the latter findings are not static. They will change as the relative prices of ingredients change, and with relative changes in the value of chicken meat at the time of consideration. In some market conditions feeding peas or beans might be more favourable than feeding high quantities of soya.

Grosjean (1985) comprehensively reviewed work up to that time on the suitability of peas for animal feeding. He considered them to be satisfactory in poultry diets provided that methionine was added. Recommended maximum inclusion rates were found to vary between authors reviewed because of variation in the types of peas used and the ways in which the peas were treated. Values from 200 g/kg to 500 g/kg were quoted for broiler feeds. Ten years later UNIP-ITCF (1995) produced a major review on peas in animal feeding, with 144 references and much of the comments on the use of peas in poultry diets by Gordon and Charles (2002) were sourced from this publication. Feeding very high concentrations of field peas was possible when the peas were micronised and the diets were supplemented with synthetic lysine (up to 400 g/kg field peas, Igbasan and Guenter, 1996). More conservative recommendations on the maximum dietary concentrations were offered by Leeson and Summers (1997), these being up to 50 g/kg field peas in the starter and up to 100 g/kg field peas in the finisher ration.

Jansen *et al.,* (1993) proposed that beans of coloured flowered varieties may be included at up 300 g/kg in broiler rations, provided that the diets are nutritionally well balanced. It is not possible from the findings of this study to say whether such high concentrations of UK blends of field beans are likely to be tolerated by modern broiler hybrids.

The litter remained mostly friable throughout the growing period and hock burn damage at 41 days of age was minimal. Neither litter dry matter, total nitrogen, uric-acid nitrogen nor ammonium-nitrogen contents at 41 days of age were affected by dietary field pea or field bean concentration. It would be useful to re-

evaluate this is birds, which have less variable performance to 42 days of age. Differences between replicate groups in feed intake might have masked any effects of protein source and utilisation for growth.

*Conclusions*

1. Broiler performance to 42 days of age was atypically very variable for small pen studies at Gleadthorpe. The reasons for such a high level of variability in performance were not fully identified. It is thought that some of the variability in performance to 42 days of age was due to variable day-old chick weights, and this was accounted for in the statistical analyses applied to the data. Generally however, the chicks were unusually large and this might have affected subsequent performance. Environment control in the study facility was good and so temperature variations within the house were minimised. Mortality to 42 days of age was low and there was no evidence of scouring or disease. Thus, background variation was minimised as per standard practice in Gleadthorpe studies.
2. The findings of this study suggest that in broilers having variable performance, feeding peas up to 200 g/kg between day-old and 42 days of age, or feeding field beans up to 160 g/kg between day-old and 21 days of age, followed by up to 120 g/kg field beans from 22 days to 42 days of age did not generally reduce broiler performance.
3. The litter remained mostly friable to 42 days of age irrespective of dietary field pea or field bean concentration. Neither litter moisture, total litter nitrogen, uric acid nitrogen nor ammonium nitrogen contents were affected by dietary field pea or field bean concentration.
4. Hock burn damage was minimal at 42 days of age across all concentrations of field peas and field beans.
5. Dietary field pea or field bean concentration did not affect the storage of zinc, manganese, copper and cobalt in the liver and spleen at 42 days of age. The findings suggest that for the concentrations of field peas and field beans used in this study, antinutritional factors present in peas or beans do not impact on the bird's storage and therefore availability of trace elements for physiological and metabolical processes.
6. As the dietary concentrations of field peas or field beans increased the costs of the diets increased and this impacted on the gross margins of live weight sales minus feed costs. It is important to note however, that the latter findings are not static. They will change as the relative price of ingredients change, and with relative changes in the value of chicken meat at the time of consideration. In some market conditions feeding peas or beans might be more favourable than feeding high quantities of soya.

Study 3 UK grown protein mix

*Introduction*

A mix of ingredients can be useful in achieving a balanced feed, and this study investigated the use of a protein rich mix based on UK grown materials. Such a mix may help to overcome the limits to inclusion rates in final diets of any one ingredient, partly because high levels of any given protein source are inevitably associated with high levels of the antinutritional factors which it contains. However a mixed protein source will normally contain a higher total number of antinutritionals, and this raises questions about the risk of possible additive deleterious effects. This study was designed to test for such possibilities. Another potential virtue of a protein mix is the opportunity for one ingredient to balance the essential amino acid content of another.

*Materials and methods*

The study examined the effects of increasing substitution rates (0% to 100% inclusive) of a 'soya protein mix' (SPM) with a 'non-soya protein mix' (NSPM) on broiler performance, welfare and litter quality when grown to 42 days of age. The responses were studied separately for males and females.

Within the range of substitution rates studied (0% to 100% inclusive), the number of intermediate substitution rates was maximised, but with replication at each substitution rate x sex treatment combination. This approach enhanced the statistical determination of growth responses for the males and females. Nine substitution rates were used (Table 78).

Table 78. Dietary treatments – SPM substitution rates with NSPM (% of the total protein mix in the diet)

| Treatment number | SPM (% of the total protein mix in the diet) | NSPM (% of the total protein mix in the diet) |
|---|---|---|
| 1 | 100.0 | 0.0 |
| 2 | 87.5 | 12.5 |
| 3 | 75.0 | 25.0 |
| 4 | 62.5 | 37.5 |
| 5 | 50.0 | 50.0 |
| 6 | 37.5 | 62.5 |
| 7 | 25.0 | 75.0 |
| 8 | 12.5 | 87.5 |
| 9 | 0.0 | 100.0 |

The compositions of the SPM and the NSPM are given in Tables 79 and 80.

Table 79. Composition of the SPM (kg/tonne)

| Ingredient | Quantity (kg/tonne) |
|---|---|
| | |
| Full-fat soya | 271.0 |
| Soya 50 | 729.0 |
| Total | 1000.0 |

Table 80. Composition of NSPM (kg/tonne)

| Ingredient | Quantity (kg/tonne) |
|---|---|
| Maize gluten 60 | 419.4 |
| Rapeseed meal | 372.0 |
| Whole rapeseed | 50.3 |
| Field beans | 48.0 |
| Field peas | 52.0 |
| Synthetic lysine | 22.1 |
| Synthetic threonine | 36.2 |
| Total | 1000.0 |

In the NSPM, blended sources of UK-grown double 00 rapeseed meal, double 00 whole rapeseed, field peas and field beans were used.

The nutrient content of the NSPM was approximately similar to the nutrient content of the SPM. This allowed a straight substitution within the basal diet; i.e. 1 kg of SPM was replaced with 1 kg of NSPM. The calculated nutrient contents of the SPM and NSPM are given in Tables 81 and 82, respectively.

Table 81. Calculated nutrient content of SPM on a fresh basis (g/kg)

| Nutrient | Content (g/kg) |
|---|---|
| Crude protein | 438.0 |
| Oil | 48.4 |
| Fibre | 37.5 |
| Ash | 56.0 |
| Calcium | 2.2 |
| Available phosphorus | 1.7 |
| Salt | 1.2 |
| Potassium | 18.3 |
| Lysine | 25.7 |
| Methionine | 5.8 |
| Methionine + cystine | 12.2 |
| Threonine | 17.4 |
| Tryptophan | 4.4 |
| Arginine | 30.6 |
| Iso-leucine | 18.3 |
| ME (MJ/kg) | 10.6 |

Table 82. Calculated nutrient content of NSPM on a fresh basis (g/kg)

| Nutrient | Content (g/kg) |
|---|---|
| Crude protein | 438.0 |
| Oil | 20.0 |
| Fibre | 67.3 |
| Ash | 38.7 |
| Calcium | 3.0 |
| Available phosphorus | 2.0 |
| Salt | 0.7 |
| Potassium | 7.4 |
| Lysine | 30.8 |
| Methionine | 9.1 |
| Methionine + cystine | 17.6 |
| Threonine | 17.4 |
| Tryptophan | 2.5 |
| Arginine | 19.4 |
| Iso-leucine | 16.7 |
| ME (MJ/kg) | 10.9 |

A three-stage ration programme consisting of a starter (0-11 days of age), grower (11 days to 28 days of age) and finisher ration (29 days to 42 days of age) was used. The crude protein content was highest in the starter ration. It was then reduced in the grower ration, and further reduced in the finisher ration. This is consistent with commercial practice and it takes into account the birds' decreasing requirements for protein with age. Thus, the total amount of protein mix, either SPM and/or NSPM, was highest in the starter, and lowest in the finisher ration, with the grower intermediate. The concentrations of SPM and/or NSPM in the starter, grower and finisher rations are shown in Tables 83, 84 and 85, respectively.

Table 83. Dietary treatments: percentages and concentrations of SPM and/or NSPM in the starter ration (g/kg)

| Treatment number | SPM (% of the total protein mix in the diet) | NSPM (% of the total protein mix in the diet) | Concentration of SPM (g/kg) | Concentration of NSPM (g/kg) |
|---|---|---|---|---|
| 1 | 100.0 | 0.0 | 283.000 | 0.000 |
| 2 | 87.5 | 12.5 | 247.625 | 35.375 |
| 3 | 75.0 | 25.0 | 212.250 | 70.750 |
| 4 | 62.5 | 37.5 | 176.875 | 106.125 |
| 5 | 50.0 | 50.0 | 141.500 | 141.500 |
| 6 | 37.5 | 62.5 | 106.125 | 176.875 |
| 7 | 25.0 | 75.0 | 70.750 | 212.250 |
| 8 | 12.5 | 87.5 | 35.375 | 247.625 |
| 9 | 0.0 | 100.0 | 0.000 | 283.000 |

Table 84. Dietary treatments: percentages and concentrations of SPM and/or NSPM in the grower ration (g/kg)

| Treatment number | SPM (% of the total protein mix in the diet) | NSPM (% of the total protein mix in the diet) | Concentration of SPM (g/kg) | Concentration of NSPM (g/kg) |
|---|---|---|---|---|
| 1 | 100.0 | 0.0 | 210.900 | 0.000 |
| 2 | 87.5 | 12.5 | 184.538 | 26.363 |
| 3 | 75.0 | 25.0 | 158.175 | 52.725 |
| 4 | 62.5 | 37.5 | 131.813 | 79.088 |
| 5 | 50.0 | 50.0 | 105.450 | 105.450 |
| 6 | 37.5 | 62.5 | 79.088 | 131.813 |
| 7 | 25.0 | 75.0 | 52.725 | 158.175 |
| 8 | 12.5 | 87.5 | 26.363 | 184.538 |
| 9 | 0.0 | 100.0 | 0.000 | 210.900 |

Table 85. Dietary treatments: percentages and concentrations of SPM and/or NSPM in the finisher ration (g/kg)

| Treatment number | SPM (% of the total protein mix in the diet) | NSPM (% of the total protein mix in the diet) | Concentration of SPM (g/kg) | Concentration of NSPM (g/kg) |
|---|---|---|---|---|
| 1 | 100.0 | 0.0 | 180.000 | 0.000 |
| 2 | 87.5 | 12.5 | 157.500 | 22.500 |
| 3 | 75.0 | 25.0 | 135.000 | 45.000 |
| 4 | 62.5 | 37.5 | 112.500 | 67.500 |
| 5 | 50.0 | 50.0 | 90.000 | 90.000 |
| 6 | 37.5 | 62.5 | 67.500 | 112.500 |
| 7 | 25.0 | 75.0 | 45.000 | 135.000 |
| 8 | 12.5 | 87.5 | 22.500 | 157.500 |
| 9 | 0.0 | 100.0 | 0.000 | 180.000 |

The diet compositions and calculated nutrient analyses are given for the starter, grower and finisher rations in Tables 86 to 91.

Table 86. Diet composition - starter ration (g/kg)

| Ingredient | Quantity (g/kg) |
|---|---|
| Wheat | 585.740 |
| Protein mix[1] | 283.000 |
| Fish meal 66 | 74.900 |
| Oil | 23.200 |
| Synthetic lysine | 1.100 |
| Synthetic methionine | 0.960 |
| Limestone | 6.900 |
| Dicalcium phosphate | 8.000 |
| Mineral/vitamin premix | 15.000 |
| Salt | 1.200 |
| Total | 1000.000 |

[1]Protein mix – either SPM and/or NSPM, depending on the dietary treatment.

Table 87. Calculated nutrient specification – Starter ration (g/kg)[2]

| Nutrient | Quantity (g/kg) |
|---|---|
| Crude protein | 235.0 |
| Oil | 44.1 |
| Fibre | 28.5 |
| Ash | 70.4 |
| Calcium | 10.0 |
| Available phosphorus | 5.0 |
| Salt | 3.2 |
| Potassium | 8.0 |
| Lysine | 13.8 |
| Methionine | 4.9 |
| Methionine + cystine | 8.8 |
| Threonine | 8.9 |
| Tryptophan | 2.5 |
| Arginine | 14.8 |
| Iso-leucine | 9.7 |
| ME (MJ/kg) | 12.6 |

[2]Based on 100% SPM.

Table 88. Diet composition – grower ration (g/kg)

| Ingredient | Quantity (kg/tonne) |
|---|---|
| Wheat | 647.452 |
| Protein mix[1] | 210.900 |
| Fish meal 66 | 73.850 |
| Oil | 38.810 |
| Synthetic lysine | 0.330 |
| Synthetic methionine | 0.778 |
| Limestone | 6.410 |
| Dicalcium phosphate | 5.270 |
| Mineral/vitamin premix | 15.000 |
| Salt | 1.200 |
| Total | 1000.000 |

[1]Protein mix – either SPM and/or NSPM, depending on the dietary treatment.

Table 89. Calculated nutrient specification – Grower ration (g/kg)[2]

| Nutrient | Quantity (g/kg) |
|---|---|
| Crude protein | 208.4 |
| Oil | 60.5 |
| Fibre | 25.6 |
| Ash | 64.1 |
| Calcium | 9.0 |
| Available phosphorus | 4.4 |
| Salt | 3.2 |
| Potassium | 6.9 |
| Lysine | 11.5 |
| Methionine | 4.4 |
| Methionine + cystine | 8.0 |
| Threonine | 7.9 |
| Tryptophan | 2.2 |
| Arginine | 12.9 |
| Iso-leucine | 8.6 |
| ME (MJ/kg) | 13.2 |

[2]Based on 100% SPM.

Table 90. Diet composition - finisher ration (g/kg)

| Ingredient | Quantity (g/kg) |
|---|---|
| Wheat | 673.900 |
| Protein mix[1] | 180.000 |
| Fish meal 66 | 73.400 |
| Oil | 45.500 |
| Synthetic lysine | 0.000 |
| Synthetic methionine | 0.700 |
| Limestone | 6.200 |
| Dicalcium phosphate | 4.100 |
| Mineral/vitamin premix | 15.000 |
| Salt | 1.200 |
| Total | 1000.000 |

[1]Protein mix – either SPM and/or NSPM, depending on the dietary treatment

Table 91. Calculated nutrient specification – finisher ration[2]

| Nutrient | Quantity (g/kg) |
|---|---|
| Crude protein | 197.0 |
| Oil | 67.5 |
| Fibre | 24.3 |
| Ash | 61.4 |
| Calcium | 8.5 |
| Available phosphorus | 4.2 |
| Salt | 3.2 |
| Potassium | 6.4 |
| Lysine | 10.5 |
| Methionine | 4.2 |
| Methionine + cystine | 7.6 |
| Threonine | 7.4 |
| Tryptophan | 2.1 |
| Arginine | 12.1 |
| Iso-leucine | 8.1 |
| ME (MJ/kg) | 13.5 |

[2]Based on 100% SPM

Experiment design

The study was run in House 1 on the poultry unit at ADAS Gleadthorpe. The experiment design was fully factorial with nine levels of factor 1 (%SPM / %NSPM) and two levels of factor 2 (sex of bird). There were four replicates of each diet and sex treatment combination. The treatment combinations were fully randomised across the 72 plots available within the house.

9 % SPM / NSPM treatments x 2 sexes x 4 replicates = 72 plots.

Each plot comprised a wood and wire pen, which was stocked with 22 day-old chicks, either male or female to give a total flock size of 1 584.

Statistical analysis

The data were analysed using a number of statistical techniques (response curve fitting, ANOVA, covariate analysis, Duncan's multiple range test, Kruksal-Wallis test and Freidman's test) using the software packages GenStat 5 (release 4.1) and Statistica (version 5.5A).

*Results*

Live weight

There was a curvilinear response to reducing dietary %SPM (increasing dietary %NSPM) in terms of live weight in both the males and the females ($p<0.001$) at 11 days, 21 days, 28 days and 42 days of age. This is illustrated for male and female live weight at 42 days of age in Figures 13 and 14, respectively. Note that the x-axis is expressed in terms of increasing dietary % SPM.

Male live weight at 42 days of age was highest when feeding between 37.5% and 75.0% SPM (62.5% and 25.0% NSPM) and lowest when feeding 0.0% SPM (100% NSPM). Female live weight at this age was highest when feeding more dietary SPM (between 50.0% and 100.0% SPM, or between 50.0% and 0.0% NSPM, respectively) but like the males, female live weight was lowest when feeding 0.0% SPM (100% NSPM).

The curvilinear response equations describing the effects of dietary %SPM on male and female live weight at 11 days, 21 days and 28 days of age and the respective $R^2$ and p values are given in Tables 92 and 93, respectively.

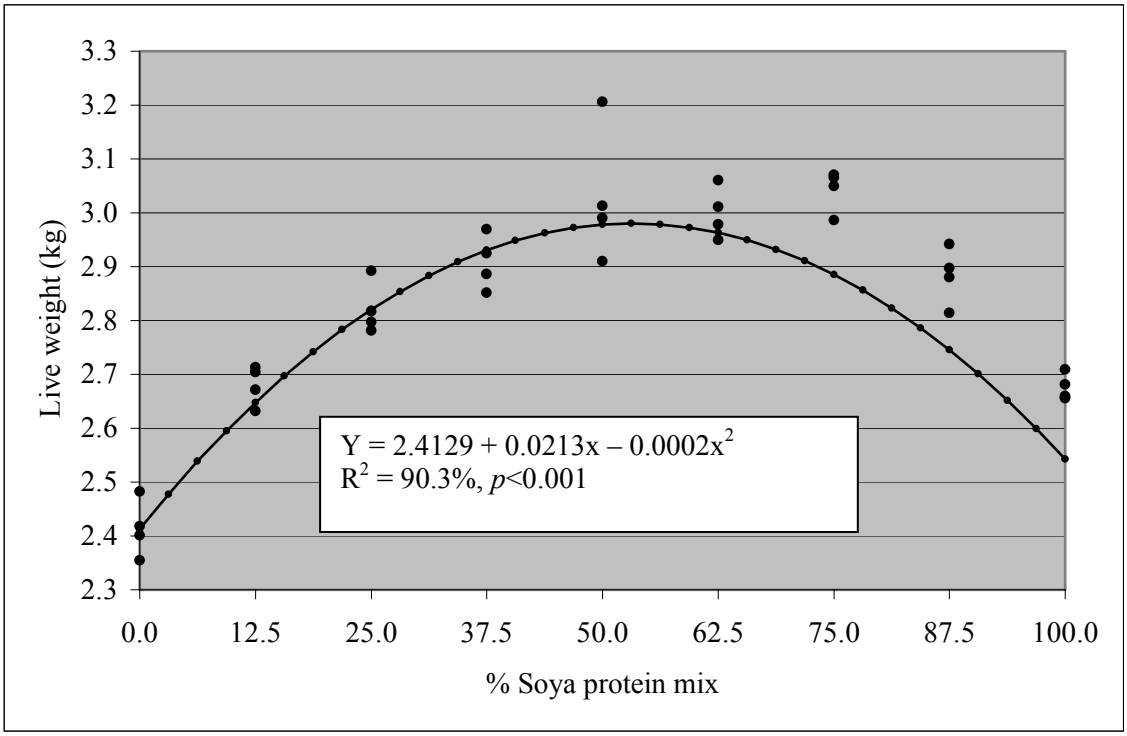


Figure 13. Effect of % 'SPM' on male live weight at 42 days of age (kg/bird)

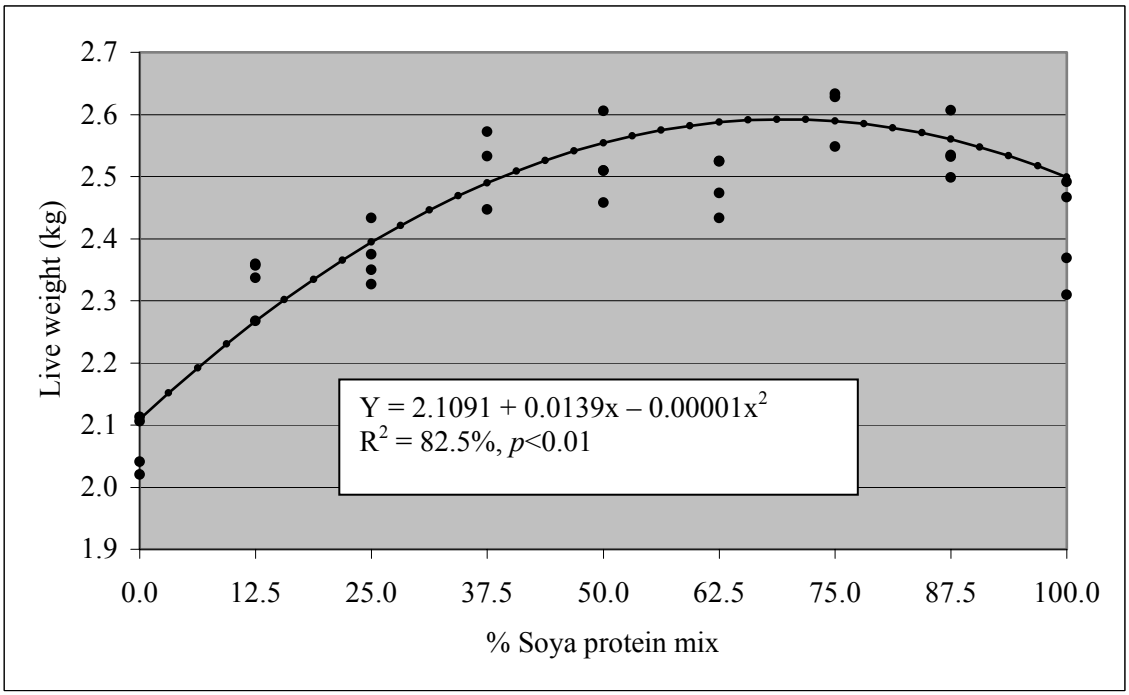


Figure 14. Effect of %'SPM' on female live weight at 42 days of age (kg/bird)

Table 92. Curvilinear response equations describing the effects of dietary %SPM on male live weight at 11 days, 21 days and 28 days of age (kg/bird)

| Age | Equation | $R^2$ value (%) | *P* |
|---|---|---|---|
| 11 | $Y = 0.227 + 0.00370x - 0.00004x^2$ | 76.4% | *P*<0.001 |
| 21 | $Y = 0.660 + 0.01180x - 0.00011x^2$ | 83.7% | *P*<0.001 |
| 28 | $Y=1.250 + 0.01140x - 0.00010x^2$ | 79.0% | *P*<0.001 |

where:

y = live weight (kg/bird), and;

x = dietary %SPM

Table 93. Curvilinear response equations describing the effects of dietary %SPM on female live weight at 11 days, 21 days and 28 days of age (kg/bird)

| Age | Equation | $R^2$ value (%) | *P* |
|---|---|---|---|
| 11 | $Y = 0.218 + 0.00319x - 0.00003x^2$ | 72.2 | *P*<0.001 |
| 21 | $Y = 0.614 + 0.00830x - 0.000072x^2$ | 81.0 | *P*<0.001 |
| 28 | $Y = 1.080 + 0.01110x - 0.00009x^2$ | 81.3 | *P*<0.001 |

where:

y = live weight (kg/bird), and;

x = dietary %SPM

Live weight data is shown on a mean-sexed basis in Table 94 and on a separate sex basis in Tables 95 to 96.

There were no interactive effects of dietary %SPM and sex on live weight at 11 days and 28 days of age. At 11 days of age, feeding 100.0% SPM (0.0% NSPM) reduced live weight to a greater extent than when feeding 0.0% SPM (100.0% NSPM), but live weight was greatest when feeding between 62.5% and 75.0% SPM (37.5% to 25.5% NSPM, respectively) (Table 94).

Mean-sexed live weight at 28 days of age was highest in birds fed 75.0% SPM (25.0%), but live weight was statistically similar to birds fed 62.5% SPM (37.5% NSPM) (Table 94). There were no statistical differences in live weight at 28 days of age between birds fed 87.5% SPM (12.5% NSPM), 62.5% SPM (37.5% NSPM), 50.0%SPM (50.0% NSPM) and 37.5% SPM (62.5% NSPM). Live weight at this age fell as the dietary %SPM was reduced below 37.5% (above 62.5% NSPM) and as the dietary %SPM increased above 87.5% (below 12.5% NSPM). Feeding 0.0% SPM (100.0% NSPM) produced the smallest birds at 28 days of age.

Male live weight was greater than female live weight at 11 days and 28 days of age ($p<0.001$, Table 94).

There were interactive effects of dietary %SPM and sex on live weight at 21 days and 42 days of age ($p<0.001$, Tables 95 and 96, respectively). The males were more sensitive to a high dietary %SPM (greater than 62.5% SPM, less than 37.5% NSPM) than the females.

Table 94. Live weight (kg/bird)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0 | 11 | 21 | 28 | 42 |
| Factor 1 Dietary %SPM | | | | | |
| 100.0 | 0.039 | 0.210[a] | 0.692[b] | 1.257[b] | 2.543[bc] |
| 87.5 | 0.040 | 0.291[d] | 0.867[de] | 1.435[e] | 2.713[d] |
| 75.0 | 0.040 | 0.312[e] | 0.926[g] | 1.492[f] | 2.823[f] |
| 62.5 | 0.039 | 0.317[e] | 0.913[fg] | 1.454[ef] | 2.744[de] |
| 50.0 | 0.039 | 0.298[d] | 0.893[ef] | 1.436[e] | 2.775[ef] |
| 37.5 | 0.040 | 0.292[d] | 0.863[d] | 1.435[e] | 2.713[d] |
| 25.0 | 0.040 | 0.274[c] | 0.802[c] | 1.378[d] | 2.596[c] |
| 12.5 | 0.039 | 0.270[c] | 0.780[c] | 1.330[c] | 2.505[b] |
| 0.0 | 0.039 | 0.229[b] | 0.641[a] | 1.143[a] | 2.242[a] |
| Sed ± | 0.00046 | 0.00500 | 0.01401 | 0.02085 | 0.02882 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.778 | < 0.001 | < 0.001 | < 0.001 | < 0.001 |
| Sig | NS | *** | *** | *** | *** |
| Factor 2 | | | | | |
| Males | 0.040 | 0.284 | 0.863 | 1.447 | 2.828 |
| Females | 0.039 | 0.270 | 0.776 | 1.300 | 2.428 |
| Sed ± | 0.00022 | 0.00236 | 0.00660 | 0.00983 | 0.01359 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | < 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 |
| Sig | *** | *** | *** | *** | *** |

Table 95. Interactions – mean live weight (kg/bird) at 21 days of age

| Dietary %SPM | Sex | |
|---|---|---|
| | Males | Females |
| 100.0 | 0.691 | 0.693 |
| 87.5 | 0.901 | 0.833 |
| 75.0 | 0.985 | 0.866 |
| 62.5 | 0.978 | 0.848 |
| 50.0 | 0.965 | 0.821 |
| 37.5 | 0.921 | 0.806 |
| 25.0 | 0.831 | 0.772 |
| 12.5 | 0.814 | 0.746 |
| 0.0 | 0.681 | 0.601 |

df = 8 $P$ = <0.001, *** Sed ± 0.01981

Table 96. Interactions – mean live weight (kg/bird) at 42 days of age

| Dietary %SPM | Sex | |
|---|---|---|
| | Males | Females |
| 100.0 | 2.676 | 2.409 |
| 87.5 | 2.883 | 2.543 |
| 75.0 | 3.043 | 2.603 |
| 62.5 | 3.000 | 2.489 |
| 50.0 | 3.030 | 2.521 |
| 37.5 | 2.908 | 2.517 |
| 25.0 | 2.822 | 2.371 |
| 12.5 | 2.680 | 2.330 |
| 0.0 | 2.414 | 2.070 |

df = 8 $P$ = <0.001, *** Sed ± 0.04076

Feed intake

There was a curvilinear response to increasing concentrations of NSPM (reducing concentrations of SPM) in terms of feed intake in both the males and the females between day-old and 21 days, between 22 days and 42 days of age and between day-old and 42 days of age ($p<0.001$). This is illustrated for male and female feed intake between day-old and 42 days of age in Figures 15 and 16, respectively. Note that the x-axis is expressed in terms of increasing dietary % SPM.

The findings for feed intake between day-old and 42 days of age were similar to that reported for 42-day live weight, except that there was little difference in feed intake over this period for males fed either 0.0% or 100.0% SPM. In addition, feed intake between day-old and 42 days of age was highest when feeding between 50.0% and 75.0% SPM.

The curvilinear response equations describing the effects of dietary %SPM on male and female feed intake between day-old and 21 days of age and between 22 days and 42 days of age, and the respective $R^2$ and *p* values are given in Tables 97 and 98, respectively.

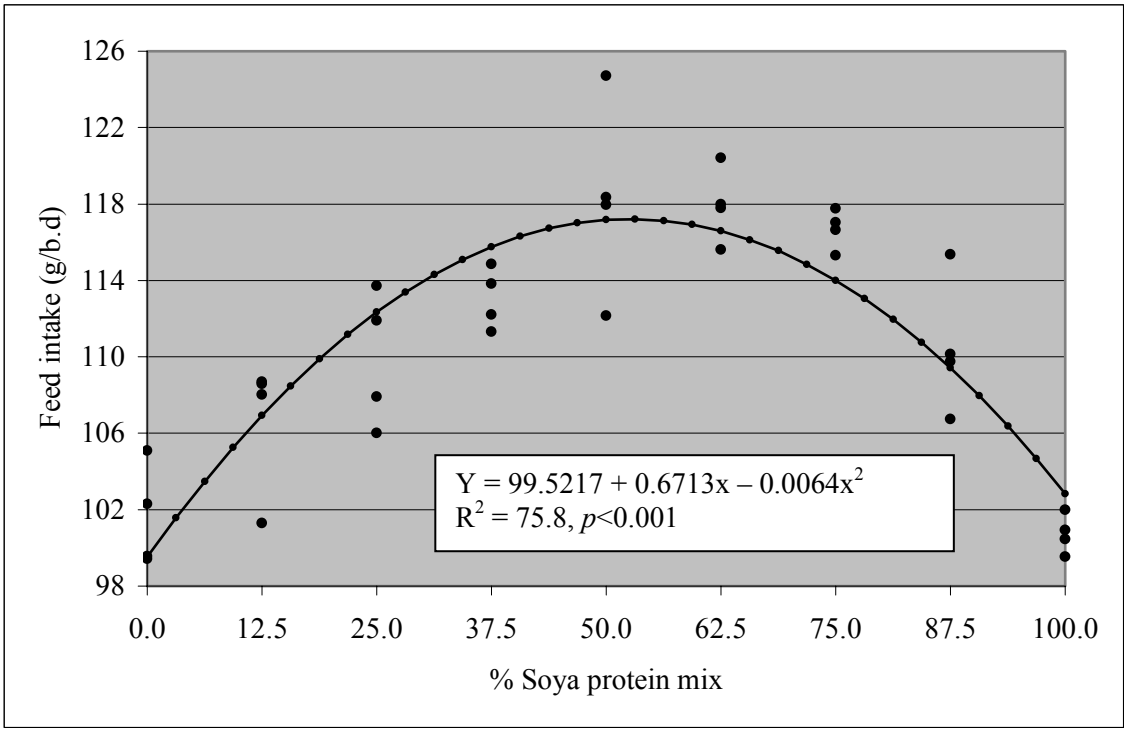


Figure 15. Effect of increasing dietary % 'SPM' on male feed intake between day-old and 42 days of age (g/bird.day)

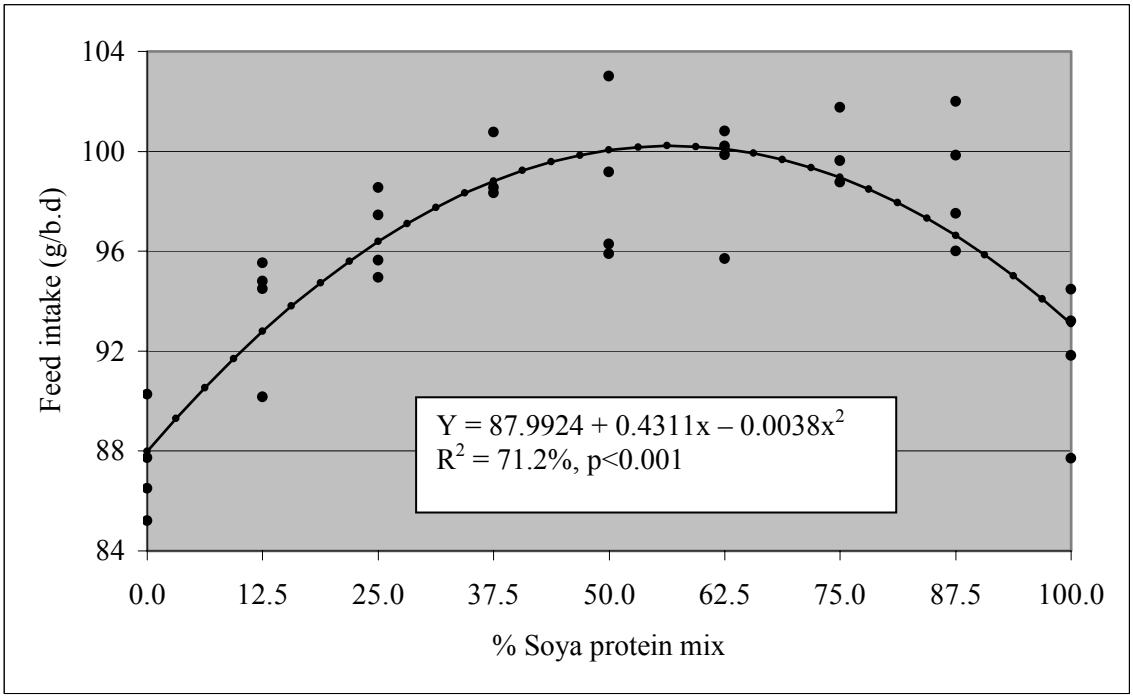


Figure 16. Effect of increasing dietary % 'SPM' on female feed intake between day-old and 42 days of age (g/bird.day)

Table 97. Curvilinear response equations describing the effects of dietary % SPM on male feed intake between 0 and 21 days of age and between 22 days and 42 days of age (g/bird.day)

| Age | Equation | $R^2$ value (%) | *P* |
|---|---|---|---|
| 0-21 | $Y = 44.0 + 0.49800x - 0.00470x^2$ | 72.5 | $P<0.001$ |
| 22-42 | $Y = 156.0 + 0.88600x - 0.00849x^2$ | 76.1 | $P<0.001$ |

where:

y = feed intake (g/bird.day), and;

x = dietary concentration of SPM (%)

Table 98. Curvilinear response equations describing the effects of dietary %SPM on female feed intake between 0 and 21 days of age and between 22 days and 42 days of age (g/bird.day)

| Age | Equation | $R^2$ value (%) | *P* |
|---|---|---|---|
| 0-21 | $Y = 42.1 + 0.33800x - 0.00314x^2$ | 60.9 | $P<0.001$ |
| 22-42 | $Y = 135 + 0.53100x - 0.00444x^2$ | 68.9 | $P<0.001$ |

where:

y = feed intake (g/bird.day), and;

x = dietary concentration of SPM (%)

There was an interaction between dietary %SPM and sex of the bird on feed intake between 22 days and 42 days of age, and between day-old and 42 days of age ($p<0.01$, Tables 99 and 100). The males were more sensitive to high dietary %SPM (greater than 62.5%, less than 37.5% NSPM) than the females.

Feed intake between day-old and 11 days of age was highest when feeding between 25.0% and 75.0% SPM (between 75.0% and 25.0% NSPM, respectively), and lowest when feeding 0.0% or 100.0% SPM (100.0% or 0.0% NSPM, respectively)($p<0.001$). Between 12 days and 21 days of age and between 22 days and 28 days of age feed intake was lowest with the two extreme dietary %SPM treatments (0.0% and 100.0% SPM,

100.0% and 0.0% NSPM, respectively) ($p$<0.001). Feed intake between 12 days and 21 days of age was highest when feeding between 87.5% and 37.5% SPM (between 12.5% and 62.5% NSPM, respectively)($p$<0.001), but between 22 days and 28 days of age intake was similar when feeding between 87.5% SPM and 12.5% SPM (12.5% NSPM and 87.5% NSPM, respectively).

Table 99. Feed intake (g/bird.day)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0-11 | 12-21 | 22-28 | 29-42 | 0-42 |
| Factor 1 Dietary %SPM | | | | | |
| 100.0 | 23[a] | 65[a] | 117[a] | 167[bc] | 96[a] |
| 87.5 | 27[b] | 79[cd] | 131[b] | 173[cd] | 105[cd] |
| 75.0 | 30[c] | 82[cd] | 133[b] | 179[e] | 108[e] |
| 62.5 | 28[bc] | 83[d] | 131[b] | 182[e] | 109[e] |
| 50.0 | 28[bc] | 81[cd] | 130[b] | 182[e] | 108[e] |
| 37.5 | 28[bc] | 79[c] | 132[b] | 176[de] | 106[e] |
| 25.0 | 28[bc] | 74[b] | 132[b] | 172[cd] | 103[c] |
| 12.5 | 26[ab] | 74[b] | 129[b] | 166[ab] | 100[b] |
| 0.0 | 24[a] | 66[a] | 117[a] | 160[a] | 95[a] |
| Sed ± | 1.33 | 1.87 | 2.23 | 2.94 | 1.36 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Sig | *** | *** | *** | *** | *** |
| Factor 2 Sex | | | | | |
| Males | 28 | 80 | 135 | 188 | 111 |
| Females | 26 | 72 | 120 | 158 | 96 |
| Sed ± | 0.63 | 0.88 | 1.05 | 1.38 | 0.64 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.006 | <0.001 | <0.001 | <0.001 | <0.001 |
| Sig | ** | *** | *** | *** | *** |

Table 100. Interactions – feed intake (g/bird/day) 0-42 days of age

| Dietary %SPM | Sex | |
|---|---|---|
| | Males | Females |
| 100.0 | 101 | 92 |
| 87.5 | 110 | 99 |
| 75.0 | 117 | 100 |
| 62.5 | 118 | 99 |
| 50.0 | 118 | 99 |
| 37.5 | 113 | 99 |
| 25.0 | 110 | 97 |
| 12.5 | 107 | 94 |
| 0.0 | 102 | 87 |

df = 8 $P = 0.005$, ** Sed ± 1.92

Feed conversion efficiency (FCE)

There was a curvilinear response to increasing concentrations of NSPM (reducing concentrations of SPM) in terms of FCE in both the males and the females between day-old and 21 days, between 22 days and 42 days of age and between day-old and 42 days of age ($p<0.001$). This is illustrated for male and female FCE between day-old and 42 days of age in Figures 17 and 18, respectively. Note that the x-axis is expressed in terms of increasing dietary % SPM.

Both males and female FCE between day-old and 42 days of age was best when feeding 100% SPM (0% NSPM) and was poorer as the rate of substitution with NSPM increased (Figures 17 and 18). In both males and females, the reduction in FCE between day-old and 42 days was greatest as the dietary %SPM fell below 37.5% (greater than 62.5% NSPM).

The curvilinear response equations describing the effects of dietary %SPM on male and female FCE between day-old and 21 days of age and between 22 days and 42 days of age, and the respective $R^2$ and $p$ values are given in Tables 101 and 102, respectively.

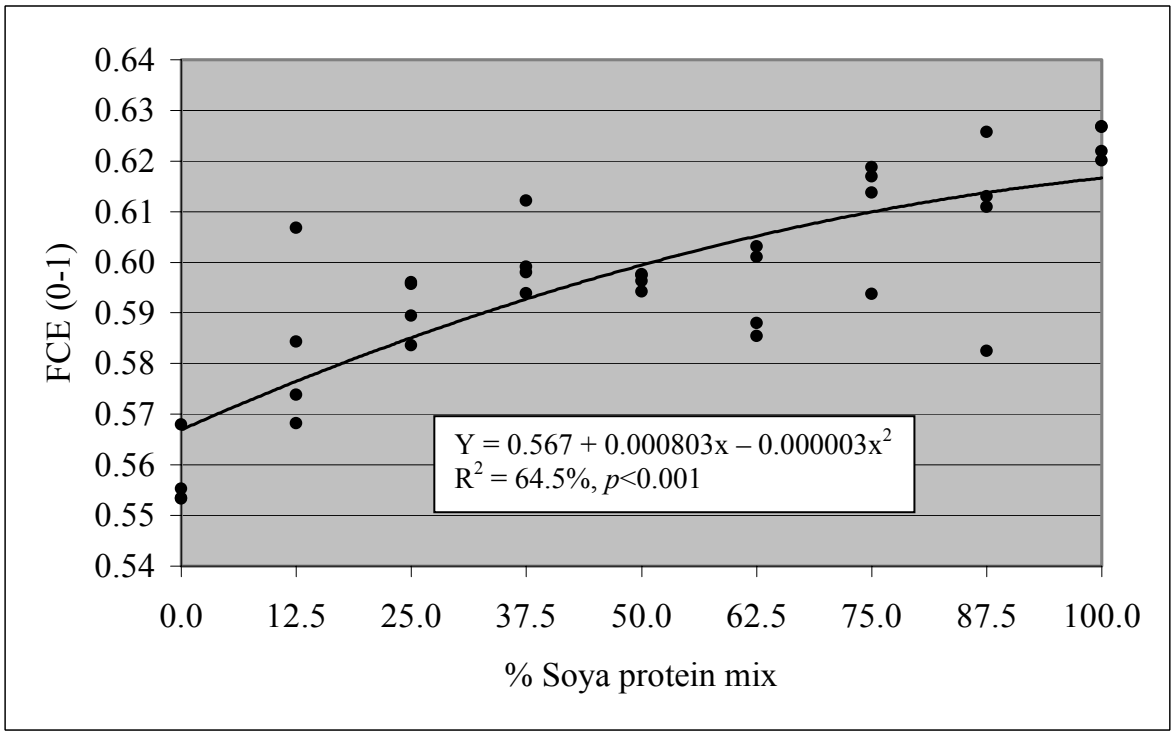


Figure 17. Effect of dietary %SPM on male FCE between day-old and 42 days of age (0-1)

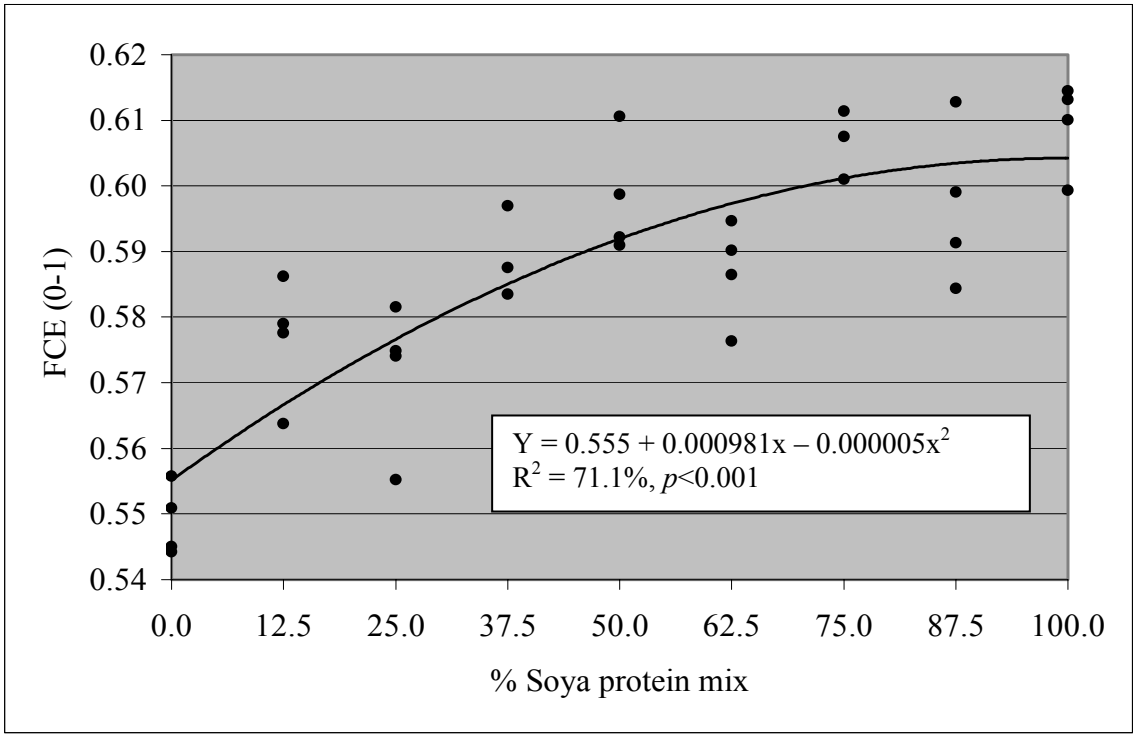


Figure 18. Effect of dietary %SPM on female FCE between day-old and 42 days of age (0-1)

Table 101. Curvilinear response equations describing the effects of dietary % SPM on male FCE between 0 and 21 days of age and between 22 days and 42 days of age (g/bird.day)

| Age | Equation | $R^2$ value (%) | *P* |
|---|---|---|---|
| 0-21 | $Y = 0.671 + 0.00373x - 0.000033x^2$ | 67.7 | *P*<0.001 |
| 22-42 | $Y = 0.537 - 0.000316x - 0.000008x^2$ | 51.6 | *P*<0.001 |

where:

y = FCE (0-1), and;

x = dietary concentration of SPM (%)

Table 102. Curvilinear response equations describing the effects of dietary %SPM on female FCE between 0 and 21 days of age and between 22 days and 42 days of age (g/bird.day)

| Age | Equation | $R^2$ value (%) | *P* |
|---|---|---|---|
| 0-21 | $Y = 0.651 + 0.00327x - 0.000025x^2$ | 82.1 | *P*<0.001 |
| 22-42 | $Y = 0.525 + 0.000047x + 0.000003x^2$ | 52.8 | *P*<0.001 |

where:

y = FCE (0-1), and;

x = dietary concentration of SPM (%)

Mean-sexed FCE between day-old and 42 days of age was best when feeding 100.0%SPM (0.0% NSPM), but statistically it was similar to birds fed 75.0% SPM (25.0% NSPM) ($p$<0.001, Table 103). As reported above for male and female FCE between day-old and 42 days of age, mean-sexed FCE for this period became increasingly poorer as dietary SPM fell below 37.5% (62.5% NSPM). Mean-sexed FCE to 42 days of age was poorest at 0%SPM (100% NSPM).

Male FCE between day-old and 42 days of age was better than the females ($p$<0.001).

Table 103. Feed conversion efficiency (FCE) (0-1)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0-11 | 11-21 | 22-28 | 29-42 | 0-42 |
| Factor 1 Dietary %SPM | | | | | |
| 100.0 | 0.667[a] | 0.742[de] | 0.689[b] | 0.551[g] | 0.617[g] |
| 87.5 | 0.838[d] | 0.723[cde] | 0.620[a] | 0.525[ef] | 0.603[ef] |
| 75.0 | 0.824[cd] | 0.747[e] | 0.610[a] | 0.533[f] | 0.609[fg] |
| 62.5 | 0.907[e] | 0.713[c] | 0.592[a] | 0.509[bcd] | 0.591[cd] |
| 50.0 | 0.834[cd] | 0.729[cde] | 0.597[a] | 0.524[def] | 0.597[de] |
| 37.5 | 0.822[cd] | 0.718[cd] | 0.621[a] | 0.516[cde] | 0.595[de] |
| 25.0 | 0.765[bc] | 0.713[c] | 0.626[a] | 0.500[ab] | 0.581[bc] |
| 12.5 | 0.801[cd] | 0.687[b] | 0.610[a] | 0.505[abc] | 0.580[b] |
| 0.0 | 0.722[ab] | 0.625[a] | 0.605[a] | 0.493[a] | 0.553[a] |
| Sed ± | 0.03109 | 0.01153 | 0.01547 | 0.00698 | 0.00485 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Sig | *** | *** | *** | *** | *** |
| Factor 2 Sex | | | | | |
| Males | 0.794 | 0.724 | 0.617 | 0.525 | 0.596 |
| Females | 0.801 | 0.698 | 0.620 | 0.509 | 0.587 |
| Sed ± | 0.01465 | 0.00543 | 0.00729 | 0.00329 | 0.00229 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.622 | <0.001 | 0.672 | <0.001 | <0.001 |
| Sig | NS | *** | NS | *** | *** |

Mortality and bird health

Mean mortality to 42 days of age was 3.6% and this was similar to commercial broiler mortality rates to 42 days of age as experienced at the time of the study. The causes of mortality were usual in that yolk sac infection due to *E.coli* is often a cause of early mortality and sudden deaths are usually experienced after 21 days of age. No birds were culled due to leg abnormalities.

There was no effect of dietary %SPM or sex on mortality between day-old and 42 days of age (Table 104).

Table 104. Mortality (%)

| Factor | Age (days) | | | | |
|---|---|---|---|---|---|
| | 0-11 | 11-21 | 22-28 | 29-42 | 0-42 |
| Factor 1 Dietary %SPM | | | | | |
| 100.0 | 3.4 | 0.0 | 0.0 | 0.0 | 3.4 |
| 87.5 | 2.8 | 0.6 | 0.0 | 1.1 | 4.6 |
| 75.0 | 2.3 | 1.1 | 0.0 | 0.6 | 4.7 |
| 62.5 | 2.3 | 0.6 | 0.6 | 0.6 | 4.0 |
| 50.0 | 0.0 | 0.6 | 1.1 | 0.0 | 1.7 |
| 37.5 | 1.1 | 1.1 | 0.0 | 0.0 | 2.7 |
| 25.0 | 2.3 | 0.6 | 0.0 | 1.1 | 4.0 |
| 12.5 | 5.1 | 0.6 | 0.0 | 0.0 | 5.7 |
| 0.0 | 1.1 | 0.0 | 0.6 | 0.0 | 1.7 |
| Sed ± | 1.736 | 0.888 | 0.489 | 0.630 | 2.174 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.199 | 0.910 | 0.207 | 0.307 | 0.614 |
| Sig | NS | NS | NS | NS | NS |
| Factor 2 Sex | | | | | |
| Males | 2.0 | 0.8 | 0.3 | 0.5 | 3.5 |
| Females | 2.5 | 0.4 | 0.3 | 0.3 | 3.7 |
| Sed ± | 0.818 | 0.419 | 0.231 | 0.297 | 1.025 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.540 | 0.370 | 1.000 | 0.399 | 0.902 |
| Sig | NS | NS | NS | NS | NS |

Feathering of both the males and the females at 42 days of age was visibly poorer in birds fed the two extreme dietary %SPM treatments (0.0% SPM (100.0% NSPM) and 100.0% SPM (0.0% NSPM)). Feathering was incomplete on the back and vent area of the birds, and this was more pronounced in the

males than the females. The latter was not surprising, as feathering is usually better in the females than the males. No other dietary treatments were affected.

There was no indication of a disease problem and this is substantiated by the low incidence of mortality to 42 days of age. There was no evidence of scouring. The poor feathering reported above was thought to have been due to a low intake of some nutrients or an imbalance of nutrient supply with the two extreme dietary %SPM treatments.

Litter quality and hock burn damage

Litter friability was good throughout the study (Tables 105 and 106). Even towards the end of the growing period the litter was friable with very little capping, and when capping did occur in localised areas, which where usually near to the drinkers, it was easily broken down.

There was no effect of dietary %SPM on litter friability score at 20 days or 39 days of age in the males and at 20 days of age in the females. There was an indication however, that litter friability at 39 days of age was affected by dietary %SPM in the females. Litter friability was higher when birds were fed 25.0% SPM (75.0% NSPM)($p<0.05$). This finding should perhaps be treated with some caution, as there was no effect of dietary % SPM on litter dry matter content (Table 108). Furthermore, the litter dry matter content at 41 days of age for females fed 25.0% SPM was high at 724.5 g/kg. Lastly, as males consume more feed than females, a dietary effect on litter quality, is likely to be more pronounced in the males than the females. In this study there was no effect of dietary %SPM on male litter friability.

Table 105. Median litter friability deterioration score (1-5) for males

| Factor | Age (days) | |
|---|---|---|
| | 20 | 39 |
| Dietary %SPM | | |
| 100.0 | 1.0 | 1.0 |
| 87.5 | 1.0 | 1.0 |
| 75.0 | 1.0 | 1.2 |
| 62.5 | 1.0 | 1.0 |
| 50.0 | 1.0 | 1.7 |
| 37.5 | 1.0 | 1.2 |
| 25.0 | 1.0 | 1.2 |
| 12.5 | 1.0 | 1.0 |
| 0.0 | 1.0 | 1.0 |
| df | 8 | 8 |
| H | 0.00 | 10.05 |
| *P* | 1.000 | 0.265 |
| Sig | NS | NS |

Table 106. Median litter friability deterioration score (1-5) for females

| Factor | Age (days) | |
|---|---|---|
| | 20 | 39 |
| Dietary %SPM | | |
| 100.0 | 1.0 | 1.0 |
| 87.5 | 1.0 | 1.0 |
| 75.0 | 1.0 | 1.0 |
| 62.5 | 1.0 | 1.0 |
| 50.0 | 1.0 | 1.0 |
| 37.5 | 1.0 | 1.0 |
| 25.0 | 1.0 | 1.2 |
| 12.5 | 1.0 | 1.0 |
| 0.0 | 1.0 | 1.0 |
| df | 8 | 8 |
| H | 0.00 | 16.46 |
| *P* | 1.000 | 0.036 |
| Sig | NS | * |

The hocks at 39 days of age were either unmarked or only slightly discoloured. There was an indication however, that male hock burn damage was affected by dietary %SPM (%NSPM) (Table 107). Hock burn damage tended to be greater in male birds fed between 0.0% and 62.5% SPM (between 100% NSPM and 37.5% NSPM, respectively). There was no effect of dietary %SPM on female hock burn score at 39 days of age.

Table 107. Median hock burn score (1-5) at 39 days

| Factor | Sex | |
|---|---|---|
| | Male | Female |
| Dietary %SPM | | |
| 100.0 | 1.3 | 1.1 |
| 87.5 | 1.2 | 1.1 |
| 75.0 | 1.4 | 1.6 |
| 62.5 | 1.6 | 1.2 |
| 50.0 | 2.0 | 1.2 |
| 37.5 | 1.5 | 1.2 |
| 25.0 | 1.6 | 1.4 |
| 12.5 | 1.6 | 1.1 |
| 0.0 | 1.5 | 1.3 |
| df | 8 | 8 |
| H | 16.21 | 5.95 |
| *P* | 0.039 | 0.653 |
| Sig | * | NS |

There was no effect of dietary %SPM on litter dry matter content at 41 days of age but there was a trend for litter dry matter content to be highest in birds fed 100.0% SPM (0.0% NSPM) and lowest in birds fed 62.5% SPM (37.5% NSPM) ($p$=0.078, Table 108).

Litter total nitrogen content at 41 days of age was numerically highest in birds fed 100.0% SPM (0.0% NSPM), but it did not differ statistically from that for birds fed 87.5% SPM (12.5% NSPM), 75.0% SPM (25.0% NSPM), 62.5% SPM (37.5% NSPM), 50.0% SPM (50.0% NSPM) or 25.0% SPM (75.0% NSPM) (Table 108). Litter total nitrogen content at 41 days of age was significantly lower in birds fed either 0.0% SPM (100.0% NSPM) or 12.5% SPM (87.5% NSPM) than in birds fed 100.0% SPM (0.0%NSPM) ($p$<0.05).

Litter uric acid-nitrogen content at 41 days of age was numerically highest in birds fed 100.0% SPM (0.0% NSPM) and 50.0% SPM (50.0% NSPM), but statistically the values only differed from that of birds fed either 0.0% SPM (100% NSPM) or 37.5% SPM (62.5% NSPM) ($p$<0.05, Table 108). The latter dietary %SPM treatments produced the lowest litter uric-acid nitrogen contents at 41 days of age.

Litter ammonium-nitrogen contents at 41 days of age were lowest at each end of the range of dietary %SPM treatments (100.0% SPM (0.0%NSPM) and 87.5% SPM (12.5% NSPM), and 12.5% SPM (87.5% NSPM) and 0.0% SPM (100.0% NSPM)) ($p$<0.01, Table 108). The highest numerical value was obtained when feeding 62.5% SPM (37.5% NSPM).

Litter pH at 41 days of age was highest with the higher dietary %SPM treatments (100.0% SPM (0.0% NSPM) to 75.0% SPM (25.0% NSPM) and lowest when the dietary %SPM was 25.0% or 0.0% (75.0% NSP or 100.0% NSPM, respectively) ($p$<0.01, Table 108).

Table 108. Litter dry matter, total nitrogen, uric acid-nitrogen and ammonium-nitrogen contents (g/kg) and pH at 41 days of age

| Factor | Litter quality variable | | | | |
|---|---|---|---|---|---|
| | Dry matter (g/kg) | Total nitrogen (g/kg) | Uric acid-nitrogen (g/kg) | Ammonium-nitrogen (g/kg) | pH |
| Factor 1 Dietary %SPM | | | | | |
| 100.0 | 740.1 | 50.0[b] | 8.2[c] | 2.7[a] | 7.9[bc] |
| 87.5 | 716.0 | 44.2[ab] | 7.1[abc] | 3.3[ab] | 8.1[c] |
| 75.0 | 676.5 | 48.4[b] | 6.7[abc] | 4.3[bc] | 7.9[bc] |
| 62.5 | 648.4 | 46.0[ab] | 6.6[abc] | 4.5[c] | 7.9[abc] |
| 50.0 | 706.6 | 43.7[ab] | 8.0[c] | 3.8[bc] | 7.7[abc] |
| 37.5 | 678.4 | 37.5[a] | 6.1[ab] | 4.0[bc] | 7.8[abc] |
| 25.0 | 695.1 | 40.7[ab] | 7.3[bc] | 4.1[bc] | 7.5[a] |
| 12.5 | 691.7 | 37.3[a] | 6.6[abc] | 4.0[bc] | 7.5[ab] |
| 0.0 | 694.7 | 35.2[a] | 5.6[a] | 3.5[ab] | 7.5[a] |
| Sed ± | 26.640 | 4.740 | 0.733 | 0.405 | 0.179 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.078 | 0.027 | 0.016 | 0.002 | 0.009 |
| Sig | NS | * | * | ** | ** |
| Factor 2 Sex | | | | | |
| Males | 677.5 | 41.9 | 6.5 | 3.9 | 7.7 |
| Females | 710.8 | 43.2 | 7.3 | 3.7 | 7.8 |
| Sed ± | 12.560 | 2.230 | 0.346 | 0.191 | 0.084 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.010 | 0.586 | 0.029 | 0.285 | 0.844 |
| Sig | ** | NS | * | NS | NS |

Liver and spleen trace element concentrations

There were effects of dietary %SPM on liver and spleen dry matter, copper, manganese and zinc contents at 42 days of age ($p<0.05$, $p<0.01$, $p<0.05$ and $p<0.05$, respectively), but not on cobalt content (Table 109).

Liver and spleen dry matter content at 42 days of age was highest when feeding 75.0% SPM (25.0% NSPM), and lowest when feeding 12.5% and 100.0% SPM (87.5% NSPM and 0.0% NSPM, respectively). However, the liver and spleen dry matter content of birds fed 0.0% SPM (100.0% NSPM) was similar to that of birds fed between 12.5% and 100.0% SPM.

Liver and spleen copper and manganese contents at 42 days of age were lowest in birds fed 0.0% and 100.0% SPM (100.0% and 0.0% NSPM, respectively). It is worth noting however, that the liver and spleen copper content at 42 days of age was similar between the following treatments 0.0%, 12.5%, 37.5%, 62.5%, 87.5% and 100.0% SPM (100.0%, 87.5%, 62.5%, 37.5%, 12.5% and 0.0% NSPM, respectively). Liver and spleen manganese contents at 42 days of age were similar between the treatments 0.0%, 12.5%, 37.5%, 62.5%, 75.0% and 100.0% SPM (100.0%, 87.5%, 62.5%, 37.5%, 25.0% and 0.0% NSPM, respectively).

The effect of dietary %SPM on liver and spleen zinc content at 42 days of age is also not clear. The lowest liver and spleen zinc contents were in birds fed 62.5% and 87.5% SPM (37.5% and 12.5% NSPM, respectively), but zinc contents did not differ from those for birds fed 0.0%, 12.5%, 37.5% SPM and 100.0% SPM (100.0%, 87.5%, 62.5% and 0.0% NSPM, respectively).

It seems that although there were statistically significant dietary effects on liver and spleen dry matter and trace element content, the reasons for this are unclear. It is unlikely that they were simply due to substituting the SPM with the NSPM.

Table 109. Liver and spleen dry matter (g/kg) and trace element concentrations (mg/kg) at 42 days of age

| Factor | Concentrations | | | | |
|---|---|---|---|---|---|
| | Dry matter (g/kg) | Cobalt (mg/kg) | Copper (mg/kg) | Manganese (mg/kg) | Zinc (mg/kg) |
| Factor 1 Dietary %SPM | | | | | |
| 100.0 | 275.1[a] | 0.03 | 3.1[ab] | 2.5[a] | 22.9[ab] |
| 87.5 | 280.7[abc] | 0.03 | 3.1[abc] | 2.8[bc] | 22.2[a] |
| 75.0 | 290.5[c] | 0.03 | 3.5[c] | 2.6[abc] | 25.0[b] |
| 62.5 | 279.2[abc] | 0.03 | 3.0[ab] | 2.6[ab] | 21.9[a] |
| 50.0 | 287.6[bc] | 0.03 | 3.3[bc] | 3.1[c] | 24.7[b] |
| 37.5 | 276.9[ab] | 0.03 | 3.1[abc] | 2.6[ab] | 23.6[ab] |
| 25.0 | 284.8[abc] | 0.03 | 3.4[c] | 2.8[bc] | 24.9[b] |
| 12.5 | 274.8[a] | 0.03 | 3.2[abc] | 2.7[abc] | 23.3[ab] |
| 0.0 | 279.6[abc] | 0.03 | 2.9[a] | 2.2[a] | 23.6[ab] |
| Sed ± | 5.210 | 0.0000 | 0.166 | 0.213 | 1.004 |
| df | 8 | 8 | 8 | 8 | 8 |
| *P* | 0.038 | - | 0.010 | 0.030 | 0.018 |
| Sig | * | NS | ** | * | * |
| Factor 2 Sex | | | | | |
| Male | 279.0 | 0.03 | 3.2 | 2.6 | 23.4 |
| Female | 283.1 | 0.03 | 3.2 | 2.7 | 23.7 |
| Sed ± | 2.460 | 0.0000 | 0.078 | 0.101 | 0.473 |
| df | 1 | 1 | 1 | 1 | 1 |
| *P* | 0.105 | - | 0.617 | 0.583 | 0.484 |
| Sig | NS | NS | NS | NS | NS |

Diet costs and gross margins of live weight sales minus feed costs

Using the ingredient prices shown in Table 110, the cost of the treatment diets have been calculated and the results are given in Table 111. The diets became more expensive as the rate of substitution of SPM with NSPM increased.

Table 110. Ingredient cost (£/tonne)

| Ingredient | Cost (£/tonne) |
|---|---|
| Wheat | 95.00 |
| Maize gluten 60 | 92.00 |
| Vegetable oil | 545.00 |
| Soya full fat | 231.00 |
| Soya 50 | 197.50 |
| Rapeseed meal | 215.00 |
| Whole rapeseed | 340.00 |
| Field peas | 260.00 |
| Field beans | 270.00 |
| Fishmeal 66 | 440.00 |
| Synthetic lysine | 1750.00 |
| Synthetic methionine | 2000.00 |
| Synthetic threonine | 5500.00 |
| Premix starter/grower | 2280.00 |
| Premix finisher | 1480.00 |
| Limestone | 54.65 |
| Dicalcium phosphate | 275.00 |
| Salt | 90.00 |

Table 111. Treatment diet cost (£/tonne)

| Dietary %SPM | Cost of starter ration (£/tonne) | Cost of grower ration (£/tonne) | Cost of finisher ration (£/tonne) |
|---|---|---|---|
| 100.0 | 200.44 | 196.96 | 183.47 |
| 87.5 | 207.27 | 202.02 | 187.80 |
| 75.0 | 214.11 | 207.17 | 192.17 |
| 62.5 | 220.95 | 212.24 | 196.50 |
| 50.0 | 227.79 | 217.36 | 200.89 |
| 37.5 | 234.62 | 222.43 | 205.22 |
| 25.0 | 241.46 | 227.58 | 209.59 |
| 12.5 | 248.29 | 232.64 | 213.91 |
| 0.0 | 255.12 | 237.71 | 218.30 |

Gross margins of live weight sales minus feed costs have been calculated (Table 112) using:

- starter feed intake and finisher feed intake data to 42 days of age (Table 99);
- diet costs (£/tonne, Table 112);
- total live weight produced at 42 days of age (based on mean live weight data at 42 days of age and mortality to 42 days of age), and;
- a value of £0.485/kg of live weight sold.

Table 112. Gross margins of live weight sales minus feed costs

| Dietary %SPM | Gross margin (£/bird) |
|---|---|
| 100.0 | 0.43 |
| 87.5 | 0.41 |
| 75.0 | 0.40 |
| 62.5 | 0.34 |
| 50.0 | 0.34 |
| 37.5 | 0.31 |
| 25.0 | 0.25 |
| 12.5 | 0.22 |
| 0.0 | 0.14 |

There was an increasing financial penalty associated with substituting the SPM with the NSPM. This reflected the higher diet costs and poorer FCEs as the rate of substitution of SPM with NSPM increased.

*Discussion*

There are two main findings from this study, one of which, was that the 100.0% SPM diet did not maximise feed intake and live weight gain in broilers grown to 42 days of age, but it did maximise FCE. Feed intake between day-old and 42 days of age was highest when feeding between 50.0% and 75.0% SPM. Male live weight at 42 days of age was highest when feeding between 37.5% and 75.0% SPM, whereas female live weight at 42 days of age was highest when feeding between 50.0% and 100.0% SPM. The relationships between dietary %SPM and feed intake and between dietary %SPM and live weight at 42 days of age were curvilinear.

The second main finding is evident from the above information but it is mentioned here for clarity. The complete substitution of SPM with NSPM was not successful in terms of bird performance. There was a pronounced depression in feed intake and live weight at 42 days of age when feeding 0.0% SPM.

Thus, neither the 0.0% nor the 100.0% SPM diets were optimal in terms of their nutrient content and/or contents of antinutritional factors. The suggestion of nutrient insufficiency is further supported by the finding that both males and females fed either 0.0% or 100.0% SPM were poorly feathered at 42 days of age, whereas feathering was normal in birds fed the intermediate diets.

In trying to determine the reasons for the poor performance in birds fed the two extreme diets it is necessary to consider the following:

- the determined nutrient contents of the diets;
- the presence and contents of antinutritionals, and;
- factors that may have exacerbated nutritional imbalances or deficiencies.

The determined crude protein contents of the starter and grower rations were mostly higher than target (Tables 83 to 84), whereas the determined crude protein contents of the finisher rations were generally slightly less than target (Table 85).

Dietary protein concentrations can affect the requirements for individual essential amino acids. Generally, as dietary protein concentration increases, essential amino acid requirements, expressed as a proportion of the diet increase, although when expressed as a proportion of the protein, the essential amino acid requirements are little affected (NRC, 1994 citing Boomgaardt and Baker, 1973, Morris *et al.,* 1987 and Robbins, 1987). Thus, if any of the essential amino acids were limiting in the study diets, the deficiency would have been exacerbated by surplus protein.

The main consideration however, is that the supply of amino acids within the diet should be balanced according to the bird's requirements for production and maintenance. The efficiency of protein synthesis will be highest when the intake of amino acids is 'balanced' according to the birds' needs. If some amino acids are in short supply, and others are in excess, protein synthesis will be less efficient. This is the basis for the ideal protein concept (Larbier and Leclercq, 1994; McDonald *et al*., 1995).

Production becomes limited when one or more amino acids are in short supply. The deficient amino acid(s) are regarded as limiting factors. The first limiting amino acid is the amino acid that is limiting performance to the level achieved by the diet. Supplementing the diet with the first limiting amino acid will increase performance, but only up to a level where the next, or second limiting, amino acid becomes restrictive. Lysine, methionine, cystine and threonine are the most important of the essential amino acids from a growth perspective, as they are usually the first limiting (Larbier and Leclercq, 1994).

There were discrepancies between the determined and calculated lysine, methionine, cystine and threonine contents of the diets. Except for threonine, the discrepancies between determined and calculated amino acid contents were greatest in the starter ration, with better agreement in the grower and finisher rations. The determined lysine content of the starter ration was low compared with target when the dietary %SPM was greater than 62.5%, and the determined methionine, methionine plus cystine and threonine contents were all low compared with target at 100.0% SPM. Fernandez *et al.,* (1994) reported the limiting order of amino acids in soya bean meal as: 1) methionine plus cystine; 2) threonine; 3) lysine and valine; 4) non-specific nitrogen, and; 5) histidine.

The determined lysine, methionine, methionine plus cystine and threonine contents of the starter ration are shown for all dietary %SPM treatments in Figure 19.

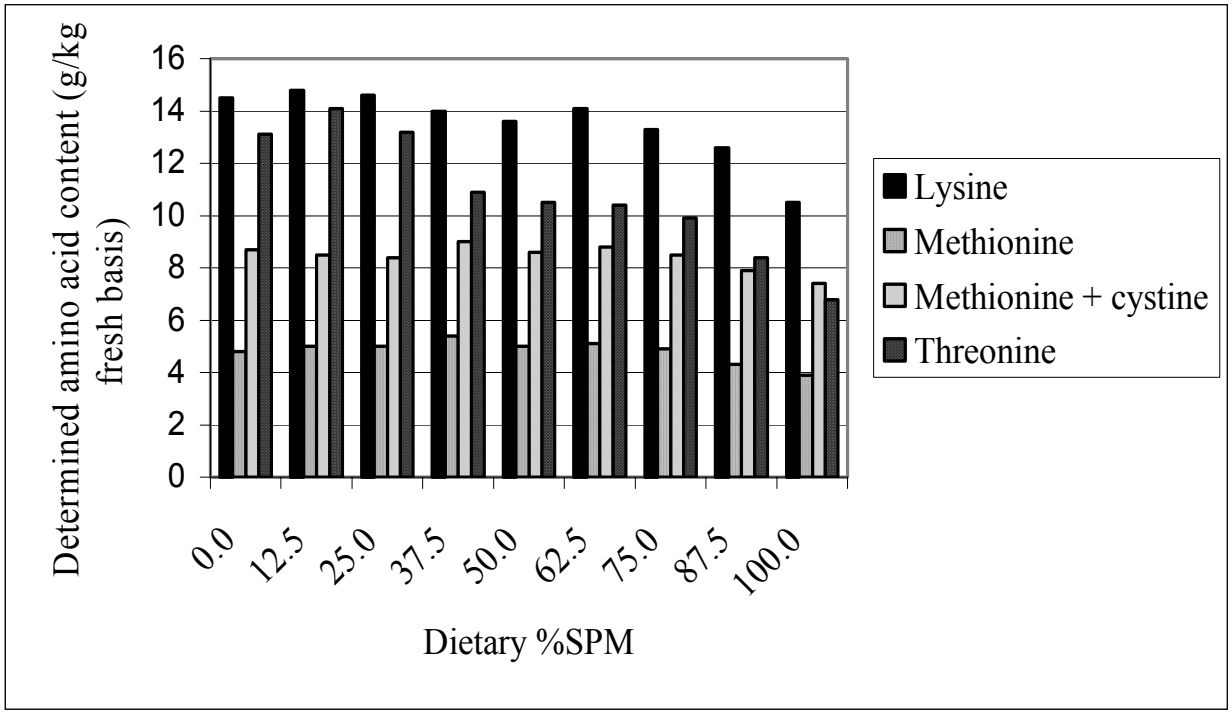


Figure 19. Determined lysine, methionine, methionine plus cystine and threonine contents of the starter rations (g/kg fresh basis)

Note: the target lysine, methionine, methionine plus cystine and threonine contents for the starter ration were 13.8 g/kg, 4.9 g/kg, 8.8 g/kg and 8.9 g/kg, respectively.

The poor growth of birds fed 100.0% SPM was most probably due to limited intakes of lysine, methionine, cystine and threonine, and poor feathering due to limited intakes of methionine, cystine and threonine. Production requirements for all of these amino acids are far greater in the young bird than the requirements for maintenance. Larbier and Leclercq (1994) provided values of amino acid requirements for growth. The requirements for lysine, sulphur amino acids and threonine were given as 1.49 g, 1.16 g and 0.75 g/100 g of live weight gain, respectively. Maintenance requirements for lysine, sulphur amino acids and threonine were only 82 mg, 60 mg and 86 mg/kg live weight.day, respectively.

The carcass is rich in lysine, sulphur amino acids and threonine (6.5 g, 4.0 g and 4.2 g/100 g protein, respectively), and the feathers are particularly rich in sulphur amino acids (7.9 g/100g protein) but also threonine (4.6 g/kg) (Larbier and Leclercq, 1994). Thus, when the dietary concentration of these nutrients is low relative to the ME value birds will fail to realise good growth rates and feathering will be poor. This was the case for birds fed 100.0% SPM.

Discrepancies in threonine content, i.e. determined *versus* calculated, were apparent in the starter, grower and finisher rations. As discussed the threonine content of the 100.0% SPM starter diet was low and this was also the case for finisher ration (7.0 g/kg determined, versus 7.4 g/kg calculated), but not the grower ration. The determined threonine content of the 100.0% SPM grower ration was as per the calculated value.

The largest discrepancies in determined *versus* calculated threonine contents however, occurred with the lower dietary %SPM treatments (25.0% SPM or less) shown in Figure 19 for the starter rations (calculated threonine content being 8.9 g/kg fresh basis). There was a large excess of threonine in the starter, grower and finisher rations when the dietary SPM content was 25.0% SPM or less.

To assess the impact of this on the bird it is useful to consider the balance of limiting amino acids in the treatment diets. As the bird's lysine requirements are best known it is conventional to express requirements for other amino acids in terms of the ratio to lysine (Larbier and Leclercq, 1994). This has been done for the starter diets and the results are shown in Figure 20. For information, an optimal balance of methionine plus cystine, threonine and tryptophan as expressed relative to lysine, published by Larbier and Leclercq (1994) is included in Figure 20.

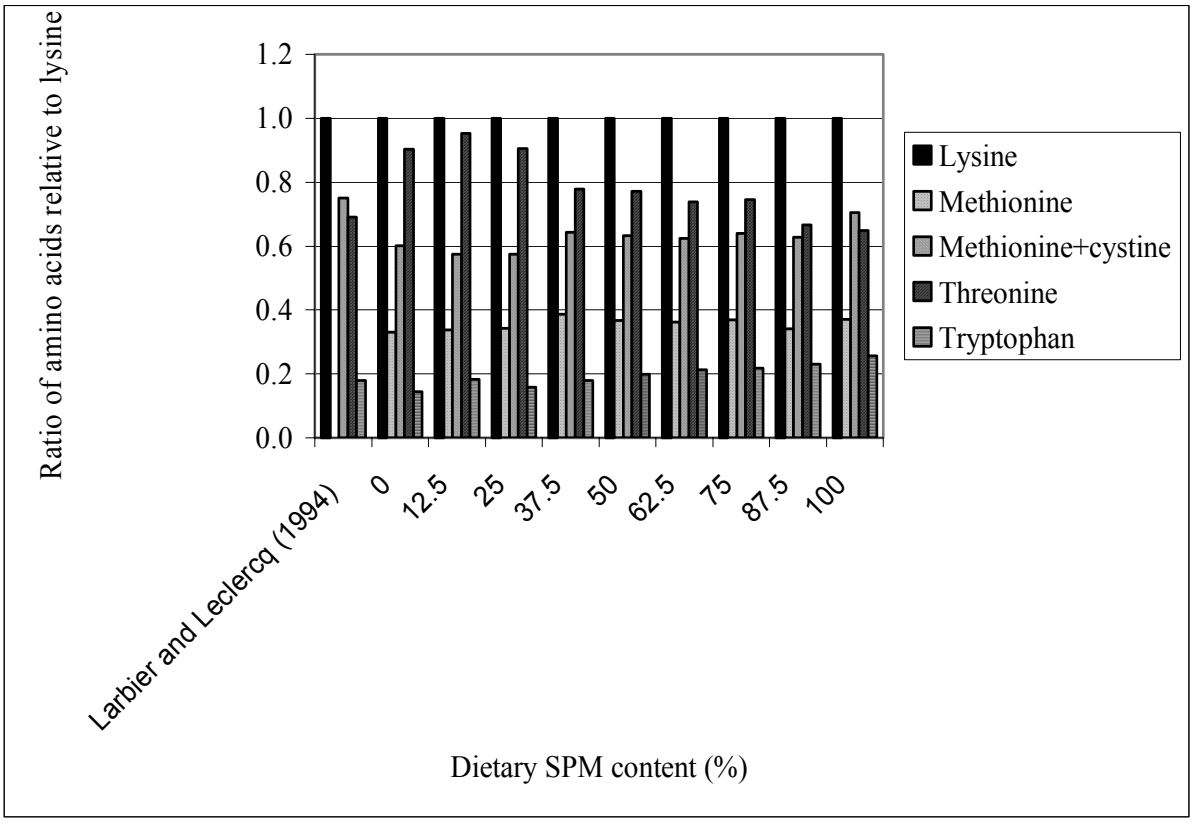


Figure 20. Determined ratio of amino acids relative to lysine for the starter treatment diets

It is apparent from the information given in Figure 20, that the supply of methionine plus cystine relative to lysine was low in most cases, but particularly at 25.0% or less SPM. The supply of threonine relative to lysine was mostly higher than that published by Larbier and Leclercq (1994): only the diets containing 87.5% and 100.0% SPM had a near-optimal ratio. In diets containing 25.0% or less SPM the supply of threonine relative to lysine was greatly in excess of Larbier and Leclercq's recommendation. Thus, in diets containing 25.0% SPM or less an excess of threonine could have increased the relative deficiency of methionine and cystine, and an otherwise presumed adequate dietary supply of lysine might have become limiting.

Low feed intakes in birds fed the 25.0% or less SPM diets could have been due to the imbalance of dietary amino acids. It has been suggested that feeding an imbalance of amino acids has a direct effect on the hypothalamic receptors (Leeson and Summers, 2001). Infusing imbalanced amino acids into the carotid artery causes a rapid reduction in the feed intake of rats. When an imbalance of amino acids is infused into the jugular vein there is a less profound effect, presumably because the liver intervenes prior to the blood reaching the brain. The authors wrote that most animals select a protein-free diet over an amino acid imbalanced diet when given a choice.

However, lower feed intakes in birds fed a low dietary %SPM did not fully account for the loss of live weight gain as FCEs were poorer. The birds were using the feed less efficiently for growth. Whether this was due more to a nutrient deficiency, than due to the contents of antinutritional factors present in the proteinaceous ingredients is difficult to ascertain with certainty. The arguments for and against the possibility that the alternative proteinaceous ingredients (rapeseed meal, whole rapeseed, peas and beans) reduced performance or contributed to poorer performance are discussed.

The 0.0% SPM starter ration has been used as an example: this ration had the highest concentrations of the alternative proteinaceous ingredients. Thus, the maximum concentrations of rapeseed meal, whole rapeseed, field beans and field peas fed were 105.3 g/kg, 14.2 g/kg, 13.6 g/kg and 14.7 g/kg, respectively. Of these, the only ingredient included at a concentration which was sufficient to perhaps cause concern was rapeseed meal. Whole rapeseed is also discussed however, because of the common antinutritional factors in whole rapeseed and rapeseed meal, namely glucosinolates and sinapine.

In an earlier study within this project (Study 1) there was a linear reduction in male and female live weight at 14 days of age, and male live weight at 21 days of age when feeding rapeseed meal at concentrations within the range of 0 g/kg to 160 g/kg. There was no effect of rapeseed meal concentration on live weight at 42 days of age, but birds fed a high concentration of rapeseed meal (greater than 60 g/kg) in the starter ration were subsequently fed 0 g/kg rapeseed meal in the finisher ration. Thus, high concentrations of rapeseed meal were not fed throughout the 42-day growing period.

In this study, the concentration of rapeseed meal fed was reduced in the grower ration (78.5 g/kg rapeseed meal), and further reduced in the finisher ration (67.0 g/kg rapeseed meal) because of the reduction in the amount of total protein being fed (as per commercial practice). The total amount of rapeseed meal fed to 42 days of age was higher however, than in Study 1. Thus, it is possible that in this study the concentration of rapeseed meal in diets having a low % SPM (perhaps 37.5% SPM or less) might have impacted on feed intake and live weight gain to 42 days of age.

If it is thought that the rapeseed meal present in the low %SPM diets impacted on feed intake and live weight gain then it is important to consider the dietary supply and intake of glucosinolates and sinapine.

There was only a small difference in the glucosinolate content of the rapeseed meal used in this study and the rapeseed meal used in Study 1 (10 μmol/g, *versus* 7 μmol/g respectively), but the maximum intake of glucosinolates to 42 days of age from rapeseed meal alone (0% SPM) was higher than the maximum intake in rapeseed meal fed birds in Study 1 (3 000 μmol/bird, *versus* 2 001 μmol/bird respectively). The additional intake of whole rapeseed in Study 3 would have added to this, and at the highest intake of whole rapeseed (0.0% SPM) there would have been an additional glucosinolate intake of 1 300 μmol/bird to 42 days of age. Thus, the maximum total glucosinolate intake to 42 days of age was 4 300 μmol/bird in Study 3. This was similar to the glucosinolate intake of birds fed 60 g/kg whole rapeseed in Study 3.

The sinapine content of the rapeseed meal used in Study 3 was higher than that used in Study 1 (13.6 g/kg, *versus* 11.7 g/kg), but the whole rapeseed used in Study 3 was less rich in sinapine than that used in Study 1 (9.4 g/kg, *versus* 10.5 g/kg). Total sinapine intake to 42 days of age in Study 3 was 4.5 g/bird (i.e. from rapeseed meal and whole rapeseed). This was higher than the sinapine intake of birds fed rapeseed meal in Study 1 (3.3 g/bird to 42 days of age), but similar to the maximum sinapine intake of birds fed 100 g/kg whole rapeseed in Study 1 (about 4.5 g/bird to 42 days of age).

If glucosinolate and sinapine intakes were responsible for the feed intake and growth depressions seen in Study 1 birds fed whole rapeseed, then there is a similar likelihood that glucosinolate and sinapine intake contributed to the poor performance of birds fed 0.0% SPM.

Other workers have reported lower feed intakes and poorer growth when feeding similar or marginally higher rapeseed meal concentrations than those used in Study 3. A recent study published by McNeill *et al.,* (2004), found lower feed intakes and live weight gains in broilers grown to 42 days of age when fed either 100 g/kg or 200 g/kg low glucosinolate, low erucic acid rapeseed meal, compared with 0 g/kg rapeseed meal. All diets were iso-energetic and iso-nitrogenous.

However, in published work, often when rapeseed meal intake impacted on live weight gain this was without affecting FCE (Salmon *et al.,* 1981; McNeill *et al.,* 2004). Similar findings were reported for Study 1: FCE to 42 days of age was not affected by feeding rapeseed meal at concentrations of up to 160 g/kg in the starter ration and up to 60 g/kg in the finisher ration.

There was a statistically significant and numerically large reduction in FCE to 42 days of age with reducing dietary %SPM. Nutrients were being used much less efficiently for growth when the dietary %SPM was reduced. It is suggested that this was probably due to amino acid imbalances at the low dietary %SPM (less than 25%), rather than an effect of rapeseed meal or its antinutritionals at the concentrations used.

The possibility of amino acid antagonisms also needs to be considered. Amino acid antagonisms may accentuate a deficiency of the first limiting amino acid, but these differ from imbalances because utilisation of the limiting amino acid is reduced (NRC, 1994). Antagonisms can occur between amino acids having side chains exhibiting similar structural and/or chemical characteristics. Increasing the dietary concentration of one that is in excess of productive requirements adversely affects the metabolism of the other. In a situation in which one essential amino acid is first limiting, increasing the other's concentration to enlarge the difference, antagonises the use of the first limiting amino acid and induces or exacerbates a deficiency.

Antagonisms have been shown to exist for leucine-isoleucine-valine, arginine-lysine, and threonine-tryptophan (NRC, 1994 citing D'Mello and Lewis, 1970). The most important of these antagonisms occurs with leucine-isoleucine (NRC, 1994). This is because certain ingredient combinations (e.g. maize plus maize gluten meal) can lead to practical diets in which leucine is high while isoleucine is marginal in adequacy.

Excess leucine reduces live weight gain but this may be corrected by supplementing with isoleucine and valine (Larbier and Leclercq, 1994). The authors suggested that about 70% of the effects of this are due to reduced appetite with the remaining 30% being attributable to metabolic effects. Excess leucine reduces feed intake and live weight gain. It increases the rate of breakdown of the isoleucine and valine, and competes effectively against them for absorption. Leucine, isoleucine and valine use the same transport system for absorption.

Soya is rich in leucine compared with wheat (e.g. soya bean meal 50 contains 4.18 g/kg leucine, compared with 0.87 g/kg leucine in wheat, Larbier and Leclercq, 1994). Iso-leucine and valine are present in soya at lower concentrations (about 67% of that leucine, *loc. sit*.). Maize gluten however, is much richer in leucine than soya (maize gluten contains 11.51 g/kg leucine, Larbier and Leclecrq, 1994). Maize gluten was a main ingredient in the NSPM (419.4 g/kg of NSPM, providing a maximum of 119 g maize gluten in the 0.0% SPM starter ration), it acted as a protein source and amino acid balancer. The UK-grown proteinaceous ingredients were however, less rich in leucine than either maize gluten or soya. For example, the leucine

contents of rapeseed meal (solvent extracted), field beans, field peas and whole rapeseed are given 2.66 g/kg, 2.15 g/kg, 1.64 g/kg and 1.50 g/kg, respectively. Thus, these ingredients plus the wheat diluted the leucine content of the ration.

The determined leucine concentrations of the starter, grower and finisher rations were higher than those recommended by the NRC (1994) (Table 113), and they were consistently higher in the 100.0% SPM diets than the 0.0% SPM diets. The determined iso-leucine and valine concentrations of the 100.0% SPM starter, grower and finisher rations were either similar or slightly higher than the concentrations recommended by the NRC (1994), whereas in the 0.0% SPM starter the determined iso-leucine concentration was low in all rations. The determined valine concentration in the 0.0% SPM diet was as recommended by the NRC (1994) for the starter, low in the grower and high in the finisher.

Table 113. Recommended nutrient requirements of broilers (g/kg fresh weight basis)

| Amino acid | Recommended requirement (g/kg fresh weight basis)[1] | |
|---|---|---|
| | 0-3 weeks of age | 3-6 weeks of age |
| Leucine | 12.0 | 10.9 |
| Iso-leucine | 8.0 | 7.3 |
| Valine | 9.0 | 8.3 |

[1]For diets having 3 200 kcal $ME_N$/kg (13.4 $MJ_N$/kg)

Thus, the recommended ratios of leucine, iso-leucine and valine were 1.000 to 0.667 to 0.750 in the starter ration (0 to 3 weeks of age) and 1.000 to 0.670 to 0.761 in the finisher ration (3 to 6 weeks of age)(NRC, 1994).

Taking the two extreme treatments as examples (i.e. 100.0% SPM and 0.0% SPM) the ratios of leucine, iso-leucine and valine have been calculated, both for the starter, grower and finisher rations (Table 114).

Table 114. Determined ratios of leucine, iso-leucine and valine in the starter, grower and finisher rations of birds fed 100.0% SPM and 0.0% SPM

| Ration | Ratio of leucine, iso-leucine and valine | |
|---|---|---|
| | 100.0% SPM | 0.0% SPM |
| Starter | 1.000 to 0.585 to 0.696 | 1.000 to 0.537 to 0.732 |
| Grower | 1.000 to 0.578 to 0.667 | 1.000 to 0.542 to 0.678 |
| Finisher | 1.000 to 0.569 to 0.672 | 1.000 to 0.580 to 0.824 |

In both the 100.0% SPM and 0.0% SPM diets the ratios of leucine to iso-leucine and to valine were less than optimal according to the recommendations of the NRC (1994). In most cases leucine was high relative to the supply of iso-leucine and valine. Interestingly, however, the ratios of leucine to iso-leucine to valine in the starter, grower and finisher rations of the 50.0% SPM were also less than optimal. For example, the ratios in the starter were 1.000 to 0.559 to 0.655, and these birds grew well. Thus, an antagonism between leucine, isoleucine and valine was unlikely to have been the cause of poor performance in birds fed the 100.0% and 0.0% SPM diets.

The antagonism between lysine and arginine has been well documented. Lysine acts antagonistically against arginine and a ratio of 1.2:1 reduces live weight gain in the young bird (Larbier and Leclercq, 1994). This may be overcome by supplementing with arginine. The antagonism occurs at the metabolic level rather than at the digestive level (*loc.sit*.). Excess lysine acts in the kidney so as to increase the rate of arginine breakdown. Leeson and Summers (2001) wrote that if moderately high concentrations of lysine are fed (16 g/kg for young chick) in combination with marginal concentrations of arginine (8 g/kg) then up to 25% of arginine can be degraded, leading to a marked decrease in weight gain.

In this study there were differences in the determined lysine and arginine concentrations of the diets, particularly in the starter ration. Thus, the ratios of lysine to arginine have been calculated for each diet and ration (Figure 21).

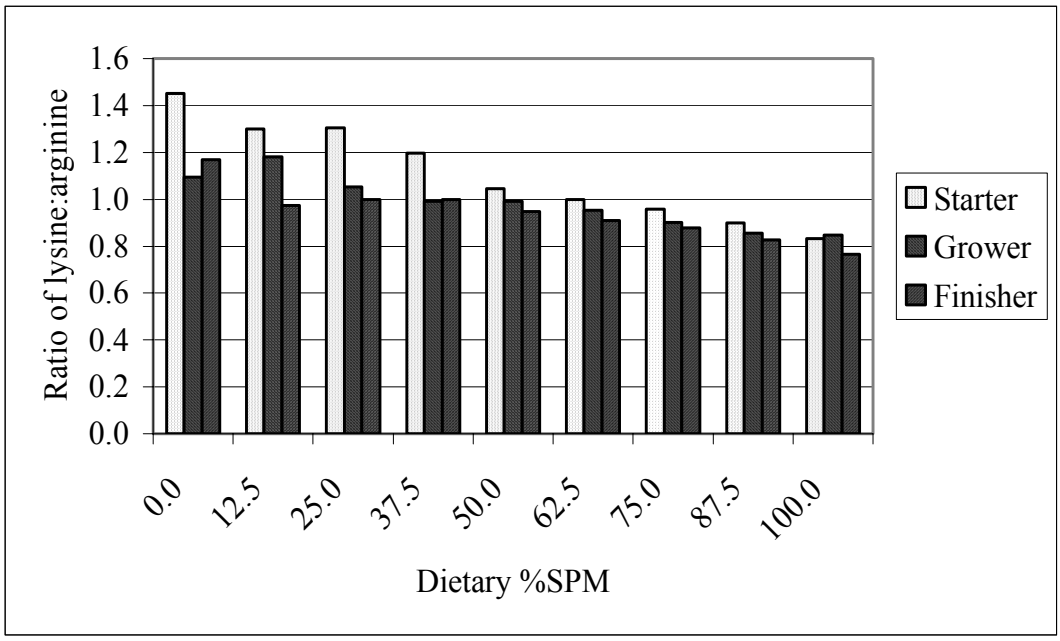


Figure 21. Ratio of lysine to arginine in the starter, grower and finisher rations

In diets having 37.5% or less SPM the lysine to arginine ratio was 1.2 or greater in the starter ration. According to Larbier and Leclercq (1994), the high ratio of lysine to arginine would have reduced live weight gain. However, the high dietary threonine concentration in diets containing 37.5% or less SPM might have partially counteracted a lysine-arginine antagonism as threonine acts in the kidney so as to reduce the rate of arginine breakdown (Larbier and Leclercq, 1994). Although, Larbier and Leclercq (1994) noted that arginine may be become deficient in the presence of excess lysine by other mechanisms, including reduced renal absorption and excessive transaminase activity in the liver.

A review by Balnave and Brake (2002) evaluated the dietary arginine and lysine interactions for modern poultry. Their work suggested optimal ratios of arginine to lysine of between 0.90 to 1.18 for growing poultry. The optimal ratio of arginine to lysine increased with increasing ambient temperature, probably because of reduced arginine absorption at high temperatures. There were interactive effects of sodium chloride on the optimal arginine to lysine ratio at high temperatures. The optimal ratio was higher when dietary sodium chloride concentrations were minimal.

The outdoor ambient temperatures experienced during the post brooding period of this study were high, and it was not possible to achieve an indoor target post brooding temperature of 21°C. The maximum post brooding temperature during this study was greater than 25 °C for 17 days, and it was greater than 30°C for

five days. This might have influenced the optimal ratio of lysine to arginine, although it is worth noting that the sodium chloride concentrations of the diet were not marginal.

The broiler is sensitive to ambient temperature: it influences feed intake, growth and fat deposition (Larbier and Leclercq, 1994). The effects of ambient temperature on feed intake and growth are of interest in the context of this study. In males, growth is slightly improved with temperatures below 20°C (+ 0.1% per °C) and is considerably reduced with temperatures beyond 20°C (-1.0% per °C) (*loc. sit*.). The response of feed consumption to temperature is virtually linear, being approximately + or – 0.9% per degree reduction or increase respectively from 20°C. Females are slightly less sensitive to temperature than males (Larbier and Leclercq, 1994).

Increasing the concentration of protein, amino acids and minerals so that the birds' requirements may be met at lower feed intakes is one means of improving performance at high temperatures. Thus, the variation in protein and amino acid content of the diets might have influenced growth. Certainly, any nutrient deficiency would have been exacerbated due to the high indoor ambient temperatures and lower than expected feed intakes.

Lastly, it is possible that differences in the digestibility of ingredients and the availability of amino acids might have influenced performance. For example, the rapeseed meal protein is less digestible than the protein within soya bean meal (72%, *versus* 88%, respectively)(Larbier and Leclercq, 1994). The true digestibility of lysine in soya bean meal is given as 91%, compared with 79% in rapeseed meal (*loc.sit*.). Over-processing (toasting) rapeseed meal reduces protein quality and amino acid availability, and particularly lysine content and availability (Anderson-Hafermann *et al.,* 1993; Newkirk *et al.,* 2003). The differences between soya bean meal and rapeseed meal in the true digestibility of sulphur amino acids are much smaller at 88% and 87%, respectively (*loc. sit*.). In terms of practical nutrition, it would be helpful to be able to formulate diets on an amino acid availability basis.

Litter friability was good throughout the study and the hock burn damage was not a problem. The litter dry matter content was generally high, and so capping was minimal and mostly confined to the areas immediate to the drinkers. Any capping was easily broken down.

There was an effect of dietary % SPM on the litter total nitrogen, uric-acid nitrogen and ammonium-nitrogen contents at the end of the 42-day growing period. Factors affecting this would have been feed intake, the supply and digestibility of protein, and the balance and availability of amino acids within the diets. Interestingly, the highest total litter nitrogen content was obtained in birds fed 100.0% SPM. FCE was optimised in birds fed 100.0% SPM, but feed intake and live weight gain to 42 days of age were not optimal.

FCE is a measure of feed utilisation for growth but it does not necessarily indicate the efficiency of feed protein utilisation for lean growth. A proportion of the total nitrogen excreted by the birds will be lost through emissions. The body protein content of the birds was not determined, and thus it is not possible to identify whether there were real differences due to dietary %SPM in total nitrogen output.

Despite its relative insolubility, once uric acid is voided it is readily converted to ammonia ($NH_3$) by micro-organisms. In a review Carlile (1984), quoting several earlier reviews, listed 19 species of bacteria, 22 species of fungi and 3 of actinomycetes, which are capable of degrading uric acid, sometimes operating in succession or in groups. They include both aerobes and anaerobes, though the aerobic population may be more significant in ammonia release. The aerobic degradation of uric acid takes place in several steps, each with its own enzyme, through allantoin, ureidoglycolate, glycolate plus urea, and then finally urease converts these to ammonia and carbon dioxide. As Valentine (1964) realised in the case of the ammonia in poultry house air, it is very soluble and tends to occur as ammonium hydroxide in solution ($NH_4OH$).

The litter total nitrogen contents reported in this study are similar to those reported by Nicholson *et al.,* (1996) for commercial broilers, but the ammonium-nitrogen contents are slightly lower, whereas the uric-acid nitrogen contents are slightly higher than mean values given by Nicholson *et al.,* (1996).

Loss pathways and plant available nitrogen when the manure is spread on land are driven by the plant available fraction of the manure: the sum of ammonium and uric acid nitrogen. Thus, manures with a low proportion of this compared with the total nitrogen will have less short-term availability to the crop and pose less of an environmental risk in terms of leaching and volatilisation losses. The lowest plant available nitrogen content of the litter manures was achieved with the 0.0% SPM diet.

There is a need for a better understanding of the utilisation of plant proteins for lean growth in broilers and the effects on nitrogen excretion and losses due to ammonia emissions.

As explained above, it is not possible to be certain why the birds fed 37.5% or less SPM performed poorly. It is suggested however, that it was most likely to have been due to amino acid imbalances and antagonisms, but also performance was possibly influenced at 0.0% SPM by glucosinolate and sinapine intake.

What is important is whether the results are specific to the protein mixes used and whether the findings may be applied in practical poultry nutrition. It is possible that the results are specific to the particular protein mixes used in this work, thus limiting the applicability of the work to other formulations of non-soya protein. However it is also likely that the results give an indication of the usefulness of the concept of such a mix.

Soya products have been the principle protein sources for the UK poultry industry for decades, and for the entire history of the intensive poultry sector. This is because soya has relatively low levels of antinutritional factors, its amino acid balance is relatively suitable for poultry compared with many other plant materials, and supplies have been reliable and usually acceptably priced. Furthermore soya has a long history of nutritional research support, and can be used with confidence. However for several reasons the reliability and price of supplies may be less dependable in the future, and there are some environmental reasons to question excessive dependence on soya.

Limits to the inclusion levels of ingredients are almost inevitable. From the point of view of the evolution of plant species antinutritional factors presumably protect plant seeds from excessive consumption by animals. It is not surprising therefore that antinutritional factors are so common in feed ingredients, and in some cases with considerable potency. Thus, when replacing so suitable and well precedented an ingredient as soya it is very important to be aware of the importance of antinutritionals, and it may sometimes be wise to use more than one protein source in a practical feed, provided that the effects of their antinutritionals are not mutually enhancing.

Despite such difficulties this series of experiments has shown that total dependence on soya need not be obligatory. Other ingredients, grown in the UK and Europe, could make more contributions to poultry nutrition than they have hitherto.

The rate of uptake of such work is not, however, limited solely by technical considerations, but also by marketing factors. Some of these are obvious, like ingredient price. Others are more subtle. There is a difficulty in breaking certain cycles of market availability. Until feed formulators demand more indigenous proteins the prices will give arable farmers no incentive to grow them. Yet at the same time feed formulators cannot be expected to use the materials if supplies are limited, unreliable and expensive due to low arable outputs. This is a real constraint on technical changes of this nature.

*Conclusions*

1. Feed intake and live weight gain between day-old and 42 days of age was not optimal at 100.0% SPM, but FCE to 42 days of age was optimised by feeding 100.0% SPM.
2. Male and female feed intake between day-old and 42 days of age and male live weight gain between day-old and 42 days of age was optimised by feeding between 37.5% SPM and 75.0% SPM. Female live weight gain to 42 days of age was optimised by feeding between 50.0% and 100.0% SPM.
3. Male and female feed intake and live weight gain to 42 days of age was poorest in birds fed 0.0% SPM.
4. The reasons for poor performance at the two extremes of dietary %SPM are probably different, but in both cases probably complex. There is a suggestion that lysine, methionine, cystine and threonine contents were limiting in the 100.0% SPM rations. By contrast, there was an excess of threonine in the diets having 37.5% or less SPM. This most likely caused an imbalance between the limiting amino acids for growth. There was also the possibility of a lysine-arginine antagonism, as the ratio of lysine to arginine was high in the low SPM diets, particularly in the starter ration. At 0.0% SPM, there was also the possibility that the concentration of rapeseed meal and whole rapeseed might have affected feed intake and live weight gain. This could have been due to glucosinolate and/or sinapine intake, but more work is needed to clarify the roles of these antinutritionals in the control of feed intake.
5. Mortality was not affected by dietary %SPM and there were no incidences of leg abnormalities. Feathering was poor in birds fed either 0.0% SPM or 100.0% SPM, and this is indicative of nutrient deficiencies. In this study, poor feathering was most probably due to a limited supply of the sulphur amino acids.
6. Litter friability was good throughout the study and the hock burn damage was not a problem.
7. There was an effect of dietary % SPM on the litter total nitrogen, uric-acid nitrogen and ammonium-nitrogen contents at the end of the 42-day growing period. Factors affecting this would have been feed intake, the supply and digestibility of protein, and the balance and availability of amino acids within the diets. The highest total litter nitrogen content was obtained in birds fed 100.0% SPM and the lowest plant available nitrogen content of the litter manure was achieved in birds fed 0.0% SPM.

Practical implications of the project findings and relevance to levy payers

Soya products have been the principal protein sources for the UK poultry industry for decades, and for the entire history of the intensive poultry sector. This is because soya has relatively low levels of antinutritional factors, its amino acid balance is relatively suitable for poultry compared with many other plant materials, and supplies have been reliable and usually acceptably priced. Furthermore soya has a long history of nutritional research support, and can be used with confidence. However for several reasons the reliability and price of supplies may be less dependable in the future, and there are some environmental reasons to question excessive dependence on soya.

This project addressed the broilers' performance responses to increasing dietary concentrations of a number of UK-grown protein sources (rapeseed meal, whole rapeseed, peas and beans). The aim was to improve confidence about their use in UK broilers diets, through a better understanding of their effects on intakes, growth, litter quality and bird body condition.

Varietal, environmental and agronomic effects on nutrient content and the presence and concentrations of antinutritional factors in proteinaceous ingredients are difficult to take into account in feeding studies. The number of treatments needed is mostly too large to be accommodated. Thus, in most published studies a limited number of dietary concentrations, usually three, and sometimes for two varieties known to differ in their antinutritional content, have been used. This perhaps explains why there are large differences between published maximum dietary concentrations for some protein sources.

In the UK it is not usually possible to source ingredients on a variety basis, and this is impossible for ingredients such as rapeseed meal, which have been subject to processing. It is a blend that is available to the livestock feed industry. The applicability therefore, of maximum recommended concentrations of known preferred varieties might not be of immediate practical use to UK broiler producers. It is likely that a blend is a less favourable ingredient for poultry, probably having higher concentrations of some important antinutritional factors, such as glucosinolates or tannins, and/or lower nutrient value. Thus, in these studies increasing dietary concentrations of blends were used so as to take into account practical limitations and to avoid the testing of a superior and mostly unavailable ingredient.

The work has produced information on recommended maximum dietary concentrations for use in broiler feeds, and it is identified some knowledge gaps. The practical recommendations are as follows:

1. Rapeseed meal may be included in starter and finisher rations at concentrations of up to 60 g/kg without apparent ill effects on live weight gain or FCE, but assuming no taint problems. According to the

literature available meat taint problems are unlikely to be incurred at this concentration, but caution is warranted if the feed contains fishmeal, and possibly supplementary choline and methionine.

2. Whole rapeseed may be included in starter and finisher rations at concentrations of up to 100 g/kg in the starter and finisher rations without apparent ill effects on FCE, although feed intake and live weight is expected to be depressed. This assumes that there are no taint problems. The risks of incurring 'fishy' taint when feeding whole rapeseed is probably similar to that for rapeseed meal, provided that the sinapine contents are similar, and that the oil does not impact on the fatty acid composition so as to increase the likelihood of meat rancidity. As for rapeseed meal, caution is warranted if feeding whole rapeseed with fishmeal.
3. A mix of alternative proteins to soya is likely to be better than relying on one or two alternatives. This might help to dilute some of the antinutritional factors present. It is possible to substitute soya with a mix of UK proteinaceous ingredients to quite high levels (up to 75% substitution with the protein mix reported) without reducing live weight. FCEs might be reduced however, and so this approach will depend on the relative prices of ingredients and the value of chicken meat at the time of consideration. There will be a need to pay careful attention to the supply and balance of essential amino acids if performance is to be optimised when using protein sources other than soya.

The relevance of the work to levy payers is that the findings provide technical support for the use of rapeseed meal and whole rapeseed in UK broiler feeds. The uptake of the results by the UK broiler industry will depend however, on market dynamics and knowledge transfer.

Recommendations for further research and knowledge transfer

1. To determine for UK-grown blends of rapeseed the variation in contents of crude protein, glucosinolates and sinapine and the protein quality of UK-produced meals.
2. To identify the factors present in rapeseed and the mechanisms by which they act within the broiler to reduce feed intake.
3. To investigate whether the manipulation of dietary nutrient concentration could be used to counteract the effects of reduced intake, by maintaining nutrient intake when feeding rapeseed. Thus, it could be worth repeating some aspects of the work using feeds which were not iso-nitrogenous.
4. To determine the effect of dietary concentration of whole rapeseed on broiler meat flavour, and the interactive effects of whole rapeseed and other sulphur-rich ingredients on meat acceptability.
5. To determine the effect of protein source on the efficiency of nitrogen utilisation for meat production and on the form and availability of nitrogen in the manure.
6. To make further improvements in ingredient quality by consistently reducing the concentrations of important antinutritional factors and by improving protein quality for monogastrics.
7. To improve the marketing of UK-grown proteinaceous ingredients to the livestock feed industry.

Publications

Gordon, S.H., Short, F.,Wilson, D.W. and Croxall, R. (2004). The effect of dietary concentration of rapeseed meal or whole rapeseed on broiler performance and litter quality. *British Poultry Science* **45** (Supplement 1): S21

Gordon, S.H. (2004). Growth responses of broiler chickens to increasing dietary concentrations of whole rapeseed or rapeseed meal. ADAS Research Review 2004. *In press*

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| | |
|---|---|
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References

Amarowicz, R., Fornal, J. and Karamac, M. (1995). Effect of seed moisture on phenolic acids in rapeseed oil cake. Grasas y Acietes 46:354-356

Anderson-Hafermann, J.C., Zhang, Y. and Parsons, C.M. (1993). Effects of processing on the nutritional quality of canola meal. Poultry Science 72:326-333

Applequist, L. and Ohlson, R. (1972). Rapeseed Cultivation, composition, processing and Utilisation. Elsevier, Amsterdam

Askbrant, S.U.S. (1988). Metabolisable energy content of rapeseed meal, faba bean meal and white flowered peas determined with laying hens and adult cockerels. British Poultry Science 29:445-455

Balnave, D. and Brake. J. (2002). Re-evaluation of the classical dietary arginine:lysine interaction for modern poultry diets: a review. World's Poultry Science Journal 58:275-289

Baniel, A., Gueguen, J., Bertrand, D. (1992). Variability of protein composition in pea seeds by high performance liquid chromatography. In: Premiere Conference europeenne sur les proteagineux. Edit. Angers, A.E.P., pp409-410

Barrier-Guillot, B., Metayer, J.P., Grosjean, F. and Peyronnet, C. (1995). Feeding value of pea presented in mash or pellets in adult cockerels, laying hens, broilers and turkey poults. 10th European Symposium Poultry Nutrition, Antalya

Bell, J. (1993). Factors affecting the nutritional value of canola meal: a review. Canadian Journal of Animal Science 73:679-689

Bell, J.M., Tyler, R.T. and Rakow, G. (1998). Nutritional composition and digestibility index as an indicator of adequately processed soya bean meal. Poultry Science 79:1592-1596

Boomgaardt, J. and Baker, D.M. (1973). Effect of age on the lysine and sulphur amino acid requirement of growing chickens. Poultry Science 52:592-597

Buraczewska, L., Gdala, J., Wasilewko, J. and Buraczewski, S. (1998). Ileal digestibility in pigs of protein and amino acids of heat treated rapeseed feeds as affected by protein associated with the NDF fraction. Oilseed Crops 19:175-186

Carlile, F.S. (1984). Ammonia in poultry houses: a literature review. World's Poultry Science Journal 40:99-113

Carre, B., Escartin, R., Melcion, J.P., Champ, M., Roux, G. and Leclercq, B. (1987). Effect of pelleting and associations with maize or wheat on the nutritive value of smooth pea seeds (*Pisum sativum*) in adult cockerels. British Poultry Science 28:219-229

Carre, B. Beaufils, E. and Melcion, J.P. (1991). Evaluation of protein and starch digestibility and energy value of pelleted or unpelleted pea seeds from winter or spring cultivars in adult and young chickens. Journal Agricultural and Food Chemistry 39:468-472

Carouee, B. and Duchene, E. (1993). Teneur en proteines du pois. Comment maitriser les variations. Perspective Agricoles 183:75-81

Cheryan, M. (1980). Phytic acid interactions in food systems. CRC Critical Reviews in Food Science Nutrition 13:297-334

Cmolik, J., Pokorny, J., Panek, J., Kanova, J., Velisek, J., Parizkova, H., Holasova, M. and Koplik, R. (1991). Effect of minor constitutes of crude rape seed oil on the stability of refined oil against the oxidative deterioration. Proceedings 8th International Rape seed Congress, Canada, 3:894-898

Conan, L., Barrier-Guillot, B., Widiez, J.L. and Lucbert, J. (1992). Effect of grinding and pelleting on the nutritional value of smooth pea seed in adult cockerel. In: Premiere conference europeenne sur les proteagineux. Edit. Agers, A.E.P., pp 479-480

Cosgrove, D. (1980). Insitol phosphates: Their chemistry, biochemistry and physiology. Elsevier Scientific Publishing Company, New York NY

Coultate, T.P. (1996). Food. The Chemistry of its Components. Royal Society of Chemistry, Cambridge

Dabrowski, K. and Sosulski, F. (1983). Extraction of phenolic compounds from canola during protein concentration and isolation. In: Proceedings 6th International Rapeseed Congress, Paris, pp1338-1342

Defra (2004). Agriculture in the United Kingdom 2003, London

D'Mello, J.P.F. and Lewis, D. (1970). Amino acid interactions in chick nutrition. 3. Interdependence in amino acid requirements. British Poultry Science 11:367

Erdman, J.J.W. (1979). Oilseed phytates: nutrition implications. Journal of American Oil Chemical Society 56:736-741

Fenwick, G.R., Curl, C.L., Pearson, A.W. and Butler, E.J. (1984). The treatment of rapeseed meal and its effect on chemical composition and egg tainting potential. Journal of the Science of Food and Agriculture 35:757-761

Fernandez, S.R., Aoyagi, S., Han, Y., Parsons, C.M. and Baker, D.H. (1994). Limiting order of amino acids in corn and soybean meal for growth of the chick. Poultry Science 73:1887-1896

Frieg, A.H., Campbell, L.D., Stanger, N.E. and Slominski, B. (1986). Absorption, excretion and metabolism of glucosinolates in poultry. Canadian Journal of Animal Science 66:331

Ganchrow, J.R., Steiner, J.E. and Bartana, A. (1990). Behavioural reactions to gaustatory stimuli in young chicks (*Gallus gallus domesticus*). Developmental Psychology 23:103-117

Gordon, S.H. and Charles, D.R. (2002). Niche and organic chicken and egg production: its technology and scientific principles. Nottingham University Press

Gordon, S.H. (2001). Effects of modifying the polyunsaturated fatty acid and antioxidant contents of poultry meat on flavour, tenderness and shelf life and its application to extensive systems. Defra, London (Defra project LS3501), 172pp

Grala, W., Buraczewska, L., Gdala, J., Pastuszewska, B. (1994). Effect of thermal processing on protein value of rapeseed oil meal for pigs. Journal of Animal Feed Science 3:33-42

Grala, W., Buraczewska, Wasilewko, J., Verstegen, M.W.A., Tamminga, S., Jansman, AJ.M., Huisman, J. and Korczynski, W. (1998). Flow of endogenous nitrogen in different segments of the small intestine in pigs fed diets with soyabean concentrate, soyabean meal or rapeseed cake. Journal of Animal Feed Science 3:33-42

Griffiths, N.M., Fenwick, G.R., Pearson, W., Neil, N.M. and Butler, E.J. (1980). Effects of rapeseed meal on broilers: studies on meat flavour, liver haemorrhage and trimethylamine oxidase activity. Journal of Science of Food and Agriculture 31:188-193

Grosjean, F. (1985). Combining peas for animal feed. In: The pea crop. Edit. Hebblethwaite, P.D., Heath, M.C. and Dawkins, T.C.K., Butterworths, London, pp 453-462

Hagerman, A. and Butler, L. (1980). Condensed tannin purification and characterization of tannin associated proteins. Journal of Agricultural Food Chemistry 28:947-952

Hallberg, L. (1987). Wheat fibre, phytates and Fe absorption. Scandanavian Journal of Gastroentrology 22:73-79

Hawrysh, Z.J., Steedman-Douglas, C.D., Robblee, A.R., Hardin, R.T. and Sam, R.M. (1980a). Influence of low glucosinolate (cv. Tower) rapeseed meal on the eating quality of broiler chickens. I. Subjective evaluation by a trained taste panel and objective measurements. Poultry Science 59:550-557

Hawrysh, Sam, R.M., Robblee, A.R., and Hardin, R.T. (1980b). Influence of low glucosinolate rapeseed meal and rapeseed screenings meal on the eating quality of broiler chickens. Poultry Science 59:2437-2443

Hawrysh, Sam, R.M., Hardin, R.T. and Robblee, A.R., (1980c). A consumer study of the eating quality of broiler chickens fed rations containing low glucosinolate rapeseed meal and rapeseed screenings meal. Poultry Science 59:2444-2448

Hawrysh, Sam, R.M., Robblee, A.R., and Hardin, R.T. (1982). Influence of low glucosinolate canola meals (cv. Regent versus Canola) on the eating quality of broiler chickens. Poultry Science 61:2375-2384

Hobson-Frohock, A., Land, D.G., Griffiths, N.M. and Curtis, R.F. (1973). Egg taints: association with trimethylamine. Nature 243: 304-305

Holmes, W.B. and Roberts, R. (1963). A perotic syndrome in chicks fed extracted rapeseed meal. Poultry Science 42:803-809

Huisman, J. and Tolman, G.H. (1992). Antinutritional factors in the plant proteins of diets for non-ruminants. In: Recent advances in animal nutrition. Edit. Garnsworthy, P.C., Haresign, W. and Cole, D.J.A., Butterworth Heinemann, Oxford

Igbasan, F.A. and Guenter, W. (1996). The enhancement of the nutritive value of peas for broiler chickens: an evaluation of micronisation and dehulling processes. Poultry Science 75: 1243-1252

Jansman, A.J.M., Huisman, J. and van der Poel, A.F. (1993). Performance of broiler chicks fed diets containing different varieties of faba bean (*Vicia faba L.*). Archiv fuer Gefluegelkunde 57: 220-227

Jensen, S., Lui, Y. and Eggum, B. (1995). The influence of variations in seed size and hull content on composition and digestibility of rapeseed. In: Proceedings 9th International Rapeseed Congress, Cambridge, pp188-190

Jensen, S., Olsen, H. and Sorenson, H. (1991). Aqueous enzymatic processing of rapeseed for production of high quality products. In: Canola and Rapeseed: Production, Chemistry, Nutrition and Processing Technology. Ed. Shahidi, F. AVI Book, New York, NY, pp331-343

Jondreville, C., van den Broecke, j., Gatel, F., Grosjean, F., van Cuwanenberghe, S., and Seve, B. (2000). Ileal amino acid digestibility and estimates of endogenous amino acid losses in pigs rapeseed meal, sunflower meal and soyabean meal. Canadian Journal of Animal Science 80:495-506

Jones, J. and Sibbald, I. (1979). The true metabolizable energy values for poultry of fractions of rapeseed Brassica napus cv Tower. Poultry Science 58:385-391

van Kempen, G.J.M. and Jansman, A.J.M. (1994). Use of EC produced oil seeds in animal feeds. In: Recent advances in animal nutrition. Edit. Garnsworthy, P.C. and Cole, D.J.A., Nottingham University Press, pp 31-56

Khattak, F.M., Acamovic, T. and Scaife, J.R. (1995). Growth and pigmentation of broilers fed diets containing either whole rapeseed or marine oil with and without vitamin E supplementation. British Poultry Science 36:847-848

Kozlowska, H., Naczk, M., Shahidi, F. and Zadernowski, R. (1991). Phenolic acids and tannins in rapeseed and canola. In: Canola and Rapeseed: Production, Chemistry, Nutrition and Processing Technology. Ed. Shahidi, F. AVI Book, New York, NY, pp193-210

Kozlowska, H. and Zadernowski, R. (1983). Production of protein preparates from rapeseed. In: Proceedings of 6th International Rapeseed Congress, Paris, pp 1412-1419

Kozlowska, H. and Zadernowski, R. (1988). Phenolic compounds of rapeseed as factors limiting the utilization of protein in nutrition. Abstract 3rd North American Chemical Congress, Toronto, ON.

Krygier, K., Sosulski, F. and Hogge, L. (1982). Free, esterified and insoluble-bound phenolic acids. 2. Composition of phenolic acids in rapeseed flour and hulls. Journal of American Food Chemistry 30:334-336

Lacassagne, L. (1988). Alimentation des volailles: substituts au tourteau de soja. INRA Production Animal 1: 47-57

Lacki, K. and Duvnjak, Z. (1996). Comparison of three methods of determination of sinapic acid ester content in enzymatically treated canola meals. Applied Microbiology Biotechnology 45:530-537

Lamb, K.J. and Acamovic, T. (1998). The effect of tannin-binding agents, with or without enzyme supplementation, on the dry matter digestibility and ME of Faba beans. In: Proceedings of the World's Poultry Science Association Annual Spring Meeting, Scarborough, pp 75-76

Larbier, M. and Leclercq, B. (1994). Nutrition and feeding of poultry. Translated and edited by Wiseman, J., Nottingham University Press, Nottingham

Leeson, S. and Summers, J.D. (1997). Commercial poultry nutrition. University Books, Guelph

Leeson, S. and Summers, J.D. (2001). Scott's Nutrition of the Chicken. 4th Edition, University Books, Guelph, Ontario, Canada

Longstaff, M. and McNab, J.M. (1989). Digestion of fibre polysaccharides of pea (Pisum sativum) hulls, carrot and cabbage by adult cockerels. British Journal of Nutrition 62: 563-577

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D. and Morgan, C.A. (1995). Animal Nutrition, 5th Edition. John Wiley & Sons, New York, pp607

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D. and Morgan, C.A. (2002). Animal nutrition. 6th edition. Pearson Education, Harlow

McManus, J., Davis, K., Beart, J., Gaffney, S., Liley, T. and Haslam, E. (1985). Polyphenol interactions. Part 1. Introduction: some observations on reversible complexation of polyphenols with proteins and polysaccharides. Journal of Chemical Society Perkin Transactions 2:1429-1438

McNeill, L., Bernard, K. and MacLeod, M.G. (2004). Food intake, growth rate, feed conversion and food choice in broilers fed on diets high in rapeseed meal and peal meal, with observations on sensory evaluation of the resulting poultry meat. British Poultry Science 45:519-523

Magna, J. (1982). Phytate: its chemistry, occurrence, food interaction, nutritional significance and methods. Journal of Agricultural Food Chemistry 30:1-9

Morris, E. (1986). Phytate and dietary mineral bioavailability. In Phytic acid: Chemistry and applications. Ed. Graf, E., Pilatus Press, Minneapolis, pp57-76

Morris, T.R., Al-Azzawi, K., Gous, R.M. and Simpson, G.L. (1987) Effects of protein concentration on responses to dietary lysine by chickens. British Poultry Science 28: 185-195

Motzok, I. (1976). Rapeseed Association of Canada 40:65-75

Naczk, M., Amarowicz, R., Sullivan, A. and Shahidi, F. (1998). Current research and developments on polyphenolics of rapeseed/canola: a review. Food Chemistry 62:489-502

Naczk, M., Diosady, L. and Rubin, L. (1986). The phytate and complex phenol content of meals produced by alkanol-ammonia-hexane extraction of canola. Lebensm-Wiss. u. Technology 19:13-16

Naczk, M., Nichols, R., Pink, D. and Sosulski, F. (1994). Condensed tannins in canola hulls. Journal of Agricultural and Food Chemistry 42:2196-2200

National Research Council (1994) Nutrient requirements of poultry. 9th Revised Edition. National Academy Press, Washington D.C.

Newkirk , R.W. and Classen, H.L. (2001). The non-mineral nutritional impact of phytate in canola meal fed to broiler chicks. Animal Feed Science and Technology 91:115-128

Newkirk , R.W., Classen, H.L. and Edney, M.J. (2003). Effects of prepress-solvent extraction on the nutritional value of canola meal for broiler chickens. Animal Feed Science and Technology 104:111-119

Nicholson, F.A., Chambers, B.J. and Smith, K.A. (1996). Nutrient composition of poultry manures in England and Wales. Bioresource Technology 58:279-284

Qaio, H. mad Classen, H.L. (2003). Nutritional and physiological effects of rapeseed meal sinapine in broiler chickens and its metabolism in the digestive tract. Journal of the Science of Food and Agriculture. 83:1430-1438

Pastuszewska, B., Jablecki, G., Buraczewska, L., Dakowski, P., Taciak, M., Matyjek, R. and Octabinska, A. (2003). Animal Feed Science and Technology 106:175-188

Picard, M., Melcion, J.P., Bertrand, D. and Faure, J.M. (2002). Visual and tactile cues perceived by chickens. In: Poultry Feedstuffs. Supply, composition and nutritive value. Poultry Science Symposium Series Volume 26. Ed.'s McNab, J.M. and Boorman, K.N., CABI Publishing, Oxon, Chapter 15, pp.279-300

Raju, M.V.L.N., Chawak, M.M., Praharaj, N.K., Rao, S.V.R. and Mishra, S.K. (1997). Interrelationships among egg weight, hatchability, chick weight, post-hatch performance and rearing method in broiler breeders. Indian Journal of Animal Sciences 67: 48-50

Ravindran, V., Selle, P.H. and Bryden, W.L. (1999). Effects of phytase supplementation, individually and in combination, with glycanase, on the nutritive value of wheat and barley. Poultry Science 78:1588-1595

Robbins, K.R. (1987). Threonine requirement of the broiler chic as affected by dietary protein level and source. Poultry Science 66:1531-1534

RPAN (1993). Nutrition guide. Rhone Poulenc Animal Nutrition 1993.

Salmon, R.E., Froehlich, D. and Butler, G. (1984). Effect of canola meal, fish meal and choline plus methionine on the sensory quality of broiler chickens. Poultry Science 63:1994-1998

Salmon, R.E., Gardiner, E.E., Klein, K.K. and Larmond, E. (1981). Effect of canola (low glucosinolate rapeseed) meal, protein and nutrient density on performance, carcass grade and meat yield and of canola meal on sensory quality of broilers. Poultry Science 60:2519-2528

Segueilha, L., Lambrechts, C., Boze, H., Moulin, G. and Galzy, P. (1992). Purification and properties of phytase from Schwanniomyces castelli. Journal of Fermentation Bioengineering 74:7-11

Seth, P.C.C. and Clandinin, D.R. (1973). Effect of including rapeseed meal in the ration of broiler-type chickens on the incidence of perosis and the ineffectiveness of supplementary manganese. Poultry Science 52:1158-1160

Shahidi, F. and Naczk, M. (1988). Effect of processing on the polyphenolic constituents of canola. Bulletin de Liason Groupe Polyphenols 14:89-92

Shahidi, F. and Naczk, M. (1989). Effect of processing on the content of condensed tannins in rapeseed meals. A research note. Journal of Food Science 54:1082-1083

Shahidi, F. and Naczk, M. (1992). An overview of the phenolics of canola and rapeseed: chemical, sensory and nutritional significance. Journal of American Oil Chemistry Society 69:917-924

Simbaya, J., Slominski, B.A., Guenter, W., Morgan, A. and Campbell, L.D. (1996). The effects of protease and carbohydrase supplementation on the nutritive value of canola meal for poultry: In vitro and in vivo studies. Animal Feed Science Technology 61:219-234

Slominski, B.A., Simbaya, J., Campbell, L.D., Rakow, G. and Guenter, W. (1999). Nutritive value for broilers of meals derived from newly developed varieties of yellow seeded canola. Animal Feed Science and Technology 78:249-262

Summers, J.D (1995). Canola meal and acid-base balance. Animal Feed Science and Technology 53:109-115

Theander, O., Aman, P., Miksche, G. and Yasuada, S. (1977). Carbohydrates, polyphenols and lignin in seed hulls of different colours from turnip rapeseeds. Journal of Agricultural and Food Chemistry 25:270-273

Thomke, S., Elwinger, K., Rundgren, M. and Ahlstrom, B. (1983). Rapeseed meal of Swedish low glucosinolate type fed to broiler chickens, laying hens and growing-finishing pigs. Acta Agriculture Scanadavia 33:75-96

Thompson, L. (1990). Phytates in canola/rapeseed. In: Canola and rapeseed: Production, chemistry, nutrition and processing technology. Ed. Shadidi, F. AVI Book, New York, pp173-192

Timms, L.M. (1983). Forms of leg abnormality observed in male broilers fed on a diet containing 12.5 per cent rapeseed meal. Research in Veterinary Science 35:182-189

Unger, E. (1990). Commercial processing of canola and rapeseed: Crushing and oil extraction. In: Canola dn rapeseed Production, Chemistry, Nutrition and processing technology. Ed. Shahidi, F., AVI Book, New York, NY, pp235-250

UNIP-ITCF (1995). Peas: utilisation in animal feeding. Edit. Carrouee, B. and Gatel, F. Interprofessional National Union for Protein Rich Crops and Technical Institute for Cereals and Forages. Paris. Translated Wiseman, J.

Valentine, H. (1964). A study of the effect of different ventilation rates on the ammonia concentrations in the atmosphere of broiler houses. British Poultry Science 5:149-160

Yule, W.L. and McBride, R.L. (1976). Lupin and rapeseed meals in poultry diets: effects on broiler performance and sensory evaluation of carcasses. British Poultry Science 17:231-239

Yule, W.L. and McBride, R.L. (1978). Rapeseed meals in broiler diets: effects on performance and sensory evaluation of carcasses. British Poultry Science 19:543-548