The effect of the dietary inclusion of canola oilcake, full-fat canola and sweet lupins on the production performance and fat composition of broilers and pigs

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MASTER OF SCIENCE IN AGRICULTURE

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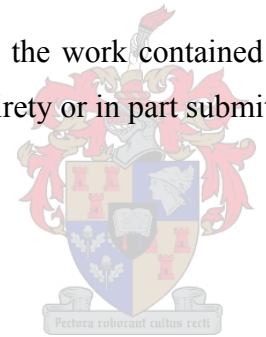
Stellenbosch March 2005

DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.



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Abstract

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The demand for protein for human and animal nutrition in South Africa is increasing and it will continuously increase. The effect of replacing soybean oilcake meal as protein source for broilers and full-fat soybean meal for weaner pigs, with different levels of sweet lupins (*Lupinus angustifolius*), canola oilcake and full-fat canola was examined. A basal diet with soybean oilcake as protein source was mixed with a diet using either sweet lupins or canola oilcake or full-fat canola in ratios of 100%, 67% and 33% respectively. In the broiler trial the test diets were fed for a period of six weeks with or without the enzyme Vegpro (Alltech). Pigs were fed the test diets, with and without Roxazyme® enzyme, *ad libitum* from 8.5 to 25 kg live weight. The fatty acid content of the fat pads of the broilers raised on the different diets was determined. The pigs were kept in the trial up to the grower- finisher phase. The fatty acid content of the carcass fat and muscle of pigs raised on the different diets was determined. The inclusion of enzymes had no effect on the growth, feed intake or feed conversion ratio of broilers fed the test diets. The provision of external dietary enzymes to the weaner pig diets failed to improve either dry matter intake or growth rate, but improved the feed conversion ratio. Broiler weights at six weeks of age were significantly higher for the control diet compared to the 20% lupin diet. There was no significant difference in the feed intake as the lupin content of the diets increased. The feed conversion ratio did not differ significantly between the control diet and the 6.6% lupin diet but became significantly poorer as the lupin content increased to 13.2% and 20% of the test diet. There were no significant differences in production performance of the control diet and the canola oilcake containing diet. The broiler weights at six weeks decreased significantly with each increase in the canola oilcake content of the diets. The feed intake of the 20% canola oilcake diet at week six was significantly less than the intake of the control diet, but not significantly less than the 6.6% and 13.2% canola oilcake diets. The feed conversion ratio of the control diet was significantly better than the 13.2% and 20% canola oilcake diets. No significant differences were found in week six between the 6.6% full-fat canola diet and the control diet for broiler weights and feed intake. The feed conversion ratio of the broilers fed the 13.2% and 20% full-fat canola diets was significantly poorer than the control diet. The final body weights of the weaner piglets fed the control

diet were significantly higher than the final body weights of weaner piglets fed the lupin containing diets. The average daily gain of the weaner piglets fed the control diet was significantly higher than the gain of the weaner piglets fed the lupin containing diets. No significant differences in the feed intake and feed conversion ratio between the different lupin inclusion levels were detected. There were no significant differences in body weight, feed intake, average daily gain and the feed conversion ratio, between the various full-fat canola containing diets and the control diet. A significant difference in body weight was found between the weaner piglets fed the 20% canola oilcake diet and the weaner piglets fed the control diet. There were no significant differences in feed intake between the various inclusion levels of canola oilcake. The control and 6.6% canola oilcake containing diets had significantly higher average daily gains than the 20% canola oilcake containing diet. In the final trial the finisher pigs fed the test diet containing 25.00% lupins, had a final body weight significantly lighter than the final body weight of the finisher pigs fed the other test diets. The finisher pigs fed the test diet containing 25.00% lupins, also had a significantly reduced average daily gain and feed intake. The feed intake of the 25.00% canola oilcake diet was significantly lees than the feed intake of the 16.75% full-fat canola containing diet. The feed conversion ratio of the 25.00% lupin containing diet was significantly poorer than the feed conversion ratio of the 16.75% lupin containing diet, 8.25% lupin containing diet, 16.75% full-fat canola containing diet, 25.00% canola oilcake containing diet and the control diet.

In a choice feeding trial growing pigs were offered four diets with four different protein sources: sweet lupins (25% inclusion level), canola oilcake (25% inclusion level), full-fat canola (25% inclusion level) and soybean oilcake (25% inclusion level), while their daily intakes were recorded. In a second choice feeding trial pigs were offered ten different diets with increasing levels (6.6%, 13.2%, 20%) of either sweet lupins, canola oilcake meal or full-fat canola meal. The pigs consumed significantly more of the soybean oilcake containing diet compared to diets containing the alternative protein sources. Pigs consumed significantly less of the full-fat canola diet compared to the sweet lupin and canola oilcake diets.

Ten different canola cultivars were collected from two different locations in the Mediterranean rainfall area of South Africa namely the Western Cape (Swartland) and Southern Cape (Rûens) grain producing areas. The sinapine and glucosinolate content of various canola cultivars was compared and the influence of locality on the sinapine and glucosinolate content of the canola cultivars was determined. There were no significant differences ($P \leq 0.05$) in sinapine content when the canola produced in the Western and Southern Cape were compared. Varola 54 and Rainbow cultivars had significantly higher ($P \leq 0.05$) sinapine contents compared to the Varola 50 cultivar.

Samples of lupins, field peas, faba beans and narbon beans were collected and analysed for amino acids, alkaloids, non-starch polysaccharides, tannin and starch. The digestible energy value of these alternative protein sources for pigs was determined. Significant differences were found in the amino acid content of the various crops. The alkaloid content of the lupins varied significantly between the sweet and bitter lupin varieties. Sweet *L. angustifolius* cultivars contained *ca* 50mg/kg and the bitter *L. angustifolius*

cultivars *ca* 15000mg/kg alkaloids. The mean alkaloid content of *L. albus* cultivars was *ca* 1300mg/kg. The faba beans, narbon beans and peas had significantly higher values for tannins and starch, compared to lupins.

Opsomming

Titel:	Die invloed van kanola oliekoek, volvet kanola en soet lupiene, insluiting in diëte, op die produksie en vetsuur profiele van braaikuikens en varke
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Graad:	MSc Agric

In Suid-Afrika is daar ‘n toenemende vraag na proteïene vir beide menslike- en dierlike gebruik. Die gebruik van soet lupiene (*Lupinus angustifolius*), kanolaoliekoek en volvetkanola is ondersoek vir die vervanging van sojaboonoliekoekmeel en volvetsojaboonmeel as proteïenbron by braaikuikens en speenvarkies. ‘n Basiese dieet, met sojaboonoliekoek as proteïenbron, is gemeng met die alternatiewe proteïenbronne, soet lupiene (*Lupinus angustifolius*), kanolaoliekoek en volvetkanola , om drie toetsdiëte met insluitingsvlakke van 100%, 67% en 33% te verkry. In die braaikuikenproef is die braaikuikens vir ses weke met of sonder die ensiem Vegpro (Alltech) gevoer. Die speenvarkies is *ad libitum* gevoer, met of sonder die ensiem Roxazyme, van 8.5 tot 25 kg lewendige gewig.

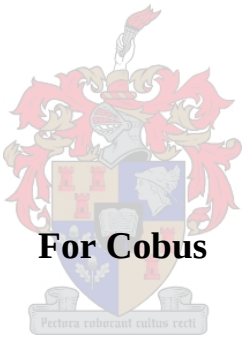
Die vetsuurinhoud van die borsvet by braaikuikens is op die verskillende diëte is bepaal. Die speenvarkies is tot afronding gehou op bogenoemde diete, waarna vetsuurprofiele van die karkasvet en vleis bepaal is. Die insluiting van ensieme het geen effek op groei, voerinname of voeromsetverhouding by die braaikuikens gehad nie, ongeag die proteïenbron in die dieet. Die byvoeging van eksterne ensieme by die speenvarkdiëte het nie die droë material inname of groei beïnvloed nie, maar het wel die voeromsetverhouding vebeter. Op ses weke ouderdom, was die braaikuiken gewigte van die kuikens wat die 20% lupien diet ontvang het betekenisvol laer as die kontrole diet. Die lupien insluiting het geen betekenisvolle verskille in die voerinnam van die braaikuikens veroorsaak nie. Daar was geen betekenisvolle verskil tussen die voeromsetverhouding van die braaikuikens wat die kontrole diet en die 6.6% lupien diet ontvang het nie, die voeromsetverhouding het egter verswak soos die lupien insluiting hoer geword het. Die braaikuiken gewigte het betekenisvol gedaal soos die kanolaoliekoek insluiting meer geword het. Die voerinname van die 20% kanolaoliekoek diet op ses weke ouderdom was betekenisvol minder as die kontrole diet, maar nie betekenisvol minder as die ander kanolaoliekoek bevattende diete nie. Die voeromsetverhouding van die kontrole diet was betekenisvol beter as die 13.2% en die 20% kanolaoliekoek diete. Daar was geen betekenisvolle verskille in die braaikuiken gewigte en die voerinname, tussen die 6.6% volvetkanola diet en die kontrole diet nie. Die voeromsetverhouding van die braaikukens wat die 13.2% en

die 20% volvetkanola diete ontvang het was betekenisvol laer as die kontrole diet. Die finale liggaams massa en gemiddelde daaglikse toename van die speenvarkies wat die kontrole diet ontvang het was betekenisvol hoer as die van die speenvarkies wat die lupien diete ontvang het. Daar was geen verskille in die voerinname en voeromsetverhouding tussen die verskillende lupien insluitingsvlakke nie. Daar was geen betekenisvolle verskille in die laggaams massa, voerinname, gemiddelde daaglikse toename en voeromsetverhouding, tussen die verskillende volvetkanola diete en die kontrole diete. Daar was ‘n betekenisvolle verskil in die ligaams massa tussen die speenvarkies wat die 20% kanola oliekoek diet ontvang het en die speenvarkies wat die kontrole diet ontang het. Geen betekenisvolle verskille is gevind in die voerinname van die kanolaoliekoek diete en die kontrole diet nie. Die speenvarkies wat die kontrole diet en die 6.6% kanolaoliekoek diet ontvang het, het betekenisvolle hoer gemiddelde daaglikse toename gehad as die speenvarkies wat die 20% kanolaoliekoek diet ontvang het. In die finale proef het die varke wat die 25% lupien diet ontvang het,‘n betekenisvol ligter liggaams massa asook ‘n laer gemiddelde daaglikse toename en laer voerinname gehad as die varke wat die ander toets diete ontvang het. Die voeromsetverhouding van die varke wat die 25%lupien diet ontvang het ewas ook betekenisvol swakker as die ander toets diete.

In ‘n volgende proef met groeiende varke, het die varke ‘n vrye keuse tussen vier diëte met vier verskillende proteïenbronne gehad. Die proteïenbronne was: sojaboonoliekoekmeel, soet lupiene (*Lupinus angustifolius*), kanolaoliekoek en volvetkanola. Die varke se daaglikse voerinnames is aangeteken. In ‘n tweede proef het die varke ‘n vrye keuse tussen tien diëte gehad, die diëte het soet lupiene, kanolaoliekoek en volvetkanola teen drie insluitings peile bevat (6.6%, 13.2% en 20%) . Die varke het aanvanklik meer van die sojaboonoliekoekdieet ingeneem as die ander diëte. Die varke het die minste van die volvetkanoladieet ingeneem, in vergelyking met die inname van die soet lupiene- en kanolaoliekoek diëte.

Tien kanola kultivars is versamel by twee lokaliteite, Swartland (Wes-Kaap) en Ruens (Suid-Kaap), in die Westelike provinsie van Suid-Afrika. Die sinapien- en glukosinolaatinhoud van die verskeie kanola kultivars is met mekaar vergelyk en die invloed van lokaliteit op die sinapien- en glukcosinolaatinhoud van die kanola kultivars is bepaal. Daar was geen betekenisvolle verskil ($P \leq 0.05$) in die sinapieninhoud tussen die kanola wat in die Wes-en Suid-Kaap geproduseer is nie. Varola 54 en Rainbow kultivars het meer sinapiene bevat as die Varola 50 kultivar.

Lupien-, voererte-, fababoon- en narbonboonmonsters is versamel en die aminosuur-, alkaloïed-, nie-stysel poliesakkaried-, tannien- en styselinhoud is bepaal. Die verteerbare energie waarde van hierdie alternatiewe proteïenbronne vir varke is bepaal. Betekenisvolle verskille is gevind in die aminosuurinhoud van die verskeie proteïenbronne. Die alkaloïedinhoud van die lupiene het betekenisvol verskil tussen die soet- en bitter lupien variëteite. Soet (*L. angistifolius)* kultivars het ongeveer 50mg/kg en bitter (*L. angistifolius*) kultivars het ongeveer 15000mg/kg alkaloïede bevat. Die gemiddelde alkaloïed inhoud van die *L. albus* kultivars was ongeveer 1300mg/kg. Die tannien- en styselinhoud van die fababone, narbonbone en voer-erte was betekenisvol hoër as die van lupiene.



For Cobus

This thesis represents a compilation of manuscripts; each chapter is an individual entity and repetition between chapters is therefore unavoidable.

Parts of this thesis have been presented at:

1. ***GSSA/SASAS Joint Congress*, Goudini, June 2004, in the form of a presentation and two posters.**

Presentation

Smith, N., Brand, T.S., Aucamp, B. & Ferreira, G., 2004. The use of sweet lupins, canola oilcake and full fat canola with or without external enzymes in diets for broilers.

Posters

Smith, N., Brand, T.S., Hoffman, L.C. & Aucamp, B., 2004. The effect of the dietary inclusion of sweet lupins, canola oilcake and full-fat canola on the fatty acid profile of the fat pad of broilers.

Smith, N., Brand, T.S., Aucamp, B. & Ferreira, G., 2004. The effect of external digestive enzymes on the performance of weanling piglets consuming sweet lupins, canola oilcake and full fat canola containing diets.

Pectora roborant cultus recti

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Chapter 1
Literature Review

1.1 General Introduction

The demand for locally produced protein sources was increased by the banning of the use of meat and bone meal in animal feed in 2001. This caused an increase in the imports of oilcakes at high prices. Crops typically used as protein sources in monogastric animal nutrition include soybeans and sunflower seeds. These crops provide raw materials for the animal feed industry, either directly or as by-products from the food industry. Soybeans are either used as full-fat soybeans or as soybean oilcake meal. Fishmeal also played an important role as a protein supplement in monogastric animal nutrition, but is currently not popular due to availability in limited quantities. Due to the shortage in local production and the increasing costs of imports, the evaluation of the nutritional value of locally produced plant protein sources is necessary.

The most important alternative protein sources include lupins, canola, field peas, faba beans and narbon beans. These crops can be cultivated successfully in the winter rainfall region of the Western Cape. The oil rich seeds of canola can contribute to both the energy and amino acid needs of the animals. It is the oil content of the seeds that is important with respect to energy. The fatty acid composition of vegetable oils is often highly unsaturated. The use of these oils may therefore also contribute to fulfil essential fatty acid requirements (Salunkhe *et al*., 1992). Most oil rich seeds also contain a high level of protein with amino acid profiles which may be limiting in some essential amino acids (Salunkhe *et al*., 1992).

Pectora roborant cultus recti

The quality of a protein source for non-ruminant feeding depends on three major factors: the composition, mainly the essential amino acid content, the amino acid availability and the occurrence and content of proteic anti-nutritional factors. In nature, plants and seeds are protected by various naturally occurring compounds against microbial infestation and predation. The presence of these substances in animal feeds may negatively influence feed intake, digestion, absorption or utilization of nutrients in domestic animals. Therefore, they are called anti-nutritional factors. For use in animal feeds, pre-treatments, which inactivate or partly eliminate harmful effects of anti-nutritional factors, may be required. However, the digestibility of protein and the amino acid availability may be affected during these pre-treatments.

1.2 Canola in monogastric nutrition

In the 1970's Canada started producing rapeseed cultivars with low levels of erucic acid in the oil and low glucosinolate levels in the meal. These nutritionally superior cultivars were trade-named Canola and are now cultivated all over the world. The development of low erucic acid, low glucosinolate cultivars of canola seed has led to the availability of a feed ingredient with substantial potential to replace soybean meal

in diets for monogastrics. Canola meal is a high quality product and when properly utilized, can be used to advantage in reducing feed costs for animal producers. In order to be called canola, the oil must contain less than 2% erucic acid while the meal must contain less than 30 micromoles per gram of glucosinolates. Two types are currently grown. Westar is the most commonly grown variety of Argentine canola (*Brassica napus*), while Candle and Tobin are the most commonly grown varieties of Polish canola (*Brassica campestris*) (Thacker, 1990).

Although canola meal is an accepted feed ingredient in diets for poultry, there are a number of reports indicating reduced performance with diets containing significant amounts of this protein supplement (Hulan & Proudfoot, 1980; Summers & Leeson, 1985; Leeson *et al*., 1987). The crude protein content of canola meal varies depending on the cultivar from which the meal is produced. Meal from cultivars of *B.campestris* contains approximately 35% crude protein while meal from cultivars of *B. napus* contains from 38% up to 40% crude protein. Canola meal produced from a mixture of these types can be expected to contain between 37% up to 38% crude protein (Clandinin *et al*., 1981). Since the protein content of canola meal is lower than the protein content of soybean meal, higher levels of canola must be included in the diet to provide the same level of dietary protein. Using average values for the amount of protein in barley, canola meal (38%) and soybean meal (48.5%), approximately 25% more canola meal must be used when formulating a ration with canola meal compared to a diet formulated with soybean meal (Thacker, 1990). The nutritive value of a protein supplement is determined to a large extent by its amino acid content (Thacker, 1990). Of particular importance are the levels of lysine, threonine and the sulphur containing amino acids due to the fact that these have been shown to be the most limiting amino acids in swine diets composed predominately of cereal grains (Sauer *et al*., 1977). Soybean meal contains more lysine than canola meal while the levels of the sulphur containing amino acids (methionine and cystine) and threonine are similar in soybean meal and canola meal (NRC, 1988). Although the amino acid profile of canola meal compares favourably with soybean meal, the availability of the amino acids is lower. The availability of lysine is approximately ten percentage units lower in canola meal than soybean meal (Sauer *et al*., 1982). Since lysine is the first limiting amino acid in cereal grains, this reduction in availability means that higher levels of canola meal must be used to supplement a swine diet than the difference in lysine content between soybean meal and canola meal would indicate (Thacker, 1990).

One of the main factors that tend to limit the nutritional value of canola meal is its relatively low digestible energy content (Saben *et al*., 1971). The low level of digestible energy in canola meal is a reflection of its high crude fibre content (Kennelly *et al*., 1978). This results from the high proportion of hull in canola relative to the size of the seed (Bailey & Hill, 1975). The yellow seeded varieties of canola have thinner hulls than the brown seeded varieties and as a result, they contain a lower crude fibre level (Bell & Shires, 1981). Since canola meal contains about 15% to 25% less digestible energy than soybean meal, it is advisable to increase the energy content of rations containing canola meal. Mixing higher energy cereal grains such as maize or wheat into the ration can do this. Inclusion of animal or vegetable fat in the diet would also increase its energy content (Thacker, 1990).

The ether extract content of canola meal is generally higher than in soybean meal (Clandinin *et al*., 1981). This occurs because gums are added by some oil processors during processing. These gums are obtained during the processing of canola oil and consist of glycolipids, phospholipids and variable amounts of triglycerides, sterols and fatty acids (Clandinin *et al*., 1981). Their addition provides a market outlet for the gums and improves the handling and pelleting characteristics of the canola meal. These procedures are however not currently followed in South Africa (T.S. Brand, personal communication) in the processing of canola oilcake meal.

Canola meal contains higher levels of calcium, iron, magnesium, manganese and zinc than soybean meal. Canola meal also contains almost twice as much available phosphorus as soybean meal. Phosphorus is an expensive ingredient in swine nutrition, giving canola meal a distinct advantage over soybean meal in this regard (Clandinin *et al*., 1981). However, the high phytic acid and fibre content of canola meal reduces the availability of phosphorus, calcium, magnesium, copper, manganese and zinc in canola meal (Nwokolo & Bragg, 1977; Keith & Bell, 1987). In spite of these lower availabilities; canola meal is still a better source of available calcium, iron, manganese, phosphorus and magnesium than soybean meal. Selenium is another element that is becoming increasingly important in ration formulation. Both the content and availability of selenium are higher in canola meal than in soybean meal (Bragg & Seier, 1974). Although canola meal is generally not looked upon as a major source of vitamins in swine diets, it contains more choline, biotin, folic acid, niacin, riboflavin and thiamine than soybean meal (Clandinin *et al*., 1981). The negative effects when feeding high levels of canola meal has previously been shown to be due to the high sulphur content of this legume oilseed. In a study with chicks fed semi purified diets, it was suggested that such an effect may be explained by an imbalance in the anion-cation ratio of the ration imparted by inclusion of this ingredient, and as such, this may be overcome by addition of meq from Na, K or Ca. Thus the feeding value of canola may be significantly upgraded by simply adjusting for dietary meq (Summers & Bedford, 1994).

Prior to the general adoption of the new cultivars of canola, the presence of glucosinolates was the major factor limiting the use of rapeseed meal in swine rations (Bell, 1984). Rapeseed contains an enzyme called myrosinase, which is capable of breaking down these glucosinolates into a variety of toxic compounds including isothiocyanates, oxazolidinethiones, nitriles and inorganic thiocyanate ion (Paik *et al*., 1980). These compounds cause the enlargement of the thyroid gland and inhibit the synthesis and secretion of the thyroid hormones (McKinnon & Bowland, 1979; Christison & Laarveld, 1981). These hormones play an essential role in the control of the body's metabolism and if deficient, may reduce the utilization of dietary nutrients causing poor growth and reproductive performance (Thacker, 1990). As a result of genetic selection, the glucosinolate content of canola meal has been reduced to about 15% of the level contained in the old rapeseed meal (Bell, 1984). Intact glucosinolates are relatively harmless (Bell, 1984). Provided the meal is properly processed, the presence of glucosinolates is no longer of major consequence when formulating rations with canola meal (Thacker, 1990). Two other groups of compounds found in canola meal that influence its feeding value are tannins and sinapine (Thacker, 1990). Tannins are found at a level of about 3% in canola meal and may adversely affect the digestibility of the protein and energy in the diet

(Clandinin & Heard, 1961; Leung *et al*., 1979). Canola meal contains approximately 1.5% sinapine which is a bitter tasting compound that may reduce the palatability of rations containing high levels of canola meal (Meuller *et al*., 1978).

Locally various trials with canola meal fed to weaner and grower/finisher pigs have been conducted. Brand *et al*. (1999) fed full-fat canola meal to weaner and grower/finisher pigs. They found that canola could be included up to 24% without any significant effect on feed intake, live weight gain or feed conversion ratio of grower/finisher pigs. In another trial by Brand *et al*. (2001) grower/finisher pigs were fed canola meal from the solvent and expeller oil extraction processes. Canola meal obtained from the solvent process fed to the pigs had no significant effect on dry matter intake, average daily gain, feed conversion ratio or dressing percentage. Canola meal obtained from the expeller process fed to the pigs also had no significant effect on the performance of pigs.

1.3 Lupins in monogastric nutrition

Lupins are annual, winter-grown legumes, which can be grown on a wide range of soils, provided they are well drained. Lupins can be used in a crop rotation as a nitrogen-fixing legume and to provide a useful break in the build-up of disease in cereals. Another advantage of lupins is that they can be sown and harvested with conventional equipment. Lupins are very susceptible to competition from weeds (King, 1990).

Various types of lupins are available. Narrow leafed varieties are of the *L. angustifolius* species and can be divided into sweet and bitter varieties. The broad leafed varieties are of the *L. albus* species. The *L. luteus* species is a sweet variety with yellow flowers. Bitter and sweet varieties from the same species have similar chemical lines except for the alkaloid content. The crude protein content of lupin seeds ranges from 28% up to 47%. The protein fraction of lupin seeds is divided into two main classes: albumin and globulin (conglutin). The latter can be separated into three fractions (conglutin α, ß andγ). There is a variation in the proportions of conglutin fractions among lupin species (Hill, 1977; Casey & Domoney, 1992). The bitter lupin has a higher alkaloid content compared to sweet lupins (Olver & Jonker, 1997). Lupin protein is relatively high in lysine and threonine, but like most legumes, the methionine content of lupins is low (King, 1990). The amino acid composition of lupin protein resembles that of many other legume proteins in being low in methionine (0.59 – 0.87g 16g N^{-1}), but it is also relatively low in lysine (4.21 – 5.21 g 16 g N^{-1}) and very high in arginine (10.60 – 13.50g 16g N^{-1}) (Edwards & van Barneveld, 1994 as cited by Edwards & van Barneveld, 1998). The protein and essential amino acids in lupins are well digested and absorbed from the small intestine; the true ileal digestibility of the essential amino acids of lupins is about 90% for pigs, which is similar to that of soybean meal (Traverner *et al*., 1983 as cited by King, 1990). Lysine in lupins has a high availability for poultry (Batterham, 1992). The low availability of lysine in lupins for pigs is not associated with low digestibility, but may reflect either the presence of an unidentified growth inhibitor or that the lysine is in a form that is digested but inefficiently utilized (King, 1990).

Lupins seeds contain a significant amount of oligosaccharides of the raffinose family (Macrae & Zand-Moghaddam, 1978; Múzquiz *et al*., 1989). They are not digested by man or monogastric animals, as mammalian intestinal mucosa lack α-galactosidase activity. However, bacteria in the lower intestinal tract are able to metabolise these sugars to carbon dioxide, hydrogen and methane, resulting in flatulence. Much of the carbohydrate in lupins is thus digested by microbial fermentation in the cecum and proximal colon (King, 1990). Energy, which is absorbed from the hindgut, is less efficiently utilized by the pig (Just, 1981). Therefore the net energy of lupins will be lower than anticipated from its gross and digestible energy contents (King, 1990). Recent estimates of the digestible energy content of lupins for pigs ranged from 12.3 MJ/kg – 15.3 MJ/kg for lupin-seed meal and 15.4 MJ/kg – 16.6 MJ/kg for lupin kernels This range in digestible energy estimates may be due to the method of preparation of the lupins prior to inclusion in experimental diets (Wigan *et al*., 1994, as cited by Edwards & van Barneveld, 1998). Heat treatment increased the metabolisable energy value of lupins because the starch in the seeds became more digestible (Prinsloo, 1993). Lupins are known to cause wet droppings attributable to their high concentrations of soluble non-starch polysaccharides (Perez-Maldonado *et al*., 1999). Due to these high levels of non-starch polysaccharides, digestible energy may not be the most appropriate measure of the available energy content of lupins for pigs. The inclusion of lupin kernels at graded levels in pig diets resulted in a significant linear decrease in the ileal digestibility of dry matter and digestible energy. There is no significant difference in faecal digestibility. This will result in a significant decrease in the efficiency of use of lupin energy by the pig due to its recovery as volatile fatty acids from hindgut fermentation, rather than absorption as monosaccharide units in the small intestine. When lupin kernels are included in pig diets, compensation should be made in the diet formulation for the lower contribution of available dietary energy to the pig (Van Barneveld *et al*., 1995 as cited by Edwards & van Barneveld, 1998). Apparent metabolisable energy of lupin meal is 8.66 MJ/kg for poultry (Bryden *et al*., 1994) and estimates for pigs range from 12.3 MJ/kg up to 15.3 MJ/kg for lupin-seed meal and 15.4 MJ/kg up to 16.6 MJ/kg for lupin kernels (Wigan, 1994 as cited by Edwards & van Barneveld, 1998).

The oil content of *L. albus* (10-14%) is double that of *L. angustifolius* and *L. luteus* (4-7%), but the crude fibre content is lower (3-10%) in the latter, compared with the others (13-18%). Lupins have a high level of crude fibre that is contained largely in the seed coat (Hill, 1977). It is well known that the chemical composition of the cell wall influences its physical structure and thereby it's biological degradation (King, 1990). Lignin accounts for only 2.1% of the acid detergent fibre fraction in lupin seed (Aguilera *et al*., 1985). The small degree of lignification in lupins may explain the relatively high digestibility of structural carbohydrates in lupins (King, 1990). Apparent digestibility of crude fibre in *L. angustifolius* is 76% (Traverner, 1975 as cited by King, 1990). Digestibility of fibre fractions of *L. albus* is in excess of 80% (Aguilera *et al*., 1985). Because of the well-digested fibre fraction and high oil content of the seed, the digestible energy content of lupins is high. Nevertheless, there are many unusual features with respect to the site and extent of dry matter and energy digestion from lupins by the pig (King, 1990). In contrast to the high absorption of amino acids in lupins from the small intestine, only about 46% of the dry matter and 51% of

the energy in *L. angustifolius* are absorbed prior to the proximal end of the small intestine of pigs (Traverner *et al*., 1975 as cited by King, 1990). Seeds of the *L. albus* may contain a very high level of manganese (up to 6900 ppm). This may cause toxicity and oxidation of oils and vitamins in feeds (Múzquiz *et al*., 1989).

The nutritive value of lupins as poultry food is dependent on the concentration of alkaloids and dietary fibre components such as oligosaccharides and soluble non-starch polysaccharides, in the seed. Alkaloids suppress both food intake and growth in poultry (Hill, 1977). The depressing effect of the alkaloids decreases as the chicks become older (Olver & Jonker, 1997). Lupins contain variable levels of quinolizidine alkaloids. The most common are lupanin, sparteine, lupinine and angustifoline (Cheeke & Kelly, 1989). Lupanine and sparteine are the most toxic (Aguilera & Trier, 1978). Plant breeders have developed sweet varieties of lupins that lack the toxic alkaloid components of the bitter seed varieties. Pigs can tolerate up to 0.2 g/kg of dietary lupin alkaloids before feed intake was reduced. The alkaloid content in the present sweet varieties of lupins is low and there have been very few reports of toxicity or feed intake depression in pigs given diets containing up to 30-40% *L. angustifolius* or *L. albus* (King, 1990). Sweet lupins do not exert any anti-nutritive effect provided the concentration of alkaloids in the sweet lupin seed is less than 0.1g/kg (Olver & Jonker, 1997).

Little work has been done to quantify the anti-nutritional effects of non-starch polysaccharides from lupins in growing pigs. It has been suggested that variable production responses to lupins may be due to the high levels of lupin non-starch polysaccharides interfering with the action of digestive enzymes and influencing microbial activity (Van Barneveld *et al*., 1994 as cited by Edwards & van Barneveld, 1998). The addition of graded levels of isolated lupin non-starch polysaccharides to sorghum-based diets resulted in a significant increase in digesta viscosity and reduced the ileal digestibility of energy, lysine and dry matter. Total non-starch polysaccharide digestion was minimal and there were no significant differences among diets. Non-starch polysaccharide inclusion levels had no significant effect on the ATP content of the digesta in any part of the digestive tract. From these results it can be concluded that increased digesta viscosity is the cause of reduced ileal digestibility of lysine and energy when high levels of lupins are fed. This may be due to interference with the action of digestive enzymes. Lupin non-starch polysaccharides do not affect microbial activity in the digestive tract (Van Barneveld *et al*., 1995 as cited by Edwards & van Barneveld, 1998). A wide variation in oligosaccharide concentration both within and between species of lupins may influence their nutritive value and could be responsible for the highly variable performance of pigs when lupins are fed (Wigan *et al*., 1994 as cited by Edwards & van Barneveld, 1998). The extraction of oligosaccharides from *L. albus* had a greater impact on energy digestibility in the small intestine than in the large intestine. As a consequence, extraction of oligosaccharides will have an even greater impact on lupin net energy contributions. The higher oligosaccharide content of *L. albus* compared with *L. angustifolius* and the subsequent effect on net energy may help to explain the comparatively poorer performance of pigs when they are fed *L. albus* (Edwards & van Barneveld, 1998). There is little evidence from the literature to suggest that oligosaccharides or non-starch polysaccharides in lupins have the same anti-nutritive effects in poultry, even though non-starch polysaccharides from cereals are known to have detrimental effects in broiler

chicken diets (Annison & Choct, 1991), and the addition of commercial enzymes in poultry diet containing lupins has been shown to influence the nutritive value. In a study by Annison *et al*. (1996) a commercial enzyme containing primarily xylanase, pentosanase and hemicellulase increased the apparent metabolisable energy of lupins from 10.01 to 11.65 MJ/kg DM when added at 0.5 g/kg. In contrast, a second enzyme containing primarily ß-glucanase, hemicellulase and pectinase activities did not affect the apparent metabolisable energy of lupins, or the ileal digestibility of other nutrients, but caused an increase in the concentrations of soluble non-starch polysaccharides in the digesta and an increase in the ileal digesta viscosity. These results demonstrate the sensitivity of poultry to changes in dietary non-starch polysaccharides, and emphasize the need to target exogenous enzyme supplementation of poultry diets specifically (Annison *et al*., 1996).

Locally some trials have been conducted to evaluate the use of lupins in poultry and pigs feed. Brand *et al*. (1995) fed sweet lupins to growing pigs and found that the feed intakes, feed conversion ratios and growth rates were reduced. Olver & Jonker (1997) fed sweet, bitter and soaked microns bitter lupins, at various inclusion levels, to broiler chickens. They found that the body weight gain was significantly reduced at six weeks of age when the diets contained 300g/kg and 400 g/kg bitter lupins and 400g/kg soaked microns bitter lupins. Bitter and soaked microns bitter lupin inclusion also reduced feed intake and the feed conversion ration at higher inclusion levels.

1.4 The use of enzymes in monogastric nutrition

The underlying principle for the application of enzyme technology is to improve the nutritive value of feedstuffs. According to Sheppy (2001), feed is the single largest factor affecting production costs, and profitability can depend on the relative cost and nutritive value of the feeds available in broiler and pig production systems. Sheppy (2001) also states that a limiting factor when formulating rations is the animal's ability to digest different components of the feed raw materials, particularly fibre. Enzyme addition may possibly reduce the inconsistency in nutritive value between feedstuffs, improving the accuracy of feed formulations. Ensuring feed consistency in this way can increase the uniformity of groups of animals, thus aiding management and improving profitability. The general health status of animals can also be directly influenced, resulting in fewer of the non-specific digestive upsets that are frequently caused by fibre components in the feed. The environmental benefits of using enzyme technology are of increasing importance and relevance to the feed industry. Since the animal better utilizes the feed, less is excreted. This results in manure volumes being reduced by up to 20% and nitrogen excretion by up to 15% in pigs and 20% in poultry (Sheppy, 2001). As significant, is the opportunity for enzymes to reduce phosphorus pollution (Sheppy, 2001).

Trials conducted on the effects of exogenous enzyme supplementation of vegetable protein meals show variable results, some showing significant changes with enzyme inclusion and other showing trends towards improvement, but not significantly. There are a number of probable explanations for these observations. In many cases it is not possible to draw direct comparisons between individual studies due to

variation in enzyme type, activity and inclusion level. The majority of trials have been conducted under experimental conditions, with high health status animals, which may not necessarily reflect commercial situations. Basal diets can vary widely between different trials depending on the availability of dietary components. It must be kept in mind that modern diets are formulated to attain maximum performance from an animal. Any increase in nutrient availability due to enzyme supplementation may not elicit a response from the animal unless the dietary factor in question is reduced to sub-optimal levels. This is not necessarily a consideration when substituting proportions of a diet with inferior feedstuffs, provided nutrient specifications do not exceed recommended levels for that species, age and genotype. It is difficult to measure the usefulness of enzyme preparations on target substrates when applied to complete diets, as all plant feedstuffs in a diet are likely to contain substrates on which enzymes can act. A number of studies on the effects of multi-activity enzyme products in broiler diets containing high levels of vegetable proteins show inconclusive results (Brenes *et al*., 1993; Classen *et al*., 1993; Roth Maier & Kirchgessner, 1994). According to Kocher (2001), the two main reasons for the inconsistency are a lack of clear understanding of the anti-nutritive effects of non-starch polysaccharides in vegetable proteins and the inability of currently available feed enzymes to depolymerise these carbohydrates.

1.5 The importance of the fat content of monogastric animal products for human nutrition

In recent years, nutrition and health concerns have had an increasing influence on consumers' food choices (NRC, 1988). This trend is associated with the relationship between dietary fats and the development of cardiovascular diseases in humans (Farrell & Gibson, 1990). The risk of coronary heart disease (CHD) increases with increasing plasma cholesterol levels because low-density lipoprotein (LDL), the major carrier of cholesterol in the plasma, is atherogenic (Margolis & Dobs, 1989). High-density lipoprotein (HDL), especially the HDL2 subfraction, protects against CHD. Hypertriglyceridemia, although not an independent risk factor for CHD, is generally accompanied by low HDL cholesterol (HDLch), which may predispose to CHD. Reducing plasma LDL and raising HDL levels are thus goals in preventing CHD. Serum LDL levels may be lowered by reducing saturated fat and cholesterol intake; weight loss may decrease LDL but is more effective in lowering plasma triglycerides and raising HDLch. The percentage of total calories consumed by humans from polyunsaturated, monounsaturated, and saturated fats should be less than 10%, up to 10-15%, and less than 10%, respectively (Margolis & Dobs, 1989). In developed countries special importance is given to the quality of nutrition. Poultry meat is considered a dietetic product because it is rich in proteins and has a low proportion of fat (Kralik *et al*., 2002). Poultry meat has gained consumer approval and is recommended by dieticians because it is lean, yet contains a high proportion of unsaturated fatty acids. However, the leanness of poultry meat varies with species, age and sex, while the amount of fat depends on a number of dietary criteria (Lessire, 2001). A substantial reduction of carcass fats and cholesterol and improvement of the fatty acid make-up of poultry meats could therefore bring about nutritional and economic benefits to consumers and producers alike. It is found that polyunsaturated fatty acids (PUFA) n-3 can prevent diseases induced by stress and unbalanced nutrition; they reduce the risk of coronary diseases, and psoriasis and are

essential for normal development of brain and nerve tissue (Kralik *et al*., 2002). PUFA are a major constituent of cell membranes and tissues and are critically important to a number of biological functions including platelet aggregation, receptors (neurotransmitter, insulin) and transport, membrane-bound enzymes and immune system functions. A deficiency of either n-6 or n-3 fatty acids has been shown to cause physical and biochemical changes. Furthermore, excess essential fatty acids also produce adverse effects. The consumption of more than 7% PUFA can increase the risk of cancer due to the free radicals of PUFA. The balance between n-6 and n-3 fatty acids depends on the ratio of the parent fatty acids in the diet. A diet rich in n-6 fatty acids shifts the physiological state to one more strongly prothrombotic and proaggregatory, with increased blood viscosity, vasospasm, and vasoconstriction and decreased bleeding time (Simpoulos, 1991). Also, a large intake of n-3 fatty acids may increase requirements for antioxidants and vitamin E, reduce platelet aggregation, inhibit amino acid metabolism for prostaglandin formation, and cause immune-suppression (Simopoulos, 1991). The World Health Organization (WHO, 1990) recommends that 30% of all daily energy should be consumed as fat, of which only 10% should be saturated fatty acids. Some fatty acids are essential because they are not synthesized by the human body and are necessary for vital functions (Harwood, 1995). The nutritive value of animal fats can be improved by using feed high in nutritionally important fatty acids and thus ensure a better supply of essential fatty acids for humans (Scaife *et al*., 1994).

Research findings have established that the carcass composition of chickens may be altered by the type of dietary fat used in poultry feed (Alao & Balnave, 1984; Hulan *et al*., 1988; Phetteplace & Watkins, 1989; Ajuyah, *et al*., 1991; Chanmugan *et al*., 1992). Broilers consuming diets supplemented with different fat sources were reported to have corresponding changes in the levels of some fatty acids in the muscle (Scaife *et al*., 1994). In a study by Coetzee & Hoffman (2002) it was found that canola oil in broiler diets can increase the ratio of n-6 to n-3 fatty acids in broiler carcasses and abdominal fat pads to 5:1, a ratio more appropriate for human health. The level of saturated fatty acids in the carcasses and abdominal fat pads of broiler chickens was also effectively reduced by increasing the level of n-3 fatty acids in the diets.

Manipulating the dietary fatty acid composition has implications for flavour of poultry meat. The meaty flavours of cooked meat are produced in reactions between carbohydrates and proteins and between breakdown products of these compounds (Wood *et al.,* 1999). Lipid oxidation products are important to the aroma of cooked chicken and some of the key odour compounds are aldehydes and ketones produced from *n*-6 and *n*-9 fatty acids (Farmer, 1999). A further two key odour compounds, these being lactones, are produced by the oxidation of triglycerides. Diet manipulation may offer the greatest potential to enhance poultry meat flavour. Triglycerides and short chain fatty acids are oxidised during cooking to form either aldehydes, ketones or lactones and these products contribute to the aroma of cooked poultry meat (Farmer, 1999). Polyunsaturated fatty acids (PUFAs) are more reactive than saturated fatty acids in oxidative reactions, and so manipulating the PUFA composition and content in poultry fat is likely to offer a greater potential for generating desirable meat flavours.

1.6 Anti-nutritional factors present in vegetable protein sources

Animal production relies heavily on the animal's capacity to ingest plants or plant parts and extract nutrients from them. From the plant side this can be seen as predation. As a defensive mechanism against such predation, plants contain a wide array of secondary metabolites, many of which are toxic to animals and humans (Tamminga & Verstegen, 1998). Glucosinolates have historically been the main barrier to the use of canola meal in poultry diets. Tannins are antinutritional factors of concern because they reduce protein utilization in monogastrics by inhibiting digestive enzymes. Sinapine is a compound in canola meal that produces a "fishy" flavour in the eggs of certain brown-shelled laying strains. Opinions vary in the literature regarding the potential antinutritional effects of oligosaccharides; however, ethanol-extraction of oligosaccharides from canola meal reduced the true metabolisable energy (TMEn) value for adult roosters (Slominski et al., 1994). Quinolizidine alkaloids, oligosaccharides or non-starch polysaccharides, phytic acid and polyphenolics are some of the undesirable compounds found in lupins.

Rapeseed contains an enzyme called myrosinase, which is capable of breaking down these glucosinolates into a variety of toxic compounds including isothiocyanates, oxazolidinethiones, nitriles and inorganic thiocyanate ion (Paik, 1980). The glucosinolate side chain may comprise aliphatic (saturated or unsaturated), aromatic, or heteroaromatic groupings (Campbell & Schöne, 1998). Among the aromatic groupings indole and phenyl groups are common and the presence of methyl, thiol and hydroxyl groups in the side chain represent additional modified groupings (Campbell & Schöne, 1998). The side chain is important in animal nutrition as it determines the chemical nature of the products of enzyme hydrolysis and thereby their biological effect and potency (Campbell & Schöne, 1998). Hydrolysis by myrosinase yields glucose and a variety of aglucone products, the exact nature of which are determined by a number of factors including pH, the presence of certain cofactors and the structure of the parent glucosinolate (Campbell & Schöne, 1998).

Heat is applied in commercial canola processing to condition the seed for improved oil extraction, to inactivate myrosinase and for solvent removal and drying of the meal. The extent of heat treatment is sufficient to cause some thermal degradation of glucosinolates, with indole glucosinolates being more susceptible to degradation than aliphatic glucosinolate (Campbell & Slominski, 1989). Thermal degradation during commercial seed processing would produce aglucone products similar to the above mentioned but due to the fact that the majority of the aglucone products are extremely reactive, and also volatile, there are generally low concentrations in commercial meal (Campbell & Schöne, 1998). As progoitrin is the most predominant glucosinolate in most canola varieties, 5-vinyloxazolidine-2-thione and the corresponding nitrile, 1-cyano-2-hydroxy-3-butene tends to be the aglucones most often detected in meal (Campbell & Schöne, 1998).

Thiocyanate ion, presumably from the decomposition of the indole glucosinolate, is also a common product in meal. Since myrosinase is usually effectively inactivated during processing, the predominant form of glucosinolates in the meal is intact glucosinolates even when the moisture content of meal is increased as

would occur in the intestinal tract of animals (Campbell & Schöne, 1998). The glucosinolate in rapeseed meal have long been known to cause thyroid dysfunction in pigs. Schöne *et al*. (1990) studied the goitrogenicity of high glucosinolate rapeseed meal in growing pigs in detail. They varied glucosinolate intake of the pigs by feeding a high glucosinolate meal (10 mmol/kg final diet) or a copper (Cu) treated meal (<1 mmol/kg final diet) and varied levels of supplemental iodine. Criteria used to assess treatment effects included growth, thyroid weight and total iodine deposition and serum thyroid hormone levels. Growth of the pigs and thyroid size were normalized only by inactivation of glucosinolate (Cu treated) combined with administration of iodine.

Schöne *et al*. (1993) showed that the addition of myrosinase to a high glucosinolate rapeseed meal had a detrimental effect on thyroid status in young chicks especially without dietary iodine supplementation. Removal ($\geq$ 90%) of glucosinolates from rapeseed meal by treatment with Cu elevated the anti-thyroid effects that differed from the effects of the myrosinase-treated meal with similar glucosinolate content. In comparing the results of chick experiments to experiments with pigs, Schöne and co-workers (1993) indicated that chicks were able to tolerate a higher level of dietary glucosinolates. Glucosinolate compounds cause the enlargement of the thyroid gland and inhibit the synthesis and secretion of the thyroid hormones (McKinnon & Bowland, 1979; Christison & Laarveld, 1981). These hormones play an essential role in the control of the body's metabolism and if deficient, may reduce the utilization of dietary nutrients causing poor growth and reproductive performance (Thacker, 1990). As a result of genetic selection, the glucosinolate content of canola meal has been reduced to about 15% of the level contained in the old rapeseed meal (Bell, 1984).

Sinapine, the choline ester of sinapic acid, is considered the major phenolic compound in rapeseed meal. Phenolic compounds may contribute to the dark colour, bitter taste and astringency of rapeseed meal. Phenolic compounds may also interact with amino acids, enzymes and other feed components; this could negatively influence the nutritional value of rapeseed meal. Sinapine as a causative agent in the development of taint in eggs of susceptible hens has been well documented (Butler *et al*., 1982). In susceptible hens a genetic defect impedes the synthesis of trimethylamine oxidase and this biochemical lesion severely impairs the metabolism of trimethylamine, which is released from sinapine by enteric bacteria. Excessive amounts of trimethylamine in egg yolks produce a taint limiting the use of rapeseed meal in the diets of susceptible brown-shelled egg laying strains. The effect can be exacerbated by the presence of tannins in the diet, which may impair the metabolism of trimethylamine by inhibiting the trimethylamine oxidase enzyme.

The non-starch polysaccharides (NSP) content of vegetable proteins used in poultry diets varies according to their plant origin, the variety, the degree of processing, and subsequently on the proportion of non-starch polysaccharides rich hull in the final product (Kocher, 2001). The total NSP content of vegetable protein ranges from 180 g/kg DM in peas and canola meal to over 350 g/kg DM in some lupin species (Kocher, 2001). The main carbohydrate reserves of the cotyledons of lupins are the non-structural polysaccharides of the cell walls, with the main components being galactose, arabinose and uronic acid (Brillouet & Riochet, 1983; Evans, 1994). NSP's are complex compounds, whose structures are not yet fully

defined. The water soluble portion, about 5% of the lupin seed, is considered to have an anti nutritional effect due to its viscous nature and effect on intestinal transit time and changes in hormonal regulation due to differential nutrient absorption rates (Petterson, 1998). The insoluble non-starch polysaccharides, about 30% in the lupin seed, have a minimal effect on nutrient utilization by monogastrics. An important attribute of insoluble non-starch polysaccharides is their ability to hold large quantities of water, about eightfold by weight for lupins and still maintain normal gut motility (Petterson, 1998).

Alkaloids are bitter compounds, often having a negative effect on feed palatability for different animal species as described in the section on lupins. After absorption from the gastro intestinal tract they may exert a wide range of toxic effects (Lallès & Jansman, 1998). The lupin alkaloids are usually bicyclic (e.g. lupinine), tricyclic (e.g. angustifoline) or tetracyclic (e.g. sparteine) derivatives of quinolizidine (Petterson, 1998). Alkaloid toxicity is strongly associated with modification of cell structures such as RNA and DNA, or by inhibition of vital processes transcription, protein synthesis, membrane stability, electron transport, enzyme inhibition and inhibition of neurotransmitter receptor hormones (Wink, 1992). As a result alkaloids can inhibit the central nervous system, circulation, digestion, reproduction and the immune system (Lallès & Jansman, 1998). Breeding of low alkaloid (sweet) varieties of lupins (< 0.5 g/kg) has been the major way of reducing the level of alkaloids in lupins (Lallès & Jansman, 1998). Bitter lupins contain up to 10-40 g alkaloids/kg seed. It is important to realise that large differences exist with regard to both alkaloid composition in lupin seed and the toxic effects of the individual alkaloids (Lallès & Jansman, 1998). More than 150 alkaloids have been identified as toxic. This is the reason that maximum tolerance levels (threshold levels) should be established for individual alkaloids rather than for the total alkaloid content for different animal species (Lallès & Jansman, 1998).

Pectora roborant cultus recti

1.7 Aim of the study

The purpose of this study was to evaluate the use of the alternative protein sources, sweet lupins and canola in broiler and pig feeds. The effect of external enzyme application on the production of broilers and weaner pigs was also investigated. In this study the acceptability of rations, where soybean meal was partially and completely replaced by full-fat canola, canola oilcake and sweet lupins, to swine and poultry was evaluated. Due to the importance of palatability, the anti nutritional factor content of the alternative protein sources was investigated. The variation in sinapine and glucosinolate content of different cultivars of canola, produced in two different locations in the Western Cape was determined. In this study the effect of sweet lupin, full-fat canola and canola oilcake inclusion in diets on the fatty acid composition of boiler and finisher pig carcasses was determined.

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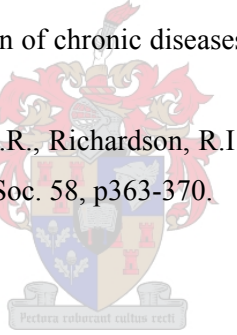

Chapter 2

The use of sweet lupins, canola oilcake and full fat canola with or without external enzymes in diets for broilers.

2.1 Abstract

The effect of replacing soybean oilcake meal as protein source with three levels (6.6%, 13.0% and 20%) of sweet lupins (*Lupinus angustifolius*), canola oilcake and full-fat canola in diets for broiler chickens was examined. A control diet with soybean oilcake as protein source was blended in ratios of 100%, 67% and 33% respectively, with the test diets containing either sweet lupins or canola oilcake or full-fat canola as protein sources. The test diets were fed for a period of six weeks with or without the enzyme Vegpro®, to determine the potential of the enzyme to enhance the nutritive value of the vegetable protein sources tested. The growth rates, feed intakes and feed conversion ratios of broilers fed the test diets were not affected by the enzyme supplementation. Broiler weights at six weeks of age were significantly higher for the control diet compared to the 20% lupin diet. There was no significant difference in the feed intake as the lupin content of the diets increased. The feed conversion ratio did not differ significantly between the control diet and the 6.6% lupin diet but became significantly poorer as the lupin content increased to 13.2% and 20% of the test diet. There were no significant differences in production performance of the control diet and the canola oilcake containing diet. The broiler weights at six weeks decreased significantly with each increment in the canola oilcake content of the diets. The feed intake of the 20% canola oilcake diet at week six was significantly less than the intake of the control diet, but not significantly less than the 6.6% and 13.2% canola oilcake diets. The feed conversion ratio of the control diet was significantly better than the 13.2% and 20% canola oilcake diets. The feed conversion ratio of the 20% canola oilcake diet was significantly inferior to the other canola oilcake containing diets. The lower feed intake of broilers on the canola oilcake diets and the higher feed conversion ratios may have attributed to the lower body weight of the broilers. No significant differences were found in week six between the 6.6% full-fat canola diet and the control diet for broiler weights and feed intake. The feed conversion ratio of the broilers fed the 13.2% and 20% full-fat canola diets was significantly poorer than the control diet. From this study it can be concluded that the addition of enzymes do not significantly improve the performance of broiler chickens. It is also clear that sweet lupin, canola oilcake and full-fat canola can be used to partially replace soya oilcake as protein source.

Keywords: Broilers, enzymes, sweet lupins, full-fat canola, canola oilcake

2.2 Introduction

Protein sources in South Africa are likely to become progressively limiting and costly, particularly for animal nutrition (Protein Advisory Committee, 1990). Exploitation of the nutritional potential of all possible protein sources is therefore necessary. Sweet lupins (*Lupinus albus* and *Lupinus angustifolius*) are cultivated as a legume ley crop in the winter rainfall region of South Africa. It is estimated that approximately 10 000 t of lupins are produced annually in the winter rainfall region of South Africa.

Although lupins are relatively high in crude protein (35.5%) (Brand *et al.*, 1995) problems could arise with the use thereof in broiler diets due to the existence of anti nutritional factors. Lupins may have undesirable levels of alkaloids (Eriksson, 1988) and α-galactosides (90g/kg) (Bourdon *et al*., 1987). Lupins have low starch content (0.3-0.5 %) (Cerning-Beroad & Fillatre, 1976 as cited by Brand *et al*., 1995) and a high level of non-starch polysaccharides (NSP) (50.2%) (Chesson, 1990), about 15% of which is soluble (Annison *et al*., 1996). As mentioned in Chapter 1 these carbohydrates are resistant to the enzymes of the chicken.

The use of supplemental enzymes which will degrade these carbohydrates could possibly counteract the anti-nutritive effects of the NSP. The unrestricted use of canola meal as a high quality protein supplement in poultry and other rapidly growing non-ruminant animals is limited by low available energy content. The metabolisable energy content of canola meal is approximately 8.4 MJ/kg for poultry. Total tract apparent protein digestibility in canola meal based diets, averages 74% in poultry (Thomke *et al*., 1983 as cited by Simbaya *et al.* 1996; Bell & Keith, 1987). Inversely related to metabolisable energy and protein contents are fibre components of canola meal, which mainly include cellulose (4-6%), non-cellulosic polysaccharides (13-16%) and lignin with associated polyphenols (8%) (Kocher *et al.* 2000*b*; Simbaya *et al.* 1996).

The application of cell wall degrading enzymes has proven beneficial in improving the digestibility of canola polysaccharides in poultry (Slominski & Campbell, 1990 as cited by Kocher *et al.* 2000*b*). It is believed that the use of carbohydrase enzymes in animal nutrition can reduce the nutrient encapsulating effect of the cell walls (Graham & Petterson, 1992 as cited by Simbaya *et al.* 1996) and could further increase the nutritive value of feedstuffs by rendering the cell wall polysaccharides available for hindgut fermentation (Chesson, 1990).

The objective of this study was to evaluate lupins, canola oilcake and full-fat canola as potential alternative protein sources in broiler diets. The effect of the application of external enzymes to the diets was also investigated.

2.3 Materials & Methods

Two mechanically ventilated broiler houses containing a total of 60 floor pens were used in this investigation. Wood shavings as litter material were used in the pens. Each pen had four tube feeders and one automatic water drinker. The lighting programme was 24 hours-bright lights for the first three days and thereafter 1 hour dimmed lights (23 Light: 1 Dark) to the end of the trial.

The starting temperature under the brooders of each pen was 33°C and the temperature was gradually decreased to 22°C on day 28. A single thermostat controlled the heaters. Ross 308 broilers were used. Eighty-five broilers were randomly distributed into each of the sixty floor pens. The stocking density was 21 birds per m^2. An external enzyme cocktail Vegpro® (Alltech (Pty) Ltd, Corner of Koelenhof & Bottelary Roads, Farm no 1277, Stellenbosch, 7599) designed for plant protein sources was provided to 50% of the diets as a dry powder and mixed with the dietary ingredients. The ingredient compositions of experimental diets are shown in Tables 2.1 and 2.2. The starter diets were formulated on an iso-nutrient basis to contain 13 MJ ME/kg feed and 20.5% crude protein. The grower/finishing diets were formulated on an iso-nutrient basis to contain 13.4 MJ ME/kg feed and 18.5% crude protein.

Table 2.1 Ingredient compositions of experimental starter diets provided to broilers from hatching up to 21 days of age

Ingredient Composition (kg/ton, as fed)	Starter diets			
	Control	Full-fat canola	Canola oilcake	Sweet Lupins
Maize meal	667.6	377.2	602.8	573.4
Acid oil	10.2	0.0	30.0	30.0
Gluten 60	20.0	0.0	20.0	20.0
Fish meal	80.0	80.0	106.5	81.2
Wheaten bran	0.0	215.0	0.0	0.0
Soybean oilcake	193.1	103.6	20.0	64.7
Full-fat canola	0.0	200.0	0.0	0.0
Canola oilcake	0.0	0.0	200.0	0.0
Sweet lupins (*L. angustifolius*)	0.0	0.0	0.0	200.0
Limestone	12.3	11.3	10.0	12.2
Monocalcium phosphorus	8.9	6.6	4.8	8.9
Synthetic Lysine	2.0	1.1	1.8	2.6
Synthetic Methionine	2.2	2.1	1.4	3.3
Synthetic Threonine	0.7	0.7	0.6	0.9
Fine Salt	1.1	0.7	0.4	1.1
Cholclor	0.9	0.7	0.7	0.7
Vitamin & Mineral Premix	1.0	1.0	1.0	1.0
Calculated nutrient composition				
ME, MJ/kg feed	13.00	13.00	13.00	13.00
Crude Protein, %	20.50	20.50	20.50	20.50
Lysine, %	1.12	1.12	1.12	1.12
Methionine, %	0.54	0.53	0.53	0.58
Total Sulphur Amino Acids, %	0.81	0.82	0.81	0.81
Threonine, %	0.74	0.74	0.74	0.74
Tryptophan, %	0.21	0.23	0.19	0.19
Arginine, %	1.06	1.14	0.93	1.25
Calcium, %	0.95	0.95	0.95	0.95
Phosphorus, %	0.45	0.45	0.45	0.45

Table 2.2 Ingredient compositions of experimental grower/finishing diets provided to broilers from 21 days of age up to slaughtering at 42 days of age

Ingredient Composition (kg/ton, as fed)	Grower/Finishing diets			
	Control	Full-fat canola	Canola oilcake	Sweet Lupins
Maize meal	657.8	481.8	628.3	597.9
Acid oil	37.8	0.0	0.0	45.0
Gluten 60	20.0	0.0	9.9	20.0
Fish meal	30.0	30.0	98.2	62.9
Wheaten bran	0.0	112.0	0.0	0.0
Soybean oilcake	220.1	146.4	0.0	43.4
Full-fat canola	0.0	200.0	0.0	0.0
Canola oilcake	0.0	0.0	200.0	0.0
Sweet lupins (*L. angustifolius*)	0.0	0.0	0.0	200.0
Limestone	14.0	12.9	10.2	12.9
Monocalcium phosphorus	11.0	9.1	3.4	8.4
Synthetic Lysine	2.3	1.3	1.3	2.5
Synthetic Methionine	2.0	1.9	1.0	2.8
Synthetic Threonine	0.8	0.7	0.4	0.9
Fine Salt	2.5	2.2	0.6	1.6
Cholclor	0.7	0.7	0.7	0.7
Vitamin & Mineral Premix	1.0	1.0	1.0	1.0
Calculated nutrient composition				
ME, MJ/kg feed	13.40	13.40	13.40	13.40
Crude Protein, %	18.50	18.50	18.50	18.50
Lysine, %	0.98	0.98	0.98	0.98
Methionine, %	0.46	0.45	0.46	0.50
Total Sulphur Amino Acids, %	0.71	0.74	0.71	0.72
Threonine, %	0.67	0.67	0.67	0.67
Tryptophan, %	0.20	0.20	0.17	0.17
Arginine, %	0.99	1.05	0.83	1.14
Calcium, %	0.90	0.90	0.90	0.90
Phosphorus, %	0.40	0.40	0.40	0.40

The experimental diets were then blended to create 4 diets containing 6.6%, 13.2% and 20% of each of the alternative protein sources as shown in Table 2.3. A sweet variety of *L. angustifolius* was used, while canola oilcake from a local oil processing plant was used. The full-fat canola was also locally produced.

Table 2.3 Composition of experimental diets fed to the broiler chickens

Diet no	Composition	
1	100 Lupin diet	: 0 Control diet (20% Lupin diet)
2	67 Lupin diet	: 33 Control diet (13.2% Lupin diet)
3	33 Lupin diet	: 67 Control diet (6.6% Lupin diet)
4	100 Canola diet	: 0 Control diet (20% Canola oilcake diet)
5	67 Canola diet	: 33 Control diet (13.2% Canola oilcake diet)
6	33 Canola diet	: 67 Control diet (6.6% Canola oilcake diet)
7	100 Full-fat Canola diet	: 0 Control diet (20% Full-fat canola diet)
8	67 Full-fat Canola diet	: 33 Control diet (13.2% Full-fat canola diet)
9	33 Full-fat Canola diet	: 67 Control diet (6.6% Full-fat canola diet)
10	Control diet (Soybean oilcake diet)	

Three replicate pens per treatment were used. The starter diet was fed from day old up to 21 days of age and grower/finisher diet was fed up to 42 days of age, when the birds were slaughtered. Marked birds from each pen were weighed and their feed intake calculated, per pen, at day old and every week thereafter until 42 days of age, when the birds were slaughtered. The effect of enzyme application and the inclusion

rate of each protein source tested were analysed by analysis of variance (4 diets x 2 enzyme levels x 3 replicates). The effect of the inclusion level of the protein source and the application of enzymes were also analysed by regression analysis and the intercepts and slopes of the regression lines were compared by analysis of variance. Lines were done separately for the starter and grower periods. The effect of the inclusion rate of each of the different protein sources were also compared to each other by regression analysis. All procedures were described in detail by Statgraphics 5.1 (1991).

2.4 Results & Discussion

The provision of external dietary enzymes failed to add any value to the protein sources, as determined by the performance of the birds (Table 2.4). Broiler weights at three and six weeks of age, feed intake and feed conversion ratio was unaffected by the addition of enzymes. There may be several reasons for the lack of response to the enzyme supplementation.

The enzymes were developed for commercial use with commonly used vegetable protein sources, with specific target substrates, the vegetable protein sources tested in this trial are not commonly used and therefore the specific target substrates may not be present in the alternative protein sources tested in this trial. The enzymes were tested on mixed diets therefore it is difficult to distinguish between effects of the enzyme on target substrates from possible effects on other components of the diet. In a further investigation the soluble and insoluble NSP fractions present in the digesta of broilers might shed more light on the exact effect of the enzymes on these fractions.

Mortalities were however significantly affected by the enzyme supplementation. The group of broilers receiving the enzyme had significantly lower mortalities at three and six weeks of age.

Pectora roborant cultus recti

Table 2.4 The effect of the application of enzymes to broiler diets containing sweet lupins, canola oilcake and full-fat canola on production performance

Treatment	Mortalities		Broiler weight (kg)		Feed intake (kg)		Feed conversion ratio (kg feed/kg broiler weight gain)	
Age	Week 3	Week 6	Week 3	Week 6	Week 3	Week 6	Week 3	Week 6
Control with Enz	3.111[b]	4.444[ab]	0.732	2.089	0.977	3.548	1.334	1.699
Control without Enz	4.000[d]	8.000[f]	0.738	2.089	1.007	3.639	1.365	1.742
Lupins with Enz	3.704[c]	4.889[bc]	0.705	1.981	1.031	3.541	1.465	1.789
Lupins without Enz	4.290[d]	5.751[d]	0.720	2.072	1.047	3.719	1.456	1.796
Canola oilcake with Enz	2.667[a]	4.444[ab]	0.611	1.703	0.957	3.324	1.580	1.977
Canola oilcake without Enz	3.111[b]	4.296[a]	0.604	1.689	0.943	3.260	1.576	1.955
Full-fat canola with Enz	3.001[b]	5.111[c]	0.710	2.034	1.030	3.621	1.452	1.782
Full-fat canola without Enz	3.990[cd]	6.659[e]	0.706	2.034	1.015	3.622	1.441	1.782
SEm	0.303	0.485	0.013	0.040	0.010	0.043	0.021	0.030

[a-e] Column means with common superscripts do not differ (P≤ 0.05)

Results of the regression analysis of the starter phase are presented in Table 2.5. There were no statistical differences in the slopes (b) and intercepts (a) of the protein sources and the enzyme application in the starter phase.

Table 2.5 The intercepts (a) and slopes (b) of the regression analysis of average daily gain (ADG), feed intake and feed conversion ratio (FCR) of the broilers in the starter phase

	ADG a	**ADG b**	**Feed Intake a**	**Feed Intake b**	**FCR a**	**FCR b**
Control with Enz	-0.012	0.022	-24.498	30.780	0.765	0.208
Control without Enz	-0.011	0.022	-24.238	31.315	0.785	0.216
Lupins with Enz	-0.014	0.023	-25.499	32.704	0.919	0.210
Lupins without Enz	-0.013	0.022	-24.568	32.194	0.963	0.201
Canola oilcake with Enz	-0.011	0.020	-23.829	30.413	0.839	0.283
Canola oilcake without Enz	-0.010	0.010	-23.260	30.274	0.878	0.269
Full-fat canola with Enz	-0.012	0.019	-25.415	32.577	0.854	0.228
Full-fat canola without Enz	-0.012	0.018	-25.056	31.938	0.831	0.235
SEm	0.000	0.001	0.273	0.341	0.023	0.011

[a-e] Column means with common superscripts do not differ (P≤ 0.05)

Results of the regression analysis on the data collected during the finisher phase are presented in Table 2.6.

Table 2.6 The intercepts (a) and slopes (b) of the regression analysis of average daily gain (ADG), feed intake and feed conversion ratio (FCR) of the broilers in the finisher phase

	ADG a	ADG b	Feed Intake a	Feed Intake b	FCR a	FCR b
Control with Enz	0.054	0.002	-133.749	64.780	1.073	0.106
Control without Enz	0.051	0.003	-124.203	62.737	1.116	0.107
Lupins with Enz	0.083	-0.001	-122.388	62.768	1.181	0.104
Lupins without Enz	0.078	0.003	-129.518	66.589	1.523	0.097
Canola oilcake with Enz	0.035	0.003	-123.355	60.204	1.284	0.116
Canola oilcake without Enz	0.031	0.004	-124.545	60.588	1.302	0.110
Full-fat canola with Enz	0.052	0.002	-128.494	64.489	1.222	0.096
Full-fat canola without Enz	0.079	-0.003	-126.003	63.590	1.184	0.100
SEm	0.007	0.001	23.892	0.756	0.049	0.002

[a-e] Column means with common superscripts do not differ ($P \leq 0.05$)

Similar results were found by Kocher *et al.* (2000*a*), where the feed conversion ratio was not affected by enzyme supplementation of lupin containing diets. In another study by Kocher *et al.* (2000*b*), the addition of enzymes to either canola meal or sunflower meal-based diets had no significant effects on growth performance. The addition of enzymes to the diets of broilers could also influence the quality of the meat produced as was found in a further study conducted by Kocher *et al.* (2001). They found that a reduction in carcass yield and quality was overcome by adding a commercial enzyme product, with pectinase activities, to canola meal based diets. Steenfeldt *et al*. (2003) conducted a study to evaluate the effects of inclusion of lupins (*Lupinus angustifolius*) in broiler diets and enzyme supplementation on production performance. They found that the substitution of soybean meal and maize with lupin depressed weight gain and feed conversion ratio significantly, but the feed intake of the lupin based diets was not decreased. In their study the weight gain was increased with the addition of galactanase enzymes.

Brenes *et al*. (1993) also failed to demonstrate an improvement in the nutritive value of lupin kernel when a α-galactosidase was added to the diet of broilers; from the results they obtained they suggested that the non-starch polysaccharides rather than the oligosaccharides are responsible for limiting the apparent metabolisable energy of the lupins. Similarly the relatively low level of available energy in canola meal (CM) could be associated with high levels of NSP found in canola seed (Bell, 1993). Slominski & Campbell (1990) determined that the digestibility of NSP, in CM, in poultry is very low (<3%) and they found that a commercial enzyme product high in poly-galacturonase increased the NSP digestibility to 37%; bird performance was however not noted. In a further investigation digestibility of the NSP present in CM and lupins should be evaluated.

The effect of dietary lupin inclusion on broiler performance analysed by multifactor analysis of variance is presented in Table 2.7. A regression analyses on the same data follows later in the chapter. Significant differences ($P \leq 0.05$) were detected in the broiler performance due to lupin inclusion in the diet. Significant differences ($P \leq 0.05$) in the broiler weights were found at week 3 as well as at 6 weeks of age. The broiler weights (week 3) at the 20.0% lupin inclusion level were significantly lower ($P \leq 0.05$) compared to the 13.2%, 6.6% lupin diets and the control diet. At week 6 the weight of the broilers fed the control diet

was significantly (P≤ 0.05) higher than the weight of the broilers fed the 20.0% lupin diet. The feed intake (week 3) of the control diet was significantly less (P≤ 0.05) than the 13.2% and 20.0% lupin diets and not significantly less (P≤ 0.05) than the 6.6% lupin diets. There were no significant differences (P≤ 0.05) in the feed intakes at week 6. The feed conversion ratio (week 3) became significantly poorer as the lupin content of the diets increased. The feed conversion ratio of the 13.2% and 20% lupin diets (week 6) was significantly poorer (P≤ 0.05) when compared to the control diet and the 6.6% lupin diet.

These results suggest that the levels alkaloids present in the sweet lupins did not affect feed intakes. Therefore alkaloid levels in the sweet lupins were low enough to not negatively affect the broilers. The lower broiler weights were due to the poorer feed conversion ratios of the broilers fed diets containing higher lupin levels. The poorer feed conversion ratios indicate that the broilers did not use the lupin containing diets as efficiently as the soybean meal diets. This is possibly due to the broilers not being able to utilize the NSP present in the lupin seeds. The slightly increase in intake of the 13.2% lupin and 20% lupin diets may be due to a lower energy availability of the diet and therefore the broilers consumed more to compensate for the lower energy availability.

At 3 weeks the broilers fed the 6.6% lupin diets had significantly fewer mortalities compared to the other treatment groups including the control group. The groups fed the 13.2% lupin and 20% lupin diets had similar mortality rates but where significantly greater compared to the control and 6.6% lupin fed groups. This may indicate that high levels of lupins can influence the survival of broilers younger than 3 weeks of age. At 6 weeks of age the mortalities of the 6.6% lupin and 13.2% lupin fed broilers was significantly lower compared to the control diet. At the 20% lupin inclusion in the diet the mortalities were significantly higher compared to the control. This may prove that broilers become more tolerant to the anti-nutritional factors present in lupins.

Pectora roborant cultus recti

Table 2.7 The effect of dietary lupin inclusion on broiler performance

Treatment	Mortalities		Broiler weight (kg)		Feed intake (kg)		Feed conversion ratio (kg feed/kg broiler weight gain)	
Age	Week 3	Week 6	Week 3	Week 6	Week 3	Week 6	Week 3	Week 6
Control	3.556^{a}	6.222^{a}	0.735^{a}	2.089^{a}	0.992^{a}	3.600	1.350^{a}	1.720^{a}
6.6% Lupins	2.667^{b}	3.778^{b}	0.729^{a}	2.064^{ab}	1.021^{ab}	3.573	1.400^{b}	1.732^{a}
13.2% Lupins	4.661^{c}	5.515^{c}	0.731^{a}	2.049^{ab}	1.056^{b}	3.675	1.444^{c}	1.792^{b}
20.0% Lupins	4.667^{c}	6.667^{d}	0.677^{b}	1.964^{b}	1.041^{b}	3.641	1.539^{d}	1.854^{c}
SEm	0.276	0.492	0.010	0.037	0.013	0.092	0.018	0.055

$^{a-e}$ Column means with common superscripts do not differ (P≤ 0.05)

The results of the regression analysis conducted on the lupin containing diets in the starter phase are presented in Table 2.8. In the starter phase the slopes (b) of the regression lines of the average daily gain (ADG) of the broilers fed the 20.0% lupin diet was significantly higher compared to the control, 6.6% lupin and the 13.2% lupin diets. The slopes (b) of the regression coefficients on feed intake were not siginificantly different for the control, the 6.6 % lupin diet, and the 13.2% lupin diet. The slope of the regression lines on feed conversion ratio(FCR) the 13.2% lupin diet was the smallest i.e. increasing the least in the starter

period, this shows that the broilers could utilise the 13.2% lupin diet more effectively. The regression lines are presented graphically in Figure 2.1, 2.2 and 2.3.

Table 2.8 The intercepts (a) and slopes (b) of the regression analysis on average daily gain (ADG), feed intake and feed conversion ratio (FCR) of the broilers in the starter phase

	ADG a	ADG b	Feed Intake a	Feed Intake b	FCR a	FCR b
Control	-0.004[a]	0.019[a]	-24.368[a]	31.048[a]	0.775[b]	0.212[b]
20.0% Lupins	-0.048[d]	0.022[b]	-75.287[c]	32.980[b]	0.699[a]	0.215[b]
13.2% Lupins	-0.016[c]	0.020[a]	-41.927[b]	32.693[a]	0.873[d]	0.186[a]
6.6% Lupins	-0.009[b]	0.010[a]	-24.536[a]	31.675[a]	0.843[c]	0.215[b]
SEm	0.010	0.001	11.983	0.449	0.039	0.007

[a-e] Column means with common superscripts do not differ (P≤ 0.05)

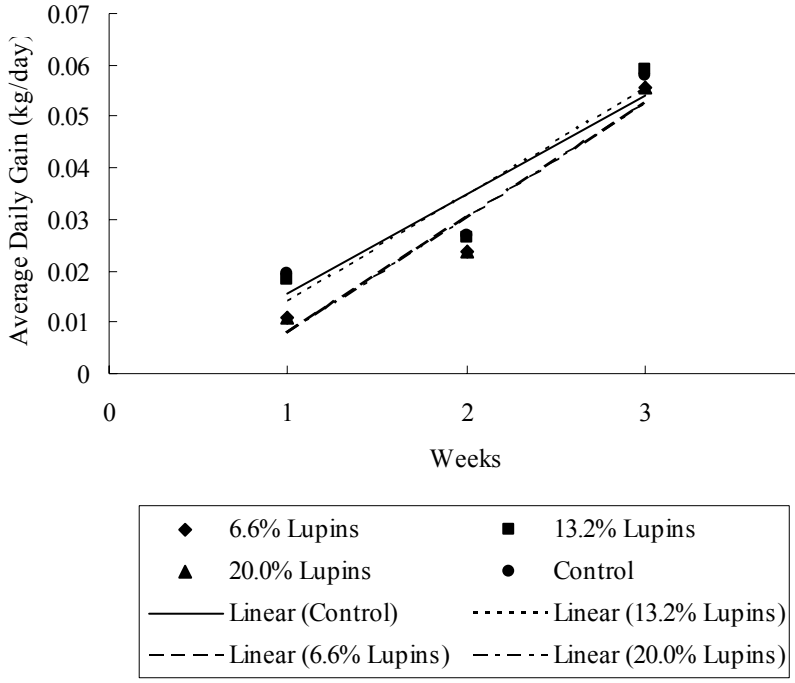

Figure 2.1 The effect of 6.6% lupins, 13.2% lupins and 20.0% lupins on the average daily gain of broilers during the starter phase

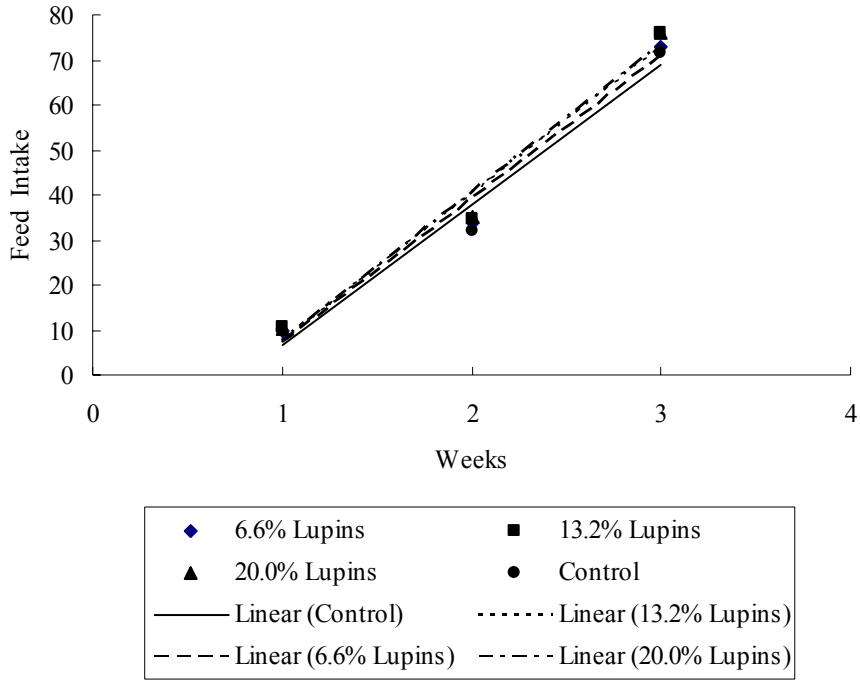

Figure 2.2 The effect of 6.6% lupins, 13.2% lupins and 20.0% lupins on the feed intake of broilers during the starter phase

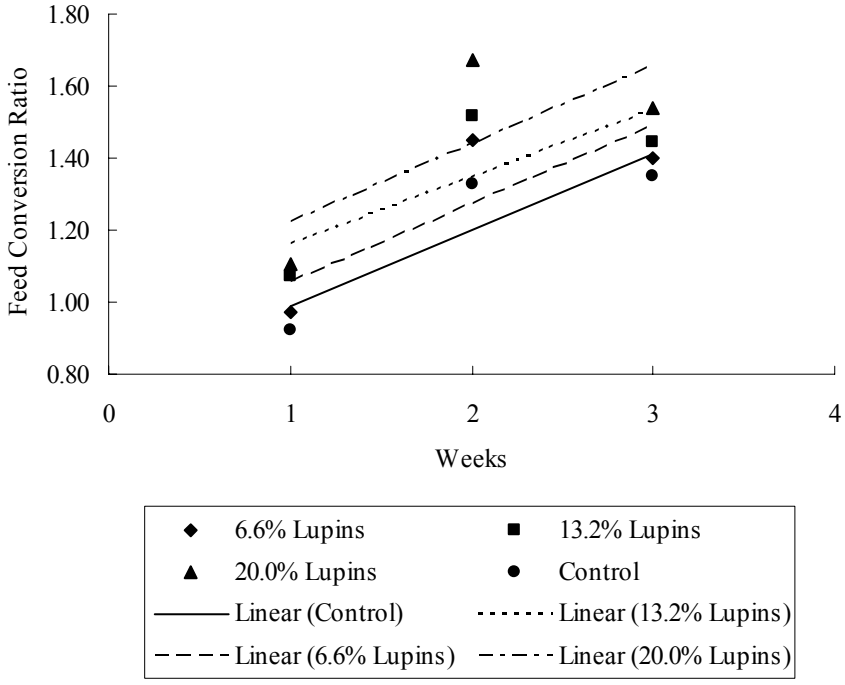

Figure 2.3 The effect of 6.6% lupins, 13.2% lupins and 20.0% lupins on the feed conversion ratio of broilers during the starter phase

The results of the regression analysis conducted on the lupin containing diets in the finisher phase are presented in Table 2.9. In the finisher phase the slopes (b) of the regression lines on ADG of the broilers fed the 13.2% lupin diet was significantly lesser compared to the other treatments. The slopes of the regression lines on feed intake were all very similar with no significant differences. The slopes of the regression lines on FCR for the 20.0% lupin diet was significantly smaller i.e. increasing the least in the finisher period. The regression lines are presented graphically in Figure 2.4, 2.5 and 2.6.

Table 2.9 The intercepts (a) and slopes (b) of the regression analysis on average daily gain (ADG), feed intake and feed conversion ratio (FCR) of the broilers in the finisher phase

	ADG a	ADG b	Feed Intake a	Feed Intake b	FCR a	FCR b
Control	0.060	0.002^{c}	63.299^{b}	63.758	1.415^{a}	0.107^{b}
20.0% Lupins	0.057	0.002^{d}	-34.543^{a}	66.255	1.440^{a}	0.091^{a}
13.2% Lupins	0.060	0.001^{a}	66.372^{c}	65.482	1.492^{b}	0.106^{b}
6.6% Lupins	0.062	0.001^{b}	64.514^{b}	52.299	1.447^{a}	0.101^{b}
SEm	0.001	0.000	24.749	0.886	0.016	0.004

[a-e] Column means with common superscripts do not differ (P≤ 0.05)

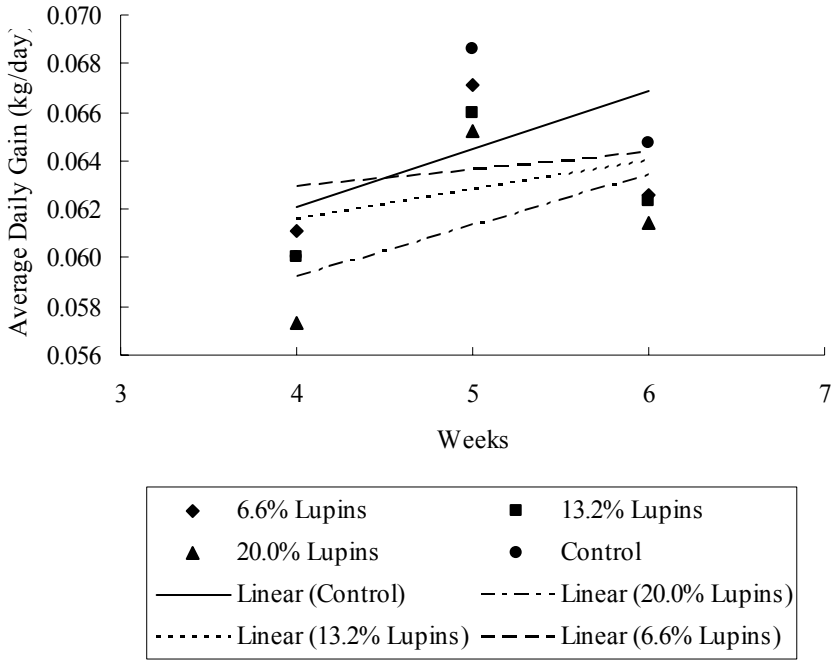

Figure 2.4 The effect of 6.6% lupins, 13.2% lupins and 20.0% lupins on the average daily gain of broilers during the finisher phase

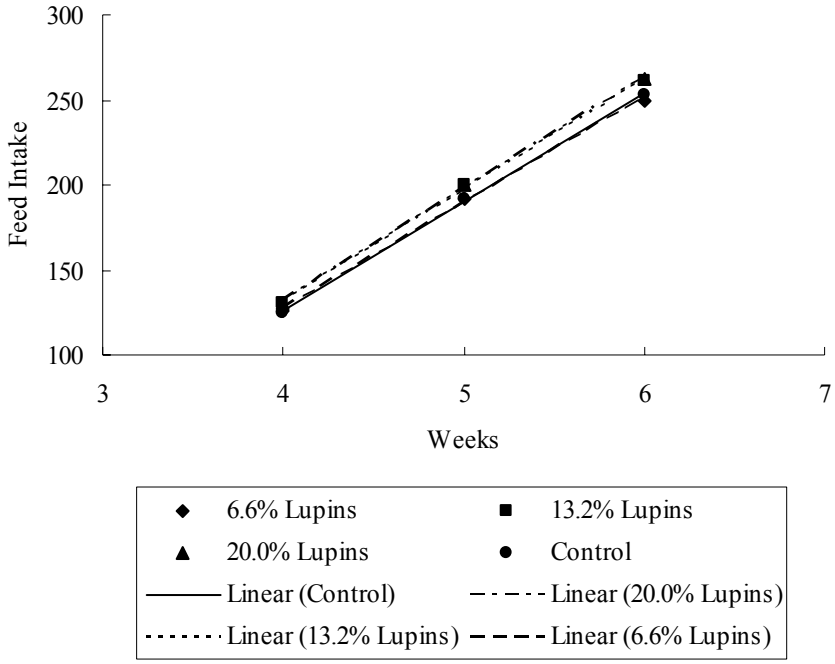

Figure 2.5 The effect of 6.6% lupins, 13.2% lupins and 20.0% lupins on the feed intake of broilers during the finisher phase

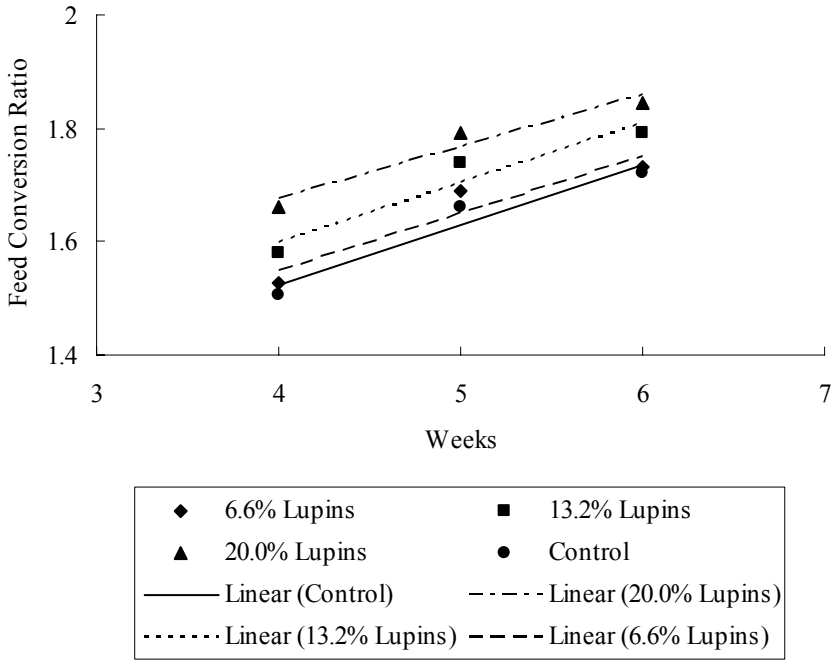

Figure 2.6 The effect of 6.6% lupins, 13.2% lupins and 20.0% lupins on the feed conversion ratio of broilers during the finisher phase

Kocher *et al. (*2000*a)* came to a similar conclusion stating the resistance of the NSP to the endogenous enzymes of the chicken, could explain the lower body weight, higher feed intake and poorer feed conversion ratio for the lupin diets compared to the values of the control diet without lupins. Whole seed lupins contain approximately 35% NSP's of which 5% to 10% are soluble (Evans *et al.,* 1993). In cereal grains, high levels of soluble NSP's increase digesta viscosity in the intestine of chickens, leading to reduced starch, protein and lipid digestion (Choct & Annison, 1990; Annison & Choct, 1991; Philip *et al.,* 1995). The cell wall material of the lupin cotyledon is characterized by a low cellulose content and high pectic substance content (Todorov *et al*., 1996). The main sugar component of cell wall material is galactose, followed by arabinose, fructose, xylanase and glucose (Carre *et al*., 1985). The possible detrimental effect of α-galactoside sugars in lupin seed are that they are not affected by digestive enzymes, but are believed to cause increased flatulence and a decreased feed transit time. As mentioned before Steenfeldt *et al*. (2003) conducted a study to evaluate the effects of inclusion of lupins (*Lupinus angustifolius*) in broiler diets on production performance, digestibility and dietary apparent metabolisable energy. They found that the substitution of soybean meal and maize with lupin depressed weight gain and feed conversion ratio significantly, but the feed intake of the lupin based diets was not decreased. These results compare well to the results found in the current study. In a similar study by Olver & Jonker (1997), it was found that there was no significant differences in body weight gain, feed intake and feed conversion ratio in 3- and 6-week-old Ross broilers when diets containing up to 400 g/kg sweet lupins were fed. These results were in agreement with an earlier study by Olver (1987) as cited by Olver & Jonker (1997) using a different variety of sweet lupin (Buttercup) with Hubbard broilers to 8 weeks of age. In a trial by Roth-Maier & Paulicks (2003), broiler chicks were fed iso-energetic and iso-nitrogenic diets containing seeds of sweet yellow lupin (*Lupinus luteus*) and sweet blue lupin (*Lupinus angustifolius*) at 20 and 30% inclusion levels. Feed intake was increased by the inclusion of lupin seed but growth performance was rather similar for all treatments. They found that up to 20% yellow lupin seed could be included in broiler diets as a replacement to soybean meal without impairing growth performance and feed-to-gain efficiency, when amino acid supplementation is adjusted. However, at the 30% inclusion level yellow lupin seed impaired feed-to-gain efficiency by 9%. The inclusion of 20% blue lupin seed showed the same growth performance as the control, but feed-to-gain efficiency was reduced by 6%.

In Table 2.10 significant differences are reported between the control diet and the canola oilcake containing diets. The broiler weights at week 3 and week 6 decreased significantly ($P \leq 0.05$) as the canola oilcake content of the diets increased. At week 3 the feed intake of the 20.0% canola oilcake diet was significantly less ($P \leq 0.05$) than the 6.6%, 13.2% canola oilcake and the control diet. The feed intakes at week 6 differed significantly ($P \leq 0.05$) between the 20.0% canola oilcake diet and the control diet. This may explain the lower broiler weights of the birds fed the 20.0% canola oilcake diet. The feed conversion ratio at week 3 increased significantly ($P \leq 0.05$) with each increase in the canola oilcake content. At week 6 the feed conversion ratio of the 20% canola oilcake diet was significantly higher ($P \leq 0.05$) than the 6.6%, 13.2%

canola oilcake diet and the control diet. The feed conversion of broilers at 3 weeks of age became less efficient as the canola content increased, which proves that the broilers could not utilize the canola as well as the soybean meal control diet. This may be due to the cellulose (4-6%), non-cellulosic polysaccharides (13-16%) and lignin with associated polyphenols (8%) (Kocher *et al.* 2000*b*; Simbaya *et al.* 1996). These compounds are not well digested by the endogenous enzymes of the broiler and essentially dilute the available energy and protein. As with lupins the high concentrations of soluble NSP increases the digesta viscosity, which leads to reduced starch, protein and lipid digestion (Kocher *et al.* 2000*b*).

Broiler mortalities at 3 and 6 weeks of age were significantly lower for the broilers receiving the diets containing canola oilcake, compared to the broilers fed the control diet.

Table 2.10 The effect of dietary canola oilcake inclusion on broiler performance

Treatment	Mortalities		Broiler weight (kg)		Feed intake (kg)		Feed conversion ratio (kg feed/kg broiler weight gain)	
Age	Week 3	Week 6	Week 3	Week 6	Week 3	Week 6	Week 3	Week 6
Control	3.556^{a}	6.222^{a}	0.735^{a}	2.089^{a}	0.992^{a}	3.600^{a}	1.350^{a}	1.720^{a}
6.6% Canola oilcake	2.444^{b}	3.333^{b}	0.680^{b}	1.938^{b}	0.985^{a}	3.472^{ab}	1.449^{b}	1.793^{ab}
13.2% Canola oilcake	3.556^{a}	5.111^{c}	0.625^{c}	1.752^{c}	0.967^{a}	3.315^{ab}	1.548^{c}	1.893^{b}
20.0% Canola oilcake	2.667^{c}	4.667^{c}	0.518^{d}	1.399^{d}	0.899^{b}	3.089^{b}	1.737^{d}	2.211^{c}
SEm	0.276	0.492	0.010	0.037	0.013	0.092	0.018	0.055

$^{a-e}$ Column means with common superscripts do not differ (P≤ 0.05)

The results of the regression analysis conducted on the canola oilcake containing diets in the starter phase are presented in Table 2.11. In the starter phase the slopes (b) of the regression lines on ADG of the broilers fed the canola oilcake containing diets decreased significantly as the canola oilcake inclusion increased. The slope (b) of the regression lines on feed intake of the 20.0% canola oilcake diet was siginificantly smaller compared to the other groups. The slopes (b) of the regression lines on feed intake of the rest of the treatments did not differ significantly. The slopes of the regression lines on FCR for the canola oilcake containing diets increased as the canola oilcake inclusion increased. The slope of the 20.0 % canola oilcake diets being significantly greater. The regression lines are illustrated graphically in Figure 2.7, 2.8 and 2.9.

Table 2.11 The intercepts (a) and slopes (b) of the regression analysis of average daily gain (ADG), feed intake and feed conversion ratio (FCR)of the broilers in the starter phase

	ADG a	**ADG b**	**Feed Intake a**	**Feed Intake b**	**FCR a**	**FCR b**
Control	-0.004^{d}	0.019^{d}	-24.368^{b}	31.048^{b}	0.775^{a}	0.212^{a}
20.0% Canola oilcake	-0.002^{a}	0.013^{a}	-22.753^{a}	28.755^{a}	0.823^{b}	0.346^{d}
13.2% Canola oilcake	-0.003^{c}	0.016^{b}	-22.828^{a}	30.153^{b}	0.929^{c}	0.242^{c}
6.6% Canola oilcake	-0.002^{b}	0.017^{c}	-25.053^{b}	32.123^{b}	0.823^{b}	0.239^{b}
SEm	0.009	0.001	0.572	0.713	0.033	0.030

$^{a-e}$ Column means with common superscripts do not differ (P≤ 0.05)

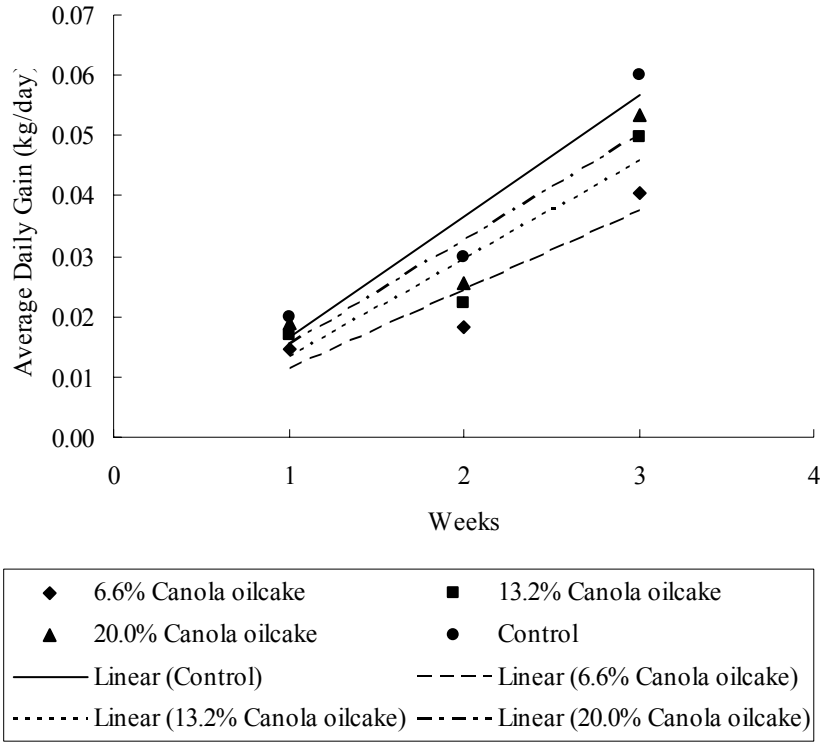

Figure 2.7 The effect of 6.6% canola oilcake, 13.2% canola oilcake and 20.0% canola oilcake on the average daily gain of broilers during the starter phase

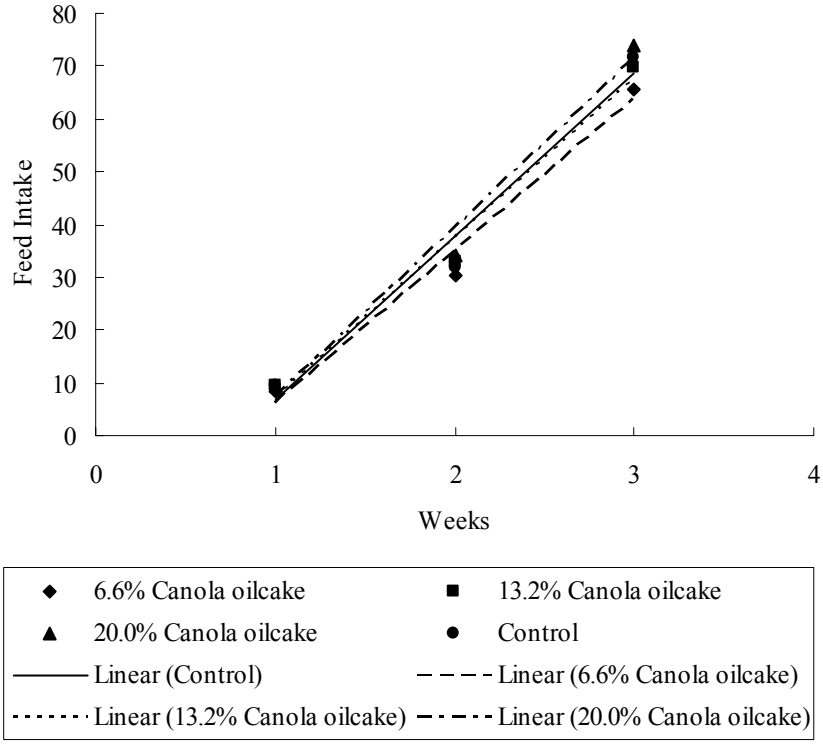

Figure 2.8 The effect of 6.6% canola oilcake, 13.2% canola oilcake and 20.0% canola oilcake on the feed intake of broilers during the starter phase

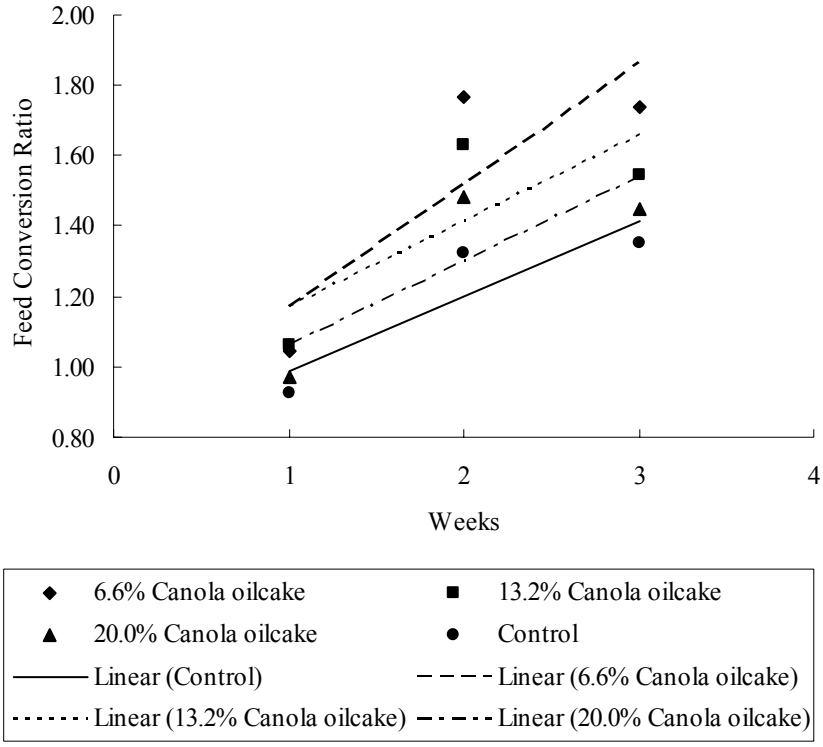

Figure 2.9 The effect of 6.6% canola oilcake, 13.2% canola oilcake and 20.0% canola oilcake on the feed conversion ratio of broilers during the starter phase

The results of the regression analysis conducted on the canola oilcake containing diets in the finisher phase are presented in Table 2.10. In the finisher phase the slopes (b) of the regression lines on ADG of the broilers were small. The slopes of the regression lines of the 13.2% and 20.0% canola oilcake containing diets were significantly greater compared to the other treatments. The slope (b) of the regression lines on feed intake of the 20.0% canola oilcake diets and the 13.2% canola oilcake diets were siginificantly smaller compared to the controls and the 6.6% canola oilcake containing diets. The slopes of the regression lines on FCR for the 200.% canola oilcake containing diets were significantly greater compared to the other treatment groups i.e. the FCR increased the most for the 20.0% canola oilcake diets. This shows that the broilers were less efficient in utilising the 20.0% canola oilcake containing diets. The regression lines are illustrated graphically in Figure 2.10 2.11 and 2.12.

Table 2.10 The intercepts (a) and slopes (b) of the regression analysis of average daily gain (ADG), feed intake and feed conversion ratio (FCR) of the broilers in the finisher phase

	ADG a	ADG b	Feed Intake a	Feed Intake b	FCR a	FCR b
Control	0.060^{d}	0.002^{a}	62.299^{b}	63.759^{b}	1.145^{a}	0.107^{b}
20.0% Canola oilcake	0.034^{a}	0.004^{d}	48.650^{a}	57.905^{a}	1.772^{d}	0.143^{c}
13.2% Canola oilcake	0.045^{b}	0.004^{c}	59.433^{b}	59.130^{a}	1.626^{c}	0.093^{a}
6.6% Canola oilcake	0.054^{c}	0.003^{b}	63.629^{b}	64.153^{b}	1.500^{b}	0.103^{b}
SEm	0.006	0.001	3.399	1.592	0.034	0.011

$^{a-e}$ Column means with common superscripts do not differ ($P \leq 0.05$)

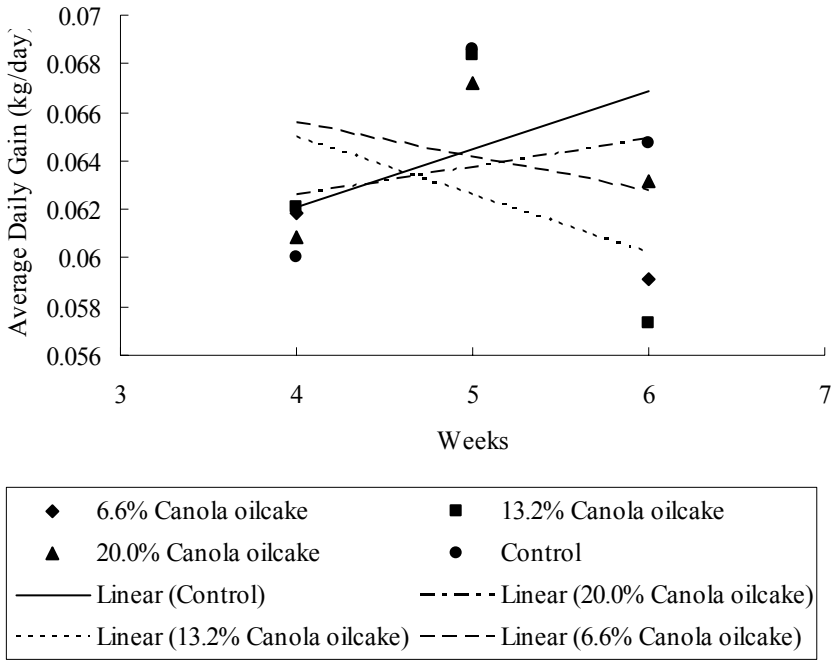

Figure 2.10 The effect of 6.6% canola oilcake, 13.2% canola oilcake and 20.0% canola oilcake on the average daily gain of broilers during the finisher phase

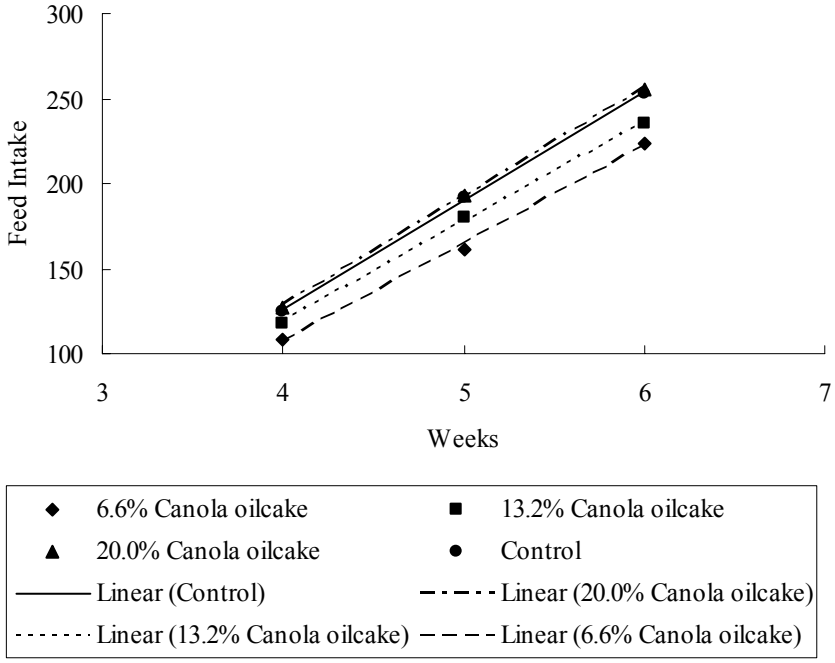

Figure 2.11 The effect of 6.6% canola oilcake, 13.2% canola oilcake and 20.0% canola oilcake on the feed intake of broilers during the finisher phase

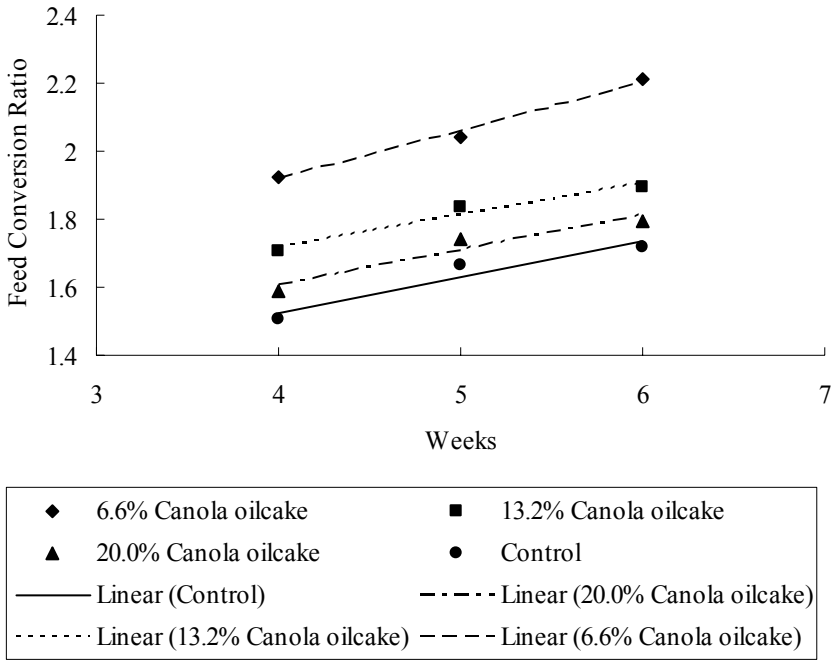

Figure 2.12 The effect of 6.6% canola oilcake, 13.2% canola oilcake and 20.0% canola oilcake on the feed conversion ratio of broilers during the finisher phase

In a study by Kocher *et al.* (2001), the results clearly indicated that high levels of canola meal can be included in broiler diets as the main dietary protein source in place of soybean meal without loss in bird performance; however the carcass yield and quality will be reduced. A study by Leeson *et al.* (1987) showed that canola meal could replace up to 100% of dietary soybean meal without major negative effects on performance, or energy or mineral utilisation, provided lysine as the limiting amino acid was added. However, the low level of available energy, the reduced level of crude protein as well as lysine, and the increased levels of indigestible carbohydrates of canola meal compared with soybean meal (Bell, 1993); make canola meal a less competitive alternative when used at high levels in broiler diets.

The effect of full-fat canola on the performance of broilers is summarized in Table 2.11. The broiler weights at week 3 were significantly lower ($P \leq 0.05$) for the 20.0% full-fat canola diet when compared to the 6.6%, 13.2% full-fat canola diets and the control diet. The feed intakes were significantly lower ($P \leq 0.05$) for the control and 20.0% full-fat canola diet at week 3, a possible explanation for the reduced broiler weight. At week 6 broiler weight and feed intake did not differ significantly ($P \leq 0.05$) between the various treatments. The feed conversion ratio of the control diet at week 3 was significantly lower ($P \leq 0.05$) than the feed conversion ratios of the other treatments. However, at week 6 the feed conversion ratio of the control diet and the 6.6% full-fat canola diet did not differ significantly, but the feed conversion ratio of the control diet was significantly lower ($P \leq 0.05$) than the feed conversion ratios of the 13.2% and 20% full-fat canola diets. The higher feed conversion ratios of the broilers fed the full-fat canola containing diets again shows reduced

efficiency in the utilisation of the full-fat canola containing diets. This effect of the full-fat canola was much more drastic at 3 weeks of age than at 6 weeks of age. In a study by Shires *et al*. (1987) the broilers fed canola based diets had a gastrointestinal tract much heavier than broilers fed soybean meal diets. The increased weight of the gastrointestinal tract is associated with longer digestive organs as a result of increased digestion of the more fibrous canola based diets. The increase in size of the gastrointestinal tract takes time to achieve therefore older broilers may have the ability to cope with higher fibre diets, which may explain the difference in the results at 3 weeks and 6 weeks of age.

At 3 weeks of age the broilers fed the 6.6% full-fat diet had the same mortality rate compared to the broilers fed the control diet. The broilers receiving the 13.2% full-fat canola diet had a significantly lower mortality rate compare to the other treatments including the control group. However at the 20% full-fat canola inclusion the mortalities were significantly greater compared to the other treatments. At 6 weeks of age the 6.6% full-fat canola group had a significantly higher mortality rate compared to the other groups. The 13.2% and 20% full-fat canola groups had a significantly lower mortality rate compared to the other groups. From these results it is highly unlikely that the full-fat canola had any influence on the mortality rate.

Table 2.11 The effect of full-fat canola on the performance of broilers

Treatment	Mortalities		Broiler weight kg		Feed intake kg		Feed conversion ratio (kg feed/kg broiler weight gain)	
Age	Week 3	Week 6	Week 3	Week 6	Week 3	Week 6	Week 3	Week 6
Control	3.556^{a}	6.222^{a}	0.735^{a}	2.089	0.992^{a}	3.600	1.350^{a}	1.720^{a}
6.6% Full-fat canola	3.556^{a}	8.222^{b}	0.739^{a}	2.077	1.048^{b}	3.658	1.418^{b}	1.745^{ab}
13.2% Full-fat canola	2.433^{b}	3.322^{c}	0.733^{a}	2.048	1.044^{b}	3.622	1.424^{b}	1.788^{b}
20.0% Full-fat canola	4.222^{c}	5.333^{d}	0.682^{b}	1.996	0.998^{a}	3.595	1.466^{b}	1.804^{b}
SEm	0.276	0.492	0.010	0.037	0.013	0.092	0.018	0.055

$^{a-e}$ Column means with common superscripts do not differ ($P \leq 0.05$)

The results of the regression lines conducted on the full-fat canola containing diets in the starter phase are presented in Table 2.12. In the starter phase the slopes (b) of the regression lines on ADG did not differ significantly, with the exception of the 20.0% full-fat canola having a significantly greater slope. The slopes (b) of the regression lines on feed intake of the 13.2% full-fat canola diet was siginificantly greater compared to the other treatment groups. The slopes of the regression lines on FCR for the full-fat canola containing diets increased as the full-fat canola inclusion increased. The slope of the 20.0 % full-fat canola diets being significantly greater. The regression lines are illustrated graphically in Figure 2.13, 2.14 and 2.15.

Table 2.12 The intercepts (a) and slopes (b) of the regression analysis of average daily gain (ADG), feed intake and feed conversion ratio (FCR) of the broilers in the starter phase

	ADG a	ADG b	Feed Intake a	Feed Intake b	FCR a	FCR b
Control	-0.004[a]	0.019[a]	-24.368[a]	31.048[a]	0.775[a]	0.212[a]
20.0% Full-fat canola	-0.017[c]	0.028[b]	-24.841[a]	31.203[a]	0.841[c]	0.245[c]
13.2% Full-fat canola	-0.005[b]	0.020[a]	-26.244[b]	33.423[b]	0.833[b]	0.227[b]
6.6% Full-fat canola	-0.004[b]	0.020[a]	-25.018[a]	32.628[a]	0.848[c]	0.222[ab]
SEm	0.003	0.002	0.400	0.573	0.017	0.007

[a-e] Column means with common superscripts do not differ (P≤ 0.05)

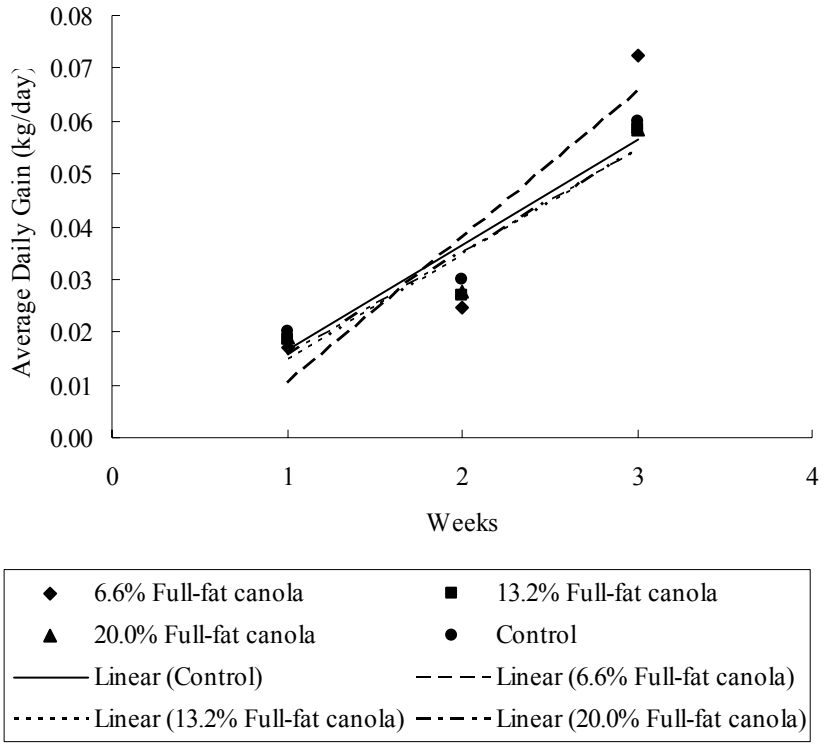

Figure 2.13 The effect of 6.6% full-fat canola, 13.2% full-fat canola and 20.0% full-fat canola on the average daily gain of broilers during the starter phase

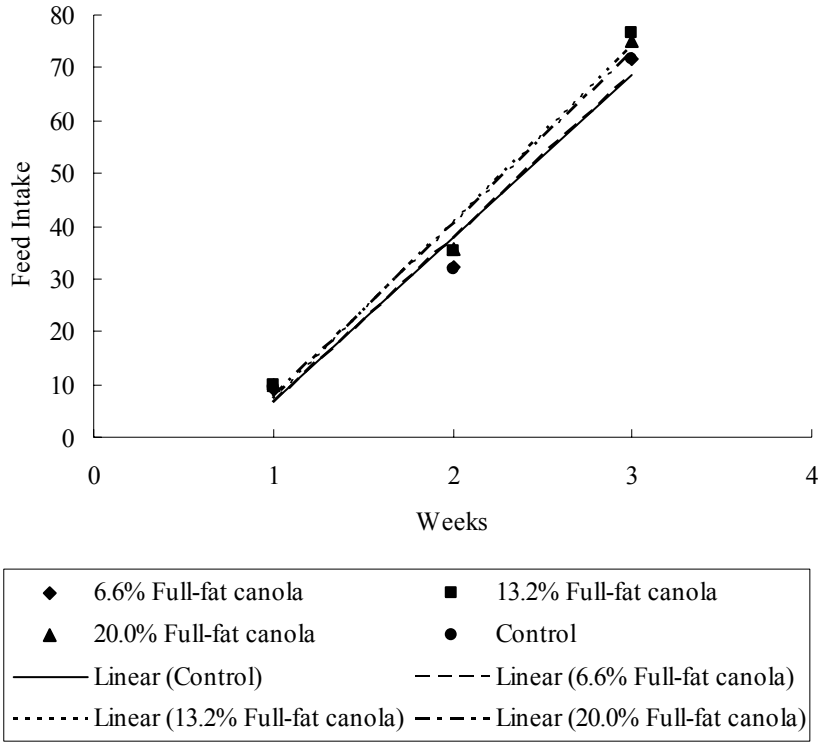

Figure 2.14 The effect of 6.6% full-fat canola, 13.2% full-fat canola and 20.0% full-fat canola on the feed intake of broilers during the starter phase

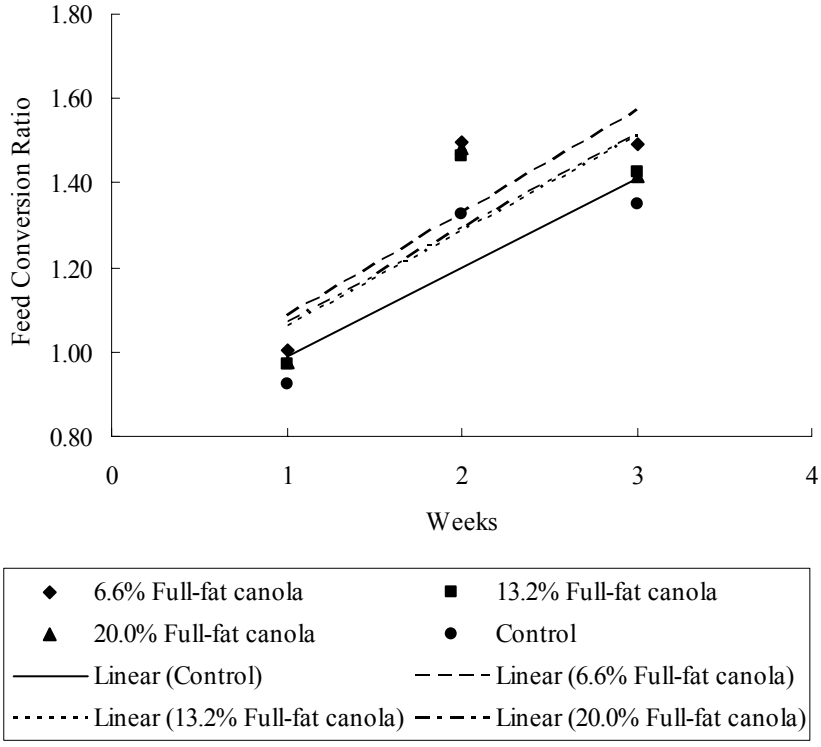

Figure 2.15 The effect of 6.6% full-fat canola, 13.2% full-fat canola and 20.0% full-fat canola on the feed conversion ratio of broilers during the starter phase

The results of the regression analysis conducted on the full-fat canola containing diets in the finisher phase are presented in Table 2.13. In the finisher phase the slopes (b) of the regression lines on ADG differed significantly, with the 13.2% full-fat canola diet regression line having a significantly smaller slope. The slopes (b) of the regression lines on feed intake did not differ significantly between the the treatment groups, with the exception of the 20.0% full-fat canola diet. The smaller slope of the feed intake regression of this group may explain the significantly smaller slope of the ADG. The slopes of the regression lines on FCR for the 20.0% full-fat canola containing diets was significantly smaller. The slopes of the 20.0% full-fat canola diets were significantly smaller compared to the slopes of the control treatments. The regression lines are illustrated graphically in Figure 2.16, 2.17 and 2.18.

Table 2.13 The intercepts (a) and slopes (b) of the regression analysis of average daily gain (ADG), feed intake and feed conversion ratio (FCR) of the broilers in the finisher phase

	ADG a	ADG b	Feed Intake a	Feed Intake b	FCR a	FCR b
Control	0.060[a]	0.002[d]	62.299[a]	63.758[a]	1.415[a]	0.107[c]
20.0% Full-fat canola	0.067[b]	-0.001[b]	60.979[a]	62.802[a]	1.541[b]	0.087[a]
13.2% Full-fat canola	0.067[b]	-0.002[a]	68.359[b]	66.518[a]	1.466[a]	0.110[c]
6.6% Full-fat canola	0.061[a]	0.001[c]	66.623[b]	63.932[a]	1.477[a]	0.095[b]
SEm	0.003	0.001	1.747	0.795	0.026	0.005

[a-e] Column means with common superscripts do not differ (P≤ 0.05)

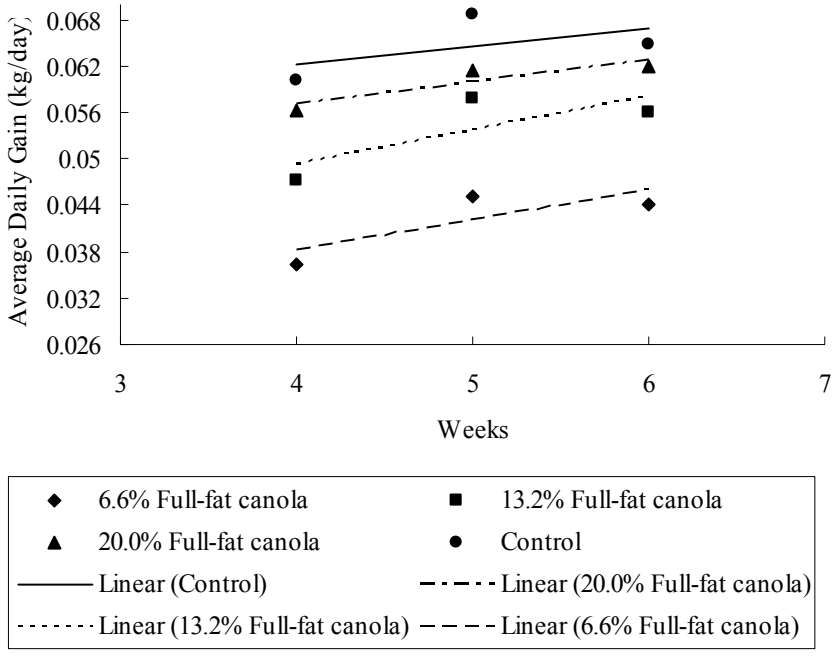

Figure 2.16 The effect of 6.6% full-fat canola, 13.2% full-fat canola and 20.0% full-fat canola on the average daily gain of broilers during the finisher phase

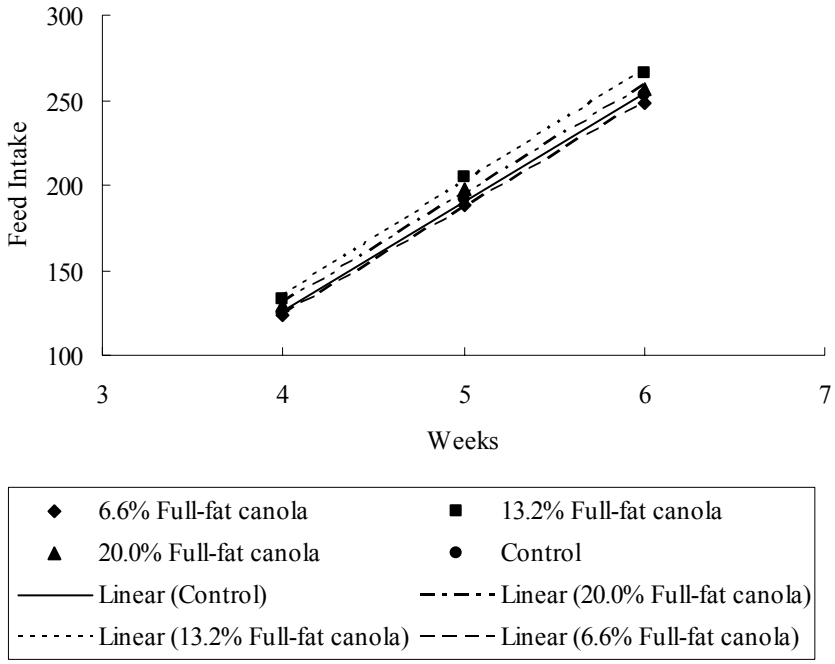

Figure 2.17 The effect of 6.6% full-fat canola, 13.2% full-fat canola and 20.0% full-fat canola on the feed intake of broilers during the finisher phase

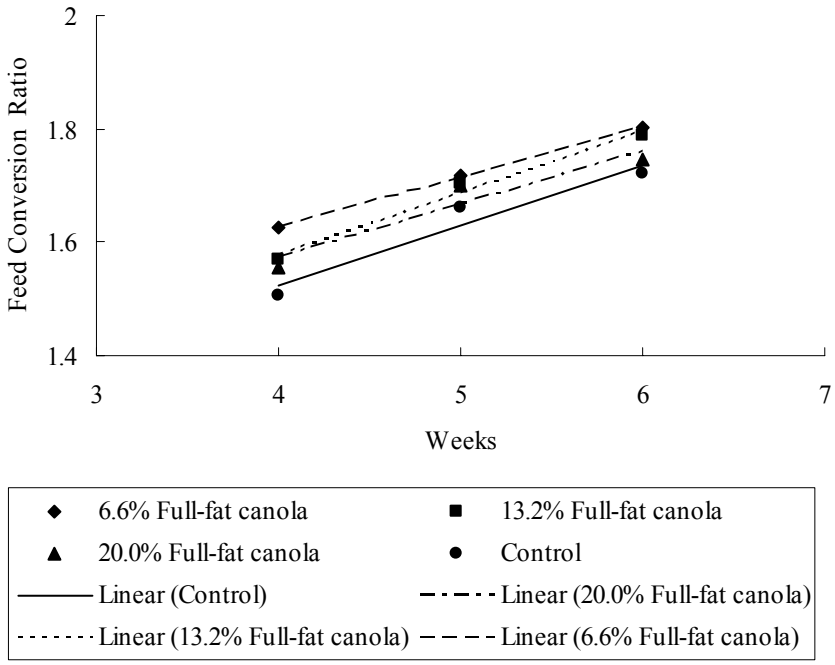

Figure 2.18 The effect of 6.6% full-fat canola, 13.2% full-fat canola and 20.0% full-fat canola on the feed conversion ratio of broilers during the finisher phase

Leeson *et al.* (1987) found that increasing the dietary proportion of full-fat canola significantly reduced feed intake and weight gain, without altering feed: gain ratio. Their results were congruent with earlier results that also showed a decrease in feed intake and weight gain with increasing dietary amounts of

full-fat canola. Nwokolo & Sim (1989) conducted a study where wheat and barley was partially replaced in broiler diets; they found that broilers fed the full-fat canola diet had significantly lower weight gains compared to the wheat and barley diets. The feed intake and feed conversion ratio was not affected. The non-starch polysaccharide content of canola is 179.0 g/kg (Bell, 1993) and as for the lupins could be a possible explanation for the significant ($P \leq 0.05$) differences in the 6-week broiler weights.

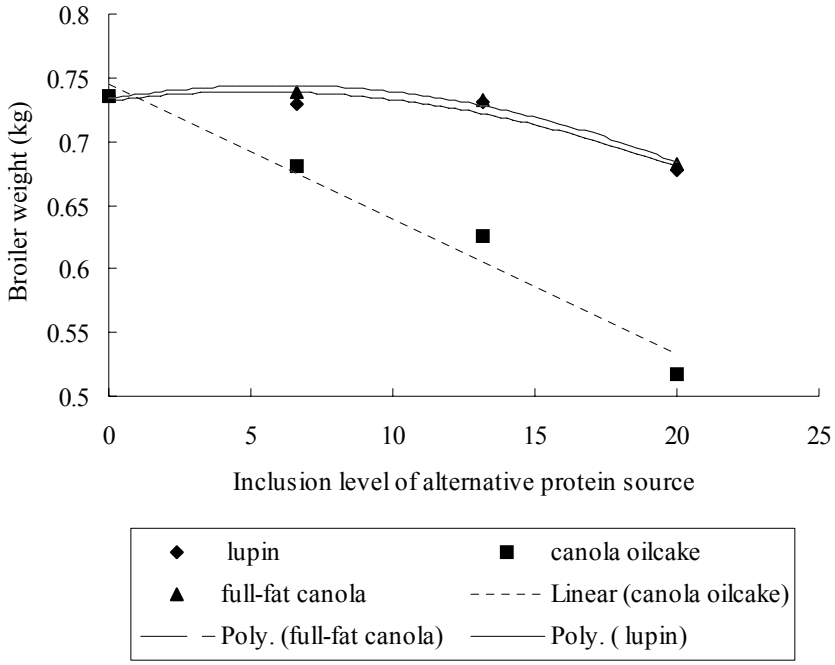

Figure 2.19 The effect of lupins ($y = -0.001x^2 + 0.003x + 0.732$; $R^2 = 0.914$; Sxy = 0.099), full-fat canola ($y = -0.001x^2 + 0.004x + 0.733$; $R^2 = 0.975$; Sxy = 0.099) and canola oilcake ($y = -0.011x + 0.745$; $R^2 = 0.971$; Sxy = 0.099) dietary inclusions on broiler weight during starter phase (hatching up to 21 days of age).

A comparison of the effect of the inclusion rate of the different protein sources on broiler weight at three weeks of age is presented in Figure 2.19. Regression analysis of the data revealed that a linear model best fits the decrease in broiler slaughter weight (hatching up to 21 days of age) due to the replacement of soybean oilcake with canola oilcake. For each percentage increase in canola oilcake inclusion, the broiler slaughter weight decreased by 1.1 g. The replacement of soybean oilcake with lupins and full-fat canola in the broiler diets decreased broiler slaughter weight (hatching up to 21 days of age) according to the best-fit curvilinear model. As the level of inclusion of lupins and full-fat canola increased in the broiler diets, the broiler slaughter weight decreased.

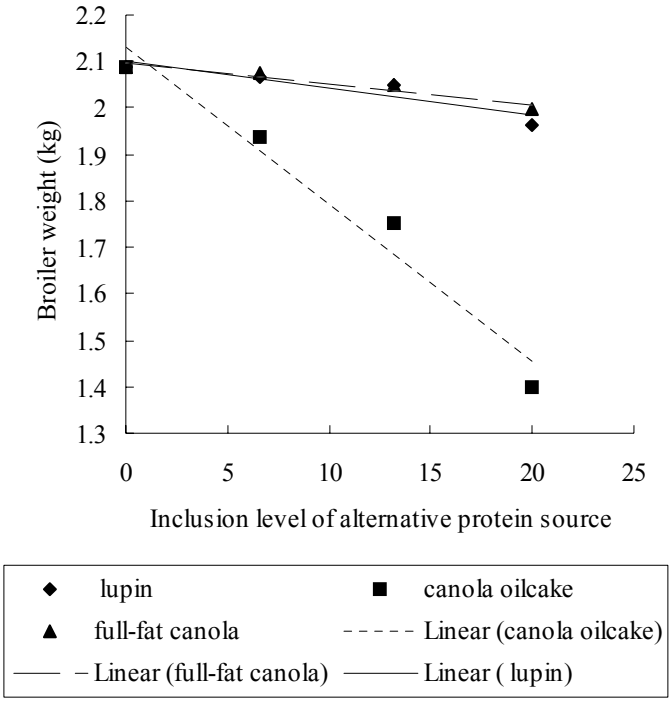

Figure 2.20 The effect of lupin (y = -0.006x + 2.100; R^2 = 0.861; Sxy = 0.025), full-fat canola (y = -0.005x + 2.099; R^2 = 0.926; Sxy = 0.014) and canola oilcake (y = -0.034x + 2.123; R^2 = 0.961; Sxy = 0.072) dietary inclusions on broiler weight during finisher phase (21 days to 42 days of age).

A comparison of the effect of the inclusion rate of the different protein sources on broiler weight at six weeks of age (finisher stage) are presented in Figure 2.20. The regression analysis revealed that during the finisher phase the broiler slaughter weight decreased linearly where soybean oilcake was replaced with lupins, full-fat canola and canola oilcake. The broiler slaughter weight decreased as the inclusion rate of the lupins, full-fat canola and canola oilcake increased. For each percentage increase in the inclusion of lupins the broiler slaughter weight decreased by 0.6 g (y = -0.006x + 2.100; R^2 = 0.861; Sxy = 0.025). For each percentage increase in the inclusion of full-fat canola the broiler slaughter weight decreased by 0. 5g (y = -0.005x + 2.099; R^2 = 0.926; Sxy = 0.014). For each percentage increase in the inclusion of canola oilcake the broiler slaughter weight decreased by 3.4 g (y = -0.034x + 2.123; R^2 = 0.961; Sxy = 0.072).

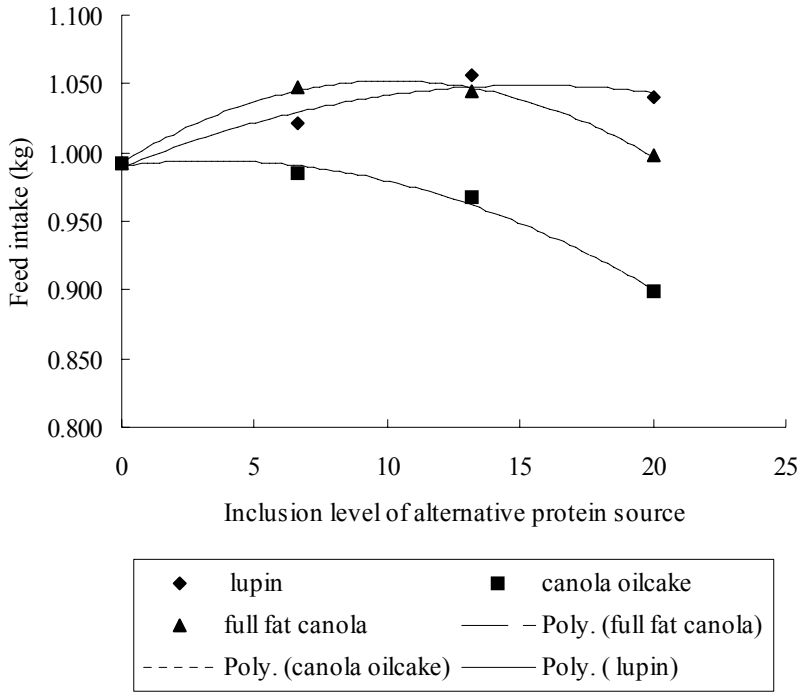

Figure 2.21 The effect of lupin ($y = -0.0003x^2 + 0.008x + 0.989$; $R^2 = 0.933$; Sxy = 0.024), full fat canola ($y = -0.0003x^2 + 0.002x + 0.990$; $R^2 = 0.988$; Sxy = 0.008) and canola oilcake ($y = -0.0001x^2 + 0.012x + 0.993$; $R^2 = 0.992$; Sxy = 0.067) dietary inclusions on feed intake during starter phase (hatching up to 21 days of age).

The effect of the inclusion of the alternative protein sources on the feed intake during the starter phase is illustrated in Figure 2.21. Regression analysis of the feed intake data showed that the feed intakes of the broiler diets during the starter phase decreased curve linearly as the inclusion rates of lupins, full-fat canola and canola oilcake increased. Canola oilcake showed the greatest decrease in the feed intake.

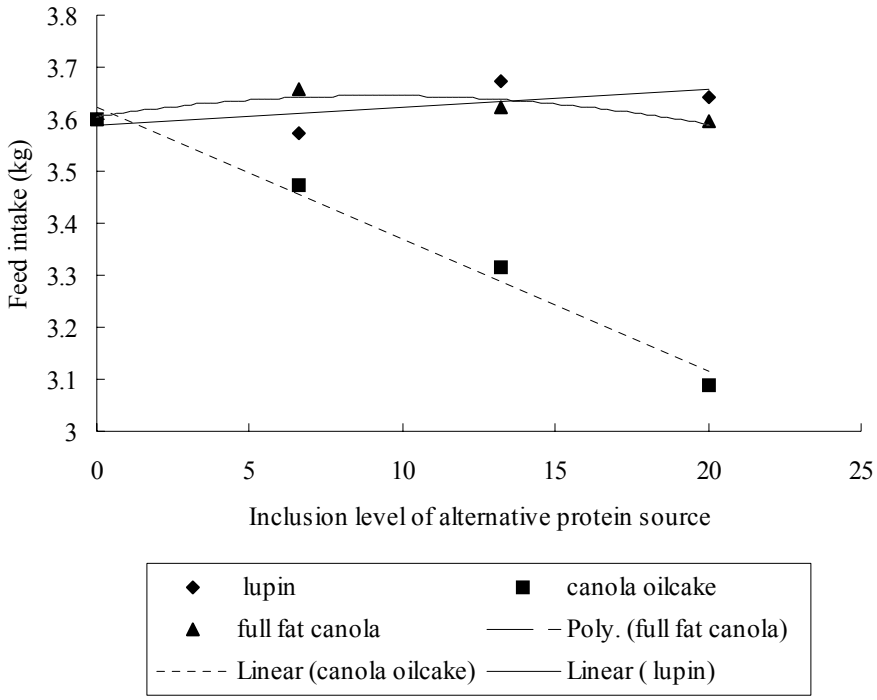

Figure 2.22 The effect of lupins ($y = 0.003x + 3.589$; $R^2 = 0.415$; Sxy = 0.042), full-fat canola ($y = -0.001x^2 + 0.009x + 3.605$; $R^2 = 0.776$; Sxy = 0.004) and canola oilcake ($y = -0.025x + 3.623$; $R^2 = 0.985$; Sxy = 0.033) dietary inclusions on feed intake during finisher phase (21 days to 42 days of age).

The effect of the inclusion of the alternative protein sources on the feed intake during the finisher phase is illustrated in Figure 2.22. Feed intake during the finisher phase decreased linearly where soybean oilcake was replaced with canola oilcake. The feed intake decreased with 2.5 g with every percentage increase in level of canola oilcake ($y = -0.025x + 3.623$; $R^2 = 0.985$; Sxy = 0.033). The feed intake was slightly higher where soybean oilcake was replaced with lupins. For every percentage increase in lupin inclusion the feed intake increased by 0.3 g ($y = 0.003x + 3.589$; $R^2 = 0.415$; Sxy = 0.042).

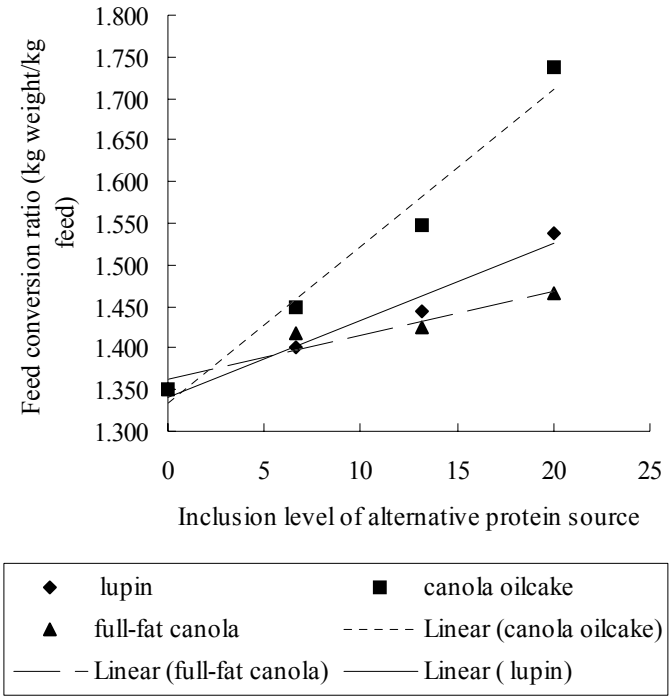

Figure 2.23 The effect of lupins ($y = 0.009x + 1.342$; $R^2 = 0.968$; Sxy = 0.033), full-fat canola ($y = 0.005x + 1.362$; $R^2 = 0.906$; Sxy = 0.018) and canola oilcake ($y = 0.019x + 1.333$; $R^2 = 0.973$; Sxy = 0.033) dietary inclusions on feed conversion rate during starter phase (hatching up to 21 days of age).

A comparison of the effect of the inclusion rate of the different protein sources on the feed conversion ratio at three weeks of age is presented in Figure 2.23. Regression analysis of the data revealed that the feed conversion ratio increased linearly as the level of lupins, canola oilcake and full-fat canola in the diet increased. For each percentage inclusion of lupins, 9 g more feed was needed to increase the broiler's body weight by 1 kg ($y = 0.009x + 1.342$; $R^2 = 0.968$; Sxy = 0.033). For each percentage inclusion of canola oilcake, 19 g more feed was needed to increase the broiler's body weight by 1 kg ($y = 0.019x + 1.333$; $R^2 = 0.973$; Sxy = 0.033). For each percentage inclusion of full-fat canola, 5 g more feed was needed to increase the broiler's body weight by 1 kg ($y = 0.005x + 1.362$; $R^2 = 0.906$; Sxy = 0.018).

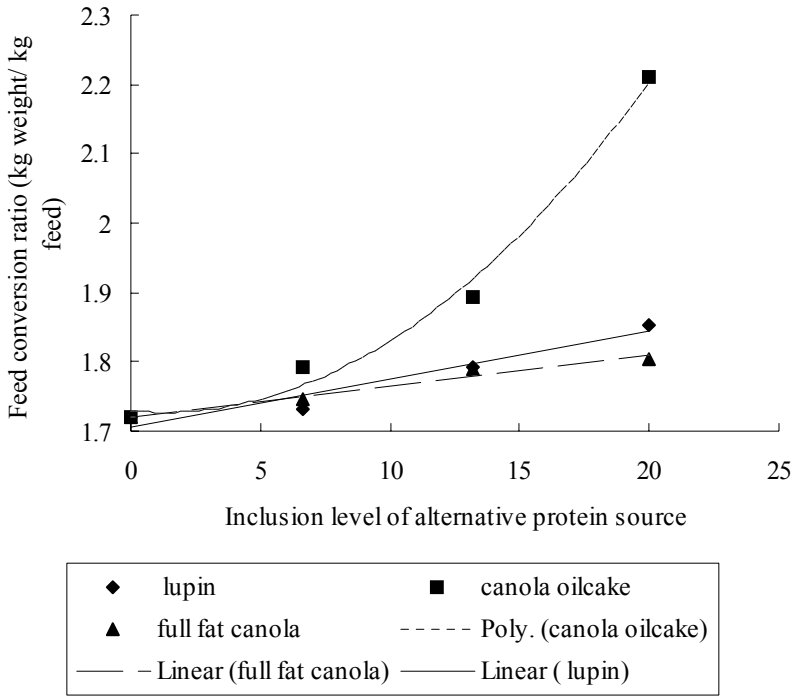

Figure 2.24 The effect of lupins ($y = 0.007x + 1.705$; $R^2 = 0.938$; Sxy = 0.019), full-fat canola ($y = 0.004x + 1.720$; $R^2 = 0.971$; Sxy = 8.05) and canola oilcake ($y = 0.001x^2 - 0.003x + 1.729$; $R^2 = 0.988$; Sxy = 0.040) dietary inclusions on feed conversion rate during finisher phase (21 days to 42 days of age)

The effect of the inclusion of the alternative protein sources on the feed conversion ratio during the finisher phase is illustrated in Figure 2.24. During the finisher phase the feed conversion ratio increased linearly where soybean oilcake was replaced with full fat canola and lupins. For each percentage inclusion of full-fat canola, 4 g more feed was needed to increase the broiler's body weight by 1 kg ($y = 0.004x + 1.720$; $R^2 = 0.971$; Sxy = 8.05). For each percentage inclusion of lupins, 7 g more feed was needed to increase the broiler's body weight by 1 kg ($y = 0.007x + 1.705$; $R^2 = 0.938$; Sxy = 0.019). The feed conversion ratio increased curve linearly as the inclusion rate increased where soybean oilcake was replaced with canola oilcake.

2.5 Conclusion

It is clear that the enzyme tested in this study did not improve the performance of broiler chickens. It is also evident that soybean oilcake can partially be replaced with sweet lupins, without significant reductions in broiler performance. Replacing soybean oilcake meal with canola oilcake reduced the growth performance of broilers possibly due to the reduced feed intake and a significantly higher feed conversion ratio. The replacement of soybean oilcake meal with full-fat canola only reduced broiler performance at the 20% inclusion level but at lower inclusion levels the broiler performance was not significantly influenced. The use of locally produced alternative protein sources investigated in this study will mainly depend on the availability and price of these raw materials.

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Pectora roborant cultus recti

Chapter 3

The effect of external enzymes on the performance of weanling piglets consuming diets containing sweet lupins, canola oilcake and full-fat canola

3.1 Abstract

Sweet lupins, canola oilcake and full-fat canola were examined as alternative protein sources in diets fed to pigs. Four diets were formulated on an iso-nutrient basis to contain 25% sweet lupins (*Lupinus angustifolius*), 25% full-fat canola seed, 25% canola oilcake meal or 25% full-fat soybean meal (control diet) as protein source. The three test diets were blended with the control diet to produce four different levels (100%, 67%, 33% and 0%) of each protein source. The test diets were fed with and without Roxazyme® enzyme. Pigs were fed *ad libitum* from 8.5 to 25 kg live weight. Pigs were kept in groups of four per pen. In this study the provision of external dietary enzymes failed to improve either dry matter intake or growth rate. The addition of enzymes improved the feed conversion ratio. The final body weights of the pigs fed the control diet were significantly higher than the final body weights of pigs fed the lupin containing diets. The average daily gain of the pigs fed the control diet was significantly higher than the gain of the pigs fed the lupin containing diets. No significant differences in the feed intake and feed conversion ratio between the different lupin inclusion levels were detected. There were no significant differences in body weight, feed intake, average daily gain and the feed conversion ratio, between the various full-fat canola containing diets and the control diet. A significant difference in body weight was found between the pigs fed the 20% canola oilcake diet and the pigs fed the control diet. There were no significant differences in feed intake between the various inclusion levels of canola oilcake. The control and 6.6% canola oilcake containing diets had significantly higher average daily gains than the 20% canola oilcake containing diet. In this study full-fat canola proved to be a very good substitute for full-fat soybean meal in diets for weaner piglets.

Keywords: Weaner pigs, enzymes, sweet lupins, full-fat canola, canola oilcake

3.2 Introduction

The development of low erucic acid and low glucosinolate cultivars of canola seed has led to the availability of a feed ingredient with considerable potential to replace soybean meal in diets for all classes of swine. Thacker in 1990 already noted that canola meal is a high quality product and when properly utilized, can be used to benefit swine producers in reducing feed costs. However, the crude protein content of canola meal varies depending on the cultivars from which the meal is produced. For example, meal from cultivars of B.campestris contains approximately 35% crude protein while meal from cultivars of B. napus contains between 38% up to 40% crude protein. Canola meal produced from a mixture of these types can be expected

to contain 37% up to 38% crude protein (Clandinin *et al*., 1981 as cited by Thacker, 1990). The nutritive value of a protein supplement to a pig is determined to a large extent by its amino acid content. Of particular importance are the levels of lysine, threonine and the sulphur containing amino acids. These have been shown to be the most limiting amino acids in swine diets composed predominately of cereal grains (Sauer *et al*., 1977 as cited by Thacker, 1990). Soybean meal contains more lysine than canola meal while the levels of the sulphur containing amino acids (methionine and cystine) and threonine are similar in soybean meal and canola meal (NRC, 1988). Although the amino acid profile of canola meal compares favourably with soybean meal, the availability of the amino acids is lower. The availability of lysine is approximately ten percentage units lower in canola meal compared to levels in soybean meal (Sauer *et al*., 1982 as cited by Thacker, 1990). This lower availability means that higher levels of canola meal must be used to supplement a swine diet than the difference in lysine content between soybean meal and canola meal would indicate (Thacker, 1990).

Canola meal contains less protein, less gross energy and three times as much fibre when compared to soybean meal (Bell, 1993). The fibre, protein and oil content of canola meal will influence the metabolisable energy (ME) content of the meal. These factors are influenced by variety and seed quality as well as by processing methods (Bell, 1993). The hull of the canola seed represents about 16% of the seed weight and about 30% of meal weight (Bell, 1993). The digestibility of the hulls vary widely especially for swine (Bell, 1993).

Although lupins have a relatively high crude protein (35.5%) content (Brand *et al*. 1992), problems could arise with the use of this source due to the presence of anti-nutritional factors. Lupins may have undesirable levels of alkaloids (Erickson, 1988) and α-galactosides (Bourdon *et al*. 1987) and manganese (Batterham, 1979 as cited by Edwards & Van Barneveld, 1998). Lupins are also deficient in lysine, sulphur amino acids and tryptophane (Bourdon *et al*., 1987).

When lupins are fed to monogastrics there is a need to account for the specific physiological effects of other dietary fibre components such as oligosaccharides and soluble non-starch polysaccharides. Little work has been done to quantify the anti-nutritional effects of non-starch polysaccharides (NSP) from lupins in growing pigs. It has been suggested that variable production responses to lupins may be due to the high levels of lupin non-starch polysaccharides interfering with the action of digestive enzymes and influencing microbial activity (Van Barneveld *et al.,* 1994 as cited by Edwards & Van Barneveld, 1998). Monogastric animals do not digest non-starch polysaccharides, as mammalian intestinal mucosa lack α-galactosidase activity. However, bacteria in the lower intestinal tract are able to metabolise these sugars to carbon dioxide, hydrogen and methane, resulting in flatulence. Much of the carbohydrate in lupins is digested by microbial fermentation in the cecum and proximal colon (King, 1990).

Due to high levels of non-starch polysaccharides in lupins, digestible energy (DE) may not be the most appropriate measure of the available energy content of lupins for pigs. This is due to a large proportion of the carbohydrates from lupins being digested in the hindgut (King, 1990). Therefore the net energy of lupins will be lower than anticipated from its gross and digestible energy contents (King, 1990). In a trial by

Van Barneveld *et al.* (1994), the inclusion of lupin kernels at graded levels in pig diets resulted in a significant linear decrease in the ileal digestibility of diet dry matter, energy and dietary DE (Edwards & Van Barneveld, 1998). The reduction in dry matter digestibility will result in a significant decrease in the efficiency of use of lupin energy by the pig due to its recovery as volatile fatty acids from hindgut fermentation, rather than absorption as monosaccharide units in the small intestine.

A wide variation in oligosaccharide concentration both within and between species of lupins may influence its nutritive value and could be responsible for the highly variable performance of pigs when lupins are fed (Edwards & Van Barneveld, 1998).

The extraction of oligosaccharides from L. albus had a greater impact on energy digestibility in the small intestine than in the large intestine. As a consequence, extraction of oligosaccharides will have an even greater impact on lupin net energy contributions. The higher oligosaccharide content of L. albus compared with L. angustifolius and the subsequent effect on net energy may help to explain the comparatively poorer performance of pigs when they are fed L. albus (Edwards & Van Barneveld, 1998). It has been suggested that variable production responses to lupins may be due to the high levels of lupin non-starch polysaccharides interfering with the action of digestive enzymes and influencing microbial activity (Edwards & Van Barneveld, 1998). In the trial by Edwards & Van Barneveld (1998), addition of graded levels of isolated lupin non-starch polysaccharides to sorghum-based diets resulted in a significant increase in digesta viscosity and reduced the ileal digestibility of energy, lysine and dry matter. Total non-starch polysaccharide digestion was minimal and there were no significant differences among diets. Non-starch polysaccharide inclusion levels had no significant effect on the ATP content of the digesta in any part of the digestive tract. From these results it can be concluded that increased digesta viscosity is the cause of reduced ileal digestibility of lysine and energy when high levels of lupins are fed. This may be due to interference with the action of digestive enzymes. Lupin non-starch polysaccharides do not affect microbial activity in the digestive tract (Van Barneveld et al., 1995 as cited by Edwards & Van Barneveld, 1998).

The application of target specific enzymes may increase the availability of NSP, and reduce the negative impact the undigested residues have on digesta viscosity. Typical digestion necessitates unrestricted movement of enzyme, substrate and digestion products throughout the digesta and especially close to the absorptive gut wall. As the viscosity of the digesta increases, the rate of diffusion decreases, and this causes reduced digestibility of all substrates (Leeson & Summers, 1997). Reduction in digesta viscosity is therefore decidedly associated with effectiveness of enzymes that can digest NSP.

This study was conducted to evaluate the performance of weaner piglets fed sweet lupins, full-fat canola and canola oilcake containing diets as well as the effect of external digestive enzymes on production when applied to the test diets.

3.4 Materials and Methods

Ten diets with and without a commercial enzyme application (Roxazyme®) were fed to 48 pens with four piglets each (10 diets x 2 enzyme levels x 2 replicates). The product Roxazyme® is a preparation of

endo-1, 4-beta-glucanase, endo-1, 3(4)-beta-glucanase and endo-1, 4-beta-xylanase, produced by *Trichoderma longibrachiatum*. Piglets were fed for 27 days, from ± 8.5 up to ± 25 kg. Diet formulations are shown in Table 3.1. Four diets were formulated on an iso-nutrient basis to contain 25% sweet lupins (*L. albus*), 25% full fat canola seed, 25% canola oilcake meal or 25% full- fat soybean meal (control diet) as protein source. The three test diets were blended with the control diet to produce four different levels of each protein source as illustrated in Table 3.2.

Table 3.1 Ingredient composition of experimental diets provided to piglets from 8.5 kg to 25 kg

Ingredient Composition (kg/ton, as fed)	Test diets			
	Sweet Lupins	Canola oilcake	Full-fat canola	Full-fat soybeans
Maize meal	486.0	555.0	434.6	489.4
Sweet lupins	250.0	0.0	0.0	0.0
Canola oilcake	0.0	250.0	0.0	0.0
Full-fat canola	0.0	0.0	250.0	0.0
Full-fat soybean	0.0	0.0	0.0	250.0
Wheaten bran	142.7	62.1	180.0	180.0
Fish meal	62.9	64.6	108.5	42.7
Acid oil	25.7	40.0	0.0	0.0
Di-calcium phosphorus	11.8	8.2	0.8	10.2
Feedlime	4.0	4.1	11.0	12.4
Synthetic Lysine	5.9	5.0	4.1	4.3
Salt	10.0	10.0	10.0	10.0
Vitamin & mineral Premix	1.0	1.0	1.0	1.0
Calculated nutrient composition				
Protein, %	19.00	19.00	19.00	19.00
Lysine, %	1.37	1.37	1.37	1.37
Methionine-Cystine, %	0.60	0.80	0.74	0.64
Tryptophan, %	0.20	0.22	0.23	0.26
Digestible Energy, MJ/kg Feed	14.50	14.50	14.60	14.60
Crude fibre, %	6.00	4.86	4.96	4.46
Fat, %	7.90	7.71	12.58	7.32
Calcium, %	0.80	0.80	1.00	1.00
Phosphorus, %	0.47	0.58	0.50	0.41

The experimental diets were then blended to create 10 diets containing 6.6%, 13.2% and 20.0% of the alternative protein sources as shown in Table 3.2.

Table 3.2 Composition of experimental diets fed to piglets

Diet no	Composition	
1	100 Lupin diet	: 0 Control diet (20% Lupin diet)
2	67 Lupin diet	: 33 Control diet (13.2% Lupin diet)
3	33 Lupin diet	: 67 Control diet (6.6% Lupin diet)
4	100 Canola diet	: 0 Control diet (20% Canola oilcake diet)
5	67 Canola diet	: 33 Control diet (13.2% Canola oilcake diet)
6	33 Canola diet	: 67 Control diet (6.6% Canola oilcake diet)
7	100 Full-fat Canola diet	: 0 Control diet (20% Full-fat canola diet)
8	67 Full-fat Canola diet	: 33 Control diet (13.2% Full-fat canola diet)
9	33 Full-fat Canola diet	: 67 Control diet (6.6% Full-fat canola diet)
10	Control diet (Soybean oilcake diet)	

Production parameters (dry matter intake, feed conversion ratio, average daily gain) were monitored every week. The effect of enzyme application and the inclusion rate of each protein source tested were analysed by analysis of variance (4 diets x 2 enzyme levels x 2 replicates). The effect of the inclusion level of the protein source and the application of enzymes were also analysed by regression analysis and the intercepts and slopes of the regression lines were compared by analysis of variance. The effect of the inclusion rate of each of the different protein sources were also compared to each other by regression analysis. All procedures were described in detail by Statgraphics 5.1 (1991).

3.4 Results & Discussion

In this study final body weight, feed intake, feed conversion ratio as well as growth rate of pigs consuming the different protein sources was unaffected by the addition of external enzymes. Further studies should include analysis of the digesta to determine exactly what proportion of the diet is better utilized due to the inclusion of the external enzyme.

Table 3.3 The effect of the application of external enzyme, Roxazyme®, to pig diets on production performance of weanling piglets

Treatment	Body weight (kg)	Feed intake (g/day/pig)	Average daily gain (kg/ day)	Feed conversion ratio (kg feed/kg body weight gain)
Lupins with Enzyme	23.5	931.0	0.460	2.026
Lupins without Enzyme	20.9	897.0	0.425	2.027
Canola oilcake with Enzyme	23.1	923.0	0.477	1.962
Canola oilcake without Enzyme	22.6	859.0	0.458	1.888
Full-fat canola with Enzyme	23.7	1042.0	0.490	2.044
Full-fat canola without Enzyme	24.6	969.0	0.503	1.935
Control with Enzyme	23.9	943.6	0.494	1.915
Control without Enzyme	24.3	952.2	0.518	1.841
SEm	0.4	16.9	10.18	0.02

[a-e] Column means with common superscripts do not differ ($P \leq 0.05$)

In a similar study by Kim *et al*. (2003) where the use of carbohydrases in corn-soybean meal-based nursery diets was tested, the average daily gain of the piglets was not affected ($P>0.05$) by treatment, but the addition of carbohydrase enzymes increased ($P<0.05$) the feed conversion ratio by 9%. Roth-Maier & Kirchgessner (1994) found no influence on production parameters of pigs where Roxazyme® was added to

sweet yellow (*L. luteus*) and sweet white (*L. albus*) lupin containing diets. In the study by Shim *et al*. (2003), where the effects of phytase and carbohydrase supplementation to the diet, with a partial replacement of soybean meal with rapeseed meal and cottonseed meal on growth performance of growing pigs was studied, dietary carbohydrase supplementation significantly improved feed conversion ratio of the growing pigs. Thacker (2001) conducted an experiment to determine the effects of enzyme supplementation on the performance of growing-finishing pigs (26.2 kg) fed diets containing either soybean or canola meal. Barley-based diets were formulated using either soybean meal or canola meal and were fed with and without enzymes (Allzyme Vegpro). Enzyme supplementation had no effect on nutrient digestibility ($P>0.05$). Weight gain, feed intake and feed conversion were unaffected by enzyme addition ($P>0.05$). In addition, he concluded that the results provided little justification for the inclusion of the Vegpro enzyme in diets fed to pigs of this weight range. From the literature cited, it can be concluded that the only noticeable advantage of the application of external enzymes is an improvement in the feed conversion ratio of weaner pigs.

The effect of dietary lupin inclusion on weaner piglet performance is shown in Table 3.4 and was determined by multifactor analysis of variance. A regression analysis of the data follows later in the chapter. The initial body weight was used as a covariant in the statistical analysis. Significant differences ($P\leq 0.05$) in the average daily gain of the pigs due to lupin inclusion in diets were detected (Table 3.4). The final body weights at the 6.6% lupin and 20.0% lupin inclusion level were significantly lower compared to the control diets. A similar pattern can be seen for average daily gain, where the control and 13.2% lupin containing diets had a significantly higher ($P\leq 0.05$) average daily gain than the 20.0% lupin containing diets. The higher average daily gain of the piglets fed the 13.2% lupin diet may be due to the greater initial body weight of this group of piglets, therefore the initial body weight was used as a covariant. There were no significant differences ($P\leq 0.05$) in the feed intake and feed conversion ratio between the different lupin inclusion levels. Therefore the alkaloids present in the sweet lupins did not affect the feed intake. The higher initial weight of the pigs fed the 13.2% lupin diet was the direct cause of the higher feed intake and greater average daily gain of this specific group. The similar feed conversion ratios for the various group shows that the pigs utilized all the diets with similar efficiency, therefore lupin inclusion does not necessarily reduce the efficiency of weaner piglets.

Table 3.4 The effect of increasing levels dietary lupin inclusion on the performance of weaner piglets (8.5kg to 25kg)

Treatment	Initial body weight (kg)	Final body weight (kg)	Feed Intake (g/pig/day)	Average daily gain (g/ day)	Feed conversion ratio (kg feed/ kg body weight gain)
Control	$10.4^{ab} \pm 0.3$	$23.9^{a} \pm 0.6$	947.9 ± 28.2	$505.5^{c} \pm 15.8$	2.0 ± 0.4
6.6% Lupins	$9.8^{ab} \pm 0.5$	$22.4^{b} \pm 1.1$	867.6 ± 48.9	$431.7^{ab} \pm 27.4$	2.0 ± 0.7
13.2% Lupins	$11.3^{b} \pm 0.5$	$23.0^{ab} \pm 1.1$	995.2 ± 48.9	$491.0^{bc} \pm 27.4$	1.9 ± 0.7
20% Lupins	$9.7^{a} \pm 0.5$	$21.7^{b} \pm 1.1$	880.0 ± 48.9	$404.4^{a} \pm 27.4$	2.1 ± 0.7

[a-e] Column means with common superscripts do not differ ($P \leq 0.05$)

The results of the regression analysis conducted on the lupin containing diets are presented in Table 3.5. The slopes (b) of the regression lines on average daily gain (ADG) of the piglets fed the 6.6% lupin diets were significantly greater than the other groups. This is most likely because of the greater initial body weights of these groups. The slopes (b) of the regression lines on feed intake differed siginificantly. The slope of the regression lines on feed intake of the 6.6% lupin diet was significantly smaller compared to the other groups. The greatest slopes were seen in the 13.2% lupin diets. The slopes of the regression lines on feed conversion ratio (FCR) for the 13.2% lupin diets were the greatest i.e. increasing the most. The slope of the regression lines on FCR of the 6.6% lupin diet was negative, but the intercept was the greatest which shows that the FCR of this group of pigs that was very poor initially improved during the trial. The regression analysis of the weaner piglets fed the lupin containing diets are presented graphically in Figure 3.1, 3.2 and 3.3.

Table 3.5 The intercepts (a) and slopes (b) of the regression analysis of average daily gain (ADG), feed intake and feed conversion ratio (FCR) of weaner piglets fed lupin containing diets

	ADG a	**ADG b**	**Feed Intake a**	**Feed Intake b**	**FCR a**	**FCR b**
Control	1.524^{c}	0.170^{b}	16.412^{b}	3.673^{c}	1.613^{a}	0.112^{c}
20.0% Lupins	1.034^{b}	0.211^{c}	13.921^{a}	3.393^{b}	2.123^{b}	-0.012^{b}
13.2% Lupins	1.571^{d}	0.129^{a}	15.809^{b}	4.425^{d}	1.529^{a}	0.200^{d}
6.6% Lupins	0.905^{a}	0.304^{d}	16.405^{b}	2.808^{a}	2.642^{c}	-0.211^{a}
SEm	0.118	0.028	0.553	0.365	0.235	0.082

[a-e] Column means with common superscripts do not differ ($P \leq 0.05$)

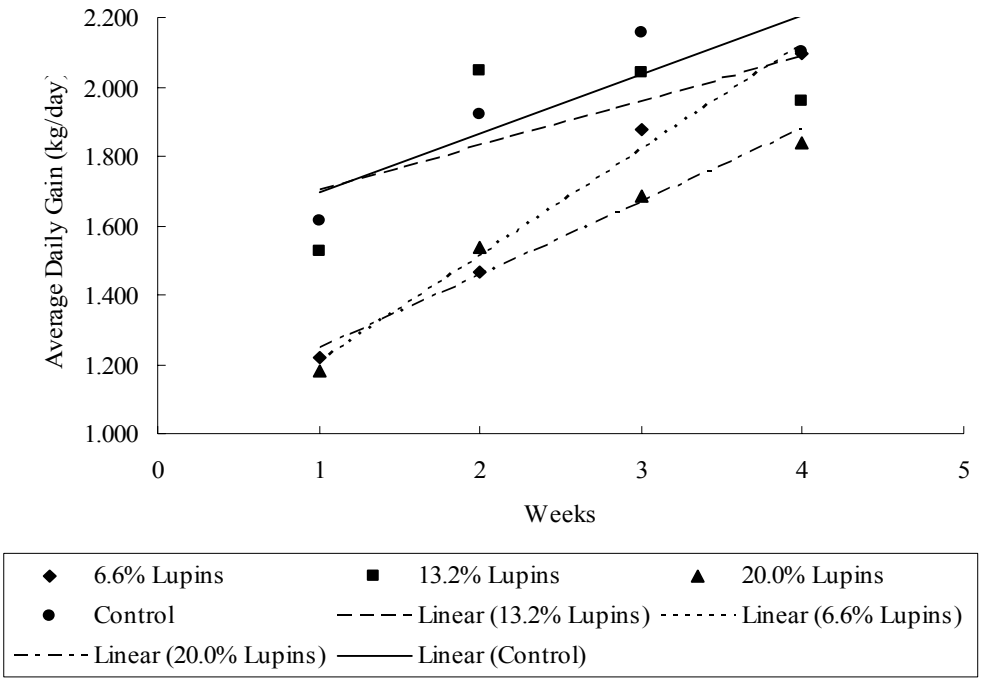

Figure 3.1 The effect of 6.6% lupins, 13.2% lupins and 20.0% lupins on the average daily gain of weaner piglets

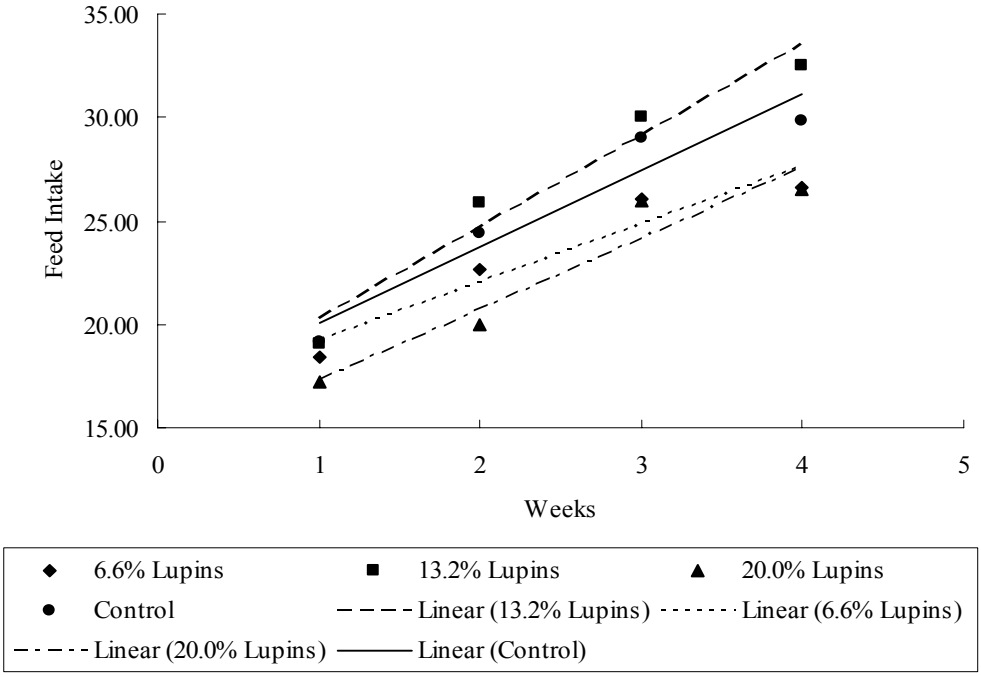

Figure 3.2 The effect of 6.6% lupins, 13.2% lupins and 20.0% lupins on the feed intake of weaner piglets

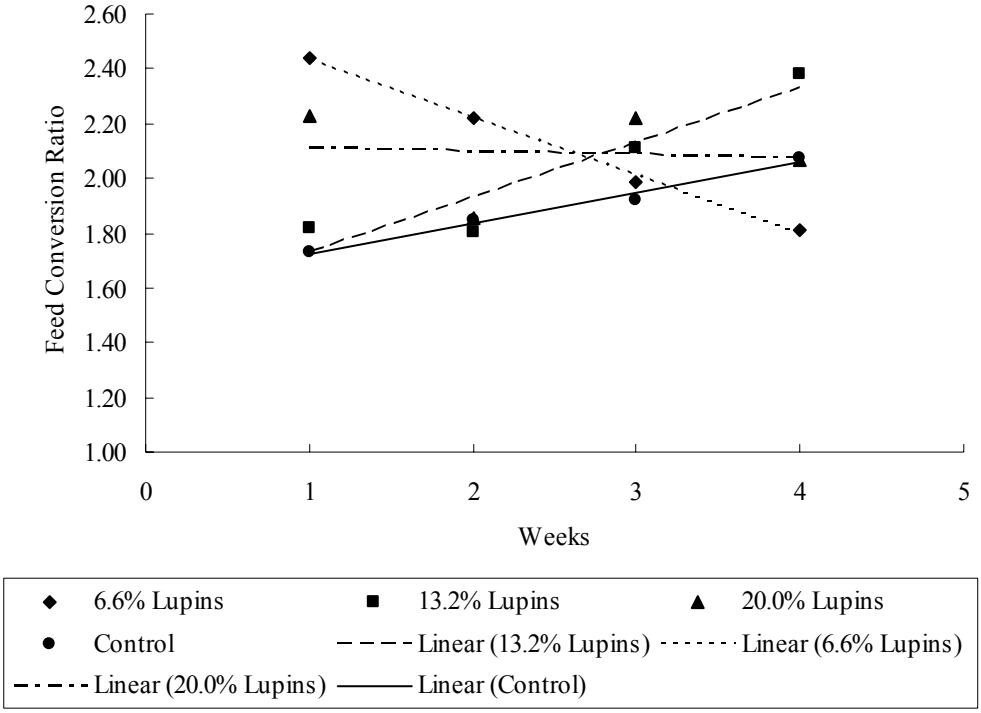

Figure 3.3 The effect of 6.6% lupins, 13.2% lupins and 20.0% lupins on the feed conversion ratio of weaner piglets

Fernandez & Batterham (1995) conducted a study to evaluate the nutritive value of lupin-seed and dehulled lupin-seed meals as protein sources for growing pigs. Their results revealed that the pigs fed lupin seed meal had a significantly higher growth rate (601 g/day) and protein deposition rate (77 g/day) than those fed dehulled lupin seed meal (514 and 71 g/day, respectively) and soybean meal (500 and 73 g/day, respectively). The addition of lupin hulls to the soybean meal diet significantly improved the growth rate and protein retention (559 and 76 g/day, respectively). In a study done by Rioperez et al. (1987), with weaner piglets where lupin seeds replaced 50% and 75% of soybean meal in the diets, growth, daily weight gain and feed efficiency did not differ significantly among groups. Hale & Millar (1985) found that the growth rate and feed conversion ratio were not altered when 25% of the soybean meal diet was replaced by sweet lupin seed meal. Locally Kemm et al. (1987) conducted a study with high and low alkaloid lupins. The high-alkaloid lupins decreased feed intake by as much as 21% and the low-alkaloid lupins had no such effect. The growth rate was retarded by 25% due to the high-alkaloid lupins and 6% due to the low-alkaloid lupins. The results of these studies compare well with the results obtained in the current study.

The results of the piglets fed the canola oilcake diets are summarised in Table 3.6. The initial body weight was used as a covariant in the statistical analysis. The final body weight of the pigs fed the diet containing 20% canola oilcake differed significantly ($P \leq 0.05$) from the body weight of the pigs fed the control diet. There were no significant differences in feed intake between the various inclusion levels of canola oilcake. There were significant differences in average daily gain between the control diet and the 20%

canola oilcake diet. There were also significant differences in feed conversion ratio between the control diet and the 20% canola oilcake diet. The final body weight and average daily gain of the piglets decreased as the canola oilcake inclusion increased. The NSP's and the other anti-nutritional factors present in canola may be the cause of the reduced performance of the piglets.

Table 3.6 The effect of increasing levels of dietary canola oil cake on pig performance

Treatment	Initial body weight (kg)	Final body weight (kg)	Feed Intake (g/pig/day)	Average daily gain (g/ day)	Feed conversion ratio (kg feed/ kg body weight gain)
Control	$10.4^{a} \pm 0.3$	$23.9^{a} \pm 0.6$	947.9 ± 28.2	$505.5^{a} \pm 15.8$	$1.9^{a} \pm 0.4$
6.6% Canola Oilcake	$10.9^{a} \pm 0.5$	$24.0^{ab} \pm 1.1$	947.6 ± 48.9	$521.1^{a} \pm 27.4$	$1.9^{a} \pm 0.7$
13.2% Canola Oilcake	$9.9^{a} \pm 0.5$	$22.9^{ab} \pm 1.1$	841.4 ± 48.9	$455.6^{ab} \pm 27.4$	$1.9^{a} \pm 0.7$
20% Canola Oilcake	$9.8^{a} \pm 0.5$	$22.1^{b} \pm 1.1$	884.6 ± 48.9	$425.0^{b} \pm 27.4$	$1.9^{b} \pm 0.7$

[a-e] Column means with common superscripts do not differ ($P \leq 0.05$)

The results of the regression analysis conducted on the canola oilcake containing diets are presented in Table 3.7. The slopes (b) of the regression lines on ADG of the weaners fed the 6.6% canola oilcake containing diets were significantly greater compared to the other treatment groups in the study. The 13.2% canola oilcake diet had the smallest slope and the greatest intercept which shows that this group had the least amount of gowth during the trial. The slope (b) of the regression line on feed intake of the 13.2% canola oilcake group was siginificantly smaller compared to the other groups. The slopes (b) of the regression lines on feed intake of the control groups and the weaners receiving the 6.6% canola oilcake diets were siginificantly greater. The slopes of the regression lines on FCR for the canola oilcake containing diets increased as the canola oilcake content increased with the control group with the greatest slope.

Table 3.7 The intercepts (a) and slopes (b) of the regression analysis of average daily gain (ADG), feed intake and feed conversion ratio (FCR) of weaner piglets

	ADG a	**ADG b**	**Feed Intake a**	**Feed Intake b**	**FCR a**	**FCR b**
Control	1.524^{b}	0.170^{c}	16.421^{a}	3.673^{c}	1.613^{a}	0.112^{d}
20.0% Canola oilcake	1.357^{a}	0.113^{b}	19.615^{c}	2.520^{b}	2.132^{c}	0.070^{c}
13.2% Canola oilcake	1.516^{b}	0.096^{a}	17.959^{b}	1.904^{a}	1.808^{b}	0.041^{b}
6.6% Canola oilcake	1.329^{a}	0.273^{d}	17.823^{b}	3.577^{c}	1.897^{b}	0.013^{a}
SEm	0.061	0.030	0.504	0.294	0.091	0.024

[a-e] Column means with common superscripts do not differ ($P \leq 0.05$)

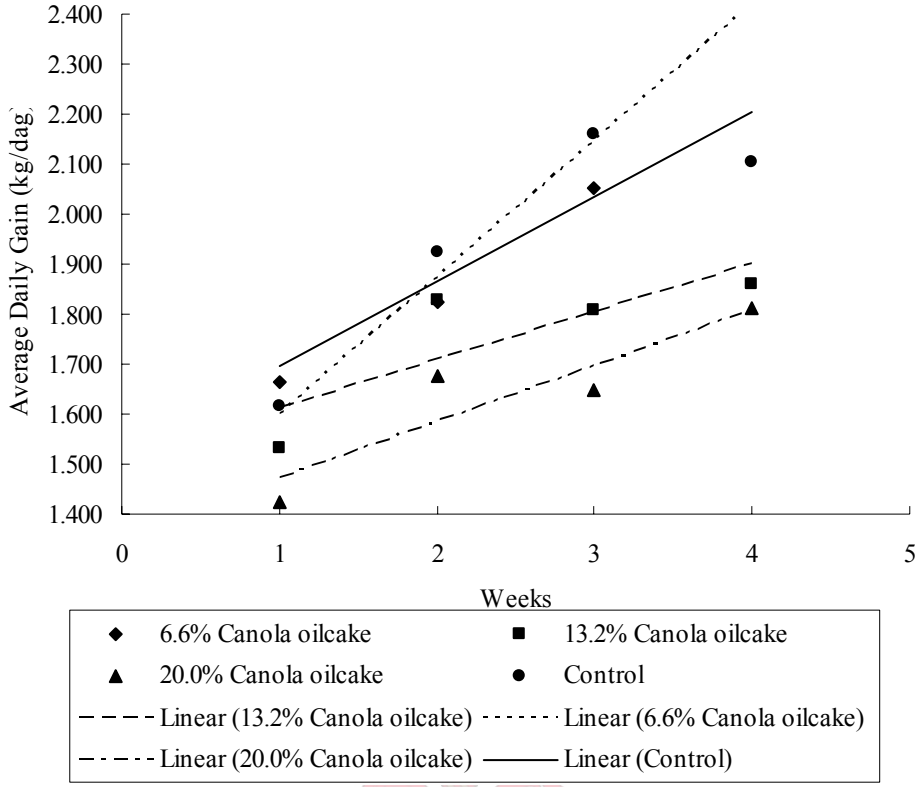

Figure 3.4 The effect of 6.6% canola oilcake, 13.2% canola oilcake and 20.0% canola oilcake on the average daily gain of weaner piglets

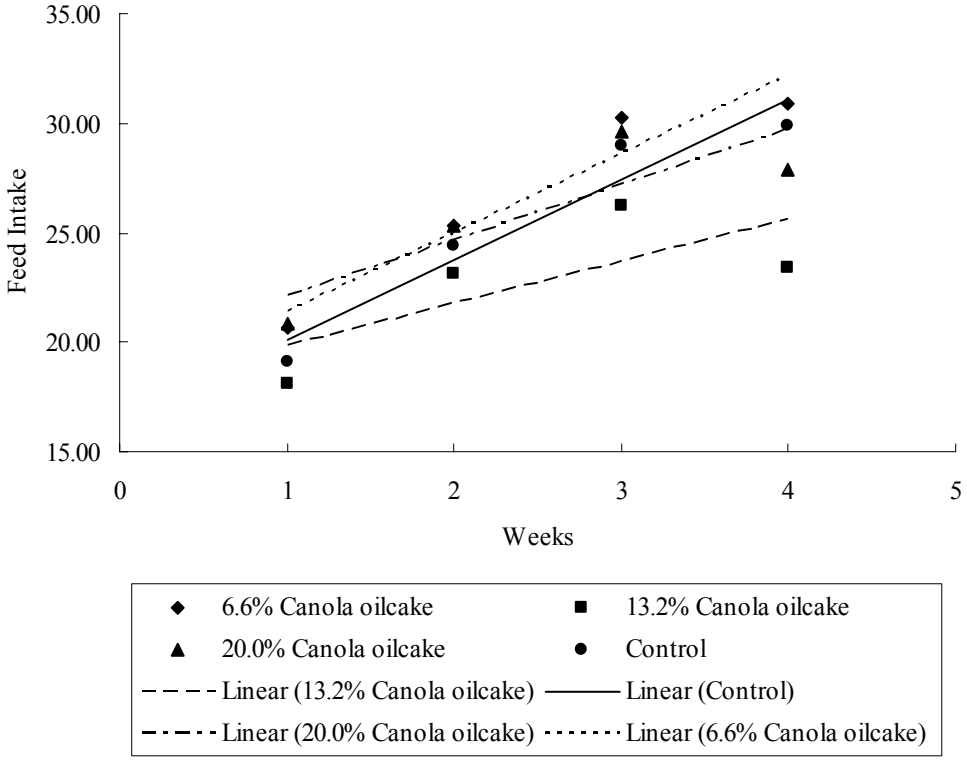

Figure 3.5 The effect of 6.6% canola oilcake, 13.2% canola oilcake and 20.0% canola oilcake on the feed intake of weaner piglets

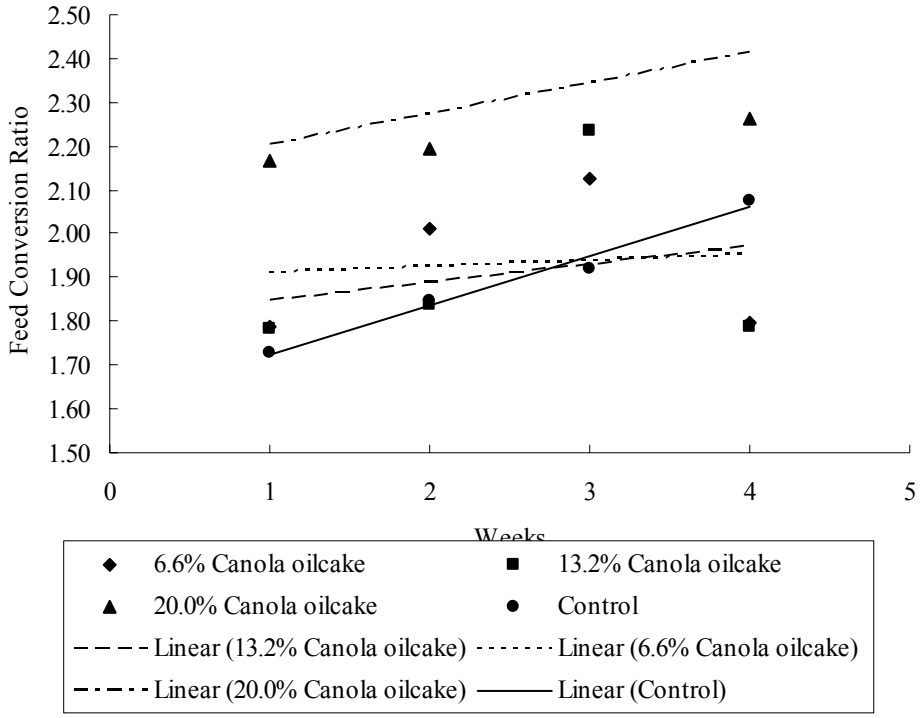

Figure 3.6 The effect of 6.6% canola oilcake, 13.2% canola oilcake and 20.0% canola oilcake on the feed intake of weaner piglets

In a study by Spiegel & Blum (1993), it was found that the feed intake and average daily gain were reduced in pigs fed canola oilcake meal (rapeseed press cake meal). Results indicated that the reduced growth performance of canola oilcake meal fed pigs was primarily the consequence of decreased feed intake. In this study the partial replacement of full-fat soybeans with canola oilcake meal did not reduce the performance of the weaner piglets but the complete replacement of full-fat soybeans with canola oilcake meal significantly ($P \geq 0.05$) reduced the performance of the piglets. Studies have shown that in younger animals the complete replacement of canola oilcake meal for soybean meal reduces performance, although, full substitution is possible in finisher pigs. It is difficult to identify a single component or fraction of canola oilcake meal responsible for these observations; therefore it is considered the result of many minor factors. It appears that the main advantage of soybean meal over canola oilcake meal, even with lysine supplementation, is that soybean meal-fed pigs are able to maintain higher feed intakes, especially in younger animals.

A summary of the performance data of the piglets fed the full-fat canola diets is presented in Table 3.8. There were no significant differences in body weight, feed intake, average daily gain and the feed conversion ratio, between the various full fat canola containing diets and the control diet (Table 3.6). The initial body weight was used as a covariant in the statistical analysis. The complete replacement of soybean oilcake meal with full-fat canola therefore seems very possible without any reduction in animal performance.

Table 3.8 The effect of full fat canola on the performance of pigs

Treatment	Initial body weight (kg)	Final body weight (kg)	Feed Intake (g/pig/day)	Average daily gain (g/ day)	Feed conversion ratio (kg feed/ kg body weight gain)
Control	$10.4^{ab} \pm 0.3$	24.4 ± 0.6	947.9 ± 28.2	505.5 ± 15.8	1.9 ± 0.4
6.6% Full Fat Canola	$10.4^{ab} \pm 0.5$	23.6 ± 1.1	1025.0 ± 48.9	480.1 ± 27.4	2.0 ± 0.7
13.2% Full Fat Canola	$10.5^{ab} \pm 0.5$	24.7 ± 1.1	1018.7 ± 48.9	523.6 ± 27.4	1.8 ± 0.7
20% Full Fat Canola	$11.2^{a} \pm 0.3$	23.1 ± 1.1	971.7 ± 48.9	486.6 ± 27.4	2.1 ± 0.7

[a-e] Column means with common superscripts do not differ ($P \leq 0.05$)

The results of the regression analysis conducted on the full-fat canola containing diets are presented in Table 3.9. The slopes (b) of the regression lines on ADG of the weaners fed the 6.6% full-fat canola containing diets were significantly greater compared to the other treatment groups in the study. The slope (b) of the regression lines on feed intake of the control group was siginificantly greater compared to the other groups. The slopes of the regression lines on FCR for the control group was siginificantly greater compared to the other groups. The 6.6% full-fat canola group having the smallest slope therefore the smallest increase in FCR.

Table 3.9 The intercepts (a) and slopes (b) of the regression analysis of average daily gain (ADG), feed intake and feed conversion ratio (FCR) of weaner piglets

	ADG a	**ADG b**	**Feed Intake a**	**Feed Intake b**	**FCR a**	**FCR b**
Control	1.524^{c}	0.170^{a}	16.412^{a}	3.673^{d}	1.613^{a}	0.112^{d}
20.0% Full-fat canola	1.416^{b}	0.184^{b}	18.111^{b}	3.251^{b}	1.854^{c}	0.060^{b}
13.2% Full-fat canola	1.604^{c}	0.166^{a}	18.870^{b}	3.454^{c}	1.706^{b}	0.096^{c}
6.6% Full-fat canola	1.316^{a}	0.211^{c}	18.584^{b}	3.058^{a}	2.093^{d}	0.001^{a}
SEm	0.058	0.014	0.566	0.189	0.071	0.022

[a-e] Column means with common superscripts do not differ ($P \leq 0.05$)

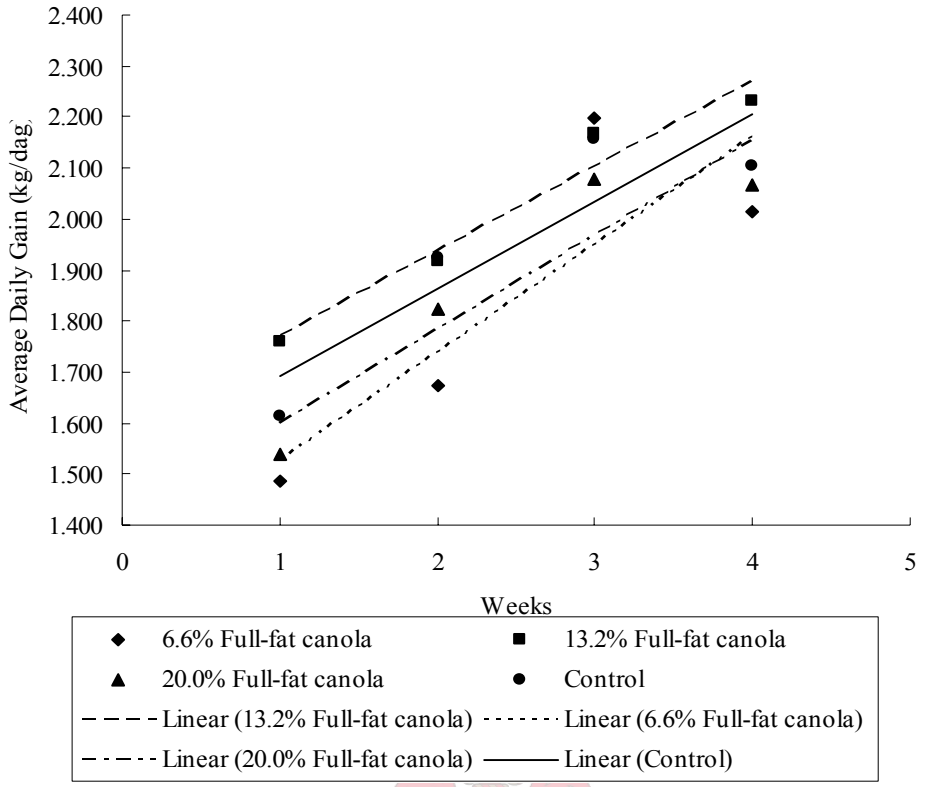

Figure 3.7 The effect of 6.6% full-fat canola, 13.2% full-fat canola and 20.0% full-fat canola on the average daily gain of weaner piglets

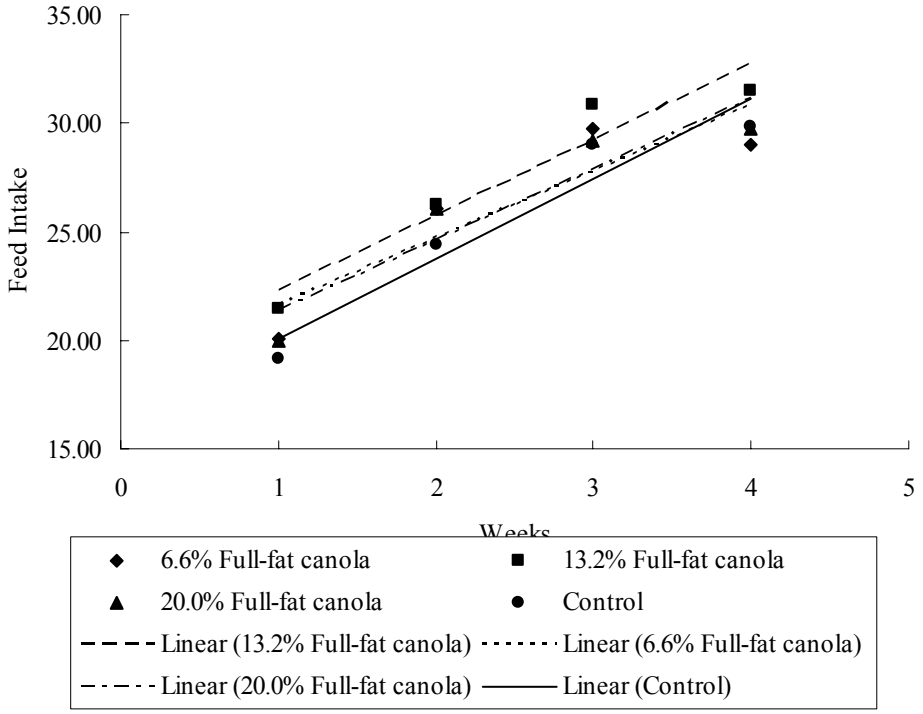

Figure 3.8 The effect of 6.6% full-fat canola, 13.2% full-fat canola and 20.0% full-fat canola on the feed intake of weaner piglets

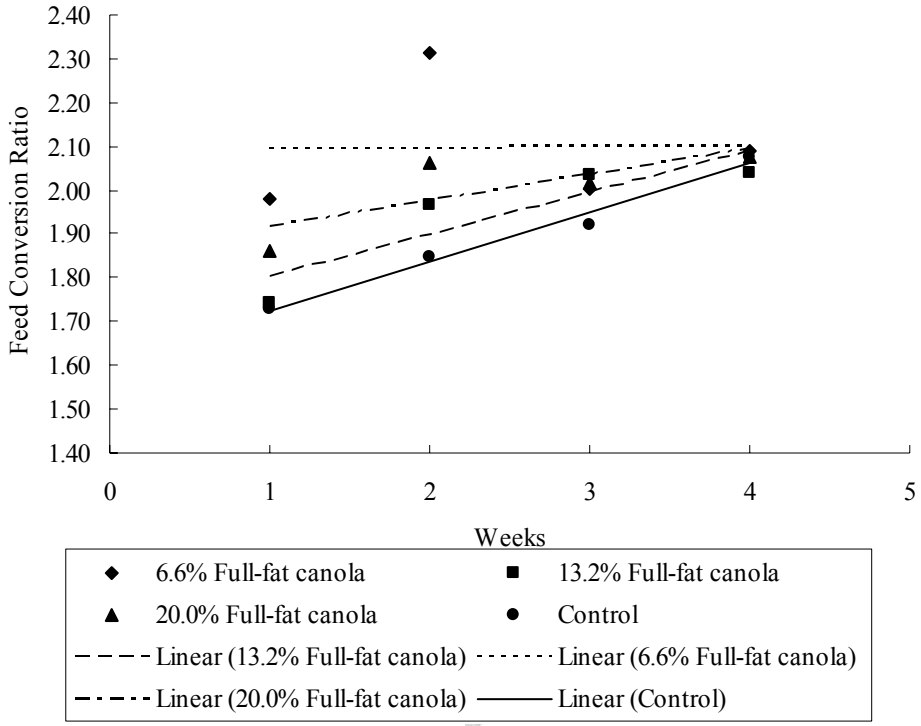

Figure 3.9 The effect of 6.6% full-fat canola, 13.2% full-fat canola and 20.0% full-fat canola on the feed conversion ratio of weaner piglets

In a study by Brand *et al*. (1999) full-fat canola was substituted into diets fed to weaner and grower-finisher pigs, replacing full-fat soybean and soybean oilcake meal. Full-fat canola inclusion did not have a significant effect on feed intake, growth rate or feed conversion in the weaner-pigs. These results to some extent agreed with results obtained by Shaw *et al*. (1990) with full-fat canola, where reductions in feed intake and growth rate of 4-week old piglets were only found at a 30% inclusion level. No significant influence on growth rate and feed intake was detected at the inclusion levels of 15%, while the feed: gain ratios were not affected at either 15 or 30% inclusion levels. Shaw *et al*. (1990) attributed the reduction in growth rate and intake of piglets at the higher inclusion level to the presence of the hydrolytic products of glucosinolates, the palatability of canola and the high fibre content of canola diets. Castell & Falk (1980) found no reduction in performance of grower- finisher pigs when raising the level of full-fat canola up to 15% of their diets.

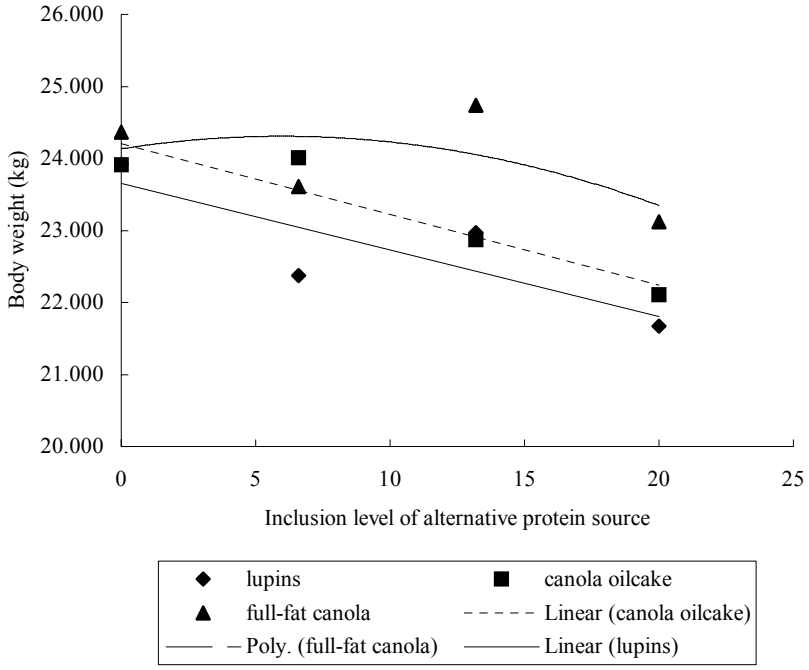

Figure 3.10 The effect of lupins (y = -0.093x + 23.652; R^2 = 0.697; Sxy = 0.6), full-fat canola (y = -0.005x^2 + 0.058x + 24.134; R^2 = 0.333; Sxy = 0.8) and canola oilcake (y = -0.098x + 24.201; R^2 = 0.875; Sxy = 0.4) dietary inclusions on body weight of weaner piglets

Regression analysis of the data revealed that a linear model was the best fit for the piglets body weight from weaning up to ± 25kg of live weight due to the replacement of soybean oilcake with lupins (y = -0.093x + 23.652; R^2 = 0.697; Sxy = 0.6). For each percentage increase in lupins inclusion, the live weight decreased by 9.3 g. Regression analysis of the data revealed a linear decrease in final body weight due to the replacement of soybean oilcake with canola oilcake (y = -0.098x + 24.201; R^2 = 0.971; Sxy = 0.4). For each percentage increase in canola oilcake inclusion, the final live weight decreased by 9.8 g. The replacement of soybean oilcake with full-fat canola decreased body weight and regression analysis revealed that a curvilinear model fit the reduction best even though the R^2 = 0.333 is relatively weak.

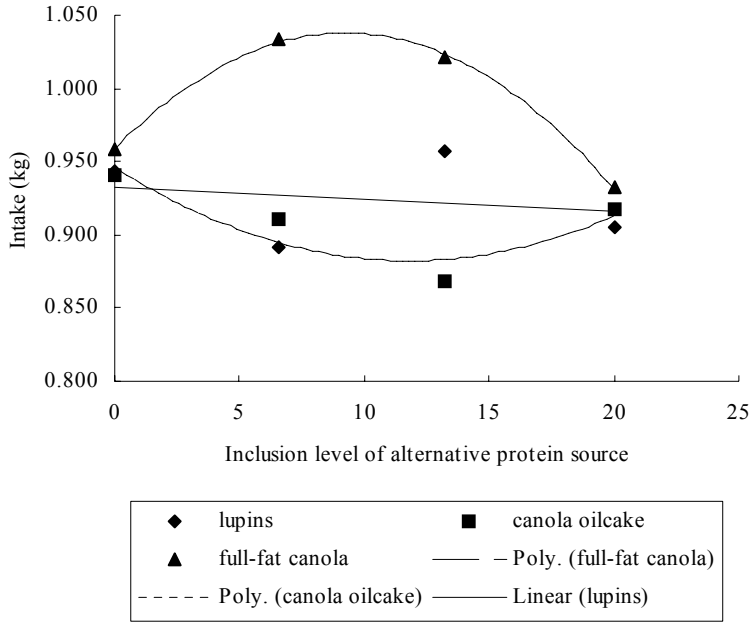

Figure 3.11 The effect of lupin ($y = -0.001x + 0.932$; $R^2 = 0.046$; Sxy = 0.04); full-fat canola ($y = -0.001x^2 + 0.017x + 0.959$; $R^2 = 0.998$; Sxy = 0.06) and canola oilcake ($y = 0.001x^2 – 0.011x + 0.946$; $R^2 = 0.815$; Sxy = 0.03) dietary inclusions on feed intake of weaner pigs

Regression analysis of the data revealed a linear model, with a very weak R^2, best fit the decrease in feed intake due to the replacement of soybean oilcake with lupins ($y = -0.001x + 0.932$; $R^2 = 0.046$; Sxy = 0.037). For each percentage increase in lupin inclusion, the feed intake decreased by 0.1 g. At the lower inclusion level (6.6%) the intake of the full-fat canola containing diets increased and a curvilinear model best fit the increase. The intake of the full-fat canola containing diets decreased curve linearly at inclusion levels higher than 10%. The intake of the canola oilcake diets are best explained by a curvilinear model with $R^2 = 0.815$. At the lower inclusion levels there was a reduction in feed intake but an increase at the higher inclusion levels.

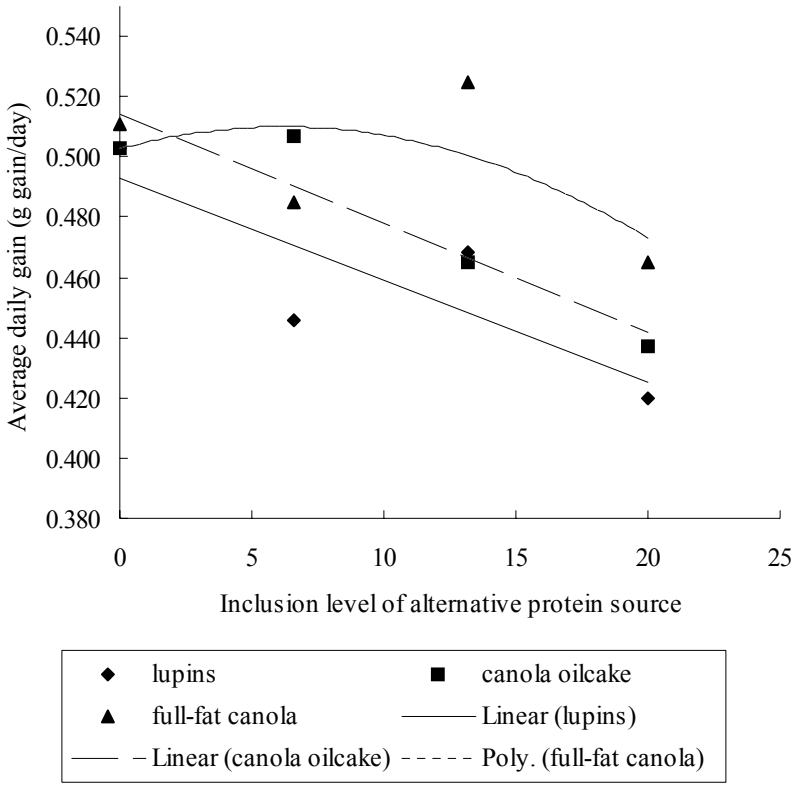

Figure 3.12 The effect of lupin (y = -0.003x + 0.493; R^2 = 0.697; Sxy = 0.024), full-fat canola (y = -0.001x^2 + 0.002x + 0.503; R^2 = 0.366; Sxy = 0.029) and canola oilcake (y = -0.004x + 0.514; R^2 = 0.871; Sxy = 0.015) dietary inclusions on average daily gain of pigs

Regression analysis of the data revealed that a linear model best fits the decrease in average daily gain due to the replacement of soybean oilcake with lupins (y = -0.003x + 0.493; R^2 = 0.697; Sxy = 0.024). For each percentage increase in lupin inclusion, the average daily gain decreased by 0.3 g. Regression analysis of the canola oilcake data revealed that a linear model best fit the decrease in average daily gain due to the replacement of soybean oilcake with canola oilcake (y = -0.004x + 0.514; R^2 = 0.871; Sxy = 0.015). For each percentage increase in canola oilcake inclusion, the average daily gain decreased by 0.4 g. A curvilinear model best explains the average daily gain reduction of piglets fed full-fat canola diets, even though the R^2 value is weak.

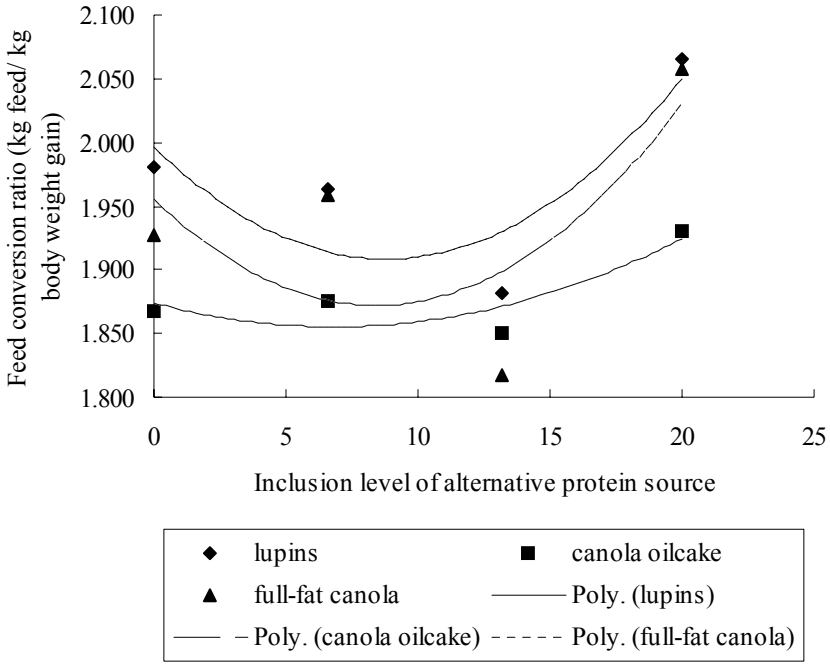

Figure 3.13 The effect of lupin ($y = 0.001x^2 + 0.02x + 1.996$; $R^2 = 0.693$; Sxy = 0.088), full-fat canola ($y = 0.001x^2 + 0.02x + 1.956$; $R^2 = 0.485$; Sxy = 0.114) and canola oilcake ($y = 0.0004x^2 + 0.006x + 1.874$; $R^2 = 0.741$; Sxy = 0.033) dietary inclusions on feed conversion rate of pigs

Regression analysis of the data revealed that a curvilinear model best fit the changes in the feed conversion ratios of piglets fed diets containing lupins, full-fat canola and canola oilcake. At the lower inclusion levels the feed conversion ratios are improved but where the protein sources are included at above 10% the feed conversion ratios increase drastically.

3.5 Conclusion

The enzyme tested in this study only improved the feed conversion ratio of weaner pigs. It is also evident that in this study replacing full-fat soybeans with sweet lupins caused significant reductions in pig performance. Replacing full-fat soybeans completely with canola oilcake reduces the growth performance of pigs possibly due to a significantly higher feed conversion ratio. However, the partial replacement did not cause significant reductions in pig performance. The replacement of full-fat soybeans with full-fat canola did not influence the growth of the piglets. The use of the alternative protein source investigated in this study will mainly depend on the availability and price of these raw materials. Therefore it can be concluded that partial replacement of full-fat soybeans with canola oilcake meal can be made without a significant reduction in performance of the piglets. In this study the final body weight and average daily gain was reduced by the complete replacement of full-fat soybeans with sweet lupins. The feed intake and feed conversion ratio was not significantly influenced. The enhanced performance of the group of piglets fed the 13.2% lupin diet could be attributed to the higher initial body weights of this group.

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Pectora roborant cultus recti

Chapter 4

The acceptability of full-fat canola, canola oilcake and sweet lupins as alternative protein sources for pigs

4.1 Abstract

In a choice feeding trial growing pigs were fed four diets with four different protein sources: sweet lupins (*Lupinus angustifolius*) (25%), canola oilcake (25%), full-fat canola (25%) and soybean oilcake (25%), while their daily intakes were recorded. In a second choice feeding trial pigs were fed ten different diets. Three test diets containing sweet lupins (25%), canola oilcake (25%), full-fat canola (25%), were blended with the control diet containing soybean oilcake (25%) to produce four different inclusion levels (100%, 67%, 33% and 0%) of each protein source. In the first trial the pigs consumed significantly more of the soybean oilcake containing diet than diets containing the alternative protein sources. Pigs consumed significantly less of the full-fat canola diet compared to the sweet lupin and canola oilcake diets. In the second trial the soybean oilcake and 33% sweet lupin diets were consumed in the largest quantities. The pigs consumed very little of the 33% canola oilcake, 33% full-fat canola and 100% full-fat canola diets. The fact that the pigs in this trial consumed significantly more of the 33% lupin diets shows that sweet lupins certified to be low in alkaloids could be fed to pigs in limited quantities without reducing the feed intake.

Keywords: Pigs, choice feeding, sweet lupins, canola oilcake, full-fat canola, soybean oilcake

4.2 Introduction

Soybean meal is the most extensively used protein supplement in swine diets, and it is used as a standard to which other protein sources are measured (Cromwell, 1998 as cited by Shelton *et al*., 2001). Locally produced alternative protein sources such as full-fat canola, canola oilcake and sweet lupins can be used to replace soybean meal, although it may have detrimental effects on production in certain circumstances.

Although canola meal is an accepted feed ingredient in diets for poultry, there are a number of reports indicating reduced performance with diets containing significant amounts of this protein supplement (Hulan & Proudfoot, 1980; Summers & Leeson, S., 1985; Leeson *et al.*, 1987). It appears that the main advantage of soybean meal compared to canola meal is that soybean meal fed pigs are able to maintain higher feed intakes, especially in younger animals. McKintosh *et al*. (1986) reported that for each percent addition of canola meal to the diet of young pigs, average daily feed intake and average daily gain are reduced by 4g and 2g per day, respectively. The effect of the breakdown products of glucosinolates on thyroid function (McKinnon & Bowland, 1979; Occhetim *et al.,* 1980) and the reduced palatability of canola meal may be possible reasons for the reduction in feed intake in diets containing canola meal. The reduced

palatability may be due to the presence of tannins, phytic acid, sinapine, glucosinolates and fibre (Chubb, 1982).

Lupins have been recognised as a potentially valuable ingredient for livestock diet for many years. Alkaloids are often cited as the reason for reduced acceptance of *L. albus* by pigs (Hill & Pastuszewska, 1993 as cited by Edwards & Van Barneveld, 1998). According to Edwards & Van Barneveld (1998), as the quantity of alkaloid in a pig diet is raised above 0.03% there is a reduction in intake, which in turn lowers live weight gain. Sweet narrow leafed lupins (*Lupinus angustifolius)* cultivars contain less than 0.081 g/kg alkaloids (Brand *et al*., 2000), which, will advantageous to the use thereof in pig diets.

In this study the acceptability of swine diets, where soybean meal was partially and completely replaced by full-fat canola, canola oilcake and sweet lupins, was evaluated.

4.3 Materials and Methods

In the first trial pigs were given a choice between four diets and each group of five pigs had access to four feeders which respectively contained containing a ration with the four different protein source. The average weight of the pigs was 23kg and they were housed five pigs per pen. Five replicate pens were used. The four diets were formulated on an iso-nutrient basis to contain 25% sweet lupins (*L. angustifolius*), 25% full fat canola seed, 25% canola oilcake meal or 25% soybean oilcake as protein source. The ingredient compositions of the diets are shown in Table 4.1. The trial was run over four days. In a second trial the four diets were blended to produce four different levels of each protein source as illustrated in Table 4.2. The second trial was run over three days. The data collected was compared by analysis of variance using Statgraphics 5.1 (1991).

Pectora roborant cultus recti

Table 4.1 Ingredient composition of experimental diets provided in a choice feeding situation to piglets at ± 23kg live weight

Ingredient Composition (kg/ton, as fed)	Test diets			
	Sweet lupins	Canola oilcake	Full-fat canola	Soybean oilcake
Maize meal	486.0	555.0	434.6	489.4
Sweet lupines	250.0	0.0	0.0	0.0
Canola oilcake	0.0	250.0	0.0	0.0
Full-fat canola	0.0	0.0	250.0	0.0
Full-fat soybeans	0.0	0.0	0.0	250.0
Wheaten bran	142.7	62.1	180.0	180.0
Fish meal	62.9	64.6	108.5	42.7
Acid oil	25.7	40.0	0.0	0.0
Di-calcium phosphorus	11.8	8.2	0.8	10.2
Feedlime	4.0	4.1	11.0	12.4
Synthetic Lysine	5.9	5.0	4.1	4.3
Salt	10.0	10.0	10.0	10.0
Vitamin Premix	1.0	1.0	1.0	1.0
Calculated nutrient composition				
Protein, %	20.50	20.50	20.50	20.50
Lysine, %	1.12	1.12	1.12	1.12
Methionine-Cystine, %	0.54	0.53	0.53	0.58
Tryptophan, %	0.81	0.82	0.81	0.81
Digestible Energy, MJ/kg Feed	0.74	0.74	0.74	0.74
Crude fibre, %	0.21	0.23	0.19	0.19
Fat, %	1.06	1.14	0.93	1.25
Calcium, %	0.95	0.95	0.95	0.95
Phosphorus, %	0.45	0.45	0.45	0.45

Table 4.2 Composition of the 10 experimental diets blended from the four test diets and provided to pigs in a choice feeding trial

Diet no	Composition
1	100 Lupin diet : 0 Basal diet
2	67 Lupin diet : 33 Basal diet
3	33 Lupin diet : 67 Basal diet
4	100 Canola diet : 0 Basal diet
5	67 Canola diet : 33 Basal diet
6	33 Canola diet : 67 Basal diet
7	100 Full-fat Canola diet : 0 Basal diet
8	67 Full-fat Canola diet : 33 Basal diet
9	33 Full-fat Canola diet : 67 Basal diet
10	Basal diet (Soybean oilcake diet)

4.3 Results & Discussion

In the first trial the pigs consumed significantly ($P \leq 0.05$) more of the soybean oilcake diet than any of the other diets. They also consumed significantly ($P \leq 0.05$) more of the sweet lupin diet than the canola (full-fat or oilcake) diets (Table 4.3).

Table 4.3 Average daily intakes of pigs when given a choice between a full-fat canola, canola oilcake, sweet lupin and soybean oilcake containing diets.

Diet	Intake (g/pig/day)	Percentage of daily consumption
20% Full-fat canola diet	90.8[a]	3.1 %
20% Canola oilcake diet	457.8[ab]	15.4 %
20% Lupin diet	890.8[b]	30.1 %
20% Soybean oilcake diet	1522.9[c]	51.4 %
SEm	177.0	

[a-e] Column means with common superscripts do not differ (P≤ 0.05)

Of the total amount of feed consumed 51.4% was the soybean oilcake containing diet and 30.1% the lupin containing diet. Only 3% of the total consumption was the full-fat canola diet (Table 4.3).

A reduction in feed intake as the level of canola meal increases in a diet is a consistent feature of similar studies considering canola meal as an alternative protein source (Aherne & Kennelly, 1982). Gill *et al.* (1995) found that the free choice intake was the lowest for rapeseed meal and the highest for a 50:50 rapeseed meal / soybean meal mix diet. It was concluded that the use of rapeseed meal did not give a satisfactory level of performance under the restricted free-choice feeding environment of that study. In a similar study, evaluating canola meal, by Baidoo *et al.* (1986), it was found that starter pigs were able to detect as little as 5% canola meal in their diets and consumed 2.5 up to 7.0 times more of a soybean meal containing diet compared to a canola meal containing diet when provided in a free choice situation. On the contrary, in a study done by Moreira *et al.* (1996) where the use of canola meal in the feeding of growing pigs was evaluated, feed intake and feed conversion values did not differ significantly between the canola and the soybean meal treatments.

In the second trial the pigs consumed significantly (P ≤ 0.05) more of the 33% sweet lupin diet. They also consumed significantly (P ≤ 0.05) more of the soybean oilcake diet and 100% sweet lupin diets, than the canola (full-fat or oilcake) diets (Table 4.4).

Table 4.4 Average intakes of pigs when given a choice between a full-fat canola, canola oilcake, sweet lupin and soybean oilcake blended diets.

Diet	Intake (g/pig/day)	Percentage of daily consumption
6.6% Canola oilcake diet	100.6[a] ± 148.5	3.1
6.6% Full-fat canola diet	102.4[a] ± 148.5	3.1
20% Full-fat canola diet	131.5[a] ± 148.5	4.0
13.2% Canola oilcake diet	180.2[ab] ± 148.5	5.5
13.2% Full-fat canola diet	187.1[ab] ± 148.5	5.8
13.2% Lupin diet	244.9[ab] ± 148.5	7.5
20% Canola oilcake diet	263.5[ab] ± 148.5	8.1
20% Lupin diet	487.2[ab] ± 148.5	14.9
20% Soybean oilcake diet	488.5[b] ± 86.7	15.0
6.6% Lupin diet	1070.8[c] ± 148.5	32.9

[a-e] Column means with common superscripts do not differ (P≤ 0.05)

The pigs consumed 32.9% of the 33% lupin diet. The 100% lupin and soybean meal diet was consumed at about 15% each of the total feed consumed in the three day period.

In this study the feed intake of lupin containing diets were very similar to the feed intake of soybean meal diets. In a study conducted by Barnett & Batterham (1980), as cited by Brand *et al*. (1995), where sweet lupins were evaluated as a protein and energy source for weaner pigs, feed intakes were very similar for pigs fed rations containing either soybean meal or sweet lupins as protein source. In a study done by Kwak *et al.* (2000), the effect of different lupin kernel levels (0, 10%, 20% and 30%) on average daily feed intake was investigated and there were no significant differences in average daily feed intake up to the 20% lupin kernel inclusion level. However, the 30% inclusion decreased average daily feed intake compared with the control. In a study done by Donovan *et al.* (1993), as cited by Brand *et al*. (1995), where the replacement of soybean meal with dehydrated lupin seeds in pig diets was investigated, starter pigs (10-20 kg) given the 25% lupin diet had similar growth rates and consumed more feed ($P<0.05$), relative to those given 0% lupin diet, but there was a linear decrease in feed intake and weight gain at higher concentrations of lupins in the diet ($P<0.05$). In a study done by Brand *et al.* (1995), growing pigs which were fed lupin containing diets consumed approximately 6% less food compared to pigs fed faba bean and fishmeal diets. In a similar study with growing pigs, the feed intake was significantly reduced when soybean meal was replaced with yellow lupins (*Lupinus luteus*) (Bugnacka, 2001). Results found in this study may however be ascribed to the use of a narrow leafed sweet lupin cultivar which is known to contain a very low level of alkaloids (Brand *et al*., 2000) while it is known that so called sweet lupins from the *Lupinus albus* types may contain variable (0.141 g/kg up to 5.038 g/kg) levels of alkaloids (Brand *et al*., 2000) which probably led to the variable results obtained with the use of lupins in pig diets

The affect of the various inclusion rates of the alternative protein sources on the feed intake of pigs in the free choice situation is shown in Figure 4.1.

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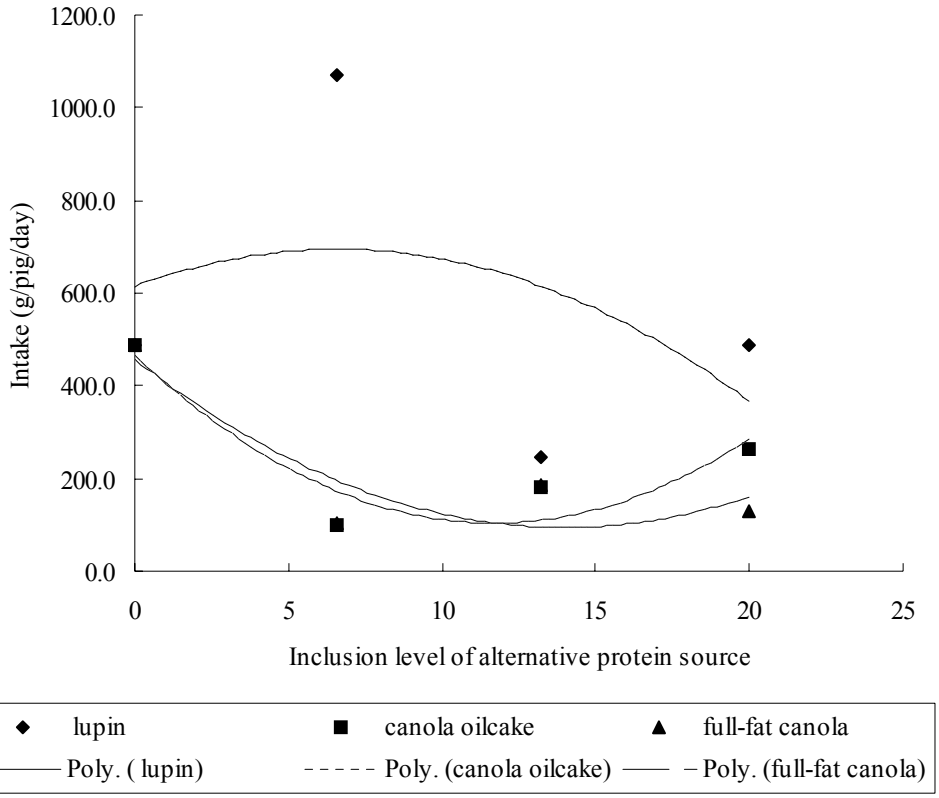

Figure 4.1 The feed intake of pigs given a free choice between various levels of lupins ($y = -1.832x^2 + 24.26x + 614.42$; $R^2 = 0.165$; Sxy = 409.7), canola oilcake ($y = 2.642x^2 - 61.746x + 464.56$; $R^2 = 0.867$; Sxy = 182.4) and full-fat canola ($y = 1.856x^2 - 51.918x + 457.31$; $R^2 = 0.8$; Sxy = 152.1)

Regression analysis of the data revealed a curvilinear model, with a weak R^2, best fit the intake pattern of the lupin containing diets ($y = -1.832x^2 + 24.26x + 614.42$; $R^2 = 0.165$; Sxy = 409.7). The intake pattern of the full-fat canola containing diets is best described by a curve linear model with a R^2 of 0.8 ($y = 1.856x^2 - 51.918x + 457.31$; $R^2 = 0.8$; Sxy = 152.1). The intake of the canola oilcake diets are well described by a curvilinear model with $R^2 = 0.867$ ($y = 2.642x^2 - 61.746x + 464.56$; $R^2 = 0.867$; Sxy = 182.4).

4.5 Conclusion

In this study pigs had a greater preference for soybean meal and lupins than either full-fat canola or canola oilcake as protein sources. The constant aversion to canola containing diets may be attributable to the presence of antinutritional factors such as glucosinolates and sinapine. In a choice feeding situation Kyriazakis & Emmans (1992; 1993), as cited by Ferguson *et al.* (2002), observed an intense avoidance pattern against foods containing toxins in pigs. In the case of lupins it seems that the alkaloid content of the sweet narrow leafed lupins (*Lupinus angustifolius)* cultivars used in this study did not elicit the same reaction.

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Chapter 5

Anti nutritional factors in canola produced in the Western and Southern Cape areas of South Africa

5.1 Abstract

The development of low erucic acid, low glucosinolate cultivars of canola seed has led to the availability of a feed ingredient with considerable potential to replace soybean meal in diets for all classes of farm animals. Canola meal is a high quality product and when properly utilized, can be used to advantage in reducing feed costs for animal producers (Thacker, 1990). The nutritional quality of the meal is compromised by the presence of anti-nutritional factors in the seed. The sinapine and glucosinolate content of various canola cultivars was compared. The influence of locality of production in South Africa was also determined. There were no significant differences ($P \leq 0.05$) in sinapine content when the canola produced in the Western and Southern Cape were compared. Varola 54 and Rainbow cultivars had significantly higher ($P \leq 0.05$) sinapine contents than Varola 50.

Keywords: Canola, anti-nutritional factors, sinapine, glucosinolate

5.2 Introduction

In order to be classified as canola, the oil of rapeseed must contain less than 2% erucic acid, while the meal must contain less than 30 micromoles of glucosinolates per gram of meal (Thacker, 1990). Prior to the general adoption of the new cultivars of canola, the presence of glucosinolates was the major factor limiting the use of rapeseed meal in swine rations (Bell, 1984). Reduced animal performance, impaired thyroid function in growing animals, foetuses and embryos, and liver haemorrhage mortality in laying hens are the major anti-nutritive effects of glucosinolates (Campbell & Schöne, 1998). Although canola meal is an accepted feed ingredient in diets for most poultry, there are a number of reports indicating reduced performance with diets containing significant amounts of this protein supplement (Hulan & Proudfoot, 1980; Summers & Leeson, 1985; Leeson *et al*., 1987).

Rapeseed contains an enzyme called myrosinase, which, is capable of breaking down these glucosinolates into a variety of toxic compounds including isothiocyanates, oxazolidinethiones, nitriles and inorganic thiocyanate ion (Paik et al., 1980). The glucosinolate side chain may comprise aliphatic (saturated or unsaturated), aromatic, or heteroaromatic groupings (Campbell & Schöne, 1998). Among the aromatic groupings indole and phenyl groups are common and the presence of methyl, thiol and hydroxyl groups in the side chain represent additional modified groupings (Campbell & Schöne, 1998). The side chain is important in animal nutrition as it determines the chemical nature of the products of enzyme hydrolysis and

thereby their biological effect and potency (Campbell & Schöne, 1998). Hydrolysis by myrosinase yields glucose and a variety of aglucone products, the exact nature of which are determined by a number of factors including pH, the presence of certain cofactors and the structure of the parent glucosinolate (Campbell & Schöne, 1998). Heat is applied in commercial canola processing, to condition the seed for improved oil extraction, to inactivate myrosinase and for solvent removal and drying of meal. The extent of heat treatment is sufficient to cause some thermal degradation of glucosinolates, with indole glucosinolates being more susceptible to degradation than aliphatic glucosinolate (Campbell & Slominski, 1989). Thermal degradation during commercial seed processing would produce aglucone products similar to those mentioned above but due to the fact that the majority of the aglucone products are extremely reactive, and also volatile, there are generally low concentrations in commercial meal (Campbell & Schöne, 1998). As progoitrin is the most predominant glucosinolate in most canola varieties, 5-vinyloxazolidine-2-thione and the corresponding nitrile, 1-cyano-2-hydroxy-3-butene tends to be the aglucones most often detected in meal (Campbell & Schöne, 1998). Thiocyanate ion, presumably from the decomposition of the indole glucosinolate, is also a common product in meal. Since myrosinase is usually effectively inactivated during processing, the predominant form of glucosinolates in the meal is as intact glucosinolates even when the moisture content of meal is increased as would occur in the intestinal tract of animals (Campbell & Schöne, 1998). The glucosinolate in rapeseed meal have long been known to cause thyroid dysfunction in pigs. Schöne et al. (1990) studied the goitrogenicity of high glucosinolate rapeseed meal in growing pigs in detail. They varied glucosinolate intake of the pigs by feeding a high glucosinolate meal (10 mmol/kg final diet) or a Cu treated meal (<1 mmol/kg final diet) and varied levels of supplemental iodine. Criteria used to assess treatment effects included growth, thyroid weight and total iodine deposition and serum thyroid hormone levels. Growth of the pigs and thyroid size were normalized only by inactivation of glucosinolate (Cu treated) combined with the administration of iodine.

Schöne et al. (1993) showed that the addition of myrosinase to a high glucosinolate rapeseed meal had a detrimental effect on the thyroid status in young chicks especially without dietary iodine supplementation. Removal ($\geq$ 90%) of glucosinolates from rapeseed meal by treatment with Cu elevated the anti-thyroid effects, which differed from those of the myrosinase-treated meal with similar glucosinolate content. In comparing the results of chick experiments to experiments with pigs, Schöne et al. (1993) indicated that chicks were able to tolerate a higher level of dietary glucosinolates. Glucosinolate compounds cause the enlargement of the thyroid gland and inhibit the synthesis and secretion of the thyroid hormones (Christison & Laarveld, 1981; McKinnon & Bowland, 1979). These hormones play an essential role in the control of the body's metabolism and if deficient, may reduce the utilization of dietary nutrients causing poor growth and poor reproductive performance (Thacker, 1990). As a result of genetic selection, the glucosinolate content of canola meal has been reduced to about 15% of the level contained in traditional rapeseed meal (Bell, 1984).

The occurrence, of liver haemorrhage mortality, among laying hens fed rapeseed meal was first reported by Jackson (1969). This relationship of glucosinolate as a causative agent in liver haemorrhage was

confirmed in a study by Campbell & Slominski (1991) in which hens were fed diets varying in glucosinolate content (0.2 up to 3.8 mmol/kg) produced by combining low and high glucosinolate meals in varying proportions.

Sinapine is a choline ester of 4-hydroxy-3, 5-dimethoxycinnamic acid (Larson *et al.*, 1983). Sinapine, the major phenolic constituent of canola meal is bitter tasting (Blair & Reichert, 1984) and mainly a constituent of the embryo (Bell & Shires, 1982). Although rarely identified as a detriment for pigs, sinapine may be removed via hydrolysis with ammonia and steam (Bell, 1984). Removal via breeding is a possible area for improvement of canola meal since its competitor soybean meal contains no sinapines (Blair & Reichert, 1984). Sinapine is a compound in canola meal, which produces a fishy flavour in the eggs of certain brown-shelled laying strains. Egg taint occurs when sinapine levels exceed 1g/kg^{-} diet, and German analysis of whole seeds indicated that sinapine levels in canola meal were approximately 6 up to 12 g/kg. The biochemical mechanism of egg taint has been reviewed by various authors (Pokorny & Reblova, 1995; Bell 1993).

The objective of this study was to quantify the variation in sinapine and glucosinolate content of different cultivars of canola, produced in two different locations in the Western Cape.

5.3 Materials and Methods

A number of canola samples were collected at two different locations in the Western Cape, the Western Cape (Swartland) and Southern Cape (Rûens) grain producing areas. Samples were analysed for sinapine and glucosinolate content. The values were then statistically compared with location and cultivar as main factors. The samples were analysed for the aliphatic glucosinolates: progoitrin (PRO), epiprogoitrin (EPI), sinigrin (SIN), glucoapaoleiferin (GNF), glucoalyssin (GAL), gluconapin (GNP) and glucobrassicanapin (GNP). The samples were also analysed for the indolyl glucosinolates: 4-hydroxyglucobrassicin (4HGB) and glucobrassicin (GBN). The samples were finally analysed for the aromatic glucosinolates: glucotropaoelin (GTR) and gluconasturtiin (GNA).

Desulfoglucosinolates were determined as described by Fiebig & Jörden (1990). Sample extraction of 0.200 g grinded seed material was carried out with 70 % (v/v) methanol at 75 °C for 10 min, twice under ultrasonic treatment. The crude extract (1 ml) was added on the top of a SAX exchange column (LiChrolut SAX 500 mg, Merck, Darmstadt, Germany) and allowed to drain. The column was washed with water and a sodium acetate buffer (1.3608 g sodium acetate x 3 H2O/ 500 mL water adjusted to pH = 4.0 by acetic acid). A sulphatase solution (10.0 mg sulfatase/25 ml water) (Type H-1 from Helix pomatia; E.C. 3.1.6.1, Sigma-Aldrich Chemie GmbH, Taufkirchen, Germany) was added and allowed to remain on the column overnight. Desulphoglucosinolates were eluted with water from the column and this solution was used for the high-pressure liquid chromatography (HPLC) on a LiChrospher 60 RP-select B column (5 µm) 125 x 4 mm (Merck, Darmstadt, Germany). Separation was performed by gradient elution using water (A) and 20 % (v/v) acetonitrile in water (B). The solvent gradient changed according to the following conditions: after 2.5 min.

with 95% (A) and 5% (B) to 80% (A) and 20% (B) in 18 min. These conditions were held for 5 min and then changed to 95% (A) and 5% (B) in 2 min. The desulfoglucosinolates were detected at 229 nm with a variable wavelength UV-detector.

The HPLC lines for sinapine were performed according to a modified method of Clausen *et al*. (1983) under isocratic conditions as described by Clausen *et al*. (1985). The extraction of sinapine was achieved with 70 % methanol as recommended by Bjerg *et al*. (1984). The centrifuged extract was diluted and then injected onto a LiChrospher 60 RP-select B column (5 µm) 125 x 4 mm (Merck, Darmstadt, Germany) used with a flow rate of 1.0 ml/min without further purification. The mobile phase consisted of 0.01 M sodium heptanesulphonic acid, 0.01 M sodium dihydrogenphosphate and 0.01 M dibutylamine in acetonitrile/water (2:8) at pH pH = 2.0. The UV-detector was set at 325 nm. Calibration and evaluation of the method was made using sinapine thiocyanate, isolated from a rapeseed sample.

The data collected was compared by analysis of variance using Statgraphics 5.1 (1991).

5.4 Results & Discussion

Results on the effect of location of production on the sinapine content of the canola are presented in Table 5.1. Samples originating from the Swartland area tended ($P \leq 0.08$) to be higher in sinapine content compared to the samples originating from the Rûens area of South Africa.

Table 5.1 Average sinapine content of canola samples collected from the Swartland and Rûens areas of South Africa

Location	Number of Samples	Sinapine content (mg/g)
Swartland	10	9.4
Rûens	10	10.5
SEm		0.4

There was a significant difference ($P \leq 0.05$) between the sinapine content of the cultivars. Varola 54 had significantly higher sinapine content than Varola 50 and Rainbow also had significantly higher sinapine content than the Varola 50.

Table 5.2 Average sinapine content of different canola cultivars

Cultivar	Number of Samples	Sinapine Content (mg/g)
Varola 50	2	7.72[a]
Monty	2	9.04[ab]
Varola 44	2	9.35[ab]
Insignia	2	9.90[ab]
Scoop	2	10.02[ab]
Hylite 200 TT	2	10.20[ab]
Hyola 60	2	10.27[ab]
Oscar	2	10.48[ab]
Varola 54	2	11.11[b]
Rainbow	2	11.53[b]
SEm		0.89

[a-e] Column means with common superscripts do not differ (P≤ 0.05)

Sinapine is the most common of all phenolic esters in canola seeds. Sinapine is a choline ester of sinapic acid, and normally constitutes 1-4 % of air-dried oil-free canola meal (Blair & Reichert, 1984; Uppstrom & Johansson, 1985).

There was no significant difference (P ≤ 0.05) between the aliphatic glucosinolate contents of the canola originating from the Swartland and the canola originating from the Rûens (Table 5.3).

Table 5.3 Average aliphatic glucosinolates content of canola samples collected from the Swartland and Rûens area of the Western Cape

Location	Number of samples	Progoitrin (µmol/g)	Epiprogoitrin (µmol/g)	Sinigrin (µmol/g)	Glucoapaoleiferin (µmol/g)	Glucoalyssin (µmol/g)	Gluconapin (µmol/g)	Glucobrassicanapin (µmol/g)	Total
Rûens	10	0.95	0.14	12.10	0.12	0.06	0.49	0.21	14.06
Swartland	10	0.98	0.11	12.10	0.12	0.04	0.63	0.18	14.17
SEm		0.12	0.03	0.00	0.01	0.008	0.07	0.03	0.21

There was no significant difference (P ≤ 0.05) between the indolyl glucosinolate contents of the canola originating from the Swartland and the canola originating from the Rûens (Table 5.4).

Table 5.4 Average indolyl glucosinolates content of canola samples from the Swartland and Rûens area of the Western Cape of South Africa

Location	Number of samples	4-Hydroxyglucobrassicin (µmol/g)	Glucobrassicin (µmol/g)	Total
Rûens	10	2.94	0.29	3.23
Swartland	10	2.95	0.32	3.26
SEm		0.1	0.03	0.11

There was no significant difference ($P \leq 0.05$) between the aromatic glucosinolates contents of the canola originating from the Swartland and the canola originating from the Rûens area (Table 5.5).

Table 5.5 Average aromatic glucosinolates content of canola samples from the Swartland and Rûens area of the Western Cape of South Africa

Location	Number of samples	Glucotropaoelin (µmol/g)	Gluconasturtiin (µmol/g)	Total
Rûens	10	0.16	0.29	0.45
Swartland	10	0.13	0.37	0.50
SEm		0.02	0.06	0.07

There was a significant difference ($P \leq 0.05$) between the GBN contents of some the cultivars (Table 5.6). Varola 54 and Varola 50 cultivars had significantly higher GBN content than the other cultivars. Oscar had the lowest glucobrassicin content.

Table 5.6 Average aliphatic glucosinolates content of various canola cultivars collected from two locations in South Africa

Cultivar	Number of samples	Progoitrin (µmol/g)	Epiprogoitrin (µmol/g)	Sinigrin (µmol/g)	Glucoapaoleiferin (µmol/g)	Glucoalyssin (µmol/g)	Gluconapin (µmol/g)	Glucobrassicanapin (µmol/g)	Total
Varola 50	2	1.17^{abc}	0.18	12.10	0.18	0.09^{c}	0.81^{c}	0.29^{de}	14.82
Monty	2	1.28^{bc}	0.11	12.10	0.09	0.06^{abc}	0.73^{c}	0.25^{d}	14.62
Varola 44	2	0.58^{a}	0.10	12.10	0.08	0.03^{a}	0.30^{a}	0.09^{ab}	13.28
Insignia	2	0.95^{abc}	0.16	12.10	0.11	0.03^{a}	0.74^{c}	0.09^{abc}	14.18
Scoop	2	1.07^{abc}	0.28	12.10	0.13	0.06^{abc}	0.57^{abc}	0.20^{cd}	14.41
Hylite 200 TT	2	0.63^{ab}	0.07	12.10	0.12	0.03^{a}	0.38^{ab}	0.18^{bcd}	13.52
Hyola 60	2	0.58^{a}	0.12	12.10	0.10	0.03^{a}	0.30^{a}	0.27^{d}	13.50
Oscar	2	0.93^{abc}	0.09	12.10	0.14	0.03^{a}	0.49^{abc}	0.08^{a}	13.85
Varola 54	2	1.01^{abc}	0.06	12.10	0.12	0.09^{bc}	0.57^{abc}	0.39^{e}	14.34
Rainbow	2	1.49^{c}	0.05	12.10	0.12	0.05^{ab}	0.70^{bc}	0.13^{abc}	14.64
SEm		0.22	0.08	0.0	0.03	0.015	0.11	0.03	0.35

$^{a-e}$ Column means with common superscripts do not differ ($P \leq 0.05$)

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There was a significant difference ($P \leq 0.05$) between the GBN contents of some cultivars (Table 5.7). Hyola 60 and Hylite 200 TT had significantly lower GBN content compared to the other cultivars. Scoop, Oscar, Monty and Varola 50 had higher GBN content compared to the other cultivars.

Table 5.7 Average indolyl glucosinolates content of canola samples from the Swartland and Rûens area of the Western Cape area of South Africa

Cultivar	Number of samples	4-Hydroxyglucobrassicin (µmol/g)	Glucobrassicin (µmol/g)	Total
Varola 50	2	3.38^{b}	0.45^{c}	3.83
Monty	2	2.76^{ab}	0.38^{bc}	3.15
Varola 44	2	2.97^{b}	0.26^{ab}	3.23
Insignia	2	2.81^{ab}	0.29^{ab}	3.10
Scoop	2	2.905^{ab}	0.35^{bc}	3.26
Hylite 200 TT	2	2.60^{a}	0.20^{a}	2.81
Hyola 60	2	2.83^{ab}	0.18^{a}	3.01
Oscar	2	2.92^{ab}	0.38^{bc}	3.29
Varola 54	2	3.17^{ab}	0.29^{ab}	3.46
Rainbow	2	3.08^{ab}	0.27^{ab}	3.34
SEm		0.2	0.04	0.22

$^{a-c}$ Column means with common superscripts do not differ ($P \leq 0.05$)

There was a significant difference ($P \leq 0.05$) between the GTR and GNA contents of some the cultivars (Table 5.8). Oscar had a lower GNA content than the other cultivars. Scoop, Hylite 200 TT, Monty, Hyola 60 and Varola 54 had higher GNA content compared to Varola 50, Varola 44, Insignia, Oscar and Rainbow. Varola 44, Rainbow and Insignia had significantly lower GTR content compared to Varola 50, Monty, Scoop and Hyola 60. Varola 50 and Hyola 60 had higher GTR content.

Table 5.8 Average aromatic glucosinolates content of canola samples from the Swartland and Rûens area of the Western Cape area of South Africa

Cultivar name	Number of samples	Glucotropaoelin (µmol/g)	Gluconasturtiin (µmol/g)	Total
Varola 50	2	0.22^{d}	0.20^{abc}	0.41
Monty	2	0.20^{cd}	0.41^{bcd}	0.61
Varola 44	2	0.09^{a}	0.27^{abc}	0.35
Insignia	2	0.07^{a}	0.18^{ab}	0.25
Scoop	2	0.19^{bcd}	0.54^{d}	0.73
Hylite 200 TT	2	0.11^{ab}	0.37^{abcd}	0.47
Hyola 60	2	0.21^{d}	0.57^{d}	0.78
Oscar	2	0.11^{abc}	0.12^{a}	0.27
Varola 54	2	0.16^{abcd}	0.45^{cd}	0.61
Rainbow	2	0.07^{a}	0.20^{abc}	0.27
SEm		0.03	0.08	0.09

$^{a-e}$ Column means with common superscripts do not differ ($P \leq 0.05$)

There was no significant difference ($P \leq 0.05$) in the total glucosinolate content of the canola originating from the Swartland area of the Western Cape of South Africa and the canola originating from the Rûens area of the Western Cape of South Africa (Table 5.9).

Pectora roborant cultus recti

Table 5.9 Average glucosinolate content of canola samples from the Swartland and Rûens areas of the Western Cape of South Africa

Location	Number of samples	Total Glucosinolate content (µmol/g)
Swartland	10	17.74
Rûens	10	17.93
SEm		0.27

$^{a-e}$ Column means with common superscripts do not differ ($P \leq 0.05$)

There were significant differences ($P \leq 0.05$) in the total glucosinolate content of the various canola cultivars. Varola 44 and Hylite 200TT had the lowest total glucosinolate content and Varola 50 had the highest glucosinolate content.

Table 5.10 Average glucosinolate content of various canola cultivars

Cultivar	Number of samples	Total Glucosinolate content (µmol/g)
Varola 50	2	19.07[c]
Monty	2	18.38[bc]
Varola 44	2	16.87[a]
Insignia	2	17.52[ab]
Scoop	2	18.40[bc]
Hylite 200 TT	2	16.80[a]
Hyola 60	2	17.29[ab]
Oscar	2	17.41[ab]
Varola 54	2	18.41[bc]
Rainbow	2	18.26[bc]
SEm		0.4

[a-e] Column means with common superscripts do not differ (P≤ 0.05)

Glucosinolates *per se* are not considered toxic; their hydrolysis by-products have established goitrogenic and hepatoxic effects. They also tend to be bitter tasting, thus potentially affecting feed intake (Sarwar *et al.* 1981; Bell & Shires 1982; Bourdon & Aumaitre, 1990). These by products are responsible for the decreased performance that affects the utilization or absorption of digestible energy and other nutrients (Yin *et al.* 1993).

In a study by Kraling *et al*. (1990) the glucosinolate pattern of 93 resynthesized rape lines was examined over 3 years, indolyl glucosinolate contents were highly variable but values were stable over 2 years. In a similar study by Velasco & Becker (2000), a collection of the genus *Brassica* was evaluated for total content and profile of seed glucosinolate. The collection contained great variability for glucosinolate content and profile. The Canadian Grain Commission (Grain Research Laboratory, Canadian Grain Commission) evaluates the glucosinolate content of canola harvests in Canada and the total glucosinolate content from 1993 to 2003 has a mean value of 12µmol/g. Our study revealed an average total glucosinolate content of 17.8µmol/g, which is higher than these values. However, it is well below the value of 30 µmol/g to be certified as canola (Brand, 2003)

In a trial conducted in Australia where Western Australian canola meal was evaluated for growing pigs, twenty samples of canola were collected in south-western Australia after the 1995 harvest (Mullan, 2000). The average total glucosinolate levels were 14µmol/g.

5.5 Conclusion

From this study it can be concluded that the location of production in South Africa had no influence on the ANF content of canola. There is some variability in the ANF content between the various cultivars. The variation in ANF's between the cultivars may lead to variation in the production performance of animals

fed different canola cultivars. However there seems to be no danger that canola cultivars used in South Africa will exceed the maximum levels set by the Canola Council of Canada.

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Chapter 6

Differences in the various anti nutritional factors and the amino acid and digestible energy content (pigs) of different lupin, field pea, faba bean and Narbon bean cultivars

6.1 Abstract

Samples of lupins, field peas, faba beans and narbon beans were collected in the Western and Southern Cape grain producing areas of South Africa and analysed for amino acids, alkaloids, non-starch polysaccharides, tannin and starch. The digestible energy value of these alternative protein sources for pigs was also determined. Significant differences were found in the amino acid content of the various crops. The alkaloid content of the lupins varied significantly between the sweet and bitter lupin varieties. Sweet *L. angustifolius* cultivars contained 49.1mg/kg and the bitter *L. angustifolius* cultivars 15204.5mg/kg alkaloids. The faba beans, narbon beans and peas had significantly higher values for tannins and starch, compared to lupins. The tannin content of the faba bean cultivars was 4.75g/kg and the starch content 378.4g/kg. The tannin content of the narbon bean cultivars was 2.55g/kg and the starch content 355.5g/kg. The tannin content of the pea cultivars was 3.45g/kg and the starch content 388.0g/kg. The lupin cultivars *L. angustifolius* (31.02g/100g) and *L. albus* (25.8g/100g) contained significantly more non-starch polysaccharides than the other crops tested. The lupin cultivars *L. luteus* (15.9 MJ/kg) and *L. albus* (14.2 MJ/kg) had significantly higher digestible energy values for pigs compared to the other legumes tested in this study.

Keywords: Lupins, field peas, faba beans, narbon beans, amino acids, alkaloids, non-starch polysaccharides, tannin, starch

6.2 Introduction

Feed formulation for monogastric animals is very complex due to the variety of feedstuffs available on the market. Anti nutritional factors (ANF's) occur in many seeds available for human and animal consumption such as cereal grains (some varieties of rye and triticle) and above all, in legume seeds (soya; peas; beans; chick peas; cow peas) (Huisman, 1989; Birk, 1987, 1989 as cited by Le Geun & Birk, 1993). Very little information on the ANF content and nutritional value to pigs and poultry is available on some of the more unconventional protein sources mentioned. Among the most important ANF's in legume seeds are protein protease inhibitors (PI), lectins, saponins, phytates, tannins, alkaloids and non-starch polysaccharides.

Protein for use in animal diets are becoming increasingly scarce and expensive, therefore the nutritive value of alternative protein sources needs to be investigated. Lupins are an important rotation crop

in the grain producing areas of the Western Cape and 10 000t lupins are cultivated each year. Faba beans have proven to be extremely adaptable and can be cultivated successfully in the Western Cape. The utilization of lupin seed for monogastric domestic animal feeding is limited by the presence of the bitter alkaloids they contain. Alkaloids either reduce or prevent intake of feeds by animals if the alkaloid concentration exceeds the animal's tolerance level. The alkaloid levels in lupins vary from 1mg/kg to 50 000mg/kg. Sweet lupin seed is sweet due to very low levels of alkaloids.

When lupins are fed to monogastric animals, there is a need to account for the specific physiological effects of dietary fibre components such as oligosaccharides and soluble non-starch polysaccharides. The non-starch polysaccharides may be subdivided into soluble and insoluble fractions. The former are soluble in water and include gums, pectins, mucilages and some hemicelluloses. The insoluble fraction includes cellulose and the majority of the hemicelluloses (McDonald *et al*., 1995). Monogastric animals do not digest non-starch polysaccharides, as mammalian intestinal mucosa lack α-galactosidase activity. However, bacteria in the lower intestinal tract are able to metabolise these sugars to carbon dioxide, hydrogen and methane, resulting in flatulence. Much of the carbohydrate in lupins is digested by microbial fermentation in the cecum and proximal colon. (King, 1990). Due to high levels of non-starch polysaccharides in lupins, digestible energy (DE) may not be the most appropriate measure of the available energy content of lupins for pigs. This is due to a large proportion of the carbohydrates from lupins being digested in the hindgut (Traverner *et al*., 1983). Different lupin species contain different levels of glycosides varying from 0.42 mg-9.57 mg HCN/100 g (Todorov *et al*., 1996). Some cultivars can contain up to 7.3% pentosanes, which are indigestible for pigs and poultry (Jacyno *et al*., 1992). Evans and Cheung as cited by Petterson (1998) found that *Lupinus angustifolius* contain approximately 4.7% arabinose and 3.63% xilose, which are the most important pentosanes in *Lupinus sp.*

Faba beans (*Vicia Faba*) are an important food legume in China, Egypt, Italy, Ethiopia and Brazil (Adsule & Akpapunam, 1996). Raw faba beans contain anti-nutritional factors such as protease inhibitors and tannins. Faba beans contain between 0.3 and 0.5% tannins (Kadirvel & Clandinin, 1974). The presence of these tannins may lead to a slight reduction in feed intake when high levels of faba beans are fed to swine (Singleton & Kratzer, 1969). In addition, tannins may inhibit the retention of certain dietary nutrients (McLeod, 1974; Marquardt *et al*., 1976). Faba beans also contain 3.2% pentosans (Jacyno *et al*. 1992), which forms part of the NSP content of the beans. In Australia where the faba bean has been used for a number of years as a rotation crop with wheat it is regarded as an important alternative to lupins. Apart from having the same beneficial effect on the soil the faba bean has several additional advantages in that it appears to be more resistant to root diseases, has a high seed yield and produces palatable protein rich forage which may be either grazed or ensiled (d'Hangest d'Yvoy, 1990).

Narbon vetch (*Vicia Narbonensis*) is a leguminous species that can be used for grain and straw production or as a source of animal feed. The crude protein content of the grain varies from 26 up to 32% (Abe El Moneim, 1992).

Peas originated in the Middle East, but are now grown in more temperate climates and can be found in Russia, China, Northern Europe and the north-western states of the USA and the Prairie province of Canada (Castell, 1987). Potential pea ANF's includes amylase, trypsin and chymotrypsin inhibitors, tannins (proanthocyanidins), phytic acid, saponins (hypocholesterolemic factors), hemagglutinins (lectins) and oligosaccharides. Peas contain about 0.24% tannins, 4.76% pentosanes and no alkaloids (Jacyno *et al*. 1992).

The chemical composition and energy content (poultry and ruminants) of these legume cultivars have already been published by Brandt (1998) and Brand *et al*., 2004. The objective of the present study is to quantify the variation in anti nutritional factor content, amino acid composition and digestible energy value for pigs of different cultivars of grain legumes produced in the Western Cape.

6.3 Materials and Methods

Two samples of each grain legume were collected in the Western Cape and Southern Cape grain producing areas of South Africa and pooled over a two-year period. The cultivars selected for analysis are presented in Table 6.1. The samples were analysed for amino acids after hydrolysis in a sealed tube on a Beckmann Model 6300 amino acid analyser. The samples were also analysed for alkaloid, tannin and starch content. The non-starch polysaccharides-, amino acid-, tannin-, starch- and alkaloid contents were compared between grain legumes by analysis of variance using Statgraphics 5.1 (1991).

The alkaloid content of the grain legumes was determined by spectrophotometry as described by Von Baer *et al*. (1978). This method is a quantitative determination of total alkaloids with bromocresol purple at 405 nm. The tannin content was determined by the modified Jerumanis procedure as described by Daiber (1975). The starch content was determined with spectrophotometry using the method described by MacRae & Armstrong (1968). The non-starch polysaccharides content was determined by the method described by Englyst & Cummings (1988). The digestible energy content was determined by the mobile nylon bag technique as described by Brand *et al*., 1989. The DE values for pigs were corrected for over estimation by the regression equation (y = 1.998 + 0,788x) as described by Brand (2000).

Table 6.1 Grain legumes and cultivars selected for comparison of the anti-nutritional factor content

Grain Legume	Cultivar
Narbon beans	ACT60188
Faba beans	Ascot
Peas	Glenroy
Peas	Alma
Lupinus albus	Astra
Lupinus albus	Buttercup
Lupinus albus	Hamburg
Lupinus albus	Kiev
Lupinus angustifolius	Moredou
Lupinus angustifolius	Eureka
Lupinus angustifolius	Helderberg
Lupinus angustifolius	Merrit
Lupinus luteus	Juno
Lupinus luteus	Borsaja
Lupinus albus	Esta
Lupinus albus	Vladimir

6.4Results & Discussion

Significant differences were found in the amino acid content of the various grain legumes (Table 6.2). Faba beans, narbon beans and peas had significantly less threonine, serine, glysine, alanine, methionine, isoleucine, leucine, phenylalanine and histidine than the lupin cultivars. The *L. albus* cultivar had significantly higher valine and tyrosine values. There were no significant differences in the lysine and arginine values of the various grain legumes.

The amino acid lines in this study showed the deficiencies in lysine and methionine, compared to FAO standards, common to most legume species, which is similar to amino acids profiles published by Petterson & Mackintosh (1994). Therefore when lupins are used in rations for poultry and pigs' synthetic lysine and methionine should be added to ensure the sufficient supply of these amino acids. Grain of narbon bean contains the amino acid gamma-glutamyl-S-ethenyl cysteine (GEC) at sufficiently high concentrations (0.1-3%) to reduce palatability to monogastrics (Siddique *et al*., 1996; Enneking, 1995). The results of the amino acid analysis in this study was similar to the results obtained by Eason *et al*. (1990), but differed vastly from the results obtained by Hadjipanayiotou & Economides (2001). Possible reasons for the difference in results obtained in the mentioned studies could be different cultivars used or diverse growing conditions.

Table 6.2 The total amino acid values, as percentage of dry matter, for narbon beans, faba beans, peas and different lupin cultivars.

Crop	Number of samples	Crude protein g/kg	Lysine g/kg	Methionine g/kg	Threonine g/kg	Arginine g/kg	Serine g/kg	Glysine g/kg	Alanine g/kg	Valine g/kg	Isoleucine g/kg	Leucine g/kg	Tyrosine g/kg	Phenylalanine g/kg	Histidine g/kg
Narbon	2	237	13.55 ± 1.49	1.00^{a} ± 0.13	6.85^{ab} ± 1.04	18.75 ± 9.35	8.55^{a} ± 1.57	7.80^{a} ± 1.75	7.95^{ab} ± 1.45	11.00^{a} ± 1.47	5.85^{a} ± 1.48	15.00^{a} ± 2.65	5.30^{a} ± 1.2	9.25^{ab} ± 1.1	4.30^{a} ± 0.6
Faba	2	260	12.90 ± 2.10	1.00^{ab} ± 0.18	6.80^{a} ± 1.47	24.10 ± 13.23	8.80^{a} ± 2.22	9.30^{ab} ± 2.47	8.20^{abc} ± 2.05	11.10^{a} ± 2.08	8.20^{ab} ± 2.10	16.00^{ab} ± 3.75	6.80^{ab} ± 1.7	9.00^{a} ± 1.6	4.30^{a} ± 0.8
Peas	4	247	14.40 ± 1.49	1.40^{bc} ± 0.13	7.05^{ab} ± 1.04	23.70 ± 9.35	9.00^{a} ± 1.57	4.55^{a} ± 1.75	4.45^{a} ± 1.45	11.95^{a} ± 1.47	8.25^{abc} ± 1.48	15.65^{a} ± 2.65	6.15^{a} ± 1.2	9.80^{abc} ± 1.1	4.65^{a} ± 0.6
L. Angustifolius	8	339	14.81 ± 0.79	1.23^{ab} ± 0.07	9.56^{ac} ± 0.56	38.30 ± 5.00	1.413^{b} ± 0.84	13.27^{b} ± 0.93	10.14^{bc} ± 0.78	14.23^{a} ± 0.80	12.33^{bd} ± 0.79	22.01^{b} ± 1.42	10.01^{b} ± 0.6	12.00^{acd} ± 0.6	6.71^{bc} ± 0.3
L. Luteus	4	394	17.85 ± 1.49	1.75^{c} ± 0.13	10.55^{acd} ± 1.04	20.15 ± 9.35	1.560^{b} ± 1.57	14.10^{b} ±1.75	11.15^{bc} ± 1.45	15.05^{ab} ± 1.47	12.80^{bde} ± 1.48	28.75^{c} ± 2.65	8.55^{ab} ± 1.2	13.20^{d} ± 1.1	7.80^{c} ± 0.6
L. Albus	12	382	16.65 ± 0.66	1.58^{c} ± 0.06	11.78^{d} ± 0.47	38.15 ± 4.18	1.625^{b} ± 0.70	14.40^{b} ± 0.78	11.31^{c} ± 0.65	16.85^{b} ± 0.66	14.55^{e} ± 0.66	26.63^{c} ± 1.18	14.10^{c} ± 0.5	13.28^{d} ± 0.5	6.39^{b} ± 0.3

[a-e] Column means with common superscripts do not differ ($P \leq 0.05$)

Table 6.3 The total amino acid values, as percentage of crude protein, for narbon beans, faba beans, peas and different lupin cultivars.

Crop	Number Of Samples	Crude Protein g/kg	Lysine g/kg	Methionine g/kg	Threonine g/kg	Arginine g/kg	Serine g/kg	Glysine g/kg	Alanine g/kg	Valine g/kg	Isoleucine g/kg	Leucine g/kg	Tyrosine g/kg	Phenylalanine g/kg	Histidine g/kg
Narbon	2	237	57.03 ± 3.97	4.21 ± 0.34	28.83 ± 2.77	78.91 ± 24.53	35.99 ± 4.17	32.83 ± 5.51	33.50 ± 4.83	46.30 ± 3.92	24.62 ± 4.35	63.13 ± 7.00	22.31 ± 3.17	38.93 ± 2.94	18.10 ± 1.60
Faba	2	260	49.62 ± 5.62	3.85 ± 0.49	26.15 ± 3.92	92.69 ± 34.69	33.85 ± 5.90	35.77 ± 7.79	31.54 ± 6.83	42.69 ± 5.55	31.54 ± 6.15	61.54 ± 9.90	26.15 ± 4.49	34.62 ± 4.16	16.54 ± 2.26
Peas	4	247	58.21 ± 3.97	5.66 ± 0.34	28.50 ± 2.77	95.80 ± 24.53	36.38 ± 4.17	18.39 ± 5.51	17.99 ± 4.83	48.30 ± 3.92	33.35 ± 4.35	63.26 ± 7.00	24.86 ± 3.17	39.61 ± 2.94	18.80 ± 1.60
L. Angustifolius	8	339	43.71 ± 2.12	3.63 ± 0.18	28.21 ± 1.48	113.01 ±13.11	41.69 ± 2.23	39.16 ± 2.95	29.92 ± 2.58	41.99 ± 2.10	36.38 ± 2.33	64.95 ± 3.74	29.55 ± 1.70	35.41 ± 1.57	19.81 ± 0.85
L. Luteus	4	394	45.35 ± 3.97	4.45 ± 0.34	26.80 ± 2.77	51.19 ± 24.53	39.63 ± 4.17	35.82 ± 5.51	28.33 ± 4.83	38.24 ± 3.92	32.52 ± 4.35	73.04 ± 7.00	21.72 ± 3.17	33.54 ± 2.94	19.82 ± 1.60
L. Albus	12	382	43.59 ± 1.78	4.14 ± 0.15	30.84 ± 1.24	99.87 ± 12.95	42.54 ± 1.87	37.70 ± 2.46	29.61 ± 2.16	44.11 ± 1.75	38.09 ± 1.95	69.71 ± 3.13	36.91 ± 1.42	34.76 ± 1.32	16.73 ± 0.71

[a-e] Column means with common superscripts do not differ ($P \leq 0.05$)

There was no significant difference ($P \leq 0.05$) in the alkaloid levels of *L.luteus* and sweet *L. angustifolius* cultivars (Table 6.3). The *L. albus* cultivars had significantly higher alkaloid levels than the *L.luteus* and sweet *L. angustifolius* cultivars. Significantly higher alkaloid levels were found in the bitter *L. angustifolius* cultivars compared to the *L. albus* cultivars, the *L.luteus* and sweet *L. angustifolius* cultivars. The lupin cultivars had significantly lower ($P \leq 0.05$) tannin levels compared to faba beans, narbon beans and the peas (Table 6.3).

Table 6.3 Total alkaloid and tannin content of the selected grain legumes for comparison

Cultivar	No. of Samples	Total Alkaloids (mg/kg)	Tannin (g/kg)
Narbon beans	2	$0.0^{ab} \pm 589.7$	$2.55^{b} \pm 0.4$
Faba beans	2	$0.0^{ab} \pm 589.7$	$4.75^{d} \pm 0.4$
Peas	4	$0.0^{a} \pm 417$	$3.45^{c} \pm 0.3$
L. Albus	12	$1302.2^{bd} \pm 240.8$	$0.00^{a} \pm 0.1$
Sweet *L. Angustifolius*	6	$49.1^{abc} \pm 373$	$0.00^{a} \pm 0.2$
Bitter *L. Angustifolius*	2	$15204.5^{e} \pm 589.7$	$0.00^{a} \pm 0.4$
L. Luteus	4	$42.6^{ab} \pm 589.7$	$0.00^{a} \pm 0.3$

[a-e] Column means with common superscripts do not differ ($P \leq 0.05$)

Alkaloid levels in raw materials are of importance when feeding monogastric animals. Pearson & Carr (1977) and Ruiz (1977) observed feed rejection when the alkaloid content of the diets exceeded 0.03%. Erickson & Elliot (1984) found that growth performance of pigs declined when the rations contained 0.04% alkaloids.

Tannins, or pro-anthocyanidins, are poly-phenolic compounds that inhibit the activity of digestive enzymes including trypsin, amylase and lipase (Yutste *et al.*, 1991). They are found in the hull (Griffiths, 1981) of coloured-flowered peas. The lower tannin levels and higher starch levels of field peas suggest that they may have potential as feed for monogastrics.

Lupin cultivars had significantly higher ($P \leq 0.05$) non-starch polysaccharide (NSP) levels compared to the other grain legumes. Mannose levels were all below 0.4 g/100g (Table 6.4). The *L. luteus* cultivar had NSP values similar to the narbon, faba beans and peas. The *L. Albus* cultivar contained significantly more ($P \leq 0.05$) NSP's compared to the *L. luteus* cultivar, the narbon, faba beans and peas. The *L. Angustifolius* cultivar contained significantly more ($P \leq 0.05$) NSP's compared to all the other legumes in this study.

Table 6.4 The non-starch polysaccharide values for Narbon beans, Faba beans, Peas and different lupin cultivars.

Cultivar	No. of Samples	Xilose (g/100g)	Arabinose (g/100g)	Galactose (g/100g)	Glucose (g/100g)	Total NSP (g/100g)
Narbon beans	2	$1.25^{a} \pm 0.47$	$2.75^{a} \pm 0.37$	$0.54^{a} \pm 0.83$	$9.65^{bc} \pm 1.08$	$14.17^{a} \pm 5.18$
Faba beans	2	$1.69^{a} \pm 0.47$	$2.16^{a} \pm 0.37$	$0.43^{a} \pm 0.83$	$9.69^{bc} \pm 1.08$	$13.96^{a} \pm 5.18$
Peas	3	$1.17^{a} \pm 0.38$	$3.01^{a} \pm 0.30$	$0.62^{a} \pm 0.68$	$5.68^{a} \pm 0.88$	$10.48^{a} \pm 3.66$
L. Albus	11	$3.59^{c} \pm 0.20$	$4.01^{b} \pm 0.16$	$9.48^{c} \pm 0.35$	$8.71^{b} \pm 0.46$	$25.80^{b} \pm 2.11$
L. Angustifolius	8	$2.82^{b} \pm 0.23$	$4.37^{b} \pm 0.19$	$12.18^{d} \pm 0.41$	$11.66^{c} \pm 0.54$	$31.02^{c} \pm 2.59$
L. Luteus	3	$4.12^{c} \pm 0.38$	$4.00^{b} \pm 0.30$	$4.43^{b} \pm 0.68$	$11.13^{c} \pm 0.88$	$17.77^{a} \pm 3.66$

[a-e] Column means with common superscripts do not differ ($P \leq 0.05$)

Factors such as plant origin, plant variety, degree of processing and the proportion of NSP-rich hull in the final product determine the NSP content of vegetable proteins. The most important NSP constituents of the cell wall are pectic polysaccharides, which contain rhamnogalacturonan, arabinans, galactans and arabinogalactans (Arora, 1983 as cited by Kocher, 2001). Rhamnogalacturonans are characterised by a linear chain of α- (1-4)-D-galacturonic acid units intermittent with rhamnopyranosyl residues and substituted with numerous side chains consisting of L-arabinose, D-galactose and D-xilose (Bacic *et al*., 1988 as cited by Kocher, 2001). In addition neutral polysaccharides lacking the galacturonic acid backbone, such as arabinans, galactans and arabinogalactans are present as separate polysaccharides or as side chains on the uronic acid backbone. Arabinogalactans found in legumes are mainly type I polymers containing D-galactose units (ß-1-4 linked) with L-arabinose units as side chains (Aspinall & Cortell, 1971 as cited by Kocher, 2001). In contrast, those found in canola or rapeseed meal (arabinogalactan type II) are characterised by the presence of 1-3 and 1-6 linked ß-galactopyranose units with terminal residues of arabinofuranose and doubly branched galactose residues (Siddique & Wood, 1972 as cited by Kocher, 2001). Other neutral polysaccharides in vegetable proteins include cellulose, xylans, arabinoxylans and glucoxylans. These structures are predominantly found in the hull fraction with only a small proportion present in the cotyledon (Kocher, 2001).

Narbon beans contain significantly less starch than faba beans and peas. The narbon beans also had the lowest digestibility energy values for pigs, but the reduction was not significant. The narbon beans, faba beans and *L. angustifolius* samples had significantly lower ($P \leq 0.05$) digestibility energy values for pigs compared to the lupin cultivars in this study (Table 6.5).

Table 6.5 The digestible energy values for pigs

Cultivar	No. of Samples	Starch (g/kg)	Digestible energy for pigs (MJ/kg Dry material)
Narbon beans	2	$355.5^{b} \pm 7.1$	$13.55^{a} \pm 0.35$
Faba beans	2	$378.4^{c} \pm 7.1$	$13.93^{a} \pm 0.35$
Peas	4	$388.0^{c} \pm 5.0$	$14.25^{ab} \pm 0.24$
L. Albus	12	$0.0^{a} \pm 2.9$	$14.18^{c} \pm 0.14$
L. Angustifolius	8	$0.0^{a} \pm 3.6$	$14.89^{a} \pm 0.17$
L. Luteus	4	$0.0^{a} \pm 5.0$	$15.92^{b} \pm 0.24$

[a-c] Column means with common superscripts do not differ ($P \leq 0.05$)

In this study, as well as in studies done by Evans (1994), it was concluded that there is virtually no starch in the lupin species. The main carbohydrate reserves are the non-starch polysaccharides, with the main components being galactose, arabinose, glucose, mannose, rhamnose, uronic acids and xilose (Evans, 1994). Lupin hulls are predominantly composed of structural polysaccharides: cellulose, hemicelluloses and pectins (Brillouet & Riochet, 1983; Evans, 1994).

The activity of several of the anti-nutritional factors present in faba beans has been shown to be reduced by autoclaving (Marquardt *et al*., 1974; Marquardt *et al*., 1976). However, feed efficiency and daily gain are not improved by heat treatment of the bean (Aherne *et al*., 1977; Ivan & Bowland, 1976). In a study done by Brufau *et al.* (1998), the nitrogen-corrected apparent metabolisable energy (AMEn) values of diets containing 600g faba beans /kg diet were affected by tannin content and autoclave treatment of faba beans, with 59% of total variance in AMEn being attributable to the effect of autoclaving. The AMEn values were 9% higher for chicks fed on the autoclaved compared with those fed on diets containing the raw faba beans, 5% higher for the near-isogenic faba beans with no tannins compared with those with tannins, and 4% difference between cultivars. Both autoclaving and the use of tannin-free faba beans improved the apparent protein digestibility (APD) of the diets by similar amounts. Processing faba beans could greatly improve their value as a feedstuff for use in diets for monogastric animals.

6.5 Conclusions

It can be concluded that there is great variability in alkaloid content of various lupin species. Due to the detrimental effect of alkaloids on utilization of lupins it is important that lupins especially *L. Albus* cultivars must be analysed before use as this type of lupin may vary in alkaloid content (Brand *et al*., 2004). It is also clear that the lupin species *L. Albus* and *L. Angustifolius* contained significantly more NSP's compared to the lupin species *L. Luteus*, narbon beans, faba beans and peas. NSP's will negatively affect the nutritional value of the *L. Albus* and *L. Angustifolius* lupin species as these carbohydrates are not digested by the endogenous enzymes of monogastrics but rather digested in the lower digestive tract by micro flora present in the ileum and ceca. The lactose and volatile fatty acids produced by the microbial fermentation provide some energy but the net efficiency of energy utilization from volatile fatty acids is considerably less when compared to that of glucose absorbed in the upper intestine (Carre, 1995 as sited by Kocher *et al*., 2000). The lupins contained no tannins and no starch when compared to the other legumes in this study. Faba beans had the highest tannin content, significantly higher than the narbon beans and peas. The high starch value of the faba beans, narbon beans and peas improves their nutritional value to monogastric animals. Further studies on the palatability of these raw materials are necessary.

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Chapter 7

The effect of dietary inclusion of sweet lupins, canola oilcake and full fat canola on the fatty acid profile of broilers

7.1 Abstract

The effect of replacing soybean oilcake meal as protein source with different levels of sweet lupins **(***Lupinus angustifolius***)**, canola oilcake and full-fat canola was examined. A basal diet with soybean oilcake meal (0% test source) as protein source was mixed with a diet containing either lupins, canola oilcake or full-fat canola as protein source in ratios of 100%, 67% and 33%, respectively. The fatty acid content of the fat pads of the broilers raised on the different diets was determined. Birds raised on diets containing sweet lupins and canola oilcake had significantly higher values for saturated fatty acids than birds raised on diets containing full-fat canola. There were no significant differences between the monounsaturated fatty acid profiles for the different treatments. The full-fat canola diets had significantly higher values for poly-unsaturated fatty acids than the diets containing sweet lupins and canola oilcake. Thus, the effect of replacing soybean oilcake meal as protein source with lupins, canola oilcake or full-fat canola caused a significant change in the fatty acid profile of the fat pads of the broilers. Increasing polyunsaturated levels in the fat pads of boilers could make broiler meat a more healthy choice for human consumption.

Keywords: Broilers, fatty acid profiles, sweet lupins, full-fat canola, canola oilcake

Pectora roborant cultus recti

7.2 Introduction

Traditionally the South African poultry meat producers' primary concern is the gross yield of poultry meat and not meat quality (Malan, 2003). However, a high fat content of poultry meat is unacceptable to consumers' conscious of their health. Health conscious consumers demand a shift from saturated to unsaturated fatty acids in their diet (Weber, 2001 as cited by Malan, 2003). It is recognized that n-3 polyunsaturated fatty acids (PUFA) are considered important components of a healthy human diets; therefore the regular consumption of these nutrients should be enhanced (Malan, 2003). Strong evidence indicates that type of dietary fat is more important than total fat intake in predicting risk of coronary heart disease, as different types of fat or fatty acids may play different or opposite roles (He *et al.*, 2003). Monounsaturated and polyunsaturated fats seem to have beneficial effects, but saturated fat and *trans* unsaturated fatty acids increase risk of coronary heart disease (Hu *et al.*, 1997). Meat has been branded as a food having a high fat content and an undesirable balance of fatty acids. But lean meat is very low in fat and pork and poultry have a favourable balance between polyunsaturated and saturated fatty acids (Wood & Enser, 1997). According to the American Heart Association (2001) saturated fatty acids raise total and low-density lipoprotein

cholesterol levels, whereas C18:0 and monounsaturated fat are neutral when substituted for carbohydrate, and n-6 polyunsaturated fatty acids lower cholesterol.

Manipulation of the fatty acid content of muscle can be very beneficial by improving the nutritional balance by increasing the polyunsaturated to saturated fatty acid value and reducing the n-6 to n-3 polyunsaturated level (Wood *et al*., 1999). Ajuyah *et al*. (1991) showed that the use of linseed oil or whole linseed in poultry diets resulted in tissue enrichment of n-3 PUFA (C20: 5n-3 and C22: 6n-3) derived from C18: 3n-3 by desaturation and elongation. Hulan *et al*. (1989) indicated that marine oils and fishmeal containing residual lipid increased the C20 and C22 n-3 PUFA concentration of poultry tissue. However with the exception of the work of Coetzee & Hoffman (2002) very little data is available on the use of canola that verifies the effects of locally produced grains on the lipid composition of broilers.

In this study the changes in the fatty acid profiles of the fat pads of the broilers fed sweet lupins, canola oilcake and full-fat canola was determined.

7.3 Materials and Methods

Two mechanically ventilated broiler houses were used. Wood shavings were used as litter material. Each pen had four tube feeders and one automatic water drinker. The lighting programme was 24 hours-bright light for the first three days and thereafter dimmed lights (23L: 1D) to the end of the trial.

The initial temperature under the brooders of each pen was 33°C and the temperature was gradually decreased until 22°C was reached, on day 28. A single thermostat controlled the heaters.

Eighty-five broilers were randomly distributed into each of the sixty floor pens. The stocking density was 21 birds per m^2. The ingredient compositions of the experimental diets that were fed *ad libitum* are shown in Tables 7.1 & 7.2.

Table 7.1 Ingredient composition of experimental starter diets provided to broilers from hatching up to 21 days of age.

Ingredient Composition (kg/ton, as fed)	Starter diets			
	Basal	Full-fat canola	Canola oilcake	Sweet Lupins
Maize meal	667.6	377.2	602.8	573.4
Acid oil	10.2	0.0	30.0	30.0
Gluten 60	20.0	0.0	20.0	20.0
Fish meal	80.0	80.0	106.5	81.2
Wheaten bran	0.0	215.0	0.0	0.0
Soybean oilcake	193.1	103.6	20.0	64.7
Full-fat canola	0.0	200.0	0.0	0.0
Canola oilcake	0.0	0.0	200.0	0.0
Sweet lupines	0.0	0.0	0.0	200.0
Limestone	12.3	11.3	10.0	12.2
Monocalcium phosphorus	8.9	6.6	4.8	8.9
Synthetic Lysine	2.0	1.1	1.8	2.6
Synthetic Methionine	2.2	2.1	1.4	3.3
Synthetic Threonine	0.7	0.7	0.6	0.9
Fine Salt	1.1	0.7	0.4	1.1
Cholclor	0.9	0.7	0.7	0.7
Vitamin Premix	1.0	1.0	1.0	1.0
Calculated nutrient composition				
ME, MJ/kg Feed	13.00	13.00	13.00	13.00
Crude Protein, %	20.50	20.50	20.50	20.50
Lysine, %	1.12	1.12	1.12	1.12
Methionine, %	0.54	0.53	0.53	0.58
Total Sulphur Amino Acids, %	0.81	0.82	0.81	0.81
Threonine, %	0.74	0.74	0.74	0.74
Tryptophan, %	0.21	0.23	0.19	0.19
Arginine, %	1.06	1.14	0.93	1.25
Calcium, %	0.95	0.95	0.95	0.95
Phosphorus, %	0.45	0.45	0.45	0.45

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Table 7.2 Ingredient compositions of experimental starter diets provided to broilers from 21 days of age up to slaughtering at 42 days of age.

Ingredient Composition (kg/ton, as fed)	Grower/Finishing diets			
	Basal	Full-fat canola	Canola oilcake	Sweet Lupins
Maize meal	657.8	481.8	628.3	597.9
Acid oil	37.8	0.0	0.0	45.0
Gluten 60	20.0	0.0	9.9	20.0
Fish meal	30.0	30.0	98.2	62.9
Wheaten bran	0.0	112.0	0.0	0.0
Soybean oilcake	220.1	146.4	0.0	43.4
Full-fat canola	0.0	200.0	0.0	0.0
Canola oilcake	0.0	0.0	200.0	0.0
Sweet lupines	0.0	0.0	0.0	200.0
Limestone	14.0	12.9	10.2	12.9
Monocalcium phosphorus	11.0	9.1	3.4	8.4
Synthetic Lysine	2.3	1.3	1.3	2.5
Synthetic Methionine	2.0	1.9	1.0	2.8
Synthetic Threonine	0.8	0.7	0.4	0.9
Fine Salt	2.5	2.2	0.6	1.6
Cholclor	0.7	0.7	0.7	0.7
Vitamin Premix	1.0	1.0	1.0	1.0
Calculated nutrient composition				
ME, MJ/kg Feed	13.40	13.40	13.40	13.40
Crude Protein, %	18.50	18.50	18.50	18.50
Lysine, %	0.98	0.98	0.98	0.98
Methionine, %	0.46	0.45	0.46	0.50
Total Sulphur Amino Acids, %	0.71	0.74	0.71	0.72
Threonine, %	0.67	0.67	0.67	0.67
Tryptophan, %	0.20	0.20	0.17	0.17
Arginine, %	0.99	1.05	0.83	1.14
Calcium, %	0.90	0.90	0.90	0.90
Phosphorus, %	0.40	0.40	0.40	0.40

The experimental diets were then blended to create 10 diets containing 6.6%, 13.2% and 20% of the alternative protein sources as shown in Table 7.3.

Table 7.3 Composition of experimental diets fed to the broiler chickens

Diet no	Composition	
1	100 Lupin diet	: 0 Control diet (20% Lupin diet)
2	67 Lupin diet	: 33 Control diet (13.2% Lupin diet)
3	33 Lupin diet	: 67 Control diet (6.6% Lupin diet)
4	100 Canola diet	: 0 Control diet (20% Canola oilcake diet)
5	67 Canola diet	: 33 Control diet (13.2% Canola oilcake diet)
6	33 Canola diet	: 67 Control diet (6.6% Canola oilcake diet)
7	100 Full-fat Canola diet	: 0 Control diet (20% Full-fat canola diet)
8	67 Full-fat Canola diet	: 33 Control diet (13.2% Full-fat canola diet)
9	33 Full-fat Canola diet	: 67 Control diet (6.6% Full-fat canola diet)
10	Control diet (Soybean oilcake diet)	

Six replicate pens were used per treatment. Two types of diets were given, a starter and a grower/ finisher. The starter diet was fed from day old up to 21 days of age and grower/finisher diet was fed up to 42

days of age, when the birds were slaughtered. The ingredients and nutrients of the diets are shown in Tables 7.2 and 7.3.

The birds were weighed and their feed intake calculated, per pen, at day old and every week thereafter until 42 days of age, when the birds were slaughtered. Production and growth performance of the broilers have been described previously (Chapter 1).

Six birds from each treatment were slaughtered at 42 days of age. The abdominal fat pad was removed and minced. The lipids in the abdominal fat pads and feed were analysed for fatty acid content. Fatty acid methyl esters (FAME) were prepared according to Morrison & Smith (1964). The FAME were analysed with a GLC: Varian Model 3300, equipped with flame ionisation detection and two 30 m fused silica megabore DB-225 columns of 0.53 mm internal diameter (J & W Scientific, Folsom, CA). Gas flow rates were: hydrogen, 25 ml/min; air, 250 ml/min; and nitrogen (carrier gas), 5-8 ml/min. Temperature programming was linear at 4°C/min with an initial temperature of 160°C and a final temperature of 220°C which was held for 10 min. Injector temperature, 240°C and the detector temperature, 250°C. The FAME was identified by comparison of the retention times to those of a standard FAME mixture (Nu-Chek-Prep Inc., Elysian, Minnesota).

An analysis of variance and regression analysis was conducted, with the protein sources as main effects; to evaluate the fatty acid data collected using Statgraphics 5.1 (1991).

7.3 Results & Discussion

The results of the growth performance of these broilers are discussed in Chapter 1. The fatty acid profiles of the diets were calculated by using literature values for maize, fishmeal, Gluten 60 and wheaten bran (Centraal Veevoederbureau, 1998). The values for lupins, canola oilcake, full-fat canola and soybean oilcake meal were determined by laboratory analysis. The fatty acid profiles of the feeds are expressed as a percentage of the total diet as can be seen in Table 7.4.

Table 7.4 The calculated fatty acid profiles of the different test diets as a % of the diet

Diet	C14:0 %	C16:0 %	C16: 1 %	C18:0 %	C18: 1 %	C18: 2 %	C18: 3 %	>C20 %
20% Lupins	0.05	0.37	0.05	0.12	0.80	1.13	0.03	0.30
13.2% Lupins	0.05	0.38	0.05	0.12	0.82	1.19	0.03	0.30
6.6% Lupins	0.05	0.39	0.05	0.12	0.83	1.25	0.03	0.29
20% Full-fat canola	0.05	0.38	0.05	0.16	0.65	1.04	0.05	0.29
13.2% Full-fat canola	0.05	0.39	0.05	0.14	0.72	1.13	0.04	0.29
6.6% Full fat canola	0.05	0.40	0.05	0.13	0.78	1.22	0.03	0.29
20% Canola oilcake	0.06	0.41	0.06	0.14	0.81	1.18	0.03	0.38
13.2% Canola oilcake	0.06	0.41	0.06	0.13	0.82	1.22	0.03	0.35
6.6% Canola oilcake	0.05	0.40	0.06	0.12	0.84	1.26	0.03	0.32
Control	0.05	0.40	0.05	0.11	0.85	1.30	0.03	0.29

The fatty acid profiles for the saturated fatty acids of the fat pads of the test birds on the different diets are shown in Table 7.5. The birds fed the diets containing lupins had significantly ($P \leq 0.05$) more SFA

in the fat pads, compared to the birds fed the full-fat canola containing diets. These results are in accordance with what was expected, as it is well known that the fatty acids profiles are affected by the feed animals receive. Therefore it was expected that the broilers fed the lupin containing diets would have a higher SFA content because lupins contain greater amounts of SFA. The SFA content of the fat pads of the birds fed the 20% and 13.2% canola oilcake containing diets was also significantly ($P \leq 0.05$) higher compared to the birds fed the full-fat canola containing diets.

Table 7.5 Fatty acid profiles (%) of saturated fatty acids (SFA) in the fat pad of broilers fed diets with increasing levels of lupins, canola oilcake or full-fat canola (as % of total fatty acids)

Diet	C14:0%	C16:0%	C18:0%	C20:0%	C22:0%	C24:0%	SFA%
20.0% Lupins	0.70	24.28^{a}	6.70^{abc}	0.13^{a}	0.04	0.02	31.87^{ab}
13.2% Lupins	0.80	23.76^{a}	7.53^{abc}	0.14^{ab}	0.05	0.01	32.25^{a}
6.6% Lupins	0.67	23.01^{ab}	7.67^{bc}	0.16^{bcd}	0.07	0.02	31.60^{ab}
20.0% Canola oilcake	0.66	22.43^{ab}	8.06^{c}	0.16^{abcd}	0.06	0.01	31.37^{ab}
13.2% Canola oilcake	0.83	23.27^{a}	7.13^{abc}	0.16^{abc}	0.05	0.03	31.46^{ab}
6.6% Canola oilcake	0.66	20.98^{abc}	6.08^{a}	0.13^{ab}	0.03	0.01	27.91^{abc}
20.0% Full-fat canola	0.61	16.74^{cd}	6.24^{ab}	0.19^{d}	0.07	0.02	23.87^{c}
13.2% Full-fat canola	0.41	16.11^{d}	6.49^{ab}	0.17^{cd}	0.04	0.01	23.24^{c}
6.6% Full-fat canola	0.39	17.51^{cd}	6.31^{ab}	0.16^{abcd}	0.06	0.02	24.44^{c}
Control	0.49	18.9^{bcd}	6.59^{abc}	0.17^{bcd}	0.05	0.03	26.23^{bc}
SEm	0.15	1.46	0.51	0.012	0.014	0.010	1.98

$^{a-e}$ Column means with common superscripts do not differ ($P \leq 0.05$)

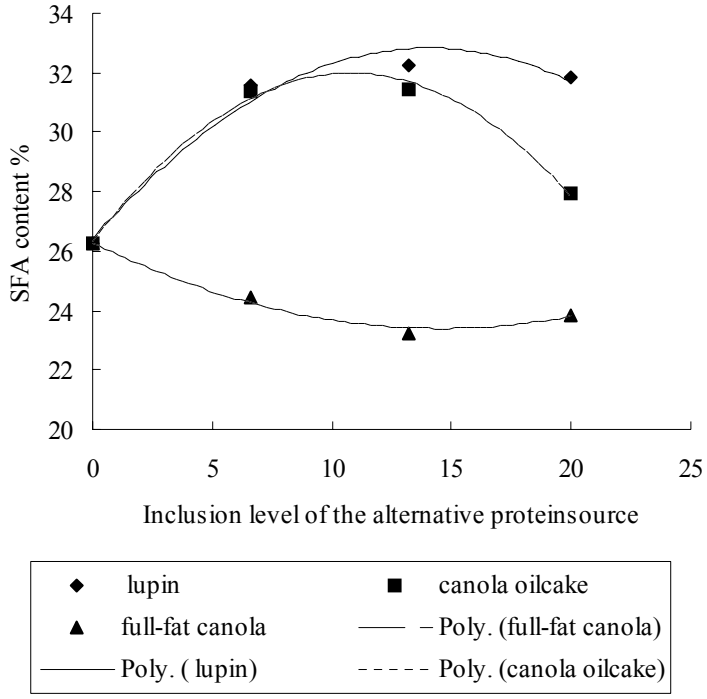


Figure 7.1 The effect of lupin ($y = -0.033x^2 + 0.913x + 26.421$; $R^2 = 0.971$; Sxy = 2.13), full-fat canola ($y = -0.014x^2 - 0.399x + 26.291$; $R^2 = 0.985$; Sxy = 0.887) and canola oilcake ($y = -0.049x^2 + 1.05x + 26.31$; $R^2 = 0.994$; Sxy = 3.09) dietary inclusion on SFA content of the fat pad of broilers.

Regression analysis of the data revealed that the changes in SFA content of the fat pad of the broilers was best described by curvilinear models in the case of lupins, canola oilcake and full-fat canola as seen in Figure 7.1. The SFA content of the fat pad of the broilers decreased curvilinear as the inclusion level of full-

fat canola increased ($y = -0.014x^2 - 0.399x + 26.291$; $R^2 = 0.985$; Sxy = 0.887). Again this is as is expected due to the lower levels of SFA present in full-fat canola. The SFA content of the fat pad of the broilers increased curve linearly when fed the lupin containing diets but at an inclusion of greater than 15% the SFA content started decreasing. The increase in the SFA content of the fat pads of these broilers is the result of the higher SFA content of the lupins they were fed. The SFA content of the fat pads of the birds fed canola oilcake containing diets follow a pattern similar to the lupin fed birds but the curvilinear decrease occurs at much lower inclusion levels and the decrease is much more pronounced. The fatty acid composition of the muscle and adipose tissue of particularly monogastric animals can be altered considerably by changes in the fatty acid composition of the diet (Hargis & Van Elswyk, 1993). The adipose tissue of broilers has been shown to be more affected by dietary lipid composition than breast muscle, presumably due to the lipid storage function of the adipose tissue (Yau *et al*. 1991).

The fatty acid profiles for the saturated fatty acids of the test ingredients in this trial: lupins, canola oilcake, full-fat canola and soybean oilcake meal are shown in Table 7.6. These values are percentages of the total chemical composition therefore the values for full-fat canola are higher because of a higher fat content in the seed. The higher level of SFA present in lupins explains the higher SFA content of the fat pads of broilers fed lupin diets.

Table 7.6 Fatty acid profiles of saturated fatty acids (%) (SFA) for different test ingredients (as % of chemical composition)

Diet	C14:0%	C16:0%	C18:0%	C20:0%	C22:0%	C24:0%	SFA%
Sweet Lupins	0.48	11.96	26.30	0.00	0.03	0.05	38.81
Canola oilcake	0.73	11.41	36.18	0.04	0.05	0.04	48.43
Full-fat canola	0.44	9.42	42.48	0.28	0.10	0.02	52.74
Soya oilcake	0.44	13.84	25.59	0.31	0.05	0.02	40.24

The fatty acid profiles for the monounsaturated fatty acids of the fat pads of the test birds on the different diets are shown in Table 7.7 and the fatty acid profiles for the monounsaturated fatty acids of the lupins, canola oilcake, full-fat canola and soybean oilcake meal are shown in Table 7.8. There were no significant differences ($P \leq 0.05$) between the MUFA profiles for the different treatments.

Table 7.7 Fatty acid profiles of monounsaturated fatty acids (%)(MUFA) in the fat pad of broilers fed diets with increasing levels of lupins, canola oilcake or full-fat canola (as % of total fatty acids)

Diet	C16: 1n7%	C18: 1n9%	C20: 1n9%	C24: 1n9%	MUFA%
20.0% Lupins	6.36^{a}	41.78^{ab}	0.37^{a}	0.08^{ab}	48.59
13.2% Lupins	5.62^{ab}	40.03^{ab}	0.37^{a}	0.02^{a}	46.04
6.6% Lupins	4.94^{bc}	40.38^{ab}	0.45^{ab}	0.04^{ab}	45.81
20.0% Canola oilcake	3.95^{cd}	40.89^{ab}	0.46^{ab}	0.05^{ab}	45.35
13.2% Canola oilcake	5.3^{ab}	38.85^{a}	0.40^{a}	0.05^{ab}	44.64
6.6% Canola oilcake	5.04^{bc}	42.09^{ab}	0.46^{ab}	0.06^{ab}	47.65
20.0% Full-fat canola	2.73^{ef}	42.15^{ab}	0.68^{c}	0.2^{ab}	45.66
13.2% Full-fat canola	2.28^{f}	46.30^{b}	0.67^{c}	0.07^{ab}	49.31
6.6% Full-fat canola	3.14^{def}	45.39^{ab}	0.62^{bc}	0.05^{ab}	49.21
Control	3.59^{de}	44.50^{ab}	0.55^{abc}	0.12^{b}	48.75
SEm	0.41	2.52	0.064	0.033	2.32

$^{a-e}$ Column means with common superscripts do not differ ($P \leq 0.05$)

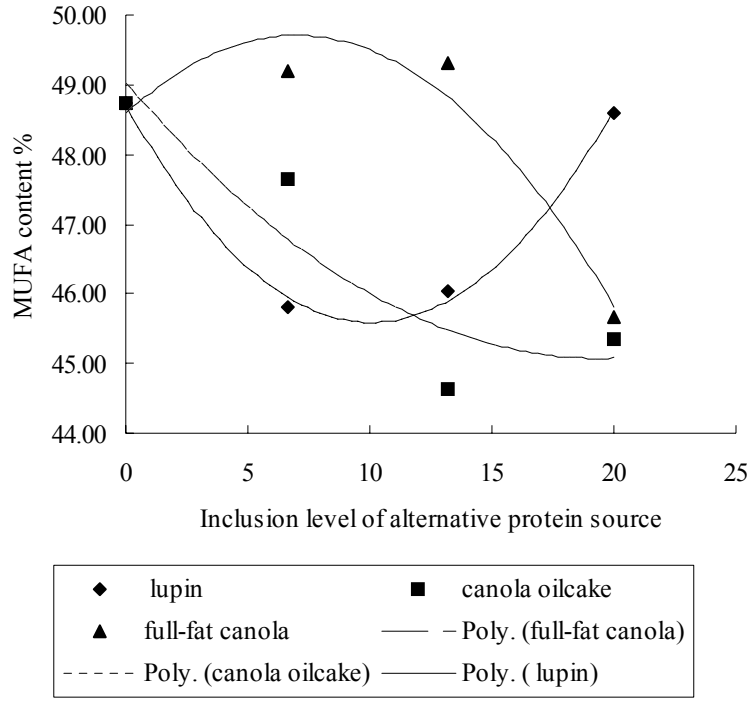


Figure 7.2 The effect of lupin ($y = 0.031x^2 - 0.619x + 48.701$; $R^2 = 0.994$; Sxy = 1.946), full-fat canola ($y = -0.023x^2 + 0.322x + 48.584$; $R^2 = 0.941$; Sxy = 1.538) and canola oilcake ($y = 0.011x^2 - 0.408x + 49.035$; $R^2 = 0.858$; Sxy = 1.110) dietary inclusion on MUFA content of the fat pad of broilers.

Regression analysis of the data revealed that the changes in MUFA content of the fat pad of the broilers was best described by curvilinear models in the case of lupins, canola oilcake and full-fat canola as seen in Figure 7.2. The MUFA content of the fat pad of the broilers, in the case of lupins replacing soybean oilcake, decreased curve linearly at the lower inclusion rate. However the MUFA content of the fat pad of the broilers increased at the two higher inclusion levels of lupins. In the case of soybean oilcake being replaced with full fat canola, the regression analysis showed that the MUFA content of the fat pad of the broilers increased curve linearly at the lower inclusion levels and decreased curve linearly at the higher inclusion levels. Where soybean oilcake was replaced with canola oilcake the MUFA content of the fat pad of the broilers decreased curve linearly.

Table 7.8 Fatty acid profiles of monounsaturated fatty acids (MUFA) for different test ingredients (as % of total fatty acids)

Diet	C16: 1n7%	C18: 1n9%	C20: 1n9%	C24: 1n9%	MUFA%
Sweet Lupins	0.53	55.83	0.17	0.01	56.55
Canola oilcake	0.8	44.13	0.14	0.02	45.08
Full-fat canola	0.69	33.11	0.11	0.03	33.94
Soya oilcake	0.65	51.14	0.08	0.02	51.91

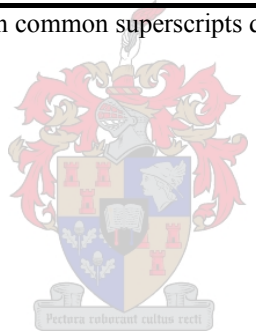
The fatty acid profiles for the polyunsaturated fatty acids (PUFA) of the fat pads of the test birds on the different diets are shown in Table 7.9 and the fatty acid profiles for the PUFA of the lupins, canola oilcake, full fat canola and soybean oilcake meal are shown in Table 7.10. The PUFA showed significant

differences for the diets. The full-fat canola diets were higher in PUFA than the other diets containing canola oilcake and lupins. The lupin diets showed the lowest values for PUFA. Canola seeds are high in fat (41-43%) and α-linolenic acid (8-12%) (Ajuyah *et al.*, 1991). The α-linolenic acid is an n-3 (omega-3) fatty acid. PUFA's especially those of the *n*-3 series have particular beneficial effects on human health by lowering blood cholesterol levels (Wood *et al.*, 1999). Therefore the emphasis in human nutrition is to reduce the intake of SFA and moderate intake of n-3 fatty acids.

Table 7.9 Fatty acid profiles of polyunsaturated fatty acids (%)(PUFA) in the fat pad of broilers fed diets with increasing levels of lupins, canola oilcake or full-fat canola (as % of total fatty acids)

Diet	C18: 2n6%	C18: 3n6%	C18: 3n3%	C20: 2n6%	C20: 4n6%	C20: 5n3%	C22: 4n6%	C22: 5n3%	PUFA%
20.0% Lupins	16.9^{a}	0.12^{a}	0.77^{a}	0.11^{a}	0.36^{a}	0.45	0.07^{a}	0.24^{a}	19.54
13.2% Lupins	18.42^{ab}	0.13^{a}	0.9^{ab}	0.13^{ab}	0.49^{abc}	0.53	0.08^{a}	0.33^{b}	21.71
6.6% Lupins	18.85^{b}	0.11^{a}	1.64^{abc}	0.14^{ab}	0.48^{abc}	0.39	0.09^{a}	0.31^{bc}	22.59
20.0% Canola oilcake	19.21^{bc}	0.11^{a}	1.74^{abc}	0.16^{bcd}	0.45^{abc}	0.47	0.08^{a}	0.38^{bcd}	23.28
13.2% Canola oilcake	20.08^{bc}	0.13^{a}	1.71^{abc}	0.14^{ab}	0.14^{ab}	0.42	0.08^{a}	0.29^{cde}	23.91
6.6% Canola oilcake	19.73^{bc}	0.14^{a}	2.52^{bcd}	0.13^{ab}	0.52^{bcd}	0.42	0.09^{a}	0.28^{de}	24.44
20.0% Full-fat canola	23.66^{d}	0.21^{b}	3.78^{d}	0.202^{d}	0.81^{f}	0.46	0.15^{b}	0.37^{h}	30.47
13.2% Full-fat canola	21.1^{c}	0.15^{a}	4.02^{d}	0.196^{cd}	0.71^{ef}	0.27	0.15^{b}	0.3^{g}	27.45
6.6% Full-fat canola	20.37^{bc}	0.14^{a}	3.62^{d}	0.198^{d}	0.63^{de}	0.32	0.16^{b}	0.32^{fg}	26.35
Control	19.92^{bc}	0.13^{a}	2.85^{cd}	0.15^{abc}	0.58^{cde}	0.25	0.10^{a}	0.26^{ef}	25.35
SEm	0.66	0.015	0.58	0.016	0.047	0.127	0.015	0.055	0.55

[a-e] Column means with common superscripts do not differ ($P \leq 0.05$)



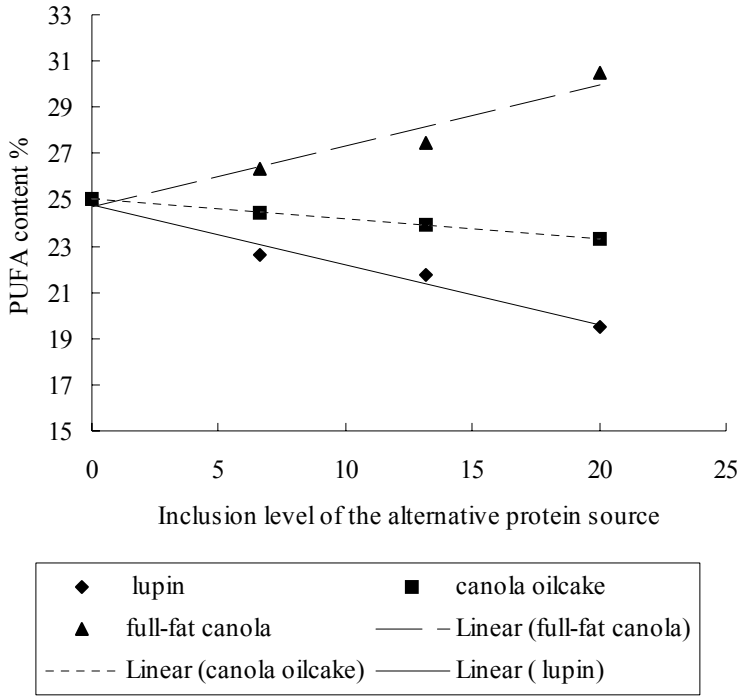


Figure 7.3 The effect of lupin (y = -0.26x + 24.80; R^2 = 0.973; Sxy = 0.45), full-fat canola (y = 0.263x + 24.711; R^2 = 0.945; Sxy = 0.667) and canola oilcake (y = -0.086x + 25.022; R^2 = 0.999; Sxy = 0.024) dietary inclusion on PUFA content of the fat pad of broilers.

Regression analysis of the data on the PUFA content of the fat pad of the broilers revealed that in the case of lupins replacing soybean oilcake, the PUFA content of the fat pad of the broilers decreased linearly (best fit model) as the level of lupin inclusion increased (y = -0.260x + 24.803; R^2 = 0.973; Sxy = 0.454) as seen in Figure 7.3. For each percentage increase in lupin inclusion the PUFA content of the fat pad of the broilers decreases by 26.01%. When soybean oilcake was replaced by canola oilcake the PUFA content of the fat pad of the broilers also decreased linearly as the inclusion level of canola oilcake increased (y = -0.086x + 25.022; R^2 = 0.999; Sxy = 0.024). For each percentage increase in canola oilcake, inclusion the PUFA content of the fat pad of the broilers decreases by 8.63%. In the case of full fat canola replacing soybean oilcake, the PUFA content of the fat pad of the broilers increased linearly as the inclusion level of full fat canola increased (y = 0.263x + 24.711; R^2 = 0.945; Sxy = 0.667). For each percentage increase in full fat canola inclusion the PUFA content of the fat pad of the broilers increases by 26.3%. This study shows that it is possible to enrich poultry meat with PUFA.

Table 7.10 Fatty acid profiles of polyunsaturated fatty acids (%) (PUFA) for different test ingredients (as % of total fatty acids)

Diet	C18: 2n6%	C18: 3n6%	C18: 3n3%	C20: 2n6 %	C20: 4n6 %	C20: 5n3 %	C22: 4n6 %	C22: 5n3 %	PUFA %
Sweet Lupins	3.32	0.21	0.03	0.01	0.78	0.01	0.14	0.02	4.59
Canola oilcake	4.73	0.28	0.13	0.01	0.99	0.02	0.14	0.01	6.46
Full-fat canola	10.18	1.18	0	0.66	0.47	0	0.25	0	12.75
Soya oilcake	5.26	0.81	0	0.29	0.89	0	0.1	0	7.50

In a study by Ajuyah *et al*. (1991), a diet containing 20% full-fat canola seed fed to broilers resulted in a substantial tissue and carcass enrichment of n-3 fatty acids. Similar results were found by Nwokolo & Sim (1989), where chicks fed raw full-fat canola seed had elevated levels of polyunsaturated fatty acids, linoleic and linolenic acids in tissue lipids. Coetzee & Hoffman (2002) found that feeding canola oil to broiler chickens increased the PUFA content of the abdominal fat pads of the broilers and reduced the SFA content. These results confirm what was found in the present study. Increasing PUFA levels may also change flavour because of their greater susceptibility to oxidative breakdown and the generation of abnormal volatile compounds during cooking (Wood *et al*., 1999). The fatty acid content of poultry meat contributes to the flavour and odour of poultry meat. Susceptibility of poultry meat to oxidation depends on the degree of unsaturation of its fatty acid profile. Increasing the PUFA content of poultry meat to improve human health through dietary manipulation causes oxidative stress (Malan, 2003); this may cause unacceptable flavours due to rancidity. In a study done by Mieczkowska *et al.* (1999) the proportion of fatty acids of n-6 to n-3 was reduced in the carcass lipids of birds fed the lupin diets. Long-chain saturated fatty acids of the lupins did not accumulate in the carcass lipids.

Pectora roborant cultus recti

From Table 7.11 it is evident that a noticeable difference exists in the ratio between saturated and unsaturated fatty acids in the fat pad of the chickens fed the lupin diets and the chickens fed the full fat canola diets. The fat pads of broilers fed the full-fat canola diets had higher unsaturated fatty acid ratios compared to those birds fed the sweet lupin or canola oil cake diets. These correlate with the fatty acid profiles of sweet lupins, canola oil cake and full fat canola. This confirms that the dietary fatty acids are absorbed by monogastric animals and deposited in tissues without significant modification (Moran, 1996).

Table 7.11 The ratio between for the saturated fatty acids and unsaturated fatty acids diets and raw materials.

Diet	Saturated Fatty Acids: Unsaturated Fatty Acids
100 Lupin diet: 0 Basal diet	1.63
67 Lupin diet: 33 Basal diet	1.49
33 Lupin diet: 67 Basal diet	1.4
100 Canola diet: 0 Basal diet	1.35
67 Canola diet: 33 Basal diet	1.32
33 Canola diet: 67 Basal diet	1.14
100 Full-fat Canola diet: 0 Basal diet	0.78
67 Full-fat Canola diet: 33 Basal diet	0.85
33 Full-fat Canola diet: 67 Basal diet	0.93
Basal diet	1.05
Sweet Lupins	8.45
Canola oilcake	7.5
Full fat canola	4.14
Soya oil cake	5.37

The diets with sweet lupins and canola oilcake showed fatty acid profiles with significantly higher levels of palmitic acid (C16:0) than the basal and full-fat canola diet. This difference can also be seen in the fatty acid profile of the sweet lupins, canola oilcake and the full-fat canola. The diets with full-fat canola showed significantly higher profiles for α-linolenic acid (C18: 3n3) and arachidonic acid (C22: 4n6) (Mieczkowska, *et al.*, 1999).

7.5 Conclusion

This study found that the fatty acid profiles of the fat pads of broilers could be altered by the replacement of soybean oilcake meal as protein source with sweet lupins, canola oil cake or full fat canola as protein sources. The broilers consuming diets containing sweet lupins were found to have higher levels of saturated fatty acids in the fat pads. Feeding broilers diets containing full-fat canola increased the poly-unsaturated fatty acid content of the fat pads of the broilers. Increasing polyunsaturated fatty acid levels in the fatty acid profile of the fats pads of broilers fed full-fat canola diets render it healthier for human consumption. Therefore should full-fat canola be fed to broilers as an alternative protein source, some value would be added to the meat of the broilers due to the higher poly-unsaturated fatty acid content.

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Chapter 8

The influence of different protein sources on the growth and carcass composition of commercially reared pigs

8.1 Abstract

The effect of replacing soybean oilcake as protein source with different levels of sweet lupins (*Lupinus angustifolius*), canola oilcake and full-fat canola was examined. A basal diet with soybean oilcake (0% test source) as protein source was mixed with a diet containing either lupins or canola oilcake or full fat canola as protein source at an inclusion level of 25% of the total diet.

The pigs fed the test diet containing 25.00% lupins, had a final body weight significantly lighter than the final body weight of the pigs fed the other test diets. The pigs fed the test diet containing 25.00% lupins, also had a significantly reduced average daily gain and feed intake. The feed intake of the 25.00% canola oilcake diet was significantly lees than the feed intake of the 16.75% full-fat canola containing diet. The feed conversion ratio of the 25.00% lupin containing diet was significantly poorer than the feed conversion ratio of the 16.75% lupin containing diet, 8.25% lupin containing diet, 16.75% full-fat canola containing diet, 25.00% canola oilcake containing diet and the control diet. The warm carcass mass of the pigs consuming the test diet containing 25.00% lupins was significantly lighter than the warm carcass mass of the pigs consuming the other diets. The warm carcass mass of the pigs consuming the test diet containing 16.75% full-fat canola was significantly heavier than the warm carcass mass of the pigs consuming the control diet and the test diet containing 8.25% canola oilcake meal. The same pattern is shown for the cold carcass mass. In the case of the P2 fat depth the only significant difference was between the 8.25% canola oilcake containing diet and the 16.75% canola oilcake containing diet. The carcasses of the pigs that were fed the 8.25% lupin containing diet were significantly leaner than the carcasses of the pigs that were fed the 16.75% canola oilcake containing diet. The fatty acid content of the carcass fat and muscle of pigs raised on the different diets was determined. The pigs fed the test diet containing 25.00% lupins, had a final body weight significantly lighter than the final body weight of the pigs fed the other test diets. Similar result can be seen for average daily gain and the feed intakes of the pigs. The pigs fed the 25.00% canola oilcake containing diet contained significantly less saturated fatty acids in their muscle and subcutaneous fat. There were no significant differences in the mono-unsaturated fatty acid content of the subcutaneous fat of the pigs. The pigs fed the 25.00% full-fat canola containing diet, contained significantly more polyunsaturated fatty acids in the subcutaneous fat.

Keywords: Pigs, fatty acid profiles, sweet lupins, full-fat canola, canola oilcake

8.2 Introduction

The development of low erucic acid, low glucosinolate cultivars of canola seed has led to the availability of a feed ingredient with considerable potential to replace soybean meal in diets for all classes of swine. Canola meal is a high quality product and when properly utilized, can be used to advantage in reducing feed costs for swine producers (Thacker, 1990). The nutritive value of a protein supplement is determined to a large extent by its amino acid content. Of particular importance are the levels of lysine, threonine and the sulphur containing amino acids. These have been shown to be the most limiting amino acids in swine diets composed predominately of cereal grains (Sauer et al., 1977 as cited by Thacker, 1990).

Canola meal contains less protein, less gross energy and three times as much fibre when compared to soybean meal (Bell, 1993). The fibre, protein and oil content of canola meal will influence the metabolisable energy (ME) content of the meal. These factors are influenced by variety and seed quality as well as by processing methods (Bell, 1993).

Although lupins have a relatively high crude protein content of 35.5% (Brand *et al*. 1992), problems could arise with the use of this legume due to the presence of anti-nutritional factors. Lupins may have undesirable levels of alkaloids (Erickson, 1988) and α-galactosides (Bourdon *et al*. 1987) or manganese (Batterham, 1979 as cited by Edwards & Van Barneveld, 1998). Lupins are also known to be deficient in lysine, sulphur amino acids and tryptophan (Bourdon *et al*., 1987).

When lupins are fed to monogastrics there is a need to account for the specific physiological effects of other dietary fibre components such as oligosaccharides and soluble non-starch polysaccharides. Little work has been done to quantify the anti-nutritional effects of non-starch polysaccharides from lupins in growing pigs. It has been suggested that variable production responses to lupins may be due to the high levels of lupin non-starch polysaccharides interfering with the action of digestive enzymes and influencing microbial activity (Van Barneveld et al., 1994 as cited by Edwards & Van Barneveld, 1998).

As the pork industry strives for efficient production of increasingly leaner pigs, reduction in fat quality can occur that may adversely affect further processing, tissue separation, and storage stability. Combining extreme leanness in the pig, with diets composed of cereal grains and supplemented with fat, often high in polyunsaturated fatty acids (PUFA), in order to maximize growth and finish performance and efficiency, can result in soft pork fat (Gatlin, 2002). These pork production techniques do help to realize consumer demands for reduced total carcass fat and saturated fatty acids, but this is in conflict with the optimal physical qualities of fat desired for further processing (Gatlin, 2002). Meat has been branded as a food having a high fat content and an undesirable balance of fatty acids. But, lean meat is very low in fat and pork and poultry have a favourable balance between polyunsaturated and saturated fatty acids (Wood & Enser, 1997). Nutritional treatment can be used to manipulate the fatty acid content of muscle to improve nutritional balance by increasing the polyunsaturated to saturated fatty acid value and reduce the n-6 to n-3 polyunsaturated level (Wood *et al*., 1999). Consistency and composition of pork fat are quality concerns

(Morgan *et al*., 1994); a lower-quality product is produced due to more miscuts because of thin bellies and soft fat. It is well established that the fatty acid composition of pork is influenced by the composition of dietary fat (Seerly *et al*., 1978; Madsen et al., 1992; Miller *et al*., 1990).

Lipid oxidation is one of the primary causes of loss of quality in meat. The rate and extent of lipid oxidation are dependent on a number of factors, the most important being the level of polyunsaturates present in the muscle system (Allen & Foegeding, 1981 as cited by Coetzee, 2000).

Because the fatty acid profile of carcass lipids in pigs is easily altered, responds to changes in dietary fat composition, and has the potential to be modified to match dietary recommendations for humans, several researchers have measured the change in fatty acid composition following dietary manipulation (Koch et al., 1968; Anderson et al., 1972; Wiseman & Agunbiade, 1998).

In this study the performance of grower/finisher pigs fed diet where soybean oilcake was replaced with sweet lupins, full-fat canola and canola oilcake was evaluated. The changes in the fatty acid profiles of the subcutaneous fat and meat were also determined.

8.3 Materials and Methods

Forty-eight commercially bred Landrace X Large White pigs, with an average body weight of *ca* 25 kg, were used in the trial. The calculated ingredient compositions of the experimental diets are shown in Table 8.1. The four diets were formulated on an iso-nutrient basis. Each diet was fed to 4 individually housed pigs and each pig was weighed weekly. Dry matter intake was also determined weekly.

Pectora roborant cultus recti

Table 8.1 Ingredient composition of experimental diets provided to pigs to evaluate the effect of various levels of lupins, canola oilcake and full-fat canola on the performance of grower/finisher pigs

Ingredient Composition (kg/ton, as fed)	Test diets			
	Sweet Lupins	Canola oilcake	Full-fat canola	Full-fat soybeans
Maize meal	682.1	682.1	504.3	558.4
Sweet lupines	250.0	0.0	0.0	0.0
Canola oilcake	0.0	250.0	0.0	0.0
Full-fat canola	0.0	0.0	250.0	0.0
Full-fat soybeans	0.0	0.0	0.0	250.0
Wheaten bran	0.0	0.0	152.5	150.5
Fish meal	35.2	23.6	62.4	0.0
Acid oil	0.0	15.0	0.0	0.0
Di-calcium phosphorus	13.1	4.4	7.5	18.0
Feedlime	4.8	9.6	8.8	8.7
Synthetic Lysine	3.7	4.4	3.6	3.5
Salt	10.0	10.0	10.0	10.0
Vitamin Premix	1.0	1.0	1.0	1.0
Calculated nutrient composition				
Protein, %	16.0	16.0	16.0	16.0
Lysine, %	0.9	0.9	0.9	0.9
Methionine-Cystine, %	0.4	0.6	0.5	0.4
Tryptophan, %	0.3	0.1	0.1	0.1
Digestible Energy, MJ/kg Feed	14.2	14.0	14.4	14.1
Crude fibre, %	5.3	4.4	6.0	4.8
Fat, %	4.3	6.8	13.4	7.3
Calcium, %	0.8	0.8	1.0	1.0
Phosphorus, %	0.4	0.2	0.7	0.7

The experimental diets were then blended to create 10 diets containing 8.25%, 16.75% and 25.00% of the alternative protein sources as shown in Table 8.2.

Table 8.2 Composition of experimental diets as fed to grower/finisher pigs, to evaluate the effect of various levels of lupins, canola oilcake and full-fat canola on the performance of grower/finisher pigs

Diet no	Composition	
1	100 Lupin diet	: 0 Control diet (25.00% Lupin diet)
2	67 Lupin diet	: 33 Control diet (16.75% Lupin diet)
3	33 Lupin diet	: 67 Control diet (8.25% Lupin diet)
4	100 Canola diet	: 0 Control diet (25.00% Canola oilcake diet)
5	67 Canola diet	: 33 Control diet (16.75% Canola oilcake diet)
6	33 Canola diet	: 67 Control diet (8.25% Canola oilcake diet)
7	100 Full-fat Canola diet	: 0 Control diet (25.00% Full-fat canola diet)
8	67 Full-fat Canola diet	: 33 Control diet (16.75% Full-fat canola diet)
9	33 Full-fat Canola diet	: 67 Control diet (8.25% Full-fat canola diet)
10	Control diet (Soybean oilcake diet)	

The pigs received the diets *ad libitum* and feed intakes were measured weekly. All the pigs were slaughtered after 73 days. Feed was withheld for ten hours prior to slaughter, with water supplied until loading and transportation. Loading and transportation were done under conditions of minimal stress; electrical prodders were not used to handle the pigs. Transportation occurred in the early morning to avoid high temperatures and animals were not overcrowded. Animals spent approximately 15 minutes in transit and were kept in lairage for about an hour prior to slaughtering. The pigs were slaughtered according to

standard commercial procedures. This involved electrical stunning (250 V AC, ear to ear for 3-5 s) and sticking within 30 s. The carcasses were subsequently eviscerated and inspected by the appropriate government health official. The P_2 fat measurement was taken on each carcass with an intrascope between the second and third last rib, 45 mm from the carcass midline (Government notice no. R. 1748, 26 June 1992). This measurement was used to calculate the lean meat percentage of each carcass using the formula:

$$\text{Lean \%} = 74.4367 - 0.4023X_1$$

Where X_1 = the fat-thickness in mm

Each carcass was weighed warm and after chilling (2°C for 24 h). After chilling for 24 hours, the *M. longissimus lumborum* muscle was removed from the last rib to the beginning of the 5th lumbor vertebrae. The skin and subcutaneous fat was then separated from the muscle. The muscle and subcutaneous fat were minced twice through a 2 mm plate, vacuum packed and stored at -13°C separately, for further chemical analysis.

Fatty acid methyl esters (FAME) were prepared according to the method of Morrison & Smith (1964). The FAME were analysed with a GLC: Hewlett Packard 5890 series II equipped with flame ionisation detection and a Supelcowax-10 fused silica glass capillary column (30 m X 0.53 mm id). The carrier gas was nitrogen with a flow rate of 2 ml/min. The temperature programme was linear at 3°C/min with an initial temperature of 120°C and a final temperature of 245°C (held for 10 minutes). The FAME was identified by comparison of the retention times to those of a standard FAME mixture (Nu-Chek-Prep Inc., Elysian, Minnesota).

The fatty acid profiles of saturated fatty acid of the test diets are shown in Table 8.3. C10:00 and C15:00 were not detected in these samples.

Table 8.3 Fatty acid profiles of saturated fatty acids (%) (SFA) for different test diets

Diet	C12:0	C14:0	C16:0	C17:0	C18:0	C20:0	SFA
25.00% Lupins	0.00	0.74	20.59	0.18	3.22	0.34	25.07
16.75% Lupins	0.00	0.96	21.11	0.00	2.72	0.31	25.10
8.25% Lupins	0.00	0.00	19.89	0.12	2.82	0.00	22.83
25.00% Full-fat canola	0.02	0.63	12.02	0.00	2.58	0.39	15.64
16.75% Full-fat canola	0.02	0.57	14.25	0.00	2.21	0.39	17.44
8.25% Full fat canola	0.02	0.39	15.19	0.12	1.98	0.31	18.01
25.00% Canola oilcake	0.03	0.52	13.54	0.00	2.38	0.40	16.87
16.75% Canola oilcake	0.00	0.26	13.57	0.10	2.14	0.30	16.37
8.25% Canola oilcake	0.00	0.24	16.25	0.00	2.29	0.00	18.78
Control	0.00	0.17	2.02	0.18	2.41	0.00	4.78

Table 8.4 shows the monounsaturated fatty acids of the test diets.

Table 8.4 Fatty acid profiles of monounsaturated fatty acids (%) (MUFA) for different test diets

Diet	C16: 1	C17: 1	C18: 1	C20: 1	MUFA
25.00% Lupins	0.98	0.00	48.62	1.36	50.96
16.75% Lupins	0.89	0.00	43.59	1.38	45.86
8.25% Lupins	0.70	0.16	39.29	0.95	41.10
25.00% Full-fat canola	1.01	0.00	49.09	0.90	51.00
16.75% Full-fat canola	0.70	0.17	45.95	0.80	47.62
8.25% Full fat canola	0.61	0.00	38.73	0.00	39.34
25.00% Canola oilcake	1.28	0.18	31.08	1.12	33.66
16.75% Canola oilcake	1.30	0.00	29.12	1.32	31.74
8.25% Canola oilcake	0.51	0.09	26.16	0.00	26.76
Control	0.44	0.12	23.96	0.00	24.52

The fatty acid profiles of polyunsaturated fatty acids for test diets are shown in Table 8.5. The C20: 2, C20: 3 and C20: 4 were not detected in these samples.

Table 8.5 Fatty acid profiles of polyunsaturated fatty acids (%) (PUFA) for different test diets

Diet	C18: 2	C18: 3n6	C18: 3n3	PUFA
25.00% Lupins	26.2	0.01	6.79	33.04
16.75% Lupins	31.1	0.00	5.54	36.64
8.25% Lupins	36.1	0.00	4.77	40.83
25.00% Full-fat canola	27.2	0.02	5.19	32.40
16.75Full-fat canola	31.2	0.00	4.76	35.96
8.25% Full-fat canola	37.9	0.00	3.98	41.83
25.00% Canola oilcake	39.6	0.00	1.65	41.27
16.75% Canola oilcake	41.1	0.00	2.03	43.13
8.25% Canola oilcake	47.8	0.00	2.65	50.40
Control	50.3	0.00	2.38	52.65

The effect of the inclusion rate of each protein source tested were analysed by analysis of variance (4 diets x 4 replicates). The effect of the inclusion level of the protein source was also analysed by regression analysis and the intercepts and slopes of the regression lines were compared by analysis of variance. The effect of the inclusion rate of each of the different protein sources were also compared to each other by regression analysis. All procedures were described in detail by Statgraphics 5.1 (1991).

The effect of the diet on production parameters, carcass parameters as well as the fatty acid profiles of the carcasses were tested with one-way analysis of variance (ANOVA). The effect of the inclusion level of protein source on production parameters (average daily gain, dry matter intake and feed conversion ratio) were also compared by means of regression analysis and the regression lines were compared by ANOVA. This was done for all ten diets used in the experiments. The effect of the inclusion rate of each of the different protein sources were also compared to each other be regression analysis. All procedures are described in detail by Statgraphics 5.1 (1991).

8.3 Results & Discussion

The production performance of the grower/finisher pigs is presented in Table 8.6. The pigs fed the test diet containing 25.00% lupins, had a final body weight significantly lighter ($P \leq 0.05$) than the final body weight of the pigs fed the other test diets (Table 8.6). The pigs fed the test diet containing 25.00% lupins, also had a significantly ($P \leq 0.05$) reduced average daily gain and feed intake. The feed intake of the 25.00% canola oilcake diet was significantly ($P \leq 0.05$) less than the feed intake of the 16.75% full-fat canola diet. The feed conversion ratio of the 25.00% lupin diet was significantly ($P \leq 0.05$) poorer than the feed conversion ratio of the 16.75% lupin diet, 8.25% lupin diet, 16.75% full-fat canola diet, 25.00% canola oilcake diet and the control diet. The reduced performance could possibly due to alkaloid levels present in the lupins included in the diet, but the alkaloid level was only 0.01% and according to (Pearson & Carr, 1976) production is only adversely affected at much higher alkaloid levels. The reduced feed conversion ratio may be explained by the NSP's present in the lupins, the NSP's are not susceptible to the degradation of the endogenous enzymes of the pig. The fibre is digested in the lower digestive tract and as explained before the products of such digestion are not utilised as efficiently as the products produced higher in the alimentary canal.

Table 8.6 The effect of increasing levels of dietary lupin, full-fat canola and canola oilcake inclusion on pig performance

Diet	Final body weight (kg)	Average daily gain (kg/day)	Feed intake (kg/day)	Feed conversion ratio (kg/kg)
25.00% Lupins	$64.6^{a} \pm 4.26$	$554.8^{a} \pm 54.67$	$1.691^{a} \pm 0.12$	$3.07^{a} \pm 0.13$
16.75% Lupins	$91.6^{b} \pm 4.26$	$885.3^{b} \pm 54.67$	$2.379^{bc} \pm 0.12$	$2.69^{b} \pm 0.13$
8.25% Lupins	$92.6^{b} \pm 4.26$	$931.5^{b} \pm 54.67$	$2.433^{bc} \pm 0.12$	$2.61^{b} \pm 0.13$
25.00% Full-fat canola	$82.8^{b} \pm 4.26$	$799.7^{b} \pm 54.67$	$2.331^{bc} \pm 0.12$	$2.92^{ab} \pm 0.13$
16.75 Full-fat canola	$93.6^{b} \pm 4.26$	$927.4^{b} \pm 54.67$	$2.481^{c} \pm 0.12$	$2.69^{b} \pm 0.13$
8.25% Full fat canola	$85.1^{b} \pm 4.26$	$818.5^{b} \pm 54.67$	$2.274^{bc} \pm 0.12$	$2.81^{ab} \pm 0.13$
25.00% Canola oilcake	$83.8^{b} \pm 4.26$	$799.7^{b} \pm 54.67$	$2.135^{b} \pm 0.12$	$2.68^{b} \pm 0.13$
16.75% Canola oilcake	$82.6^{b} \pm 4.26$	$787.7^{b} \pm 54.67$	$2.179^{bc} \pm 0.12$	$2.79^{ab} \pm 0.13$
8.25% Canola oilcake	$86.0^{b} \pm 4.26$	$828.8^{b} \pm 54.67$	$2.233^{bc} \pm 0.12$	$2.74^{ab} \pm 0.13$
Control	$86.5^{b} \pm 2.46$	$853.9^{b} \pm 31.57$	$2.240^{bc} \pm 0.07$	$2.64^{b} \pm 0.07$

[a-e] Column means with common superscripts do not differ ($P \leq 0.05$)

The results of the regression analysis conducted on the lupin containing diets are presented in Table 8.7. The slopes (b) of the regression lines on average daily gain (ADG) of the pigs increased as the lupin inclusion increased. The slopes (b) of the regression lines on feed intake of the pigs decreased as the lupin inclusion increased. The slopes of the regression lines on feed conversion ratio (FCR) for the 16.75% lupins containing diet and the 8.25% lupins containing diet were similar and smaller compared to the control. The slope of the 25.00% lupin group was negative which shows that the FCR improved as the trial went on. The significantly greater intercept also supports this statement.

Table 8.7 The intercepts (a) and slopes (b) of the regression analysis of average daily gain (ADG), feed intake and feed conversion ratio (FCR) of finisher pigs fed diets containing lupins

	ADG a	ADG b	Feed Intake a	Feed Intake b	FCR a	FCR b
Control	0.550[b]	0.062[c]	8.993[b]	1.337[d]	2.667[a]	0.079[c]
25.00% Lupins	0.154[a]	0.077[d]	8.100[a]	0.772[a]	4.734[b]	-0.348[a]
16.75% Lupins	0.645[c]	0.051[b]	12.548[c]	0.876[b]	2.795[a]	0.024[b]
8.25% Lupins	0.721[d]	0.045[a]	12.112[c]	1.027[c]	2.571[a]	0.021[b]
SEm	0.126	0.007	1.111	0.123	0.516	0.098

[a-e] Column means with common superscripts do not differ (P≤ 0.05)

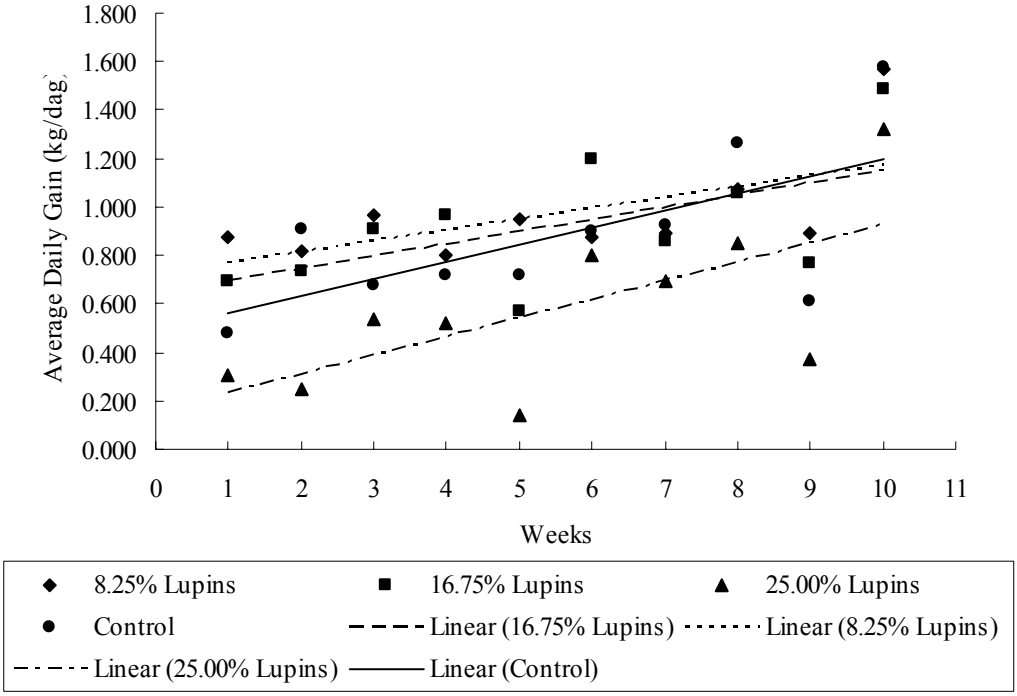

Figure 8.1 The effect of 8.25% lupin, 16.75% lupin and 25.00% lupin on the average daily gain of finisher pigs

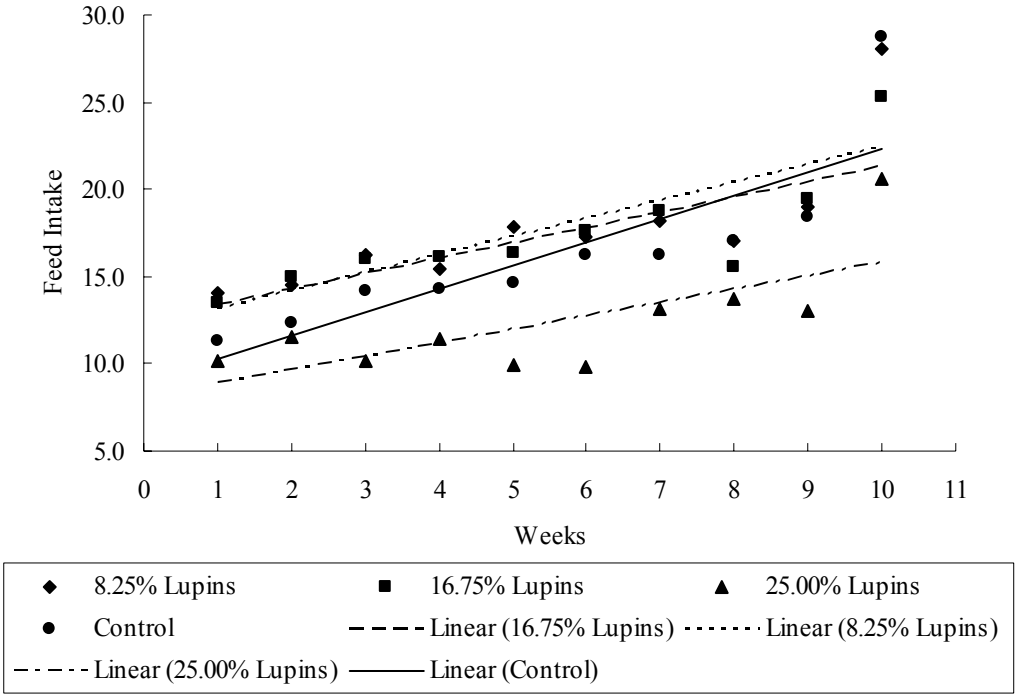

Figure 8.2 The effect of 8.25% lupin, 16.75% lupin and 25.00% lupin on the feed intake of finisher pigs

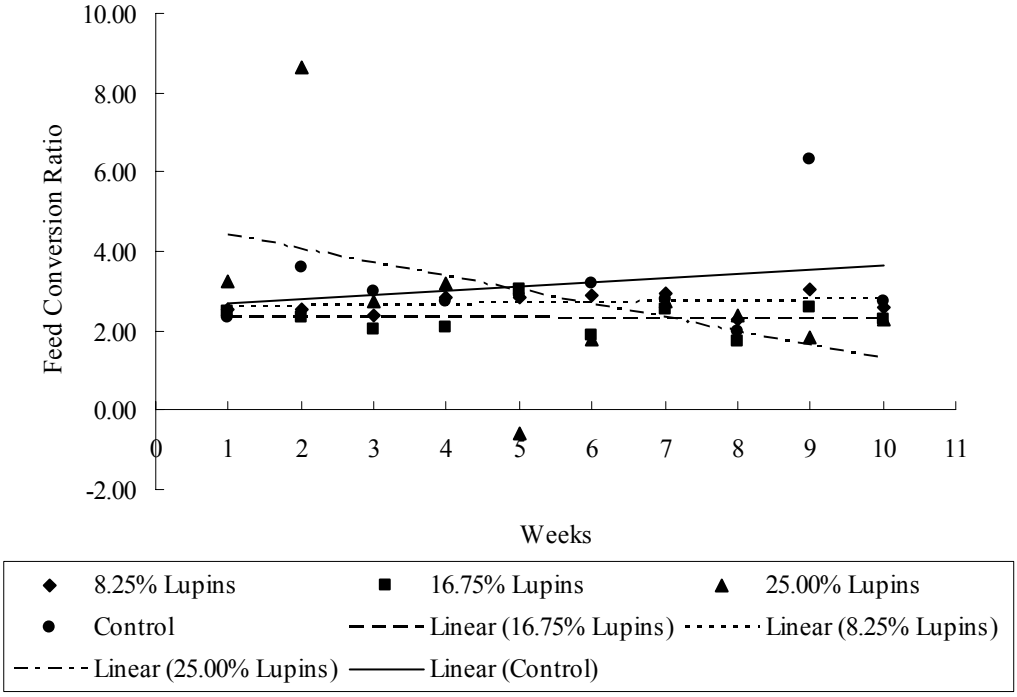

Figure 8.3 The effect of 8.25% lupin, 16.75% lupin and 25.00% lupin on the feed conversion ratio of finisher pigs

The results of the regression analysis conducted on the canola oilcake containing diets are presented in Table 8.8. The slopes (b) of the regression lines ADG of the pigs increased as the canola oilcake inclusion increased. The slopes (b) of the regression lines on feed intake of the pigs fed the control diet and the 25.00% canola oilcake diet did not differ significantly. The slope of the the 16.75% canola oilcake group was significantly smaller. The slopes of the regression lines on FCR for the control and the 8.25% canola oilcake containing diet differed significantly but were positive. The slope of the 25.00% canola oilcake and 25.00% canola oilcake group was negative which shows that the FCR improved as the trial went on.

Table 8.8 The intercepts (a) and slopes (b) of the regression analysis of average daily gain (ADG), feed intake and feed conversion ratio (FCR) of finisher pigs fed diets containing lupins

	ADG a	ADG b	Feed Intake a	Feed Intake b	FCR a	FCR b
Control	0.550^{b}	0.062^{b}	8.993^{b}	1.337^{c}	2.667^{a}	0.079^{d}
25.00% canola oilcake	0.392^{a}	0.080^{d}	8.290^{a}	1.326^{c}	2.949^{b}	-0.011^{b}
16.75% canola oilcake	0.411^{a}	0.075^{c}	10.657^{c}	0.954^{a}	4.252^{d}	-0.208^{a}
8.25% canola oilcake	0.545^{b}	0.058^{a}	10.563^{c}	1.044^{b}	3.121^{c}	0.016^{c}
SEm	0.042	0.005	0.586	0.098	0.348	0.062

$^{a-e}$ Column means with common superscripts do not differ ($P \leq 0.05$)

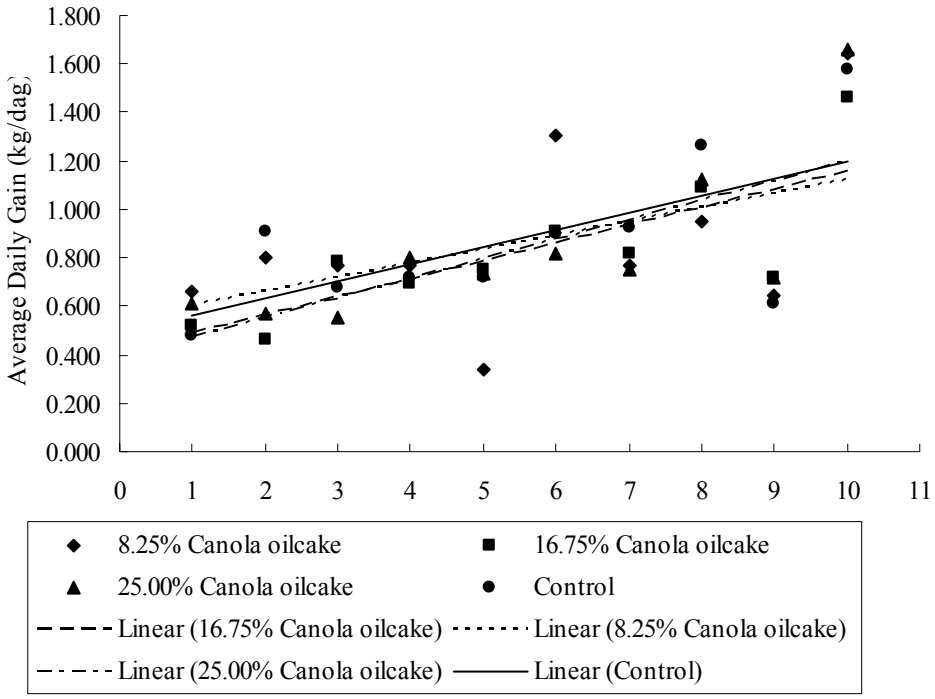

Figure 8.4 The effect of 8.25% canola oilcake, 16.75% canola oilcake and 25.00% canola oilcake on the average daily gain of finisher pigs

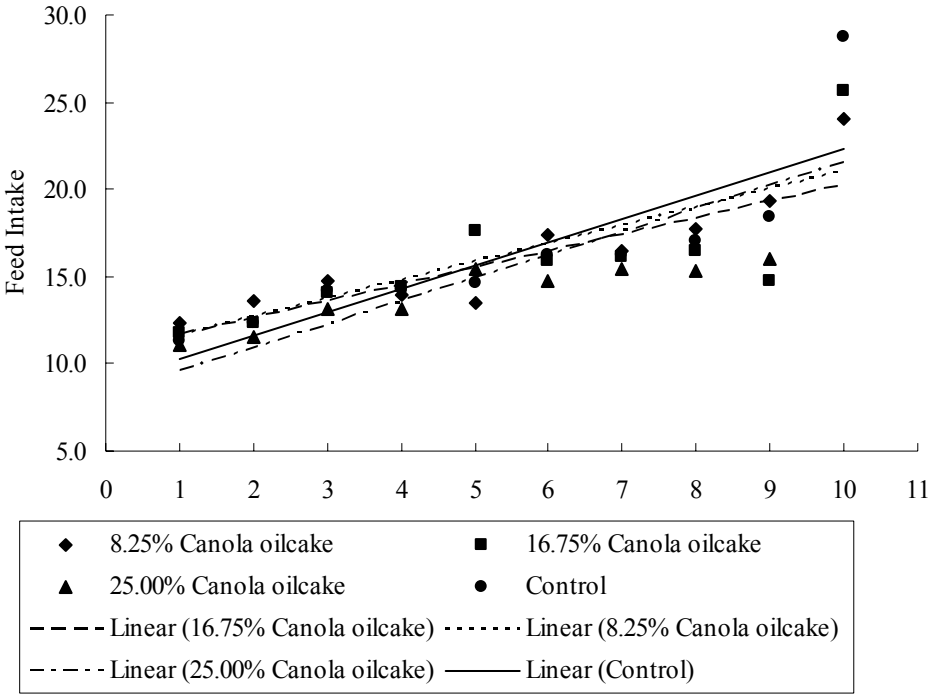

Figure 8.5 The effect of 8.25% canola oilcake, 16.75% canola oilcake and 25.00% canola oilcake on the feed intake of finisher pigs

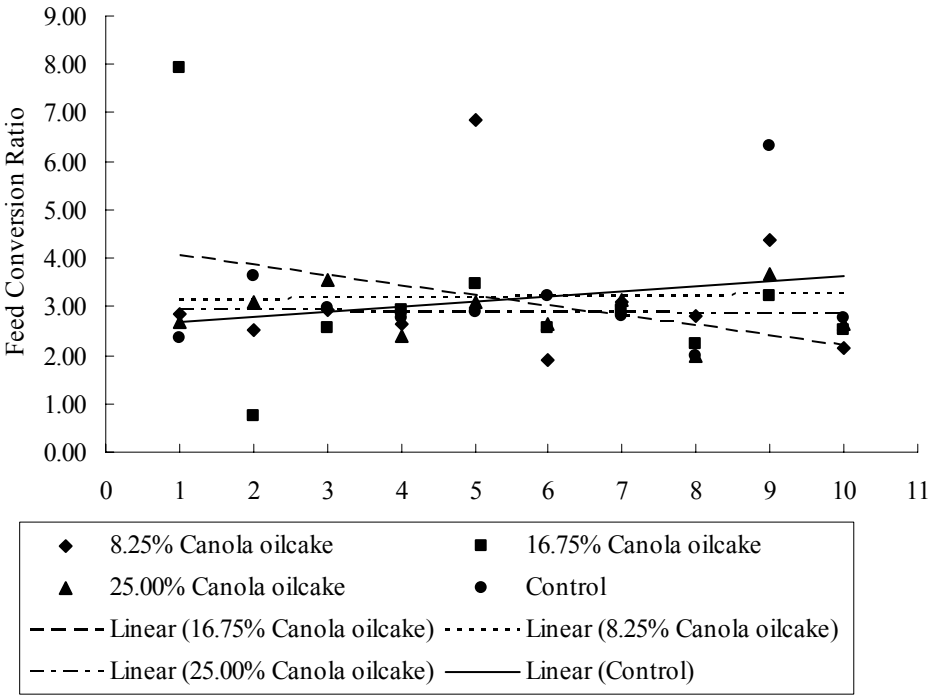

Figure 8.6 The effect of 8.25% canola oilcake, 16.75% canola oilcake and 25.00% canola oilcake on the feed conversion ratio of finisher pigs

The results of the regression analysis conducted on the full-fat canola containing diets are presented in Table 8.9. The slopes (b) of the regression lines on ADG of the pigs increased as the full-fat canola inclusion increased. The slope (b) of the regression lines on feed intake of the pigs fed the 16.75% full-fat canola diet was significantly greater compared to the other treatments. The slope of the regression lines on FCR for the 25.00% full-fat canola containing diet was negative which shows that the FCR improved as the trial went on. The significantly greater intercept also supports this statement.

Table 8.9 The intercepts (a) and slopes (b) of the regression analysis of average daily gain (ADG), feed intake and feed conversion ratio (FCR) of finisher pigs fed diets containing full-fat canola

	ADG a	ADG b	Feed Intake a	Feed Intake b	FCR a	FCR b
Control	0.550[b]	0.062[c]	8.993[a]	1.337[a]	2.667[a]	0.079[c]
25.00% Full-fat canola	0.432[a]	0.073[c]	9.709[c]	1.328[a]	4.450[d]	-0.185[a]
16.75% Full-fat canola	0.632[c]	0.061[b]	9.914[c]	1.491[b]	2.023[a]	0.192[d]
8.25% Full-fat canola	0.538[b]	0.057[a]	9.335[b]	1.321[a]	3.027[c]	0.035[b]
SEm	0.041	0.003	0.204	0.041	0.513	0.079

[a-e] Column means with common superscripts do not differ (P≤ 0.05)

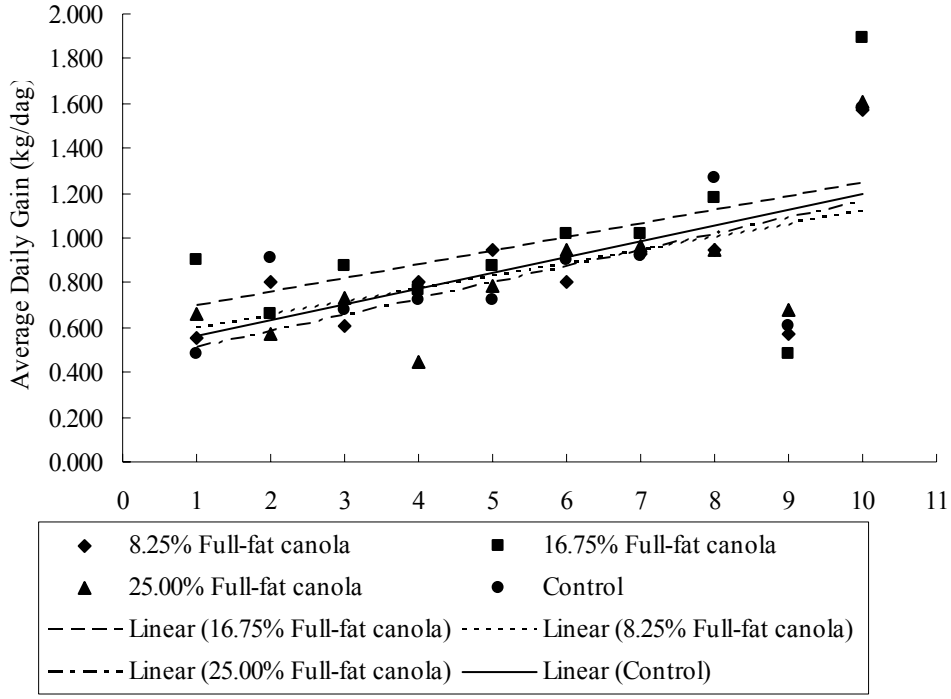

Figure 8.7 The effect of 8.25% full-fat canola, 16.75% full-fat canola and 25.00% full-fat canola on the average daily gain of finisher pigs

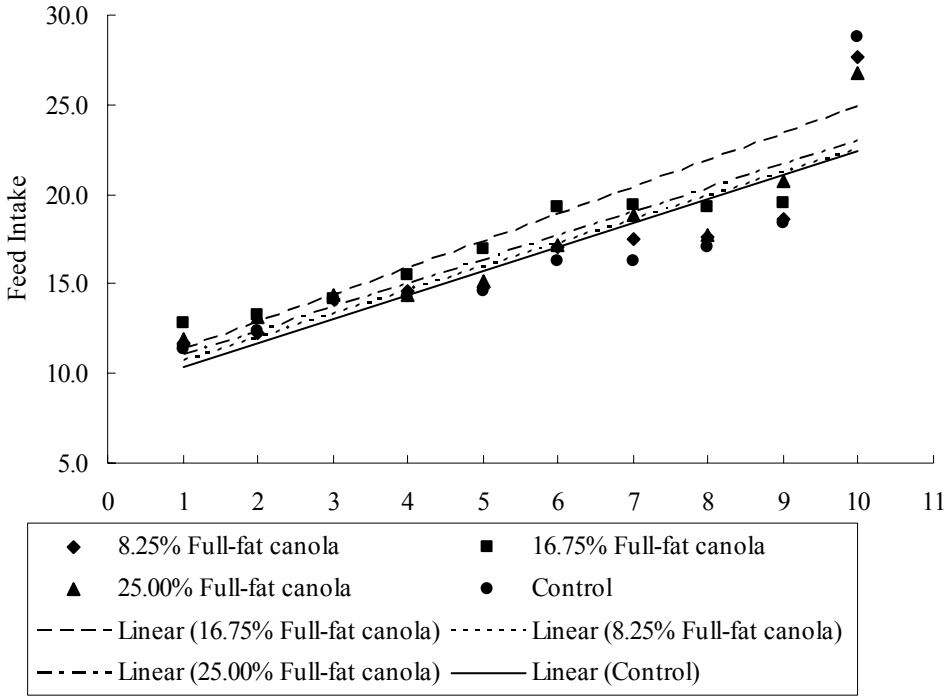

Figure 8.8 The effect of 8.25% full-fat canola, 16.75% full-fat canola and 25.00% full-fat canola on the feed intake of finisher pigs

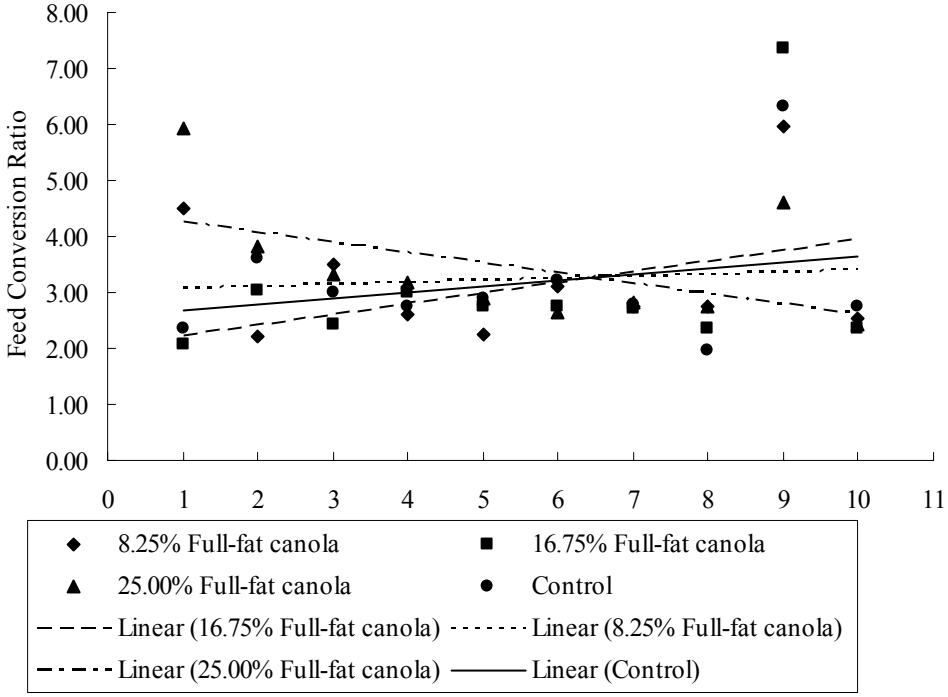

Figure 8.9 The effect of 8.25% full-fat canola, 16.75% full-fat canola and 25.00% full-fat canola on the feed conversion ratio of finisher pigs

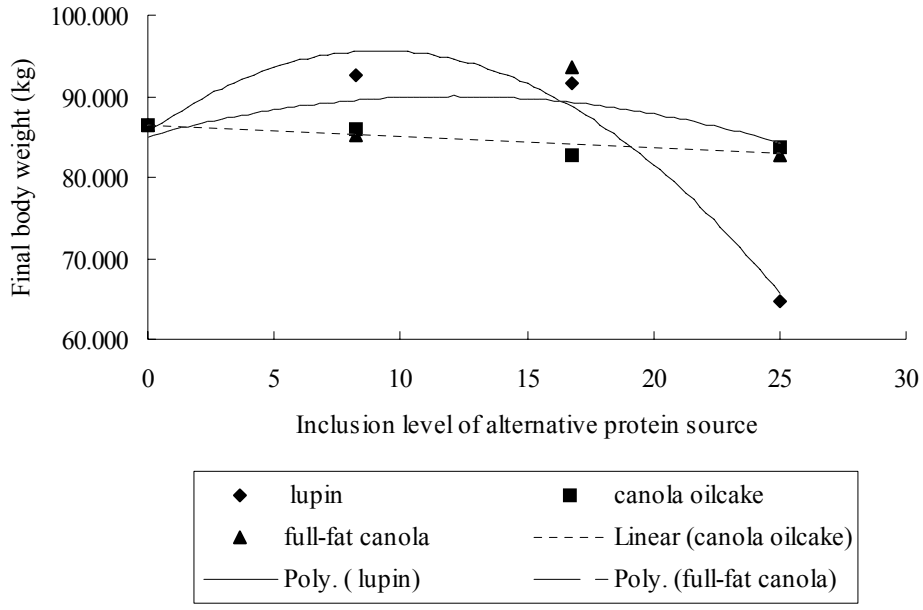

Figure 8.10 The effect of lupins ($y = -0.120x^2 + 2.195x + 85.559$; $R^2 = 0.964$; Sxy = 12.089), full-fat canola ($y = -0.034x^2 + 0.823x + 85.05$; $R^2 = 0.346$; Sxy = 5.715) and canola oilcake ($y = -0.141x + 86.495$; $R^2 = 0.676$; Sxy = 1.291) dietary inclusions on final body weight of finisher pigs

A comparison of the effect of the inclusion rate of the different protein sources on final body weight of finisher pigs is presented in Figure 8.10. Regression analysis of the data revealed that a curve linear model best fit the decrease in final body weight of finisher pigs due to the replacement of soybean oilcake with lupins ($y = -0.120x^2 + 2.195x + 85.559$; $R^2 = 0.964$; Sxy = 12.089). The reduction in final body weight of finisher pigs, when soybean oilcake was replaced with canola oilcake in their diets, is best described by a linear model ($y = -0.141x + 86.495$; $R^2 = 0.676$; Sxy = 1.291). The changes in the final body weight of finisher pigs, when soybean oilcake was replaced with full-fat canola in their diets, is best described by a curve linear model, with a weak R^2, ($y = -0.034x^2 + 0.823x + 85.05$; $R^2 = 0.346$; Sxy = 5.715).

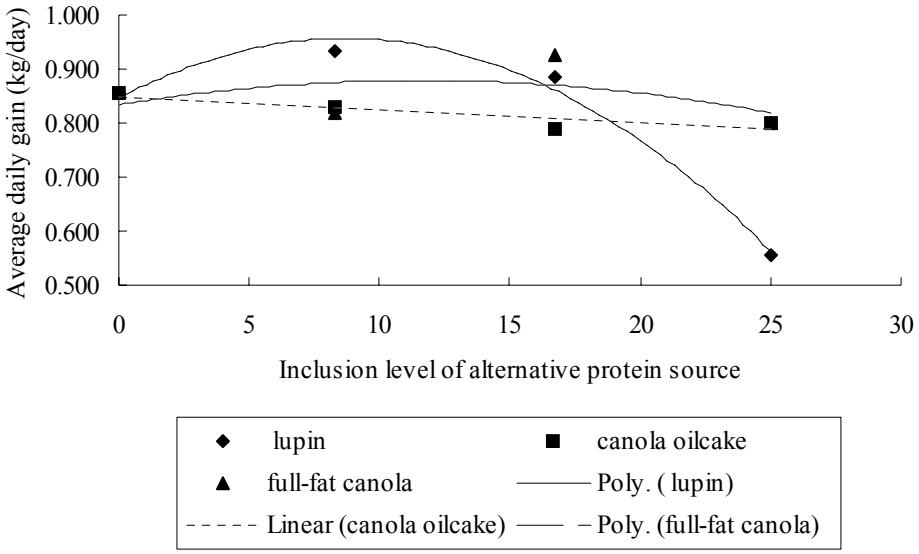

Figure 8.11 The effect of lupins ($y = -0.002x^2 + 0.026x + 0.846$; $R^2 = 0.985$; Sxy = 0.147), full-fat canola ($y = -0.001x^2 + 0.008x + 0.835$; $R^2 = 0.232$; Sxy = 0.068) and canola oilcake ($y = -0.002x + 0.848$; $R^2 = 0.783$; Sxy = 0.017) dietary inclusions on the average daily gain of finisher pigs

A comparison of the effect of the inclusion rate of the different protein sources on the average daily gain of finisher pigs of age is presented in Figure 8.11. Regression analysis of the data revealed that a curve linear model best fit the decrease in the average daily gain of finisher pigs due to the replacement of soybean oilcake with lupins ($y = -0.002x^2 + 0.026x + 0.846$; $R^2 = 0.985$; Sxy = 0.147). The reduction in the average daily gain of finisher pigs, when soybean oilcake was replaced with canola oilcake in their diets, is best described by a linear model ($y = -0.002x + 0.848$; $R^2 = 0.783$; Sxy = 0.017). The reduction in the average daily gain of finisher pigs, when soybean oilcake was replaced with full-fat canola in their diets, is best described by a curve linear model, ($y = -0.001x^2 + 0.008x + 0.835$; $R^2 = 0.232$; Sxy = 0.068).

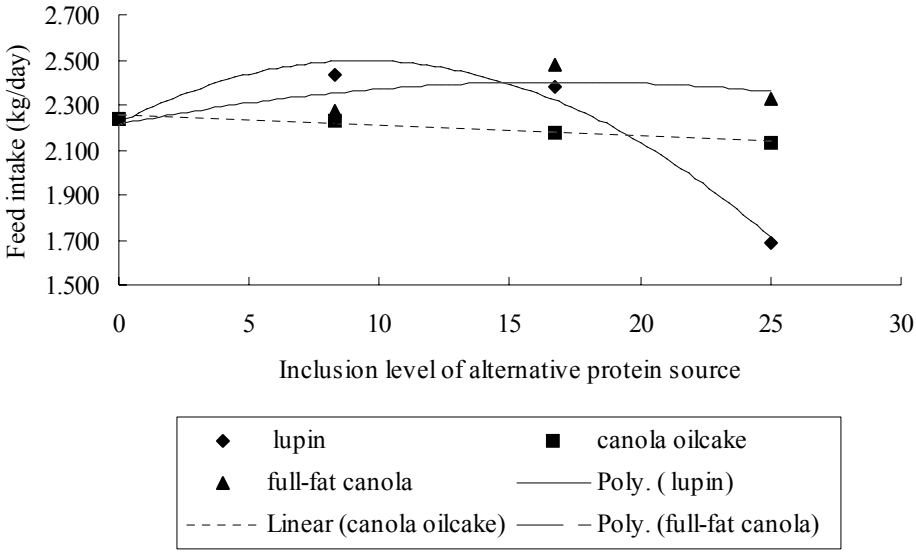

Figure 8.12 The effect of lupins ($y = -0.003x^2 + 0.059x + 2.220$; $R^2 = 0.977$; Sxy = 0.318), full-fat canola ($y = -0.001x^2 + 0.022x + 2.213$; $R^2 = 0.592$; Sxy = 0.106) and canola oilcake ($y = -0.004x + 2.252$; $R^2 = 0.933$; Sxy = 0.016) dietary inclusions on the daily feed intake of finisher pigs

A comparison of the effect of the inclusion rate of the different protein sources on the daily feed intake of finisher pigs of age is presented in Figure 8.12. Regression analysis of the data revealed that a curve linear model best fit the decrease in the daily feed intake of finisher pigs due to the replacement of soybean oilcake with lupins ($y = -0.003x^2 + 0.059x + 2.220$; $R^2 = 0.977$; Sxy = 0.318). The reduction in the daily feed intake of finisher pigs, when soybean oilcake was replaced with canola oilcake in their diets, is best described by a linear model ($y = -0.004x + 2.252$; $R^2 = 0.933$; Sxy = 0.016). The reduction in the daily feed intake of finisher pigs, when soybean oilcake was replaced with full-fat canola in their diets, is best described by a curve linear model, ($y = -0.001x^2 + 0.022x + 2.213$; $R^2 = 0.592$; Sxy = 0.106).

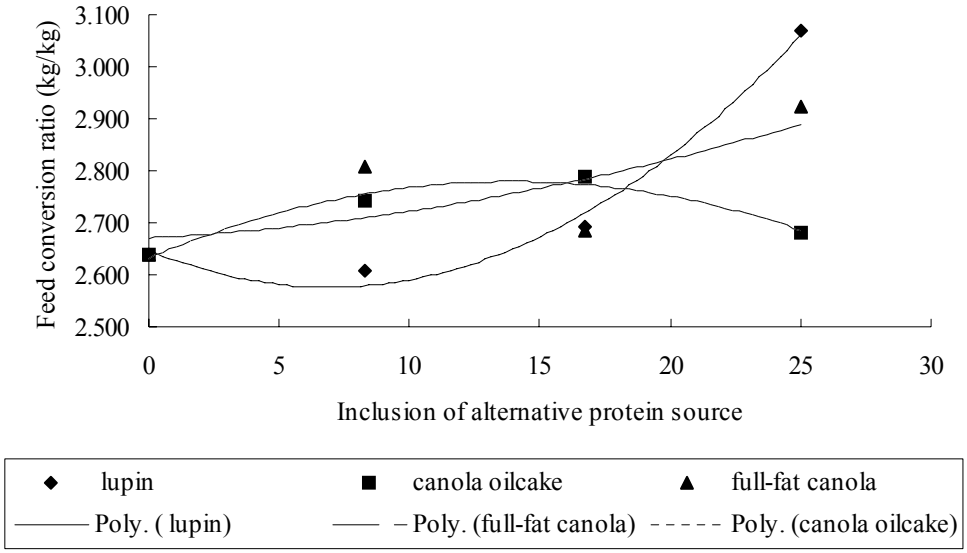

Figure 8.13 The effect of lupins ($y = 0.002x^2 - 0.020x + 2.646$; $R^2 = 0.988$; Sxy = 0.147), full-fat canola ($y = 0.001x^2 + 0.003x + 2.670$; $R^2 = 0.564$; Sxy = 5.715) and canola oilcake ($y = -0.001x^2 + 0.021x + 2.632$; $R^2 = 0.967$; Sxy = 1.291) dietary inclusions on the feed conversion ratio of finisher pigs

A comparison of the effect of the inclusion rate of the different protein sources on the daily feed intake of finisher pigs of age is presented in Figure 8.13. Regression analysis of the data revealed that a curve linear model best fit the increase in the feed conversion ratio of finisher pigs due to the replacement of soybean oilcake with lupins ($y = 0.002x^2 - 0.020x + 2.646$; $R^2 = 0.988$; Sxy = 0.147). The increase in the feed conversion ratio of finisher pigs, when soybean oilcake was replaced with canola oilcake in their diets, is best described by a linear model ($y = -0.001x^2 + 0.021x + 2.632$; $R^2 = 0.967$; Sxy = 1.291). The reduction in the feed conversion ratio of finisher pigs, when soybean oilcake was replaced with full-fat canola in their diets, is best described by a curve linear model, ($y = 0.001x^2 + 0.003x + 2.670$; $R^2 = 0.564$; Sxy = 5.715).

The lower body weight and carcass mass of the pigs fed the test diet could possibly be due to lower feed intake and reduced growth rate. Fagan (1977) conducted a study where the performance of pigs fed sweet lupin meal was compared to pigs fed diets with meat meal and skimmed milk as sources of protein. The results showed that the pigs' weight gain was slightly greater on meat meal, but feed conversion ratio was slightly better in pigs fed sweet lupins. In a similar study by Santos Oliveira *et al.* (1991) they found that the inclusion of up to 9% of lupin meal in diets for growing/finishing pigs, as a substitute for soybean meal, did not significantly affect their performance. Higher percentages appeared to affect their performance, but the carcasses were much leaner. More recently in a study by Fernandez & Batterham (1995), pig performance was compared when pigs were fed diets containing lupins or soybean meal as protein sources. The growth performance of the pigs fed the lupin diets compared well with the pigs fed the soybean diets. Falkowski *et al*. (2004) conducted a study where the performance of pigs fed rapeseed meal diets were compared to pigs fed soybean diets. No significant differences in performance were found. These results

compare very favourably to the results obtained in the present study. Locally Brand *et al*. (1999) evaluated full-fat canola as alternative protein source for pigs. Full-fat canola was included at increasing increments replacing soybean oilcake meal. No significant effect of full-fat canola inclusion on intake, growth rate or feed conversion of grower/finisher pigs was found.

The meat characteristics of the grower/finisher pigs are presented in Table 8.10. The warm carcass mass of the pigs consuming the test diet containing 25.00% lupins was significantly ($P \leq 0.05$) lighter than the warm carcass mass of the pigs consuming the other diets (Table 8.10). The warm carcass mass of the pigs consuming the test diet containing 16.75% full-fat canola was significantly heavier than the warm carcass mass of the pigs consuming the control diet and the test diet containing 8.25% canola oilcake meal (Table 8.10). The same pattern is shown for the cold carcass mass. In the case of the P2 fat depth the only significant difference was between the 8.25% canola oilcake diet and the 16.75% canola oilcake diet. The carcasses of the pigs that were fed the 8.25% lupin diet were significantly leaner than the carcasses of the pigs that were fed the 16.75% canola oilcake diet.

Table 8.10 The effect of increasing levels of dietary lupin, full-fat canola and canola oilcake inclusion on meat characteristics

Diet	Warm carcass mass (kg)	Cold carcass mass (kg)	P2 Fat depth (mm)	Lean meat (%)
25.00% Lupins	$49.3^{a} \pm 3.43$	$48.7^{a} \pm 3.38$	$14.2^{ab} \pm 1.62$	$68.4^{ab} \pm 0.71$
16.75% Lupins	$73.2^{bc} \pm 3.43$	$71.9^{bc} \pm 3.38$	$16.3^{ab} \pm 1.62$	$67.2^{ab} \pm 0.71$
8.25% Lupins	$66.7^{bc} \pm 3.43$	$65.7^{bc} \pm 3.38$	$13.7^{ab} \pm 1.62$	$68.8^{a} \pm 0.71$
25.00% Full-fat canola	$68.9^{bc} \pm 3.43$	$67.9^{bc} \pm 3.38$	$14.1^{ab} \pm 1.62$	$68.2^{ab} \pm 0.71$
16.75% Full-fat canola	$75.3^{c} \pm 3.43$	$74.1^{c} \pm 3.38$	$13.4^{ab} \pm 1.62$	$68.5^{ab} \pm 0.71$
8.25% Full-fat canola	$71.0^{bc} \pm 3.43$	$69.4^{bc} \pm 3.38$	$15.3^{ab} \pm 1.62$	$67.9^{ab} \pm 0.71$
25.00% Canola oilcake	$69.6^{bc} \pm 3.43$	$68.6^{bc} \pm 3.38$	$15.9^{ab} \pm 1.62$	$67.6^{ab} \pm 0.71$
16.75% Canola oilcake	$66.8^{bc} \pm 3.43$	$65.8^{bc} \pm 3.38$	$17.9^{a} \pm 1.62$	$66.6^{b} \pm 0.71$
8.25% Canola oilcake	$64.3^{b} \pm 3.43$	$63.4^{b} \pm 3.38$	$12.7^{b} \pm 1.62$	$68.5^{ab} \pm 0.71$
Control	$66.2^{b} \pm 1.98$	$65.1^{b} \pm 1.95$	$15.2^{ab} \pm 0.94$	$68.9^{ab} \pm 0.41$

[a-e] Column means with common superscripts do not differ ($P \leq 0.05$)

In a study by Bourdon *et al*. (1980) leaner carcasses were obtained when *L. albus* was used in the diets of 30 to 100kg pigs. They concluded that this was due to lower daily food intake. In the current study there was no significant difference in the lean meat percentage between the lupin containing diets and the control diet. In a study by Shelton *et al*. (2001) there no significant difference in the lean meat percentage between the canola meal diets and the soybean meal control diet. These studies confirm the results of the present study.

The saturated fatty acid profiles of the muscle of the pigs are shown in Table 8.11. From Table 8.11 it is clear that the muscle of the pigs fed the 25.00% canola oilcake diets and the 16.75% full-fat canola diets contained significantly less saturated fatty acids than the muscle of the pigs fed the 8.25% canola oilcake diets and the control diets. No significant difference was found in the neutral C18:0 fatty acid content between the various diets.

Table 8.11 Fatty acid profiles (%) of saturated fatty acids (SFA) in the muscle of pigs fed diets with increasing levels of lupins, canola oilcake or full-fat canola

Diet	C10:0	C12:0	C14:0	C15:0	C16:0	C17:0	C18:0	C20:0	SFA
25.00% Lupins	0.000±0.018	0.095^{b}±0.025	1.295^{abc} ± 0.19	0.048 ± 0.06	27.763^{a} ± 0.73	0.485^{abc} ± 0.199	12.068 ± 0.86	0.000^{a} ± 0.014	41.753^{ab}±1.27
16.75% Lupins	0.000±0.018	0.048^{ab}±0.025	1.508^{bc} ± 0.19	0.040 ± 0.06	28.290^{a} ± 0.73	0.213^{ab} ± 0.199	10.888 ± 0.86	0.000^{a} ± 0.014	40.985^{ab}±1.27
8.25% Lupins	0.000±0.018	0.033^{ab}±0.025	1.358^{abc} ± 0.19	0.168 ± 0.06	29.205^{ab} ± 0.73	0.770^{bc} ± 0.199	10.650 ± 0.86	0.025^{ab}±0.014	42.208^{ab}±1.27
25.00% Full-fat canola	0.095±0.018	0.053^{ab}±0.025	1.265^{ab} ± 0.19	0.075 ± 0.06	29.298^{ab} ± 0.73	0.273^{ab} ± 0.199	10.408 ± 0.86	0.018^{ab}±0.014	41.435^{ab}±1.27
16.75% Full-fat canola	0.000±0.018	0.048^{ab}±0.025	1.288^{abc} ± 0.19	0.123 ± 0.06	27.660^{a} ± 0.73	0.850^{c} ± 0.199	10.748 ± 0.86	0.000^{a} ±0.014	31.368^{a}±1.27
8.25% Full fat canola	0.080±0.018	0.083^{b}±0.025	1.823^{c} ± 0.19	0.073 ± 0.06	30.410^{b} ± 0.73	0.425^{abc} ± 0.199	10.360 ± 0.86	0.045^{b} ±0.014	43.238^{ab}±1.27
25.00% Canola oilcake	0.110±0.018	0.070^{ab}±0.025	1.633^{bc} ± 0.19	0.065 ± 0.06	28.875^{ab} ± 0.73	0.120^{a} ± 0.199	10.695 ± 0.86	0.000^{a} ±0.014	31.230^{a}±1.27
16.75% Canola oilcake	0.000±0.018	0.000^{a}±0.025	0.960^{a} ± 0.19	0.000 ± 0.06	27.973^{a} ± 0.73	0.358^{abc} ± 0.199	10.800 ± 0.86	0.000^{a} ±0.014	40.090^{ab}±1.27
8.25% Canola oilcake	0.070±0.018	0.053^{ab}±0.025	1.788^{bc} ± 0.19	0.088 ± 0.06	29.458^{ab} ± 0.73	0.585^{abc} ± 0.199	12.413 ± 0.86	0.023^{ab} ±0.014	44.423^{b}±1.27
Control	0.093±0.010	0.040^{ab}±0.014	1.508^{bc} ± 0.11	0.048 ± 0.03	28.854^{ab} ± 0.42	0.452^{abc} ± 0.115	11.213 ± 0.50	0.006^{a} ±0.008	42.143^{b}±0.73

$^{a-e}$ Column means with common superscripts do not differ (P≤ 0.05)

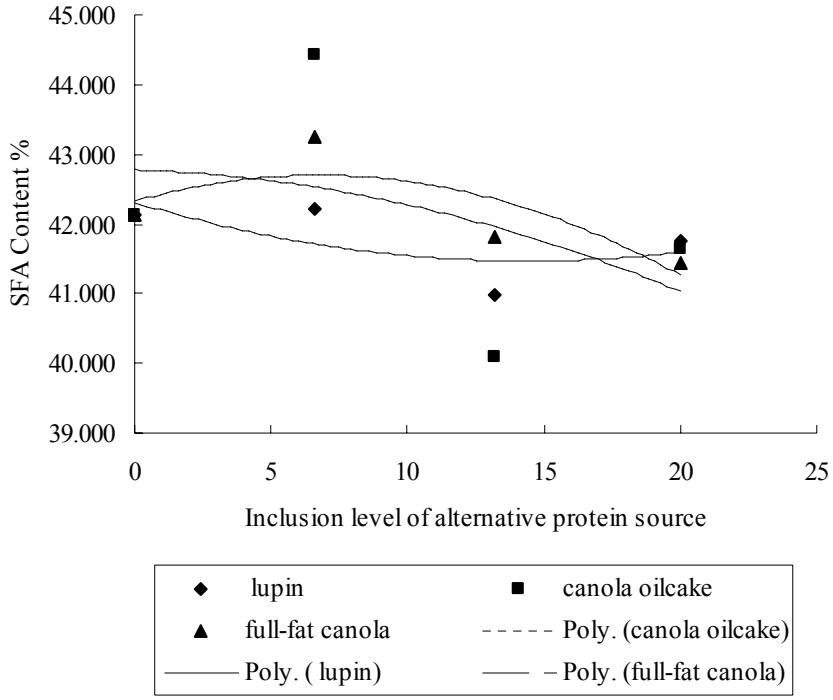

Figure 8.14 The effect of lupin ($y = 0.004x^2 – 0.117x + 42.309$; $R^2 = 0.436$; Sxy = 0.577), full-fat canola ($y = -0.008x^2 + 0.110x + 42.324$; $R^2 = 0.644$; Sxy = 0.765) and canola oilcake ($y = -0.004x^2 – 0.014x + 42.778$; $R^2 = 0.187$; Sxy = 1.995) dietary inclusion on SFA content of the muscle of pigs

Regression analysis of the data revealed that a curvilinear model best fit the decrease in the saturated fatty acid content of the muscle of the pigs as the soybean oilcake was replaced with lupins, canola oilcake and full-fat canola at increasing levels, as can be seen in Figure 8.14.

The saturated fatty acid content of the subcutaneous fat of the pigs is presented in Table 8.12. The saturated fatty acid content of the subcutaneous fat of the pigs fed the 25.00% full-fat canola diet was significantly less than the subcutaneous fat of the pigs fed the 25.00% lupin diet and the 16.75% full-fat canola diet. The saturated fatty acid content of the subcutaneous fat of the pigs fed the 25.00% canola oilcake diet was significantly less than the subcutaneous fat of the pigs fed the 25.00% lupin diet, the 8.25% lupin diet, the 16.75% full-fat canola diet and the control diet. Pigs fed the 25.00% lupin diet contained significantly more of the neutral fatty acid C18:0, in their subcutaneous fat compared to the pigs receiving the 25.00% canola oilcake diet and the control diet.

Table 8.12 Fatty acid profiles (%) of saturated fatty acids (SFA) in the subcutaneous fat of pigs fed diets with increasing levels of lupins, canola oilcake or full-fat canola

Diet	C10:00	C12:00	C14:00	C15:00	C16:00	C17:00	C18:00	C20:00	SFA
25.00% Lupins	0.073^{ab}±0.013	0.125^{ab}±0.014	2.190^{ab}±0.24	0.150±0.06	30.220^{bc}±1.43	0.765±0.22	19.055^{a}±1.26	0.133±0.012	52.710^{a}±2.02
16.75% Lupins	0.073^{ab}±0.013	0.113^{ab}±0.014	2.188^{ab}±0.24	0.225±0.05	26.408^{ab}±1.43	1.030±0.22	18.825^{ab}±1.26	0.108±0.012	48.968^{abc}±2.02
8.25% Lupins	0.090^{ab}±0.013	0.128^{ab}±0.014	2.348^{ab}± .24	0.263±0.05	30.270^{bc}±1.43	0.910±0.22	16.960^{ab}±1.26	0.135±0.012	51.103^{ab}± 2.02
25.00% Full-fat canola	0.080^{ab}±0.013	0.120^{ab}±0.014	2.145^{ab}±0.24	0.143±0.05	25.548^{a}± 1.43	0.678±0.22	17.973^{ab}±1.26	0.140±0.012	46.825^{bc}± 2.02
16.75% Full-fat canola	0.075^{ab}±0.013	0.105^{a}±0.014	2.068^{ab}±0.24	0.250±0.05	30.895^{c}± 1.43	0.940±0.22	18.833^{ab}±1.26	0.130±0.012	53.295^{a}± 2.02
8.25% Full fat canola	0.085^{ab}±0.013	0.138^{ab}±0.014	2.463^{b}± 0.24	0.188±0.05	28.515^{abc}±1.43	0.960±0.22	17.050^{ab}±1.26	0.125±0.012	49.523^{abc}±2.02
25.00% Canola oilcake	0.083^{ab}±0.013	0.138^{ab}±0.014	1.690^{a}± 0.24	0.278±0.05	25.923^{a}± 1.43	0.870±0.22	15.348^{b}± 1.26	0.128±0.012	44.455^{c}± 2.02
16.75% Canola oilcake	0.055^{a}±0.015	0.128^{ab}±0.014	2.445^{b}± 0.24	0.135±0.05	29.415^{abc}±1.43	0.640±0.22	16.080^{ab}±1.26	0.143±0.012	49.041^{abc}±2.02
8.25% Canola oilcake	0.105^{b}±0.013	0.150^{b}±0.014	2.373^{ab}±0.24	0.168±0.05	29.458^{abc}±1.43	0.513±0.22	16.630^{ab}±1.26	0.130±0.012	49.525^{abc}±2.02
Control	0.078^{ab}±0.007	0.119^{ab}±0.008	2.363^{b}± 0.14	0.203±0.03	29.996^{c}± 0.82	0.913±0.12	16.036^{b}± 0.73	0.142±0.006	49.849^{ab}± 1.17

[a-e] Column means with common superscripts do not differ ($P \leq 0.05$)

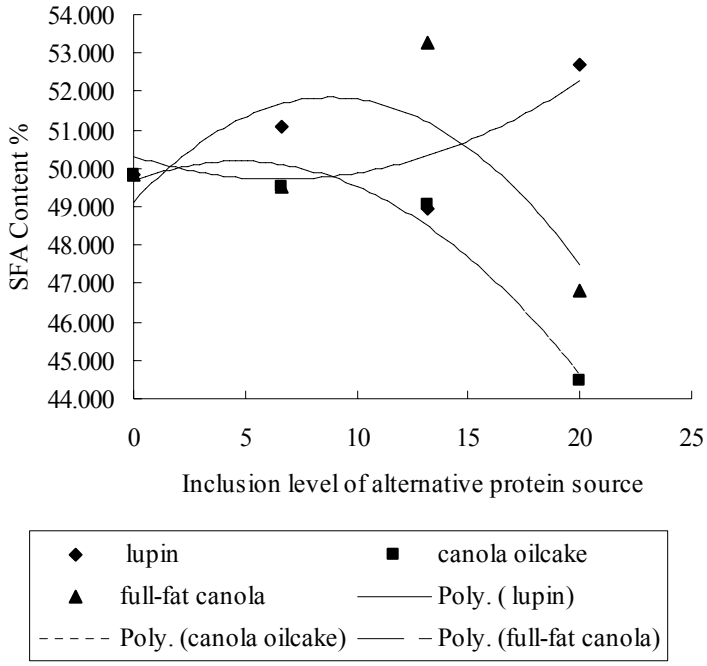

Figure 8.15 The effect of lupin ($y = 0.014x^2 – 0.184x + 50.315$; $R^2 = 0.467$; Sxy = 1.703), full-fat canola ($y = -0.035x^2 + 0.614x + 49.130$; $R^2 = 0.524$; Sxy = 3.134) and canola oilcake ($y = -0.024x^2 + 0.224x + 49.657$; $R^2 = 0.962$; Sxy = 1.611) dietary inclusion on SFA content of the subcutaneous fat of pigs

Regression analysis of the data revealed that curvilinear models best fit the changes in the saturated fatty acid content of the subcutaneous fat of the pigs, as can be seen in Figure 8.15. The saturated fatty acid content of the subcutaneous fat of the pigs decreased as the soybean oilcake was replaced with canola oilcake and full-fat canola at increasing levels. There was a curvilinear increased in the saturated fatty acid content of the subcutaneous fat of the pigs due to the replacement of soybean oilcake with lupins, this is most likely due to the higher saturated fatty acid content of the lupins the pigs were fed.

The pigs fed the lupin containing diets had leaner carcasses and the saturated fatty acid content of the fat was greater than the pigs fed the other diets. This is due to the higher saturated fatty acid content of the sweet lupins the pigs were fed. In a study done by Zettl (1995) slaughter performance and meat quality were not different for pigs fed lupins, except for pigs given the 25.00% lupin diet, where fatty acid composition of back fat resulted in inferior back fat consistency. It was recommended to limit dietary inclusion of sweet white lupin seeds to 10%. In a study by Castell & Falk (1980) the saturated fatty acid content of the back fat of pigs was reduced significantly ($P < 0.01$) when fed diets containing full-fat canola. The results of these studies compare well with results obtained in the current study.

In Table 8.13 the monounsaturated fatty acid profiles of the muscle of the pigs are reported. It can be seen that the muscle of the pigs fed the 16.75% full-fat canola diet contained significantly less monounsaturated fatty acids than the 8.25% full-fat canola diet, the 25.00% lupin diet and the control diet. The muscle of the pigs fed the 25.00% lupin diet contained more of the neutral fatty acid C18: 1, even

though the only significant difference was when it was compared to the muscle of the pigs fed the 16.75% full-fat canola diet.

Table 8.13 Fatty acid profiles of monounsaturated fatty acids (%)(MUFA) in the muscle of pigs fed diets with increasing levels of lupins, canola oilcake or full-fat canola

Diet	C15: 1	C16: 1	C17: 1	C18: 1	C20: 1	MUFA
25.00% Lupins	0.125±0.349	2.548^{a}±0.502	0.838^{ab}±0.272	41.430^{a}±2.46	0.353±0.161	45.293±2.567
16.75% Lupins	0.635±0.349	4.88^{b}±0.502	0.308^{ab}±0.272	34.835^{ab}±2.46	0.255±0.161	40.930±2.567
8.25% Lupins	0.490±0.349	4.418^{b}±0.502	0.925^{ab}±0.272	37.105^{ab}±2.46	0.423±0.161	43.360±2.567
25.00% Full-fat canola	0.757±0.403	4.640^{b}±0.502	0.410^{ab}±0.272	37.160^{ab}±2.46	0.165±0.161	42.943±2.567
16.75% Full-fat canola	0.325±0.349	4.290^{b}±0.502	1.043^{b}±0.272	34.200^{b}± 2.46	0.283±0.161	40.140±2.567
8.25% Full fat canola	0.533±0.349	4.525^{b}±0.502	0.613^{ab}±0.272	38.770^{ab}±2.46	0.433±0.161	44.873±2.567
25.00% Canola oilcake	0.153±0.349	3.733^{ab}±0.502	0.213^{a}±0.272	38.118^{ab}±2.46	0.130±0.161	42.058±2.567
16.75% Canola oilcake	0.285±0.349	3.470^{ab}±0.502	0.605^{ab}±0.272	36.910^{ab}±2.46	0.153±0.161	41.423±2.567
8.25% Canola oilcake	0.395±0.349	4.255^{b}±0.502	0.780^{ab}±0.272	35.058^{ab}±2.46	0.295±0.161	40.783±2.567
Control	0.393±0.202	4.239^{b}±0.290	0.607^{ab}±0.157	36.553^{ab}±1.42	0.256±0.093	42.048±2.567

$^{a-e}$ Column means with common superscripts do not differ ($P \leq 0.05$)

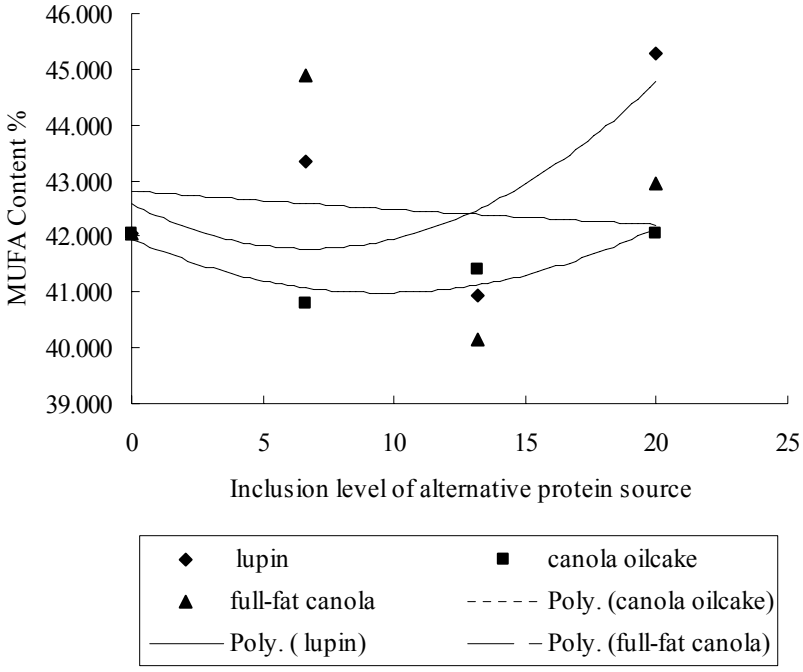

Figure 8.16 The effect of lupin ($y = 0.017x^2 – 0.235x + 42.577$; $R^2 = 0.483$; Sxy = 1.977), full-fat canola ($y = -0.030x + 42.8$; $R^2 = 0.017$; Sxy = 2.388) and canola oilcake ($y = 0.011x^2 – 0.202x + 41.949$; $R^2 = 0.827$; Sxy = 0.736) dietary inclusion on MUFA content of the muscle of pigs

A linear model best fit the changes in the monounsaturated fatty acid content due to the replacement of soybean oilcake with full-fat canola, as can be seen in Figure 8.16. The R^2 value was very weak. Regression analysis of the data revealed a curvilinear model best fit the increase in the monounsaturated fatty acid content of the muscle of the pigs as the soybean oilcake was replaced with lupins. A curvilinear model best fit the changes in the monounsaturated fatty acid content of the muscle of the pigs as the soybean oilcake was replaced with canola oilcake.

Presented in Table 8.14 are the fatty acid profiles of monounsaturated fatty acids in the subcutaneous fat of the pigs. There were no significant differences in the total monounsaturated fatty acid content of the carcass fat of the pigs. No significant differences were found in the neutral fatty acid C18: 1 content of the subcutaneous fat of the pigs.

Table 8.14 Fatty acid profiles of monounsaturated fatty acids (%)(MUFA) in the subcutaneous fat of pigs fed diets with increasing levels of lupins, canola oilcake or full-fat canola

Diet	C15: 1	C16: 1	C17: 1	C18: 1	C20: 1	MUFA
25.00% Lupins	0.000^{a} ±0.009	2.623^{ab}± 0.3	0.575± 0.2	30.688± 2.2	0.908± 0.07	34.793± 2.3
16.75% Lupins	0.010^{ab}±0.009	2.833^{ab}± 0.3	0.863± 0.2	32.823± 2.2	0.860± 0.08	37.173± 2.3
8.25% Lupins	0.000^{a}±0.009	2.650^{ab}± 0.3	0.750± 0.2	29.428± 2.2	0.780± 0.07	32.945± 2.3
25.00% Full-fat canola	0.008^{ab}±0.009	2.398^{ab}± 0.3	0.543± 0.2	31.378± 2.2	0.923± 0.07	35.248± 2.3
16.75% Full-fat canola	0.000^{a}±0.009	3.143^{b}± 0.3	0.848± 0.2	29.790± 2.2	0.880± 0.07	34.660± 2.3
8.25% Full-fat canola	0.008^{ab}±0.009	2.975^{ab}± 0.3	0.823± 0.2	30.680± 2.2	0.798± 0.07	35.283± 2.3
25.00% Canola oilcake	0.023^{ab}±0.007	2.215^{a}± 0.3	0.595± 0.2	35.243± 2.2	0.885± 0.07	38.960± 2.3
16.75% Canola oilcake	0.000^{a}±0.009	2.855^{ab}± 0.3	0.668± 0.2	31.980± 2.2	0.888± 0.07	36.390± 2.3
8.25% Canola oilcake	0.015^{ab}±0.009	2.750^{ab}± 0.3	0.403± 0.2	32.248± 2.2	0.780± 0.07	36.195± 2.3
Control	0.019^{b}±0.004	2.968^{b}± 0.2	0.713± 0.1	31.847± 1.2	0.803± 0.04	36.349± 1.3

$^{a-e}$ Column means with common superscripts do not differ ($P \leq 0.05$)

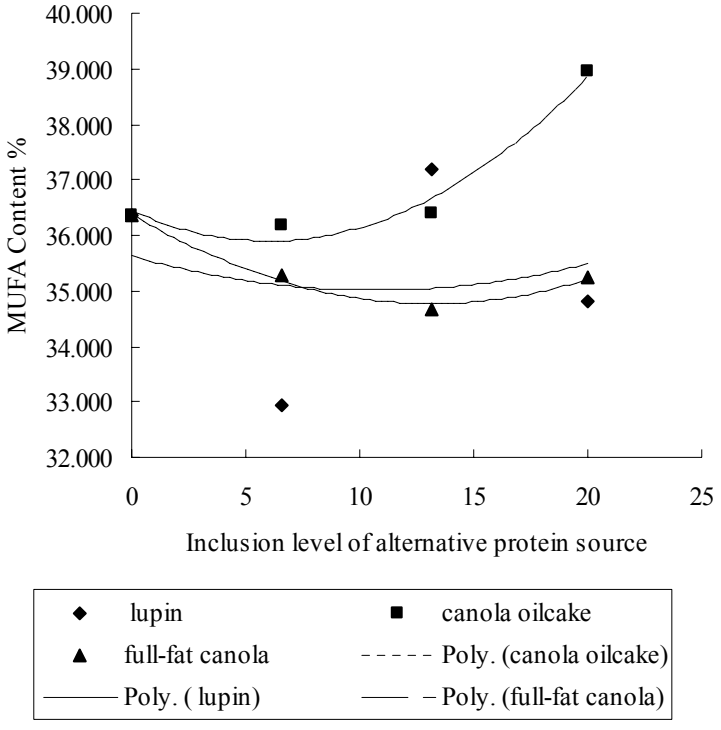

Figure 8.17 The effect of lupin ($y = 0.005x^2 – 0.115x + 35.626$; $R^2 = 0.023$; Sxy = 2.280), full-fat canola ($y = 0.009x^2 – 0.246x + 36.387$; $R^2 = 0.981$; Sxy = 0.602) and canola oilcake ($y = 0.015x^2 – 0.183x + 36.447$; $R^2 = 0.964$; Sxy = 1.006) dietary inclusion on MUFA content of the subcutaneous fat of pigs

Regression analysis of the data revealed that curvilinear models best fit the changes in the monounsaturated fatty acid content of the subcutaneous fat of the pigs. As can be seen if Figure 8.17 there

was a curvilinear increase in the monounsaturated fatty acid content of the subcutaneous fat of the pigs as the soybean oilcake was replaced with canola oilcake. Regression analysis of the data revealed a curvilinear decrease in the monounsaturated fatty acid content of the subcutaneous fat of the pigs as the soybean oilcake was replaced with lupins and full-fat canola at increasing levels.

In a study by Castell & Falk (1980) the palmitoleic acid (C16: 1) content was significantly reduced when full-fat canola was included in the diets of grower/finisher pigs. The oleic acid (C18: 1) content was increased by the inclusion of rapeseed meal was included in the diets of grower/finisher pigs. The results of these studies compare well with results obtained in the current study.

The polyunsaturated fatty acid content of the muscle of the pigs is presented in Table 8.15. The muscle of the pigs fed the 16.75% full-fat canola diet contained significantly more polyunsaturated fatty acids than the muscle of the pigs fed 8.25% full-fat canola diet, the 8.25% lupin diet (Table 8.15). The muscle of the pigs fed 8.25% full-fat canola diet contained significantly less polyunsaturated fatty acids than the muscle of the pigs fed the 25.00% and the 16.75% lupin diet and the 16.75% canola oilcake diet. The muscle of the pigs fed 25.00% full-fat canola diet and the 16.75% canola oilcake diet contained significantly less of the protective fatty acid C18: 3n6 (linoleic acid) than the muscle of the pigs fed the 16.75% full-fat canola diet and the control diet. The 8.25% full-fat canola diet had the lowest value for the protective fatty acid C18: 3n3 (α-linolenic acid) and the 25.00% canola oilcake diet, the highest value.

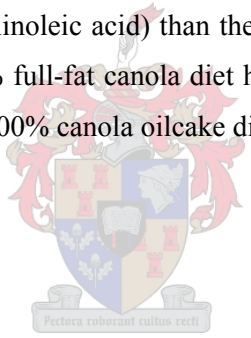

Table 8.15 Fatty acid profiles of polyunsaturated fatty acids (%)(PUFA) in the muscle of pigs fed diets with increasing levels of lupins, canola oilcake or full-fat canola

Diet	C18: 2	C18: 3n6	C18: 3n3	C20: 2	C20: 3	C20: 4	PUFA
25.00% Lupins	14.500^{a}± 1.39	0.138^{ab}± 0.055	1.243^{bcd}± 0.19	0.307^{a}± 0.113	0.097± 0.042	1.843^{abc}± 0.405	17.565^{bc}± 1.64
16.75% Lupins	14.933^{a}± 1.39	0.138^{ab}± 0.055	1.225^{abcd}± 0.19	0.083^{ab}± 0.098	0.103± 0.042	1.853^{bc}± 0.350	18.333^{bc}± 1.64
8.25% Lupins	12.615^{ab}± 1.39	0.095^{ab}± 0.055	0.730^{bc}± 0.19	0.175^{ab}± 0.098	0.020± 0.042	0.760^{a}± 0.350	12.395^{ab}± 1.64
25.00% Full-fat canola	13.103^{ab}± 1.39	0.020^{a}± 0.055	0.703^{bc}± 0.19	0.103^{ab}± 0.098	0.053± 0.042	0.788$^{a.}$ ± 0.350	14.768^{abc}± 1.64
16.75% Full-fat canola	15.483^{a}± 1.39	0.228^{b}± 0.055	1.045^{abcd}± 0.19	0.125^{ab}± 0.098	0.083± 0.042	2.180^{c}± 0.350	19.143^{c}± 1.64
8.25% Full fat canola	10.008^{b}± 1.39	0.073^{ab}± 0.055	0.698^{a}± 0.19	0.083^{ab}± 0.098	0.108± 0.042	1.345^{abc}± 0.350	12.313^{a}± 1.64
25.00% Canola oilcake	13.795^{ab}± 1.39	0.083^{ab}± 0.055	1.378^{d}± 0.19	0.213^{ab}± 0.098	0.075± 0.042	1.408^{abc}± 0.350	16.950^{abc}± 1.64
16.75% Canola oilcake	15.745^{a}± 1.39	0.000^{a}± 0.055	1.290^{cd}± 0.19	0.000^{b}± 0.098	0.000± 0.042	1.413^{abc}± 0.350	18.448^{bc}± 1.64
8.25% Canola oilcake	12.478^{ab}± 1.39	0.123^{ab}± 0.055	0.978^{abcd}± 0.19	0.173^{ab}± 0.098	0.065± 0.042	1.490^{abc}± 0.350	15.305^{abc}± 1.64
Control	13.445^{a}± 0.80	0.150^{b}± 0.031	0.851^{abc}± 0.110	0.141^{ab}± 0.056	0.053± 0.024	1.156^{ab}± 0.202	15.795^{abc}± 0.94

$^{a-e}$ Column means with common superscripts do not differ ($P \leq 0.05$)

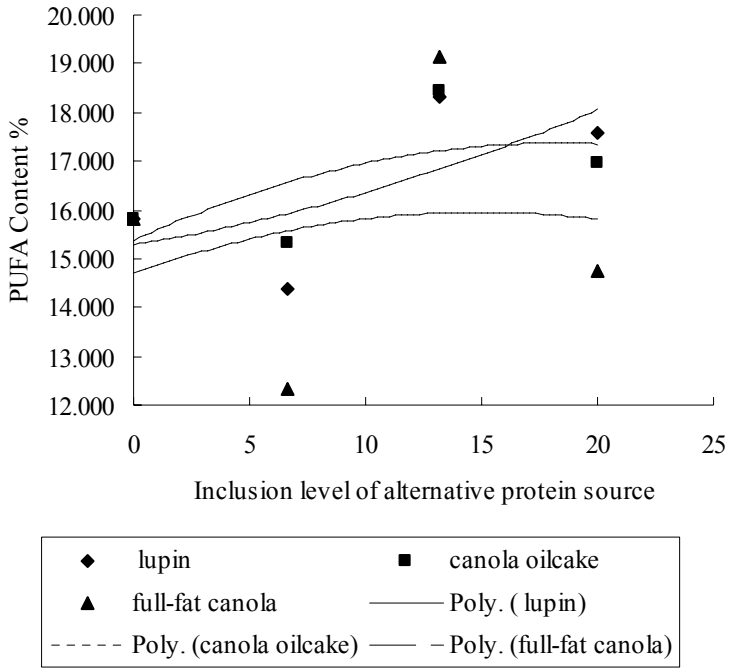

Figure 8.18 The effect of lupin ($y = 0.003x^2 + 0.076x + 15.284$; $R^2 = 0.460$; Sxy = 1.607), full-fat canola ($y = -0.006x^2 + 0.167x + 14.705$; $R^2 = 0.038$; Sxy = 3.419) and canola oilcake ($y = 0.011x^2 – 0.202x + 41.949$; $R^2 = 0.827$; Sxy = 1.361) dietary inclusion on PUFA content of the muscle of pigs

Regression analysis of the data revealed that curvilinear models best fit the changes in the polyunsaturated fatty acid content of the muscle of the pigs as the soybean oilcake was replaced with lupins, canola oilcake and full-fat canola at increasing levels.

The polyunsaturated fatty acid content of the subcutaneous fat of the pigs is presented in Table 8.16. There were no significant differences in the total polyunsaturated fatty acid content of the carcass fat of the pigs. There were no significant ($P \leq 0.05$) differences in the protective fatty acid C18: 3n6 (linoleic acid) content, of the subcutaneous fat of the pigs. The 16.75% lupin diet had the lowest value for the protective fatty acid C18: 3n3 (α-linolenic acid) and the 8.25% lupin diet, the highest value, there were no significant differences between the other diets.

Table 8.16 Fatty acid profiles of polyunsaturated fatty acids (%)(PUFA) in the subcutaneous fat of pigs fed diets with increasing levels of lupins, canola oilcake or full-fat canola

Diet	C18:02	C18: 3n6	C18: 3n3	C20:02	C20:03	C20:04	PUFA
25.00% Lupins	13.055 ± 1.53	0.100±0.016	1.933^{ab}± 0.41	0.483^{b}±0.037	0.188^{a}±0.030	0.145^{ab}±0.020	15.903± 1.8
16.75% Lupins	14.638± 1.53	0.100±0.016	2.155^{b}± 0.41	0.343^{a}±0.043	0.080^{b}±0.035	0.120^{a}±0.023	17.435± 1.8
8.25% Lupins	12.525± 1.53	0.078±0.016	0.983^{a}± 0.41	0.475^{ab}±0.037	0.105^{ab}±0.030	0.110^{a}±0.020	14.275± 1.8
25.00% Full-fat canola	13.560± 1.53	0.093±0.016	1.900^{ab}± 0.41	0.460^{ab}±0.037	0.190^{b}±0.030	0.118^{a}±0.020	16.320± 1.8
16.75% Full-fat canola	13.500± 1.53	0.088±0.016	1.463^{ab}± 0.41	0.518^{b}±0.037	0.153^{ab}±0.030	0.135^{ab}±0.020	15.855± 1.8
8.25% Full fat canola	12.340± 1.53	0.068±0.016	1.158^{ab}± 0.41	0.475^{ab}±0.037	0.133^{ab}±0.030	0.125^{ab}±0.020	14.298± 1.8
25.00% Canola oilcake	10.923± 1.53	0.075±0.018	2.015^{ab}± 0.41	0.450^{ab}±0.037	0.135^{ab}±0.030	0.185^{b}±0.020	13.783± 1.8
16.75% Canola oilcake	12.790± 1.53	0.065±0.016	1.680^{ab}± 0.41	0.465^{ab}±0.037	0.153^{ab}±0.030	0.130^{ab}±0.020	15.283± 1.8
8.25% Canola oilcake	12.515± 1.53	0.080±0.016	1.595^{ab}± 0.41	0.410^{ab}±0.037	0.158^{ab}±0.030	0.125^{ab}±0.020	14.883± 1.8
Control	12.588 ± 0.88	0.075±0.001	1.255^{ab}± 0.24	0.452^{ab}±0.022	0.124^{ab}±0.017	0.138^{ab}±0.011	14.632± 1.0

$^{a-e}$ Column means with common superscripts do not differ ($P \leq 0.05$)

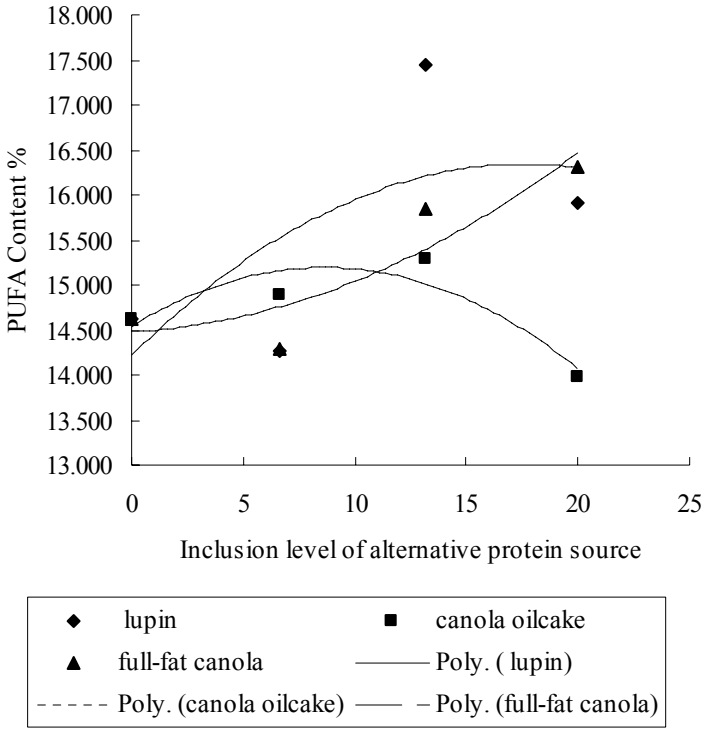

Figure 8.19 The effect of lupin ($y = -0.007x^2 + 0.243x + 14.216$; $R^2 = 0.453$; Sxy = 1.368) full-fat canola ($y = 0.004x^2 + 0.013x + 14.479$; $R^2 = 0.837$; Sxy = 0.549) and canola oilcake ($y = -0.009x^2 + 0.151x + 14.54$; $R^2 = 0.816$; Sxy = 0.620) dietary inclusion on PUFA content of the subcutaneous fat of pigs

The results of the regression analysis are presented graphically in Figure 8.19. Regression analysis of the data revealed that curvilinear models best fit the changes in the polyunsaturated fatty acid content of the subcutaneous fat of the pigs. The polyunsaturated fatty acid content of the carcass fat of the pigs decreased as the soybean oilcake was replaced with canola oilcake. Regression analysis of the data revealed a curvilinear increase in the polyunsaturated fatty acid content of the carcass fat of the pigs as the soybean oilcake was replaced with lupins and full-fat canola, at increasing levels.

In this study the polyunsaturated fatty acid content of the carcass fat increased as the full fat canola content of the diet increased. Kracht *et al*. (1996) found that the content of polyunsaturated fatty acids (PUFA) in the body fat increased, with increasing rapeseed levels. In a similar study by Busboom et al. (1991) pigs fed rapeseed oil meal had greater ($P<0.05$) proportions of mono- and polyunsaturated fatty acids and less ($P<0.05$) saturated fatty acids in peri-renal adipose tissue and subcutaneous adipose tissue. The differences were greater for peri-renal adipose tissue than for subcutaneous adipose tissue. In the longissimus muscle, pigs fed rapeseed oil meal tended to have increased unsaturated fatty acids at the expense of the saturated fatty acids, but this was only significant for linolenic acid. The fatty acid composition of intramuscular adipose tissue was not affected by diet ($P<0.05$). It was concluded that 25.00% rapeseed meal did not affect growth performance or carcass characteristics of pigs. Feeding of rapeseed oil meal increased the un-saturation of peri-renal adipose tissue and subcutaneous adipose tissue, but had less effect on intra-

muscular adipose tissue and longissimus muscle. Castell and Falk (1980) reported a significant effect upon back-fat composition of pigs fed increasing amounts of full-fat canola.

8.5 Conclusion

This study found that the fatty acid profiles of the fat of pigs could be altered by the replacement of soybean oilcake as protein source with sweet lupins, canola oil cake or full fat canola as protein sources. Lupins will increase the leanness and saturated fatty acid content of the fat of the pigs. Full-fat canola will increase the monounsaturated and polyunsaturated fatty acid content of the fat of pigs. Although increasing the content of unsaturated fatty acids in pork, by using feeds including canola, may have benefits with regard to human nutrition, this can lead to increased autoxidation in the feed or in the meat product due to the presence of relatively high levels of linolenic acid (C18:3). Also, a marked increase in the degree of unsaturation, leads to abnormally softer fat, which could adversely affect the grade and processing of the carcass.

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Chapter 9
Conclusion

The purpose of the investigation was to evaluate alternative protein sources in broiler and weaner rations. Soybean oilcake meal was used as the control and sweet lupin; full-fat canola and canola oilcake were substituted into the rations at three dietary inclusion levels, namely 6.6%, 13.2% and 20.0%. It is evident from the results obtained that sweet lupins can partially (up to 13.2%) replace soybean oilcake meal in broiler diets, without significant reductions in broiler performance. However, when replacing full-fat soybeans with sweet lupins in weaner pig diets, performance was significantly reduced. Substituting soybean oilcake meal with canola oilcake reduced the growth performance of broilers, possibly due to a reduced feed intake and a resultant significantly poorer feed conversion ratio. Replacing full-fat soybeans totally with canola oilcake in weaner pig diets reduced the growth performance of weaner pigs. The reduced performance (in this study),was the result of the pigs not utilising the canola oilcake as efficiently as the soybean oilcake meal in this study, as this was demonstrated by the significantly higher feed conversion ratio. The complete replacement of soybean oilcake meal with full-fat canola, in broiler diets, significantly reduced broiler performance, but at lower inclusion levels of full-fat canola the broiler performance was not significantly influenced. The replacement of full-fat soybeans with full-fat canola had no influence on the growth of the piglets. This assessment has shown that sweet lupins, canola oilcake and full-fat canola can be utilized successfully and partly replace soybean oilcake meal in monogastric feeds, hence their use will depend on the availability and the price of these raw materials.

The possible improvement in animal performance, with the application of external enzymes to compliment the animals' endogenous enzymes, was examined. In this study the enzyme Vegpro (Alltech) did not improve the performance of broiler chickens. It is evident from the literature that enzymes are not always successful in improving the dietary utilisation of feeds and that the origin and composition of the raw materials used in the diet play a role in the effectiveness of an enzyme. The energy content of the diet may also effect the effectivity of the enzyme provided. The enzyme Roxazyme® tested in the weaner piglet study only improved the feed conversion ratio of weaner pigs and did not affect any of the other production parameters measured.

The acceptability of sweet lupins, canola oilcake and full-fat canola to pigs, in a free choice situation, was tested. The motivation for such a trial transpired from previous studies, in which the use of these protein sources was limited due to their presumed un-palatability. When these protein sources were initially evaluated, certain lupin species contained high levels of alkaloids which are bitter and thus reduced feed intake and canola contained high levels of glucosinolates and erucic acid which also reduced feed intake. The results showed that in the current study, pigs had a greater preference for soybean meal and sweet lupins rather than either full-fat canola or canola oilcake as protein sources. These results prove that low alkaloid sweet lupins will not negatively affect the feed intake of growing pigs.

The anti-nutritional factor content of canola, lupins, narbon beans, faba beans and peas were evaluated, as these anti-nutritional factors play an important role in the use of these legume crops in rations for monogastric animals. Anti-nutritional factors such as alkaloids, sinapine, glucosinolates, tannins and non-starch polysaccharides may have a negative influence on the animal consuming the protein sources in which they are present. There was a significant variability in alkaloid content of various lupin species tested in this evaluation confirms the necessity to analyse lupins before use if provided by an unknown source. An additional aspect that will have an effect on the use of these unconventional protein sources in monogastric diets is the disparity in NSP content that was found among the products. The lupin species *L. Albus* and *L. Angustifolius* contained significantly more NSP's compared to the lupin species *L. Luteus*, narbon beans, faba beans and peas. NSP's will negatively affect the nutritional value of the *L. Albus* and *L. Angustifolius* lupin species as these carbohydrates are not digested by the endogenous enzymes of monogastrics. The lupins contained no tannins and no starch when compared to the other legumes in this study. Faba beans had the highest tannin content, significantly higher than the narbon beans and peas. The high starch values of the faba beans, narbon beans and peas improve their nutritional value to monogastric animals. Futher studies on the palatability of these raw materials are necessary.

The carcasses of the broilers and pigs were analysed for its fatty acid composition. The fatty acid profiles of the fat pads of the broilers and the subcutaneous fat of the pigs were determined. The fatty acid profiles of the fat are important to consumers concerned about their cardiovascular health. Increasing polyunsaturated fatty acid levels in the fatty acid profile of the fats pads of broilers fed full-fat canola diets render it healthier for human consumption. According to the American Heart Association (2001) saturated fatty acids raise total and low-density lipoprotein cholesterol levels, whereas C18:0 and monounsaturates are neutral when substituted for carbohydrate, and n-6 polyunsaturated fatty acids lower cholesterol. The fatty acid profiles of the fat pads of broilers can be altered by the replacement of soybean oilcake meal as the protein source with sweet lupins, and canola oil cake or full-fat canola as protein sources. The lupins used in the experimental diets had higher saturated fatty acid levels when compared to the other protein sources. Therefore, as expected, the fat pads of the broilers fed the lupin containing diets had higher the saturated fatty acids levels compared to the fatty acid profiles of the fat pads of the broilers fed the diets containing full-fat canola and canola oilcake. The full-fat canola used in the diets had higher mono unsaturated and poly unsaturated fatty acid levels compared to the lupins. Therefore as expected the fat pads of the broilers fed the full-fat canola containing diets had higher the mono unsaturated and poly unsaturated fatty acids levels compared to the fatty acid profiles of the fat pads of the broilers fed the diets containing lupins.

This study also found that the fatty acid profiles of the fat of pigs can be altered by the replacement of soybean oilcake as protein source with sweet lupins, and canola oilcake or full-fat canola as protein sources. Lupins will increase the leanness and saturated fatty acid content of the fat of the pigs because the lupins contain more saturated fatty acids. Full-fat canola will increase the mono-unsaturated and

poly-unsaturated fatty acid content of the fat of pigs because full-fat canola contains more mono-unsaturated and poly-unsaturated fatty acids.

Chapter 10
Future Prospects

An aspect that may improve the utilisation of alternative plant protein sources is the treatment of canola and lupins before they are included in diets for broilers and pigs. Numerous international studies regarding the treatment of canola and lupins have been conducted, however very little research has been done locally. Olver & Jonker (1997) conducted a study were soaked micronised bitter lupins were fed to broilers. The bitter lupins were micronised and soaked to reduce their alkaloid content thereby improving their utilization by broilers. They found that the soaking of the micronised bitter lupins reduced the alkaloid content but it was still higher than the alkaloid level of sweet lupins. In a recent study by Brenes (2003) dehulling lupins greatly improved the nutritional value thereof. Clark *et al*. (2001) conducted a study to determine the value of partially dehulled canola meal compared to conventional canola meal in broiler diets. The results showed that dehulled canola meal contained a higher concentration of crude protein and amino acids and the utilization of energy and amino acids was improved. When considering the treatment of canola and lupins to be included in diets for monogastric animals the cost of the treatment must be compared with the cost benefit of feeding the treated product to the animals. Heat and chemical treatment may be very expensive but if the cost benefit of treating canola and lupins is greater than the cost of the treatment, it is certainly worth considering.

The anti-nutritive effects of non-starch polysaccharides in vegetable proteins need further investigation. A better understanding of the exact mechanisms involved may be an indication of what treatments to apply to vegetable proteins to improve the efficiency with which vegetable proteins are utilised by monogastric animals.

Results obtained with the inclusion of external enzymes remain variable. More research is needed to determine the circumstances under which external digestive enzymes will generate a positive result.

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Pectora roborant cultus recti