LUPINS AS A PROTEIN SOURCE
IN PIG DIETS

A Thesis
Submitted to the Graduate Faculty
in Partial Fulfilment of the Requirements
for the Degree of
Master of Science
in the Department of Health Management
Faculty of Veterinary Medicine
University of Prince Edward Island

Bernadette C. Donovan
Charlottetown, P.E.I.
December, 1990

ISBN 0-315-62409-4

The author has agreed that the Library, University of Prince Edward Island, may make this thesis freely available for inspection. Moreover, the author has agreed that permission for extensive copying of this thesis for scholarly purposes may be granted by the professor or professors who supervised the thesis work recorded herein or, in their absence, by the Chairman of the Department or the Dean of the Faculty in which the thesis work was done. It is understood that due recognition will be given to the author of this thesis and to the University of Prince Edward Island in any use of the material in this thesis. Copying or publication or any other use of the thesis for financial gain without approval by the University of Prince Edward Island and the author's written permission is prohibited.

Requests for permission to copy or to make any other use of material in this thesis in whole or in part should be adressed to:

Chairman of the Department of Health Management

Faculty of Veterinary Medicine

University of Prince Edward Island

Charlottetown, P. E. I.

Canada C1A 4P3

SIGNATURE PAGES

iii-iv

REMOVED

ABSTRACT

To determine the potential use of sweet lupin seeds (Lupinus albus) grown on P.E.I. as a protein source in nonruminant diets, the chemical composition and the protein quality (net protein ratio (NPR)) of lupin seeds were estimated. In addition, growth performance of pigs (66 - 100kg) given a corn-based diet containing lupins as the sole protein source were compared to those given a corn-based diet containing roasted soybeans or soybean meal (SBM) as the sole protein source. The fatty acid composition of the lupin, roasted soybean and SBM corn-based diets and the influence of these diets on carcass fatty acid composition of pigs was evaluated. The effect of incremental replacement of SBM with lupins in barley-based diets on the growth performance of pigs (10-100kg) was also determined.

The lupin seeds used in this study contained 30 - 35% crude protein and the concentrations of manganese (1456 mg kg^{-1}) and alkaloids (0.015%) were below the content that was recognized as being toxic to rats and pigs. A rat growth study determined that the NPR of lupins, cultivars Primorski and Ultra, supplemented with methionine (81.1% and 79.1%, respectively) was better than roasted soybeans (71.4%) ($P<0.05$) and similar to SBM (83.1%). Lupin diets (Primorski and Ultra) not supplemented with methionine were poor in protein quality (57.5% and 58.0%, respectively). When lupin diets were supplemented with lysine alone, the protein quality was similar to the protein quality of unsupplemented lupin diets.

Pigs given the lupin, roasted soybean or SBM corn-based diet had a similar feed efficiency. Pigs given the lupin diet had lower feed intakes and reduced body weight gains than those given the roasted soybean or SBM diet ($P<0.05$). This was due to a palatability problem with the lupin diet. Pigs given the lupin corn-based diet had lower dressing percentages but had leaner carcasses with higher index values and backfat higher in unsaturated fatty acids than those given the roasted soybean or the SBM corn-based diet ($P<0.05$).

Including lupins at 20 or 32% of the barley-based diet (75 or 100% lupin-barley diet) resulted in reduced body weight gain of starter pigs, relative to pigs given the SBM-barley diet, as a result of reduced feed intake. The reduction in feed intake may have been due to the high fiber content of the barley-based diet containing 20 or 32% lupins. Lupins included at 6% of a barley-based diet (25% lupin-barley diet) for starter pigs (10-20kg), 12% (75% lupin-barley diet) for grower pigs (20-50kg) and 9% (75% lupin-barley diet) for finisher pigs (50-100kg), resulted in the pigs having a similar growth performance as those given the 0% lupin barley-based diet. Pigs given the lupin barley-based diets had a similar carcass quality as those given the SBM barley-based diet.

The available nutrient content, low level of alkaloids in lupins and the growth performance of pigs obtained on the lupin-barley or corn diets make lupins suitable for usage in diets for pigs.

ACKNOWLEDGEMENTS

I sincerely thank Dr. Mary McNiven (faculty supervisor) for her guidance and support throughout the entirety of the project. I especially appreciated her being very approachable. Her complementary words and continued interest and attention in my work made me feel confident and secure with my accomplishments. In addition, her interest in personal matters not directly related to this project, made this project even that more enjoyable and her kindness will never be forgotten. To my other supervisory committee members, Dr. Derek M. Anderson, Dr. John A. MacLeod, Dr. Luis Bate and Dr. Robert Curtis, I thank them for their time and valued opinions. Dr. Derek M. Anderson and Dr. John A. MacLeod are greatfully acknowledged for their technical advice that was beneficial to the development and outcome of these experiments. A sincere thank you to my supervisory committee for always being there when I needed them and for making this Masters project an enjoyable and memorable experience.

Dr. Dian Patterson (Department A imal Science, Nova Scotia Agricultural College) is acknowledg for her advice with the design of the experiments. Dr. Alar onald is also acknowledged for his advice with the statistica alysis. I thank David J. Harris, Perth, Western Australia, he alkaloid standards and technical advice with regards to th loid analysis and to Mrs. Linda Townsend for her help with t aloid analysis. The lupin study was made possible through nancial assistance made by Agriculture Canada, Charlottetow search Station, under the Alternative Enterprises Initiativ

TABLE OF CONTENTS

1. INTRODUCTION

Lupin seeds are grain legumes that contain 34-44% crude protein and are, therefore, a potential plant protein supplement for many species of animals (1). Protein supplements are defined by the National Academy of Science (NAS) (2) as those feedstuffs which have a crude protein content greater than 20%. Lupins can be used in cereal-based diets to complement or replace other protein sources (3). Lupins grow well in cool climates in acid sandy soils with low levels of plant nutrients (1). Therefore, lupins have great potential to be grown in Atlantic Canada and to be used either as a protein supplement in livestock feeds or as a cash crop.

1.1 General History of Lupins

Wild lupins, with their many shades of purple, pink and white, that are found growing in fields and along roadsides in Atlantic Canada, are ancestors to the cultivated lupins fed today to livestock and man (1). Historically (2000 B.C.), people added lupin grain to their diet as a source of protein. At that time, peasants were primarily the people who cultivated lupins and, therefore, lupins were known as the poor man's food. Lupinus is the latin name for lupins which means wolf. The term wolf possibly signified that only people of low social status cultivated and consumed lupins (4).

1.2 Present Day Usage of Lupins

Presently, lupins are used in many areas of the world such as Australia, New Zealand, Union of Soviet Socialist Republics, South Africa, Chile, Brazil, Peru, Spain, Poland and France for livestock and human consumption. In Western Australia, for example, lupin seeds comprise 24% of commercial pig grower diets, 10-20% of dairy rations, up to 30% of beef diets, 15% of diets for laying hens and 12% for broiler diets (3). In Chile, bread, pasta and cookies are examples of human foods made from lupin flour (5). However, to this day, lupins are not used as a protein feedstuff to a great extent in Canada.

1.3 Climate and Soil

Cultivated lupins grow under a wide range of environmental conditions. They can tolerate temperatures as low as -9°C and optimal temperature for growth is between 15-25°C (1). Therefore, in Atlantic Canada, lupins should be planted as soon as the soil can be cultivated to reach maturity early in the fall. Lupins grow well on soils that are of poor fertility, slightly acidic, and are of sandy loam to fine textured or clay-like (1). Lupins require no nitrogen fertilization when the pH of the soil is slightly acidic (below pH 6). At this pH there is usually enough inoculum (more than 100 bacteria per gram of soil) for good nodulation (6). Nitrogen fertilizer will increase lupin yield only when there is no rhizobia in the soil and no inoculation has been carried out (7). Root nodules appear on lupins four to six weeks after sowing and nitrogen fixation begins 15 days later (1). Lupins are an excellent rotational crop (8) for crops such as potatoes or corn. The root system of lupins penetrates deep into the soil and recycles leached nutrients back to the soil surface. This also permits succeeding crops with easy access to nutrients and moisture (3). Therefore, lupins improve the structure of the soil and have positive effects on soil quality (4). Since the climate of Atlantic Canada favours high yields of lupins, they may also be valuable to farmers as a cash crop.

1.4 Effect of Lupin Chemical Composition on Animal Performance

The presence of undesirable or toxic compounds is a problem with many plant protein sources. Soybeans, cottonseed and linseed are examples of plant protein supplements that contain toxic compounds ([illegible]). Soybeans must be heat-treated prior to feeding to nonruminants to inactivate trypsin inhibitors and hemagglutinins (9). Cultivated lupins do not require roasting prior to feeding to nonruminants since they do not contain anti-nutritional heat-sensitive factors (10).

Wild lupins contain bitter quinolizidine alkaloids as a defence mechanism to protect the lupins from insect damage but these alkaloids are toxic to animals. Alkaloids have been shown to cause respiratory depression and failure in cats and dogs (11), induce uterine contractions in guinea pigs and cause cardiac arrest (12). Lack of appetite, cramps, violent stomach pain, fever and vomiting in humans and animals have also been reported following ingestion (13).

Cultivated lupins that are grown today may be fed directly to animals and man because they contain low levels of alkaloids (14). These lupins are not toxic and are termed sweet lupins. The pauper gene is responsible for the sweetness of the lupins (15). A sweet lupin, L. albus was produced by Von Sengbusch in Germany in 1930 (4).

Erickson (16) stated that the alkaloid content of lupin seeds must be less that 0.03% before it can be included in diets for pigs. Hill (5) concluded that reduced intake in pigs occurred when they were given L. albus lupins at levels greater than 5% of the diet. When L. angustifolius lupins were given to pigs as the sole protein supplement no negative effects on growth performance occurred. Hill (5) concluded that the presence of alkaloids in the L. albus lupins may have been responsible for the reduced intake of pigs. In a study conducted by Pearson and Carr (17), it was determined that the intake of a diet containing L. albus (cultivar Neuland) lupin seeds was similar to that of L. angustifolius (cultivar Uniwhite) after the alkaloid concentration in the Neuland lupin seeds was reduced from 0.09 to 0.02%. Variability of alkaloid content in lupin seeds does exist as a result of genetic factors (18). The alkaloid content of sweet lupin seeds range from

0.006 to 0.013% (19). The lupin seeds grown on P.E.I. have not been previously analyzed for alkaloid concentration.

Ingestion of lupins containing mycotoxins produced by the fungus Phomopsis leptostromiformis causes lupinosis (20). Phomopsis leptostromiformis grows on dead lupin plants or stubble. Lupinosis is common in Australia where animals are grazed on the infected dead lupin plants or stubble (21). Sheep are more prone to develop lupinosis in the field than cattle or horses (3).

L. albus has a high concentration of manganese (Mn) (160-3400 mg Mn kg^{-1}, air dry basis) (22). This may limit its inclusion in pig diets (23). The recommended maximum tolerance level pigs have for Mn is 1000mg kg^{-1} of diet (dry matter basis) (24). However, there were no signs of Mn toxicity reported in pigs given a lupin diet containing up to 1330 mg Mn kg^{-1} of the diet (as fed basis) (25). King (25) determined that similar growth performance occurred in pigs given 72 or 1330 mg Mn kg^{-1} of the diet. He stated that since the maximum tolerance level of 1000 mg Mn kg^{-1} (24) was based on only four experiments that indicated a range of tolerance of 500-4000 mg kg^{-1}, pigs were able to tolerate the level of 1330 mg Mn kg^{-1} in the diet.

Crude fiber (CF) represents variable amounts of the cellulose, hemicellulose, lignin and other complex carbohydrates in plant material (26). Neutral detergent fiber (NDF) includes cellulose, hemicellulose and lignin materials of plant cell walls while acid detergent fiber (ADF) includes only cellulose and lignin from the cell walls (26). These components of fiber are only partially utilized by nonruminants (9). In nonruminants, some dietary fiber may be fermented to volatile fatty acids (VFAs) by microbial activity in the large intestine (27). The VFAs are absorbed into the blood and they contribute to meet the energy requirement of the pigs (27). VFAs from fiber provide a smaller amount of useful energy than an equal weight of glucose from soluble carbohydrates such as starch since some of the gross energy of the fiber is lost as heat of bacterial fermentation or as methane (27). Therefore, the efficiency of use of digestible energy (DE) decreases as the proportion of dietary energy being digested in the large intestine increases (27). Diets that have a high concentration of fiber are known as low nutrient density diets since a high fiber content results in a low concentration of DE (28). If the concentration of DE in a diet is low, the stomach capacity may limit the ability of the pig to consume sufficient quantities of the diet to meet its daily DE requirement (27). For starter (10-20kg) and grower (20-50kg) pigs, the high fiber content of a barley-based diet reduced feed intake and growth (27). On the other hand, finisher pigs (50-100kg) have a greater stomach capacity than starter and grower pigs and were able to consume more of the high fiber barley-based diet and growth rate was not reduced since the increase in intake may have compensated for the lower DE concentration of the diet (27).

Lupins (L. albus cultivar Ultra) have a high NDF content (204 g kg^{-1} of seed, as fed basis) compared to soybean meal (SBM) (116g kg^{-1} of meal, as fed basis) (29). However, Aguilera et al. (30) determined using pigs that the digestibility value of NDF was

83.2% in *L. albus* variety Multolupa lupins. The ADF, cellulose and hemicellulose contents in *L. albus* variety Multolupa (dry matter basis) were 163g kg^{-1}, 160g kg^{-1} and 3.39g kg^{-1}, respectively. These fiber fractions had digestibility values of 87.8%, 90.4% and 62.2%, respectively for ADF, cellulose and hemicellulose (30). Even though Aguilera et al. (30) determined that much of the fiber in lupins was digested, the VFAs produced from fiber digestion provide only a portion of the DE of glucose (27).

With turkeys, lupins were incorporated into a corn-based diet at 15, 30, 45 and 60% (31). Compared to a SBM diet, poor feed efficiency occurred with the diets containing 45 and 60% lupins while depressed daily weight gains occurred with the diets containing 30, 45 and 60% lupin (31). Halvorson et al. (31) suggested that the higher fiber content in the lupin diets may have caused the lower intake, decrease in daily gain and poor feed efficiency. Feed intake of pigs weighing 20 to 30kg was reduced when they were given a diet containing 37% *L. albus* cultivar Neuland compared to a mixture of fish meal and dried blood in a barley-based diet (17). Pearson and Carr (17) concluded that neither alkaloids nor fiber were likely responsible since the alkaloids were removed with ethanol and the fiber was low in lignin and highly digestible. On the other hand, starter pigs (6-20kg) were given a wheat-based diet containing up to 43% lupin seeds without any negative effects on feed intake (32). The growth performance of pigs given diets containing P. E. I. grown lupin seeds has not been determined and such a study can determine the value of those lupin as a protein supplement for growing pigs.

There appears to be a consistent effect of the inclusion level of lupins in the diet on carcass dressing percentage. The dressing percentage of pigs given a diet containing 20.7% lupins (L. albus cultivar Hamburg) was depressed compared to the pigs given SBM (25). Pearson and Carr (33) also determined that the dressing percentage declined 0.08 percentage units for every 1% increase of lupins in the diet. The lupins were included at 0, 12, 24 and 37% of a barley-based diet and the decrease in dressing percentage was significant at the 12% level of inclusion. They speculated that this effect of lupin was due to the increased gut contents of fiber that was not digested, as a result of the high fiber content in lupins combined with barley.

The oil in lupin seeds (10-12%) consists mostly of long chain unsaturated fatty acids (1). Diets containing lupin seeds could have a positive effect on the content of unsaturated fatty acids in the fat of pigs given those diets. The lipid composition of pork fat can be influenced by dietary level of fatty acids in swine rations (34). Pork meat low in saturated fatty acids was highly acceptable by a taste test panel even after the pork was stored for four months (35). However, soft pork fat is undesirable to consumers. Pork carcasses are judged to be soft and unacceptable to consumers when the linoleic acid (unsaturated fatty acid) content of the backfat is more than 12% of the total fatty acid content (36). A high content of unsaturated fatty acids in the backfat may have a negative impact on pork quality. Linoleic acid content greater than 12% has been measured in pigs given a diet containing more than 15% roasted soybeans (36). Therefore, the backfat fatty acid composition of pigs given a lupin diet should be determined.

Lupin seeds contain little starch (37) but appreciable amounts of oligosaccharides (5). More than 50% of the saccharide fraction in lupin seeds is composed of α-galactosides which are not digested by nonruminants (38). Grosjean (39) and Cazes et al. (40) suggested that the poor performance of pigs given lupins may have been due to the high content of oligosaccharides derived from galactose in the lupins, that reduced the digestible energy content of the lupins.

1.5 Evaluation of Protein Quality in Lupins

The protein quality of a feed ingredient is an estimate of its ability to supply the essential amino acids in the proper proportions to meet the animal's needs for growth and maintenance (41). The formation of body proteins will be maximized when all the essential amino acids are available in adequate amounts in the diet and in the ratio required for protein deposition (41). The amino acid composition of a protein feed ingredient does not reveal the extent to which a particular amino acid is utilized by the animal. Net protein ratio (NPR) is an assay for protein quality evaluation. The calculated NPR value of a protein feedstuff is an estimate of the bioavailability of amino acids in a protein feed ingredient (42). NPR estimates the protein utilized by the animal for both growth and maintenance. The relative NPR value that is calculated for a protein feedstuff is expressed relative to a value of 100 for a reference protein feedstuff. The reference protein feedstuff often used is casein since the digestibility of protein and availability of amino acids in casein is about 100% (43). An estimate of the protein quality is essential before lupins can be incorporated into nonruminant diets. Camacho et al. (44) determined with rats that the protein quality of lupins (L. albus cultivar Multolupa) supplemented with methionine was similar to that of casein. However, the protein quality of lupins (L. albus) grown on P. E. I. has not previously been investigated.

Overall objective:

To determine if lupins can be used as a plant protein feed ingredient in significant amounts in nonruminant diets.

The objectives of this thesis were:

To determine the chemical composition of the lupins grown on P. E. I. including protein, amino acids, energy, alkaloids, NDF, and minerals.

To evaluate protein quality of lupins by calculation of NPR of the protein in lupins, casein, roasted soybeans and SBM. To determine the ability of lupins to supply the essential amino acids in the proper proportion in a diet to meet the animal's protein requirements for growth and maintenance by the use of NPR.

To determine if supplementation of lupins with methionine and lysine is required to improve protein quality.

To compare growth performance of pigs (66-100kg) given corn-based diets containing lupins, roasted soybean or SBM as a supplemental protein source.

To determine the relationship between fatty acid composition of lupin, roasted soybean and SBM diets based on corn and the carcass fatty acid composition of pigs given these diets.

To determine the effect of incremental replacement of SBM with lupins in barley-based diets on the growth performance of pigs (10-100kg).

2. PROTEIN QUALITY OF TWO CULTIVARS OF LUPIN SEEDS EVALUATED IN WEANLING RATS

2.1 Abstract

The protein quality of two sweet white lupin cultivars, Primorski and Ultra, of the species Lupinus albus, was compared with those of soybean meal (SBM), soybeans (raw or roasted) and casein. The value of supplementation of the lupin cultivars with 0.2% methionine and 0.1% lysine was determined. A 3-week feeding trial was conducted with 128 male Sprague Dawley weanling rats. Total feed consumption (TFC), total weight gain (TWG), feed to gain ratio (F:G), net protein ratio (NPR) and relative NPR (RNPR) values were determined for all diets. The RNPR values of Primorski and Ultra, supplemented with methionine at 0.2% of the diet, were 81.1% and 79.1%, respectively of that of casein. RNPR for lupins supplemented with methionine was significantly better than for roasted soybeans (71.4%) ($P<0.05$) and similar to that of SBM (83.1%). Additional supplementation of lupins with lysine improved ($P<0.05$) the RNPR of the Ultra cultivar (88.0%) but not that of Primorski (81.9%). The RNPR values of SBM, Ultra or Primorski supplemented with lysine and methionine were similar. Sweet lupins, Ultra and Primorski, supplemented with 0.2% methionine provided an amino acid profile that was comparable to SBM and of better quality ($P<0.05$) than roasted soybeans.

Therefore, lupins have the potential to be included in pig diets as a source of protein.

2.2 Introduction

Sweet lupins (Lupinus albus) contain 34 - 44% crude protein and 10 - 12% oil (1). The oil consists mostly of long chain unsaturated fatty acids (1). Lupins germinate well at cool temperatures; high yields are obtained when temperatures during the summer do not exceed 25°C and they grow well on slightly acidic soils (1). Lupins do not contain antinutritional heat-sensitive factors such as trypsin inhibitor or hemagglutinins (10), and, therefore, do not require roasting prior to feeding to nonruminant livestock. Previously, lupin cultivars were soaked for several days in water before consumption to remove the bitterness and toxicity caused by the quinolizidine alkaloids (1). Genetic selection has produced sweet lupins that no longer require treatment to reduce alkaloid toxicity since the seed has only a low concentration (< 0.05%) of the toxic alkaloids (14).

The objectives of this study were to compare the protein quality of lupin (Lupinus albus) cultivars, Primorski and Ultra to that of casein, soybean meal (SBM), roasted and raw soybeans, and to determine if supplementation of Ultra and Primorski cultivars with methionine and lysine is required to improve the protein quality.

2.3 Materials and Methods

Animals, diets and experimental procedure

Diets containing ground Ultra, Primorski, SBM, soybeans (raw or roasted) or casein (Table I) were isonitrogenous, each containing 10% crude protein, except for the protein-free diet. Lupin diets were evaluated with or without supplements of lysine, methionine or lysine and methionine. Methionine and lysine were supplemented at 0.2% and 0.1%, respectively, of the diet. Methionine was added at 0.2% of the diet since Ballester et al. (14) determined that the protein efficiency ratio of *L. albus* improved with supplementation of 0.2% methionine. Prieto and Aguilera (45) determined that the true protein digestibility of *L. albus* var Multolupa lupins increased with supplementation of 0.1% lysine in addition to methionine. Therefore, lysine was added at 0.1% of the diet to determine if lysine was limiting in the lupins grown on P.E.I. Each diet was given to 10 rats with the exception of the protein-free diet which was given to 8 rats.

One hundred and twenty-eight, 3-week-old, male, Sprague Dawley rats, mean weight of 54g $\pm$ 7g, were housed individually in stainless steel wire-floored cages. Body weights were recorded immediately after random allocation to experimental treatment and then recorded weekly for the 21 - day feeding period. Feed from stainless steel jars fitted with antispill devices and water from a drip water system were provided *ad libitum*. Feed consumption was measured weekly. The room temperature was maintained between 20 and 22°C and rats were subjected to a 12-h light: 12-h dark lighting regime.

Total weight gain (TWG), total feed consumption (TFC), feed to gain ratio (F:G), and net protein ratio (NPR) (41) were determined for all diets. The relative NPR (RNPR) was calculated using the methods described by Sarwar et al. (43). The RNPR of the test diets was expressed relative to a value of 100 for the NPR of the casein diet.

The rats were cared for in accordance with the guidelines of the Canadian Council on Animal Care.

This experiment was a completely randomized design. Statistical analysis was carried out using analysis of variance (46) and significant differences between diets were determined by the Student Neuman-Keuls test at the alpha=0.05 level (47). Factorial statistical analysis (46) was performed to determine if there was an effect of interaction between cultivar and supplementation.

Chemical analysis

The lupin cultivars as well as roasted and raw soybeans were ground to pass through a 2 mm screen. Dry matter content was determined in duplicate for all diets and test ingredients by Association of Official Analytical Chemists (AOAC) Methods (48). Crude protein (nitrogen * 6.25) on test diets and ingredients was determined in duplicate by the Dumas method (49), using a nitrogen gas analyzer, Leco, FD-228 (Leco Corporation, St. Joseph, Michigan, U.S.A.). Gross energy analysis was done in duplicate on all diets and test ingredients using an adiabatic bomb calorimeter (Parr Adiabatic Calorimeter, Parr Instrument Company, Illinois). Amino acid analysis was done in triplicate on lupins and roasted soybeans using a Beckman System 6300 High-Performance Amino Acid Analyzer. The samples were subjected to acid hydrolysis using the procedure of Gehrke et al. (50). Methionine and cystine were determined on the samples following performic acid digestion (51). Neutral detergent fiber, (52) and calcium, phosphorus, magnesium, potassium, manganese (Mn), copper, zinc and iron were determined in duplicate on the test ingredients (Inductively-coupled argon plasma spectrophotometry, Jerrel-Ash 9000). The alkaloids lupanine and 13-hydroxylupanine were determined in duplicate for lupin seeds (53).

2.4 Results

Analytical results

The Mn and alkaloid concentrations for Ultra were higher than that for Primorski (Table II). Lupanine and 13-hydroxylupanine are alkaloids present in lupin seeds (3). In Ultra and Primorski the total amount of these alkaloids were lower than those determined by Ballester et al. (14) for *L. albus*. The methionine and lysine concentrations in the lupin diets (Table III) were below the requirement of the weanling rats. Cystine content was similar in Primorski and Ultra diets and cystine plus methionine did not meet the methionine requirement of rats.

Feed intake, body weight gain and feed efficiency

Lupin seed diets (Primorski and Ultra) supplemented with 0.2% methionine were consumed in amounts similar to those for diets containing casein or SBM and greater than for the roasted soybean diet ($P<0.05$) (Table IV). Lupin diets supplemented with lysine and methionine were consumed in similar amounts as lupin diets supplemented with methionine alone. Body weight gains on lupin diets supplemented with methionine did not differ from those for SBM but were greater than those obtained with roasted soybeans ($P<0.05$). Supplementation of Ultra with lysine in addition to methionine increased the weight gain of rats ($P<0.05$) compared to methionine supplementation alone. However, this improvement was not statistically significant for Primorski-fed rats. There was no significant difference in consumption, weight gain of rats or protein quality between the lupin cultivars in response to supplementation with either or both amino acids (Table V). Casein produced higher body weight gains than the other protein sources ($P<0.05$). There were no differences in feed efficiency among rats given diets containing casein, SBM, roasted soybeans or lupins supplemented with methionine alone or in addition to lysine. Supplementation of lupin diets with methionine alone increased feed intake, body weight gain and feed efficiency (P<0.05) (Table IV). Supplementation of Ultra or Primorski diets with lysine alone did not increase feed intake, weight gain or feed efficiency.

Protein quality of lupins, roasted soybeans and SBM

Protein quality of the diets was indicated by RNPR (Table IV). Methionine supplementation improved the RNPR of lupins, Primorski and Ultra, to values similar to that for SBM and better than that for roasted soybeans (P<0.05). Lysine supplementation in addition to methionine improved the protein quality of Ultra but not Primorski (P<0.05) compared to supplementation with methionine alone. However, there was no significant difference between the lupin cultivars in response to additional supplementation with lysine (Table V). There were no significant differences in RNPR of SBM, Primorski or Ultra supplemented with lysine in addition to methionine, although Ultra was slightly higher in protein quality. In the present feeding trial, the protein quality of casein was better than the other diets (P<0.05).

2.5 Discussion

Supplementation of Ultra or Primorski with methionine increased the RNPR to values similar to that for SBM. Therefore, Ultra or Primorski supplemented with methionine may provide protein of sufficient quality for the growing rat. Schoeneberger et al. (54) determined that lupins are deficient in methionine, but when supplemented, they provide protein of high nutritional value to the rat. Since there were no significant differences in RNPR between the lupin cultivars in response to additional supplementation with lysine (Table V), supplementation of Ultra with methionine alone may be sufficient for the growing rat. However, since lysine supplementation in addition to methionine improved the protein quality of Ultra (P<0.05) but not Primorski compared to similar diets supplemented with methionine alone, diets containing Ultra may require additional supplementation with lysine when the lysine content of the diet is below that of the requirement of nonruminants.

Lupin diets not supplemented with methionine were poor in protein quality. This may be attributed to the methionine content of the lupin diets being below the requirement of the weanling rats (Table III). When lupin diets were supplemented with lysine alone, the protein quality was similar to the protein quality of unsupplemented lupin diets. The improvement in performance on these lupin diets with supplemental methionine indicated that methionine is the first limiting amino acid in the lupin cultivars, Ultra and Primorski. This is consistent with findings of Savage et al. (55) who reported that additions of methionine increased the biological value of lupin protein to values similar to those of soybeans. The addition of 0.1% methionine to lupins (L. albus cultivar Multolupa) increased NPR to a value that did not differ significantly from casein (44). In other words, the Multolupa lupins when supplemented with methionine had a similar quality of protein as that of casein. The RNPR of 94% calculated from their data for Multolupa lupins plus methionine was higher than the RNPR values for Primorski and Ultra plus methionine determined in this study. The difference in the RNPR values may be due to cultivar difference.

Roasted soybean should have the same proportion of amino acids in its protein as SBM (9) however, the RNPR for SBM was better than for roasted soybeans ($P<0.05$) (Table IV). The lower crude protein content of the roasted soybean diet (8.6%) compared to the SBM diet (9.8%) or the possibility that all of the trypsin inhibitor in the roasted soybeans was not inactivated may have been responsible for the lower RNPR value of the roasted soybean diet ($P<0.05$). However, it was determined in a study (56) that the protein efficiency ratio (PER) of roasted soybeans supplemented with methionine was greater than the PER of roasted soybeans not supplemented. Therefore, judging by the methionine concentration of the roasted soybeans (Table III), the lower RNPR value for the roasted soybeans may have also been due to their low methionine concentration. The RNPR of raw soybeans was lower than that for roasted soybeans ($P<0.05$) (Table IV), supporting the findings of Rackis (57) that raw soybeans are of lower protein quality than roasted soybeans or SBM. He concluded that this was because of the presence of heat-sensitive proteins in raw soybeans that inhibit the activity of trypsin, thereby, reducing protein digestibility.

The low level of alkaloids detected (Table III) did not appear to have had an effect on the feed intake since consumption of lupin diets when supplemented with methionine was no less than that of casein or SBM.

Of the concentration of minerals present in L. albus lupins, Mn may limit the inclusion level of these lupins in diets for nonruminants since the content of Mn in diets containing these lupins may exceed the maximum tolerance level those animals have for Mn (23). It was determined that the Mn content of 1330 mg kg^{-1} in diets containing L. albus cv. Hamburg was tolerated by growing pigs and growth performance was not affected by the Mn content (25). The lupin variety Ultra had a higher content of Mn than Primorski but the level of Mn in Ultra diets did not exceed 300 mg kg^{-1}. Meeting the protein requirement of the rat with lupin seed as the only source of protein in the diet would not result in toxic effects of Mn.

2.6 Conclusions

Lysine supplementation in addition to methionine improved the protein quality of Ultra but not Primorski. Unsupplemented lupins were similar in protein quality to lupins supplemented with lysine alone. Thus, methionine is the first limiting amino acid in lupin protein for rats. Sweet lupins, cultivars Ultra and Primorski of the species *Lupinus albus*, supplemented with 0.2% methionine provided protein that was biologically available to the rat, comparable to SBM and of better quality ($P<0.05$) than roasted soybeans. From this experiment, lupins may be included in nonruminant diets as a substitute for other protein concentrates if proper supplementation is carried out.

Table I. Composition of experimental diets.

Ingredients (%) (as fed basis)	Diets[a]												
			Primorski				Ultra						
	Casein	SBM	P	P_l	P_m	P_{l+m}	U	U_l	U_m	U_{l+m}	Roasted Soybeans	Raw Soybeans	Protein Free
Casein[b]	11.8												
Soybean meal		20.7											
Primorski			28.3	28.3	28.3	28.3							
Ultra							29.7	29.7	29.7	29.7			
Roasted soybeans											22.5		
Raw soybeans												23.3	
Basal mix[c]	81.2	72.3	64.7	64.6	64.5	64.4	63.3	63.2	63.1	63.0	70.5	69.7	93.0
Vitamins[d]	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Salt mixture[e]	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Lysine HCL[f]				0.1		0.1		0.1		0.1			
DL methionine[g]					0.2	0.2			0.2	0.2			
Chemical composition (as fed basis)													
Dry matter (%)	91.7	92.0	91.8	91.6	92.4	92.4	92.4	92.4	92.4	92.3	92.2	91.5	91.8
Gross energy (kJ g^{-1})	16.0	15.8	15.9	16.2	16.4	16.3	16.4	16.5	16.4	16.2	16.3	16.3	15.4
Crude protein (%)	9.9	9.8	9.9	10.0	9.9	9.9	9.5	10.0	10.0	9.7	8.6	8.5	0.0

a SBM = soybean meal; U = Ultra P = Primorski; l = lysine; m = methionine.

b Sigma chemical company. P.O. Box 14508, St. Louis, Mo, 63178, USA.

c 89.06 g $100g^{-1}$ corn starch + 3.33 g $100g^{-1}$ cerelose (dextrose) + 5.21 g $100g^{-1}$ α-cellulose + 2.4 g $100g^{-1}$ corn oil.

d 0.2 g $100g^{-1}$ vitamin A (500×10^6 IU kg^{-1}) + 0.01 g $100g^{-1}$ vitamin D (500×10^6 IU kg^{-1}) + 3.75 g $100g^{-1}$ Vitamin E (500000 IU kg^{-1}) + 0.03 g $100g^{-1}$ vitamin K (50%) + 0.02 g $100g^{-1}$ Biotin (2%) + 50 g $100g^{-1}$ Choline Chloride (60%) + 0.03 g $100g^{-1}$ Folic Acid (3%) + 5.0 g $100g^{-1}$ Inositol + 0.75 g $100g^{-1}$ Niacin (98%) + 0.4 g $100g^{-1}$ calcium pantothenate (45%) + 0.2 g $100g^{-1}$ Riboflavin (98%) + 0.06 g $100g^{-1}$ Thiamin + 0.35 g $100g^{-1}$ B_6 (Pyridoxine) + 0.003 g $100g^{-1}$ B_{12} (0.1%) + 0.5 g $100g^{-1}$ Para amino benzoic acid + 0.1 g $100g^{-1}$ ethoxyquin + 3.0 g $100g^{-1}$ TM-50 premix (antibiotic 110 mg g^{-1}) + 34.597 g $100g^{-1}$ corn starch + 1.0 g $100g^{-1}$ corn oil.

e Salt mixture USP, XVIII, ICN Pharmaceuticals, Inc. Life Sciences Group, Cleveland, Ohio, USA.

f 75% available lysine.

g 99% available methionine.

Table II. Chemical composition of test ingredients (Dry matter basis).

	Lupin seed		Soybeans		
	Primorski	Ultra	Roasted	Raw	Soybean meal
Dry matter (%)	95.9	97.6	94.7	92.1	89.4
Crude protein (%)	36.8	34.4	47.0	46.6	54.1
Gross energy (kJ g^{-1})	20.14	19.93	22.19	22.20	-
Neutral detergent fiber (g kg^{-1})	230.4	214.1	127.8	124.9	-
Calcium (g kg^{-1})	2.1	2.9	1.5	1.7	3.0
Phosphorus (g kg^{-1})	3.8	4.7	8.4	8.4	9.7
Magnesium (g kg^{-1})	2.0	1.7	2.5	2.6	3.6
Potassium (g kg^{-1})	10.8	11.7	21.1	21.0	27.9
Manganese (mg kg^{-1})	307.6	1034.8	29.6	38.0	42.3
Copper (mg kg^{-1})	4.9	6.0	15.1	21.5	18.8
Zinc (mg kg^{-1})	17.3	33.7	48.4	51.9	63.9
Iron (mg kg^{-1})	20.9	56.4	132.0	135.7	111.9
Alkaloids					
Lupanine (%)	0.011	0.004	-	-	-
13-hydroxylupanine (%)	0.004	0.005	-	-	-

Table III. Amino acid profile of lupins, roasted soybeans and non-supplemented diets compared to amino acid requirement of weaning rats (as fed basis).

Amino acid	Amino acid composition (%)							
	Primorski		Ultra		Roasted Soybeans		Amino acid requirement[a]	
	Grain	Diet	Grain	Diet	Grain	Diet	Growth	Maintenance
Isoleucine	1.55	0.44	1.43	0.42	1.63	0.37	0.50	0.31
Leucine	2.33	0.66	2.23	0.66	2.46	0.55	0.75	0.18
Lysine	1.52	0.43	1.41	0.42	1.74	0.39	0.70	0.11
Methionine	0.24	0.07	0.24	0.07	0.41	0.09	0.40	0.15
Cystine	0.24	0.07	0.25	0.07	0.29	0.07	0.20	0.08
Phenylalanine	1.29	0.37	1.19	0.35	0.83	0.19	0.53	0.12
Threonine	1.41	0.40	1.36	0.40	1.12	0.25	0.50	0.18
Valine	1.49	0.42	1.44	0.43	1.70	0.38	0.60	0.23
Arginine	3.33	0.94	2.65	0.79	2.47	0.56	0.60	-
Histidine	0.77	0.22	0.73	0.22	0.83	0.19	0.30	0.08
Aspartic acid	3.94	1.12	3.56	1.06	5.16	1.16	0.40	-
Serine[b]	1.05	0.30	1.00	0.30	1.82	0.41	-	-
Glutamic acid	5.64	1.60	5.10	1.51	7.01	1.58	4.00	-
Proline	1.10	0.31	0.98	0.29	1.58	0.36	0.40	-
Glycine[b]	1.45	0.41	1.37	0.41	1.80	0.41	-	-
Alanine[b]	1.07	0.30	1.04	0.31	0.66	0.15	-	-
Tyrosine	1.21	0.34	1.10	0.33	1.02	0.23	-	-
Ammonia	0.76	0.22	0.74	0.22	0.78	0.18	-	-

a (58). National Research Council. No. 10. Nutrient requirements of laboratory animals.

b Mixture of glycine, alamine and serine: Growth = 0.59; maintenance = 0.48.

Table IV. Total feed consumption (TFC), total body weight grain (TWG), feed efficiency (F:G), net protein ration (NPR) and relative net protein ration (RNPR) in lupin, soybean meal, soybean and casein diets.

	Casein	Lupin								Soybean Meal	Full fat soybeans		
		Ultra$^{a}_{l+m}$	Ultra$_{m}$	Ultra$_{l}$	Ultra	Primorski$_{l+m}$	Primorski$_{m}$	Primorski$_{l}$	Primorski		Roasted	Raw	SD^{b}
TFC (g)	330^{c}	345^{c}	346^{c}	201^{ef}	198^{ef}	348^{c}	331^{c}	183^{f}	178^{f}	340^{c}	284^{d}	220^{e}	27.84
TWG (g)	118^{c}	108^{d}	96^{e}	40^{g}	35^{g}	100de	94^{e}	30^{g}	31^{g}	99de	69^{f}	32^{g}	8.62
F:G	2.81^{f}	3.23^{ef}	3.61^{def}	5.12^{cdef}	5.82^{cde}	3.48^{def}	3.54^{def}	6.12^{cd}	5.93^{cde}	3.42^{ef}	4.14^{def}	7.01^{c}	1.97
NPR	3.84^{c}	3.38^{d}	3.04^{e}	2.42^{g}	2.23^{hi}	3.15^{de}	3.11^{e}	2.15^{h}	2.21^{gh}	3.19^{de}	2.74^{f}	1.87^{i}	0.22
RNPR	100^{c}	88.0^{d}	79.1^{e}	63.1^{g}	58.0^{gh}	81.9^{de}	81.1^{e}	56.1^{h}	57.5^{gh}	83.1^{de}	71.4^{f}	48.6^{i}	5.80

a *l = lysine, m = methionine.*
b Pooled standard deviation.
c-i Means within a row followed by the same letter are not significantly different; $P<0.05$.

Table V. Significance level of the interaction of lupin cultivar and supplementation on TFC, TWG, F:G, NPR and RNPR[a]

	Cultivar*methionine	Cultivar*lysine	Cultivar*methionine*lysine
TFC	NS[b]	NS	NS
TWG	NS	NS	NS
F:G	NS	*	NS
NPR	NS	**	NS
RNPR	NS	**	NS

a See Table IV for description.
b Statistical level: NS = not significant; * $P<0.05$; ** $P<0.01$.

3. GROWTH PERFORMANCE OF FINISHER PIGS GIVEN DIETS CONTAINING ROASTED SOYBEANS, SOYBEAN MEAL OR SWEET LUPIN SEEDS

3.1 Abstract

Ninety-six Yorkshire pigs with an initial weight of 66.6 kg ± 7.5 kg were placed in pens in groups of four on one of three corn-based isonitrogenous diets containing dehydrated lupin seeds (Lupinus albus cultivar Ultra), roasted soybeans (Glycine max cultivar Maple Isle) or soybean meal (SBM). Diets were fed until the animals were marketed at 94kg. Pigs given the lupin-corn diet had a similar feed efficiency to those given the roasted soybean or SBM corn diet. Pigs consumed approximately 22% less of the dehydrated lupin seed diet than the roasted soybean or the SBM corn diet ($P<0.05$). This was due to a palatability problem with the lupin-corn diet. There were no significant differences between the roasted soybean and SBM corn diets with regards to feed consumption. As a result of the lower feed intake, lupin-fed pigs had a 23% reduction in daily body weight gain and leaner carcasses of higher index values than those given the roasted soybean or the SBM corn diet ($P<0.05$). These pigs also had backfat higher in unsaturated fatty acids than those given the roasted soybean or SBM corn diet ($P<0.05$). Since the lupin-fed pigs were leaner, the dressing percentage of these pigs was lower than those of pigs receiving the roasted soybean or SBM corn diet ($P<0.05$). The feed efficiency and carcass index values of pigs given the lupin-corn diet indicate that lupins have the potential to be included as a

plant protein feedstuff in pig corn-based diets. However, since reduced feed intake, slower gain in body weight and lower dressing percentages of pigs resulted when they were given lupins at 18% of the corn-based diet, lupins should not be included at this level of the diet. Further research is needed to determine specifically what caused the reduced feed intake of pigs given the lupin corn-based diet.

3.2 Introduction

Rates of inclusion (> 5%) of lupins (L. albus) in diets for growing pigs have been associated with depressed pig performance but the reason for this is unclear (5). It was determined from a slope-ratio assay that the lysine availability of L. albus was low (44-57%) compared to the lysine availability of soybean meal (SBM) (80%) (20). In another study with pigs (59), it was determined that the availability of methionine or tryptophan in lupins was not low. The poor performance of pigs given a lupin diet in a study conducted by Castell and Tsukamoto (60) was attributed to the presence of alkaloids in the lupins. King (25) determined that growth rate was suppressed when lupin (L. albus cultivar Hamburg) was included in a diet at more than 10%, relative to a diet containing a mixture of SBM and meat and bone meal. He suggested that this was the result of either a low utilization of synthetic lysine or to the low availability of lysine in lupins. Pearson and Carr (17) found that voluntary intake of lupin (L. angustifolius or L. albus) diets was suppressed in pigs weighing 20-30kg when lupins were 37% of the diet but the factor causing this is unknown. They stated that alkaloids or fiber were not likely responsible for the depressed intake since the alkaloids had been extracted with ethanol and the lupins were highly digestible and low in lignin.

On the other hand, satisfactory growth performance of 0.54kg day^{-1} resulted when pigs (12-20kg) were given wheat-based diets containing up to 43% L. angustifolius cultivar Unicrop and adequate levels of lysine and methionine (32). This was compared to the growth rate of 0.55kg day^{-1} of pigs given a SBM diet (32). L. angustifolius cultivar Uniwhite also has the potential to be used as a source of protein in barley-based diets, included at up to 26% for starter pigs (12-25kg), provided that the diets contain adequate amounts of lysine and methionine (33). These starter pigs gained 500g of body weight per day which was similar to that of pigs given a barley-based diet containing fish meal and dried blood (33). It was concluded that L. angustifolius lupins could be used as the sole protein supplement in pig diets (5). Hill (5) concluded that only a limited amount of L. albus lupins (5-10% of the diet) could be included in a diet for pigs due to the presence of alkaloids. However, since there were only trace amounts of alkaloids present in the lupins (L. albus cultivar Ultra) grown on P. E. I. (Chapter 2), these lupins may have the potential to be used as the sole protein supplement in pig diets.

With weanling rats we determined that the protein quality of lupins supplemented with methionine was similar to that of SBM and significantly better than that of roasted soybeans (Chapter 2). These results indicate that lupins have the potential to be used as a protein feedstuff in pig diets. Thus, the growth trial being reported with pigs given diets containing lupin seeds (L. albus cultivar Ultra) grown on P. E. I. was done to test this hypothesis.

Dietary content of saturated fatty acids may be associated with elevated levels of cholesterol in the blood which increases the risk of arteriosclerosis in humans (61). Fats high in polyunsaturated fatty acids are required to maintain adequate blood levels of essential fatty acids (62). Some food products that are already highly accepted, pork meat, for example, can be modified to contain a more desirable ratio of unsaturated : saturated fatty acids (63). For example, Villegas et al. (34) stated that the lipid composition of pork fat can be influenced by dietary level of fatty acids in swine rations. Inclusion of roasted soybeans in swine diets increased the content of unsaturated fatty acids in backfat compared to that of pigs given SBM diets (34). The influence of the dietary addition of lupin seeds on the fatty acid profile of pork fat has not been reported previously. Since lupin seeds contain 10-12% oil (1), the amount of unsaturation that can be obtained in the pork fat of lupin-fed pigs should be determined.

The objective of the experiment being reported was to evaluate the nutritional quality of corn diets containing either dehydrated lupins (L. albus cultivar Ultra), roasted soybeans or SBM as the sole supplemental protein source. The evaluation consisted of the measurement of feed intake, body weight gain and feed efficiency.

Another objective was to determine the quality of the carcass with respect to dressing percentage, leaness, commercial grade index and backfat content of saturated and unsaturated fatty acids.

3.3 Materials and Methods

Ninety-six, purebred Yorkshire pigs (48 gilts and 48 barrows) weighing 66.6kg ± 7.5kg were allotted, within sex, among three dietary treatments. Pigs were placed in groups of four. Three isonitrogenous corn-based diets (Table VI), that contained either dehydrated lupin seeds, SBM or roasted soybeans were formulated to meet nutrient requirements of pigs at 50-100kg (64). Synthetic lysine and methionine were added to diets that were deficient in meeting the requirements of the pigs. The lupins had been previously dehydrated at a temperature between 70 and 90°C for 45 min. Feed was provided ad libitum.

Pens were 2.4 * 4.2 m in size with solid concrete floors bedded with sawdust. Each pen contained an automatic nipple drinker providing water ad libitum. The temperature in the barn was maintained at 19 ± 2°C.

Pigs were given two weeks to adjust to the diets. Feed consumption on a pen basis and individual weight gains were recorded weekly. Pigs were weighed and sent to slaughter at a mean weight of 93kg ± 4.4kg liveweight with dressed weight, lean yield class and grade index data determined on the hot carcass (65). A section of approximately 200g of the longissimus dorsi muscle from over the 13th rib was removed from pigs and stored at -18°C in an atmosphere of nitrogen prior to analysis of fatty acid content.

Samples of each batch of mixed diet were taken and analyzed for dry matter, crude protein, NDF and ADF. Dry matter and crude protein contents were determined in duplicate for all diets and test ingredients similar to the procedure previously reported (Chapter 2 pages 13 and 14). NDF and ADF were determined in duplicate on diets using the procedure of Goering and Van Soest (52). Amino acid analysis was done in triplicate on lupins and roasted soybeans by the procedure previously reported (Chapter 2 page 14). The concentration of alkaloids, lupanine and 13-hydroxylupanine, were determined for lupin seeds similar to the procedure previously reported (Chapter 2 page 14). After all fat was removed, a 100g sample was taken and used for fatty acid analysis. Fatty acid composition of diets and backfat samples were determined using the fat extraction method of Bligh and Dryer (66). The methylated fat was suspended in 2mL of hexane for gas chromatographic analysis (67).

Statistical analysis was carried out using one way analysis of variance (46) and significant differences between diets were determined by the Student Neuman-Keuls test at the alpha=0.05 level (47). Variation due to the effects of diet, replicate, sex, diet*sex and pen(diet*replicate) were removed from the residual sum of squares with the exception of feed consumption and feed efficiency (feed:gain) from which variation due to diet, sex, diet*sex and replicate were removed. Starting weights were used as a covariate.

3.4 Results

Chemical composition of protein feedstuffs and diets

The lupin-corn diet contained approximately 2.6 times the ADF content of the SBM-corn diet and approximately 1.3 times the ADF content of the roasted soybean-corn diet (Table VI). The crude protein content and the calculated DE values for the lupin, roasted soybean and SBM corn diets were similar. The crude protein content of the lupin seeds was similar to that of the roasted soybeans, while SBM had the highest content of crude protein (Table VII). Since the diets were formulated on the basis of crude protein requirement, lupins or roasted soybeans were included at a higher concentration than SBM in the corn-based diets. The manganese (Mn) concentration for the lupin seeds was higher than that for the roasted soybean or SBM but the level of Mn in the lupin-corn diet was below the level that is toxic to pigs (64). The total amount of the alkaloids, lupanine and 13-hydroxylupanine, were lower than those determined by Ballester et al. (14) for L. albus. Therefore, alkaloids or Mn concentrations in the lupin-corn diet were not considered as factors in the performance of pigs.

Diets containing lupin seeds had a higher proportion of unsaturated fatty acids than diets containing roasted soybeans or

SBM (Table X). The lupin-corn diet contained a higher content of palmitoleic and oleic acids and a lower content of linoleic acid than the other two diets. Linolenic acid was higher in the roasted soybean-corn diet. The lupin-corn diet had a lower proportion of saturated fatty acids than the roasted soybean or SBM corn diet. The content of the saturated fatty acid, palmitic acid, was lower in the lupin-corn diet than in the roasted soybean or SBM corn diet.

Performance of pigs

The effect of diet*sex was not significant for any of the variables.

Pigs given the dehydrated lupin-corn diet had a slower daily weight gain than those given the roasted soybean or the SBM corn diet ($P<0.05$) (Table VIII). Weight gains obtained on the roasted soybean and SBM corn diets were similar.

Feed consumption by pigs on the lupin-corn diet was lower than the consumption of the roasted soybean or SBM corn diets ($P<0.05$) (Table VIII). There were no significant differences between SBM and roasted soybean corn diets with regards to feed consumption (Table VIII).

Pigs given the lupin-corn diet had a similar feed efficiency to those given the roasted soybean or SBM corn diet (Table VIII).

Pigs given the lupin-corn diet required 10.9 more days on test than those given the roasted soybean-corn diet and only gained weight at 77% of the rate achieved by those pigs on the SBM-corn diet (P<0.05) (Table VIII) .

Carcass quality and fatty acid composition

Market weight was similar in all pigs. Pigs given the roasted soybean or SBM corn diets had similar dressing percentages which were higher than those of pigs given the lupin-corn diet (P<0.05) (Table IX). Commercial carcass grade index is determined from lean depth, loin fat and weight of pigs (65). Pigs given the lupin-corn diet had leaner carcasses with a higher commercial carcass grade index than pigs given the roasted soybean or SBM corn diets (P<0.05). Lean yield class values assigned to pig carcasses range from 1 to 17, with the estimated lean yield highest for class 1 (65). Pigs given the roasted soybean or SBM corn diets had similar lean yield class values and were fatter than those pigs given lupins although the DE in the diet was calculated to be the same for all diets.

Pigs given the lupin-corn diet had a higher content of unsaturated fatty acids in the backfat than those given diets containing roasted soybeans or SBM (P<0.05) (Table X). Pigs given the roasted soybean or SBM corn diet had similar contents of unsaturated fatty acids in the backfat. The profile of the unsaturated fatty acids, palmitoleic, oleic and linoleic acids in the backfat of pigs given the three protein feedstuffs were similar. However, pigs given the lupin-corn diet had a higher content of arachidonic acid in the backfat ($P<0.05$). Those given the roasted soybean or SBM corn diet had a similar content of arachidonic acid in the backfat. The content of linolenic acid in the backfat of pigs was not reported since only trace amounts were obtained from the backfat and were too small to determine accurately.

The backfat of pigs given the lupin-corn diet was lower in saturated fatty acids than that of pigs given the roasted soybean or SBM corn diet ($P<0.05$) (Table X). Roasted soybean and SBM fed pigs had similar concentrations of saturated fatty acids in their backfat. There were no significant differences in the quantities of myristic or stearic acids in the backfat of pigs given the lupin, roasted soybean or SBM corn diet. However, palmitic acid was of lower content in the backfat of pigs given the lupin-corn diet ($P<0.05$). Pigs given the roasted soybean or SBM corn diet had a similar content of palmitic acid in the backfat.

3.5 Discussion

Performance of pigs

The lupin-corn diet, balanced for the nutrient requirements of finisher pigs, was utilized as efficiently as the roasted soybean or SBM corn-based diet (Table VIII). However, this was not the case in a study conducted by Batterham et al. (59). In their study, a lupin (*L. angustifolius*) diet was supplemented with free lysine to exceed the estimated available lysine content supplied in the SBM diet and it was also supplemented with methionine and tryptophan to meet the nutrient requirements of pigs. The lupins were supplemented with lysine on the basis that 54% of the total lysine in lupins was available to pigs. The supplemented lupin diet significantly improved the feed efficiency value compared to the lupin diet deficient in only lysine. However, they determined that the feed efficiency value of the lupin diet supplemented with lysine was significantly inferior to that of the SBM diet. Heat treatment was not responsible for the inhibited utilization of the free lysine supplement (59). Methionine or tryptophan in the lupin diet was not low in availability to the pig (59). Batterham et al. (59) concluded that the lysine availability in lupins (L. angustifolius) was low, possibly because the lysine was in a form that was inefficiently utilized (68). In the present study, the lupin-corn diet was supplemented with free lysine on the basis that 100% of the total lysine in lupins was available to pigs. Therefore, it seems that the available lysine content in the lupin-corn diet may be adequate for the requirement of finisher pigs.

In another study, it was concluded from a slope-ratio analysis on growing pigs that the availability to pigs of lysine in lupins (L. albus) was low (51%) compared to the availability of lysine in SBM (80%) (20). The availability of lysine in roasted soybeans is 71% (69). However, the ileal digestibility of lysine in cultivars of L. albus was high (82%) (70). Therefore, Batterham et al. (20) stated that the low lysine availability was not due to impaired digestibility of lysine since the ileal digestibility of lysine is 82%. Batterham et al. (59) also speculated that if the lysine was efficiently utilized, lupin seeds may contain an unidentified growth inhibitor that is heat resistant. The feed efficiency value of pigs given the lupin-corn diet in this study indicates that it is highly unlikely that such a factor exists. On the other hand, the reduced feed intake and slow daily weight gain of the pigs may indicate otherwise. Batterham et al. (20) concluded that the low lysine availability was not due to a lower net energy content in the lupin diet, since depressed protein deposition and increased fat deposition resulted in pigs given a lupin diet that contained a similar net energy content as the SBM diet. Since the feed efficiency value of pigs given the lupin-corn diet in this study was similar to that of pigs given the roasted soybean or SBM corn diet, it seems unlikely that the lupin-corn diet was deficient in net energy or that the availability of lysine in lupins was as low as 51% as reported by Batterham et al. (20). The value of 82% reported by Taverner (70) is likely a more accurate estimate of the availability of lysine in the lupins used in this study.

Batterham et al. (29) also speculated that the low availability of lysine may have been due to an unidentified growth inhibitor present in the seed or that lysine was in a form that was absorbed but inefficiently utilized. Reactions involving the ε-amino group of lysine were not associated with reduced availability in the lupins (29). The low lysine availability they suggest is specific to pigs since lysine in lupins is highly available to rats (82%)

and chicks (89%) (29). However, Taverner (70) determined that this may not always be the case with pigs or with all L. albus lupins since they estimated that the ileal digestibility value of lysine in L. albus was 82%. The effect of lysine supplementation on pig performance was not evaluated in this trial. However, because the feed efficiency of the lupin-corn diet was similar to that of the roasted soybean and SBM corn diets, the amino acid availability of the lupin-corn diet that was balanced for lysine and methionine, appeared to be adequate for the finisher pig.

The feed intake of pigs given the lupin-corn diet was approximately 22% lower than that of pigs given the roasted soybean or SBM corn diet and was below the requirements of pigs of that size (64) (Table VIII). This may explain why pigs given the lupin-corn diet had a lower body weight gain than those given either the roasted soybean or SBM corn diet, resulting in the lupin-fed pigs remaining in the barn longer than the roasted soybean-fed pigs. There was obviously a palatability problem associated with the lupin-corn diet to have caused the reduced intake. The reduced feed intake resulted in a greater difference in consumption of DE and crude protein between the lupin-fed pigs and the roasted soybean or SBM-fed pigs. There was approximately a 23% reduction in growth rate of pigs given the lupin-corn diet relative to those given the roasted soybean or SBM corn diet. The amount of crude protein consumed was calculated (feed intake * crude protein content of diet, as fed) to be 348, 429 and 472g day^{-1}, respectively, for the lupin, roasted soybean and SBM-fed pigs, with the lupin-fed pigs consuming only 86% of their daily requirement. The calculated daily intake of DE (feed intake * DE content of diet, as fed) was 36, 46 and 48 kJ, respectively for the lupin, roasted soybean and SBM-fed pigs, with the lupin pigs consuming approximately 80% of their daily DE requirement. The DE CP^{-1} ratios for the lupin, roasted soybean and SBM corn diets were similar and were, therefore, not likely responsible for the differences in body weight gain between pigs given the lupin-corn diet and those given the roasted soybean or SBM corn diet.

Fiber is a complex carbohydrate of low available energy concentration (28). A small amount of the fiber is broken down by bacteria in the large intestine of pigs and volatile fatty acids (VFAs) are produced. The VFAs provide the pig with a source of energy but VFAs provide only a portion, approximately three-quarters, of the energy of glucose (27). Therefore, the efficiency of use of DE decreases as the proportion of dietary energy digested in the large intestine increases (27). Lupins have a higher fiber content than SBM (29). Taverner et al. (71) determined that the difference between the digestibility of protein, energy and dry matter of lupin seeds (L. angustifolius) measured in the feces and at the ileum was 4, 32 and 39, respectively. While the ileal digestibility value of protein was 86.3%, the ileal digestibility value of energy and dry matter was only 55.3% and 48.4%, respectively (71). In other words, since lupins have a high fiber content and what little fiber is broken down takes place in the large intestine, this may explain why 32% of the energy and 39% of the dry matter in lupins was broken down in the large intestine (71). Since very little digestion and absorption of nutrients takes place in the large intestine of pigs, this is thought to result in a lower net energy absorption (72). However, in the present study it is unlikely that the higher fiber (ADF) content of the lupin-corn diet (Table VI) decreased the concentration of DE of the diet (28) to the extent to have negatively affected the weight gain of pigs given the lupin-corn diet, relative to those given the roasted soybean or SBM corn diet ($P<0.05$) since there were no differences in feed efficiency among the three diets (Table VIII). In support of this, Batterham et al. (29) concluded that the efficiency of energy absorption appeared to be similar to that based on digestion in the small intestine because the lupin wheat-based diets were adequate in net energy compared to that of a SBM wheat-based diet (29). Batterham et al. (29) supplemented the lupin diet with soybean oil to equalize the estimated net energy of the diet to that of the SBM diet. The result of this was depressed protein and increased fat deposition in the lupin-fed pigs. They then concluded that the net energy content of the lupin diet was sufficient in meeting the requirement of the grower pigs.

There was a palatability problem associated with the lupin-corn diet to have caused the reduced feed intake of pigs (Table VIII). Some lupin varieties contain alkaloids and Mn that affect feed intake. An alkaloid content of less than 0.03% in the lupin seeds was necessary for pigs to consume adequate amounts of the lupin diets (16). The alkaloid content of the lupins given in this study was less than 0.015% (Table VII) and therefore, was not likely responsible for the reduction in feed intake. There were no significant differences in feed intake between a lupin diet and a diet containing a mixture of SBM and meat and bone meal even when the lupin diet contained up to 1330 mg Mn kg^{-1} (25). The Agricultural Research Council (24) recommended a maximum tolerance level for Mn of 1000 mg kg^{-1} of diet (dry matter basis). Since the Mn content of the lupin-corn diet in this study was calculated to be about 240 mg kg^{-1} Mn, the Mn concentration probably did not affect intake of the lupin-corn diet. The daily ADF intake of pigs given the lupin, roasted soybean and SBM corn diets were 143, 88.7 and 73.6 g, respectively. Since only a small amount of the ADF is broken down in the large intestine, lupin-fed pigs had greater contents of dietary matter in the large intestine which may have had a negative effect on feed intake. In addition, the increased contents of dietary fiber in the digestive tract increases the water holding capacity of the hind gut (27) which may have left the lupin-fed pigs feeling somewhat bloated and with little appetite. There may have also been a problem with gas production in the intestinal tract from fermentation of oligosaccharides in lupins (5) causing reduced intake.

Pigs given the roasted soybean-corn diet in this study had a similar rate of body weight gain as those given the SBM-corn diet (Table VIII) which suggests that the roasted soybean and SBM corn diets have the same proportion of amino acids. A study conducted by Skelley et al. (35) also determined that a roasted soybean diet produced a similar daily weight gain of pigs as a SBM diet.

Carcass quality and fatty acid composition

Fatter pigs will have a higher dressing percentage than leaner pigs (73). Since the pigs given the lupin-corn diet had leaner carcasses than those given the roasted soybean or SBM corn diet (Table IX), they had lower dressing percentages, resulting in lower carcass weights ($P<0.05$). Carcass weights and dressing percentages of pigs are determined after the intestinal tracts and their contents are removed. Therefore, it is possible that pigs given the dehydrated lupin-corn diet had lower dressing percentages resulting in lower carcass weights than those given the roasted soybean or SBM corn diet as a result of the increased undigested ADF contents in the intestinal tract. King (25) determined that there was a significant negative linear relationship between dressing percentage in swine and dietary level of _L. albus_ cultivar Hamburg. In a swine growth study, Pearson and Carr (33) determined that each 1% increase in _L. angustifolius_ cultivar Uniwhite in a diet resulted in a reduction of 0.08 percentage units in dressing percentage. Those researchers suggested that the depressed dressing percentage of pigs given the lupin diet was due to the increased gut contents that results when pigs were given increased levels of fiber (74). Since pigs given the lupin-corn diet grew more slowly than pigs given the roasted soybean- or SBM-corn diet due to their lower feed intake, they had leaner carcasses with higher index values than those given the roasted soybean or SBM corn diet (P<0.05). In other words, the lupin-fed pigs utilized most of the nutrients consumed for growth and maintenance and little for backfat deposition. Castell and Tsukamoto (60) also determined that pigs given a lupin diet were leaner and they attributed the leaness to the low feed intake.

The lipid composition of pork fat can be influenced by dietary level of fatty acids (34). Since the proportion of unsaturated fatty acids of the lupin-corn diet was higher than that of the roasted soybean or SBM corn diet, the pigs given the lupin-corn diet had a higher content of unsaturated fatty acids in the backfat (P<0.05) (Table X). A higher content of unsaturated fatty acids in the backfat may be desirable to today's health conscious consumer (61). However, a higher content of unsaturated fatty acids in the backfat means that the backfat of pigs given the lupin-corn diet may not be as firm as those given the roasted soybean- or SBM-corn diet. This does not mean that the pork meat of lupin-fed pigs is not acceptable to consumers. Pork carcasses are soft and unacceptable to consumers when the linoleic acid content of the backfat is more than 12% of the total fatty acids (36). In this trial, the linoleic acid content in the backfat of pigs given the lupin-corn diet was 10% and not significantly different from those given the roasted soybean or SBM corn diet. Therefore, the backfat of the lupin-fed pigs in this study would not be judged as being soft and unacceptable to consumers.

Long chain fatty acids, mostly the unsaturated type, are readily susceptible to partial oxidation (9). Oxidation causes rancidity in the fat. This will occur when the meat comes in contact with ultraviolet light or iron or chromium in the presence of oxygen. Oxidation results in the formation of peroxides which produce the rancid, offensive flavours (9). This may be a problem with meat obtained from lupin-fed pigs due to the high content of unsaturated fatty acids in the backfat (Table X). However, Skelley et al. (35) stated that there was no change after four months of storage in the taste of pork meat that had an unsaturated fatty acid content in the backfat of 64% of total fatty acids. In addition, Wahlstrom et al. (75) reported that meat obtained from pigs containing a backfat content of 70.5% of unsaturated fatty acids was also acceptable. Since the backfat of lupin-fed pigs had a content of unsaturated fatty acids less than 70.5% of total fatty acids, the meat from these pigs would be as acceptable to consumers as that obtained from pigs given the roasted soybean or SBM corn diet. Pigs given the roasted soybean- or SBM-corn diet had similar contents of unsaturated fatty acids in the backfat.

The proportion of the saturated fatty acid, palmitic acid, was lower in the backfat of pigs given the lupin-corn diet than those given the roasted soybean or SBM corn diet ($P<0.05$) (Table X) as a result of the higher content of unsaturated fatty acids in the lupin-corn diet. Koch et al. (76) determined that palmitic acid content decreased in the backfat of pigs when diets contained high levels of unsaturated fatty acids. In addition, the lower content of palmitic acid in the lupin-corn diet may also explain this difference.

3.6 Conclusions

The lupin-corn diet was utilized as efficiently as the roasted soybean or SBM corn diet. However, the slower gain in body weight and lower dressing percentages of lupin-fed pigs, relative to those given the roasted soybean or SBM corn-based diets, were a result of the lower feed intake. The reduced intake of pigs given the corn-based diet containing lupins as the sole supplemental protein source was probably due to a palatability problem with the diet, the level of fiber or the presence of gas-producing oligosaccharides. Alkaloids or Mn were not responsible for the reduced feed intake. Lupins should not be added as the sole supplemental protein feedstuff in pig corn-based diets. Further research is necessary to determine the cause of the reduced feed intake and optimal levels of inclusion in corn-based diets.

Table VI. Composition of finisher corn-based diets containing dehydrated lupins, roasted soybeans or SBM.

	Lupins	Roasted Soybeans	SBM
Ingredients (%) (as fed basis)			
Dehydrated lupins	17.9		
Roasted soybeans		17.3	
SBM			12.2
Corn	79.1	80.0	84.9
Dicalcium phosphate	0.6	0.6	0.7
Limestone	1.0	1.0	1.0
Vitamin-mineral premix[a]	0.5	0.5	0.5
Amino acid premix	0.4[b]	0.1[c]	0.2[d]
Iodized salt	0.5	0.5	0.5
Chemical Analysis (Dry matter basis)			
Dry matter (%)	89.3	89.4	90.2
Crude protein (%)	15.6	15.0	15.4
NDF ($g\ kg^{-1}$)	171.0	133.0	118.0
ADF ($g\ kg^{-1}$)	64.0	31.0	24.0
Calculated analysis[e] (as fed basis)			
DE (kJg^{-1})	14.2	14.5	14.0
Lysine (%)	0.61	0.61	0.61
Methionine & cystine (%)	0.34	0.39	0.37

a 0.24 g $100g^{-1}$ vitamin A (500×10^6 IU kg^{-1}); 0.6g $100g^{-1}$ vitamin D_3 (50 x 106 IU kg^{-1}); 0.88g $100g^{-1}$ vitamin E (500,000 IU g^{-1}); 0.1g $100g^{-1}$ riboflavin (98%); 0.9g $100g^{-1}$ DL calcium pantothenate (45%); 0.6g $100g^{-1}$ niacin (98%); 0.88g $100g^{-1}$ vitamin B_{12} (1000 mg kg^{-1}); 0.4g $100g^{-1}$ folic acid (3%); 0.1g $100g^{-1}$ biotin (2%); 41.7g $100g^{-1}$ choline choloride (50%); 0.16g $100g^{-1}$ manganese oxide (56%); 2.0g $100g^{-1}$ zinc oxide (80%); 0.48g $100g^{-1}$ copper sulfate. (25%); 6.6g $100g^{-1}$ selenium premix (450 mg kg^{-1}); 3.4g $100g^{-1}$ ferrous sulfate (27%); 28.96g $100g^{-1}$ wheat middlings; 10.0g $100g^{-1}$ ground limestone; 2.0g $100g^{-1}$ ethoxyquin.

b Amino acid premix contains 2500 g lysine HCL and 500 of DL methionine and 1000 g wheat middlings per tonne of diet.

c Amino acid premix contains 600 g lysine HCL and 400 g wheat middlings per tonne of diet.

d Amino acid premix contains 1200 g lysine HCL and 800 g wheat middlings per tonne of diet.

e Calculated from NRC (64) nutrient requirements for swine and the NAS. United States - Canada Tables of Feed Composition (2).

Table VII. Chemical composition of dehydrated lupins, roasted soybeans and soybean meal (Dry matter basis).

	LUPINS	SOYBEANS	SOYBEAN MEAL[a]
Dry matter %	91.0	89.6	90.0
Crude protein (%)	38.2	39.8	53.0
Lysine (%)	1.62	2.28	3.5
Methionine & cystine (%)	0.55	1.11	1.2
Threonine (%)	1.55	1.34	2.1
Leucine (%)	2.46	3.45	4.2
Isoleucine (%)	1.58	1.72	2.3
Phenylalanine & tyrosine (%)	2.55	2.95	4.4
Valine (%)	1.66	1.84	2.3
Manganese (mg kg^{-1})	1456	33	43
Lupanine (%)	0.007	-	-
13-hydroxylupanine (%)	0.008	-	-

a (2) NAS. United States - Canada Tables of Feed Composition.

Table VIII. Growth performance, feed consumption (as fed basis) and feed efficiency of pigs given corn-based diets containing lupins, roasted soybeans or SBM.

Diet	Start wt (kg)	End wt (kg)	Total Test Days	Gain d^{-1} (kg)	Intake $pig^{-1}d^{-1}$ (kg)	Feed:gain
Dehydrated Lupins	67.3[c]	94.9	45.7[b]	0.67[c]	2.5[c]	3.7
Roasted Soybeans	63.6[c]	93.5	34.8[c]	0.88[b]	3.2[b]	3.7
SBM	71.5[b]	94.3	26.8[d]	0.87[b]	3.4[b]	3.9
SD[a]	7.53	4.17	10.20	0.11	0.50	0.70

a Pooled standard deviation.
b-d Means within a column followed by the same letter are not significantly different; $P<0.05$.

Table IX. Carcass characteristics of pigs given corn-based diets containing dehydrated lupins, roasted soybeans or soybean meal.

Diet	Market wt (kg)	Carcass wt (kg)	Dressing %	Lean Yield Class	Index
Lupins	94.9	75.4[c]	80.3[c]	3.8[c]	108.1[b]
Roasted Soybeans	93.5	78.5[b]	84.2[b]	6.8[b]	104.5[c]
SBM	94.3	79.2[b]	84.0[b]	5.9[b]	105.9[c]
SD[a]	4.17	3.88	3.01	2.00	3.76

a Pooled standard deviation.
b-c Means within a column followed by the same letter are not significantly different; $P<0.05$.

Table X. Fatty acid content of diets and backfat of pigs given dehydrated lupins, roasted soybeans or SBM diets.

Fatty acids	Diets			Backfat			
	Lupins	Roasted Soybeans	SBM	Lupins	Roasted Soybeans	SBM	SD[a]
Saturated Fatty Acids (% of Total Fatty Acids)							
Myristic	0.1	0.1	0.1	1.0	1.0	1.1	0.11
Palmitic	7.2	11.1	11.8	23.3[d]	24.8[c]	24.9[c]	1.22
Stearic	2.3	2.0	1.8	8.1	8.3	8.9	0.86
Other[b]	1.4	0.2	0.4	0.1	0.3	0.2	-
Total Saturated	11.0	13.4	14.1	32.5[d]	34.4[c]	35.1[c]	1.98
Unsaturated Fatty Acids (% of Total Fatty Acids)							
Palmitoleic	0.4	0.1	0.2	3.3	3.1	3.7	0.94
Oleic	33.0	22.3	25.4	49.4	48.1	49.9	5.50
Linoleic	50.3	56.8	57.4	10.0	9.3	8.2	2.89
Linolenic	2.9	5.6	1.6	-	-	-	-
Arachidonic	-	0.1	-	2.1[c]	1.3[d]	1.5[d]	0.63
Other[b]	2.4	1.7	1.3	2.7	3.8	1.6	-
Total Unsaturated	89.0	86.6	85.9	67.5[c]	65.6[d]	64.9[d]	1.86

a Pooled standard deviation.

b Not included in statistical analysis.

c-d Means within a row followed by the same letter are not significantly different; $P<0.05$.

4. REPLACEMENT OF SOYBEAN MEAL WITH DEHYDRATED LUPIN SEEDS IN PIG FEED

4.1 Abstract

One hundred and forty-four pigs with an initial weight of 11.6kg ± 2.2kg were given one of six isonitrogenous, isocaloric diets. The treatments consisted of replacement of soybean meal (SBM) at 0, 25, 50, 75 and 100% of its inclusion level in a diet with dehydrated lupin seeds (*L. albus* cultivar Ultra). Barley was added as the cereal grain to five diets and corn was added to one of the 50% lupin diets. Starter pigs (10-20kg) given the 25% lupin barley-based diet had a similar growth performance and consumed more feed ($P<0.05$), relative to those given the 0% lupin barley-based diet. However, at 75 or 100% replacement, starter pigs had reduced daily body weight gains ($P<0.05$), relative to the 0% lupin diet, as a result of reduced feed intakes. This may have been due to the high ADF content of the barley-based diet containing 75 or 100% replacement of SBM with lupins. While feed intake was not reduced, poor growth performance resulted when starter pigs were given the 50% lupin barley-based diet. This was because the crude protein concentration of the diet was below the requirement of starter pigs. Grower pigs (20-50kg) given the 100% lupin barley-based diet had a similar feed efficiency and feed intake as those given the 0% lupin barley-based diet. These 100% lupin-fed grower pigs consumed an amount of crude protein that met their daily requirement, but they gained only 87% of their expected gain, having met their nutrient requirements. Finisher pigs given the

100 or 0% lupin diet had similar feed intakes and weight gains. Even though there were no significant differences in feed efficiency, finisher pigs required 1.1kg more of the 100% lupin-barley diet to gain 1kg of body weight than those given the 0% lupin-barley diet. Pigs given the 50% lupin corn-based diet had similar growth performance and during the grower phase gained weight at a faster rate ($P<0.05$) than those given the 0% lupin barley-based diet. There were no significant differences in dressing percentages, lean yield class values or commercial grade indexes of pigs given the 0, 25, 50, 75 or 100% lupin barley-based diet or the 50% lupin corn-based diet. Lupin seeds included at 6% (25% lupin barley-based diet) for starter pigs, 12% (75% lupin barley-based diet) for grower pigs and 9% (75% lupin barley-based diet) for finisher pigs had similar growth performance as those given the barley-based diet containing SBM as the sole supplemental protein source.

4.2 Introduction

There have been reports of reduced growth performance of pigs given diets containing more than 5% lupin seeds (*L. albus*) (5). However, this has not been the case for *L. angustifolius* (5). It was suggested that the presence of alkaloids in the *L. albus* lupins was the major cause of the reduction in intake (5). It was determined in a study conducted by Pearson and Carr (17) that the lower intake of a barley-based diet containing 37% *L. albus* cultivar Neuland lupins was due to the presence of alkaloids in the lupins. When the alkaloid concentration in the Neuland lupins was reduced from 0.09 to 0.02%, the feed intake of the diet containing the Neuland lupins was similar to that of the barley-based diet containing 37% L. angustifolius cultivar Uniwhite lupins. However, pigs (20-30kg) given the control diet, a mixture of fish meal and dried blood, had the highest feed intake (17). The reason for the reduced intake of the lupin diet is unknown (17).

Lupin seeds, L. angustifolius, were used as the sole protein supplement in a barley-based (57) or a wheat-based (35) diet for pigs without negative effects on feed intake or weight gain. Other studies (17,20,53) have attributed the reduced growth performance of pigs given a lupin diet to the low utilization of lysine in the lupins (L. albus or L. angustifolius) or to the low utilization of synthetic lysine added to the lupin diets. However, the high ileal digestibility value for lysine in L. albus (82%) (70) and in L. angustifolius (93%) (71) indicates that the amount of lysine in lupins available to pigs may not always be the cause of reduced growth performance of pigs.

Some researchers (29) speculated that the high fiber content in the lupin seeds compared to that of SBM (29), may have been responsible for the lower dressing percentage in pigs given lupin-based diets. This was verified by Pearson and Carr (33) who determined that the dressing percentage decreased when the dietary level of lupin seed was 12%.

Previously in the thesis (Chapter 3), we determined that pigs, given a corn-based diet containing 18% lupin seeds, had a lower feed intake, reduced weight gain and dressing percentage resulting in lower carcass weight than those given roasted soybean or SBM corn-based diets. The lupins were used as the sole supplemental protein source in the diet for the finisher pigs. Since the feed efficiency of the lupin diet was similar to that for the roasted soybean or SBM diet and the lupins contained only trace amounts of alkaloids, lupins may have the potential to be included in pig diets to complement other protein sources. In this present study we determined the effect of incremental replacement of SBM with lupins in barley-based diets on the growth performance of pigs.

One objective of this trial was to approximate the level that lupins can be included in a barley-based diet for starter, grower and finisher pigs to achieve similar feed intake, body weight gain and feed efficiency as those given a SBM barley-based diet. Another objective was to determine the quality of the carcass of pigs given the diets containing incremental replacement of SBM with lupins.

4.3 Materials and Methods

One hundred and forty-four, purebred Yorkshire pigs (72 gilts and 72 barrows) with an initial weight of 11.6kg $\pm$ 2.2kg were randomly placed, within sex, in groups of two on one of six treatments. In each growth phase (starter (10-20kg), grower (21-

50kg) and finisher (51-100kg)), the six isonitrogenous, isocaloric diets (Tables XI, XII and XIII), consisted of replacement of SBM with dehydrated lupin seeds at 0, 25, 50, 75 and 100% of the inclusion level needed to adequately supplement the diet. The dehydrated lupin seeds were from the same source as those used in the pig trial described in Chapter 3. Barley was added as the cereal grain to five diets and corn was added to one of the 50% lupin diets. Diets were formulated to be given sequentially in starter, grower and finisher phases. All diets were formulated to meet the nutrient requirements of pigs in the weight ranges 10-20kg, 20-50kg or 50-100kg (64). Synthetic lysine and methionine were added to diets that were deficient in meeting the requirements of the pigs. Tallow was used to adjust all diets to be isocaloric (digestible energy 13.6kJ g^{-1}). Feed was provided ad libitum from self feeders.

Pens were 1.2 * 3.0m in size with solid concrete floors bedded with sawdust. Each pen contained an automatic nipple drinker providing water ad libitum. The temperature in the barn was maintained at 19°C ± 2°C.

Feed consumption on a pen basis and individual weight gains were recorded weekly. Pigs were weighed and sent to slaughter at a mean weight of 94kg ± 2.1kg liveweight with dressed weight, lean yield class and commercial grade index data determined on the hot carcass (65).

Samples of diets were taken from each batch of mixed diet and analyzed for dry matter, crude protein and ADF concentration.

Dry matter and crude protein contents were determined in duplicate for diets and test ingredients similar to the procedure previously reported (Chapter 2 pages 13 and 14). ADF levels were determined in duplicate on diets similar to the procedure previously reported (Chapter 3, page 30).

The R-square values were very small (< 0.3%) therefore, a multiple comparison test was performed. Statistical analysis was carried out using one way analysis of variance (46) and significant differences between diets were determined by the Student Neuman-Keuls at the alpha=0.05 level (47). Variation due to the effects of diet, sex, diet*sex, replicate and pen (diet*replicate) was removed from the residual sum of squares with the exception of feed consumption and feed efficiency (feed:gain) from which variation due to diet, sex, diet*sex and replicate was removed.

4.4 Results

Diets

The diets were formulated to contain 20, 16.7 and 15.6% crude protein (dry matter basis), respectively, for starter, grower and finisher diets; however, there was variability among the diets (Table XI, XII and XIII). Most notable was the 50% lupin barley-based diet which had a protein concentration of only 82% that of the 0% lupin barley-based diet. The ADF concentration of the 25% lupin-barley diet was 30% higher than that of the 0% lupin-barley diet, but only 1.8% lower than that of the 100% lupin-barley diet. The 50% corn-based lupin diet had the lowest ADF content.

Performance of pigs

The effect of diet*sex was not significant for any of the variables.

Starter pigs given the 25% lupin diet had the highest feed intake (Table XIV) ($P<0.05$) and there were no significant difference in intake between the 50% lupin corn-based diet, 0 or 50% lupin barley-based lupin diets. However, pigs given the 100% lupin diet had the lowest feed intake ($P<0.05$) but did not differ from those given the 75% lupin diet. Similar intakes occurred between the 50% lupin corn-based diet and 75% lupin barley-based diet. The starter pigs given the 50% lupin corn-based diet, 25 or 0% lupin barley-based diet had similar body weight gains which were greater than those given the 100, 75 or 50% lupin barley-based diets (Table XV) ($P<0.05$). There were no significant differences in daily gains of pigs given the 50, 75 or 100% lupin barley-based diets. In addition, starter pigs given the 50% lupin corn-based diet had similar feed efficiency to those given the 0, 75 and 25% lupin diets (Table XIV) while pigs given the 50% lupin barley-based diet had the poorest feed efficiency ($P<0.05$). Pigs given the 100% lupin diet had similar feed efficiency as those given the 75% lupin and 25% lupin diets.

Feed intake of all diets given to grower or finisher pigs was similar (Table XIV). However, grower pigs given the 25% lupin barley-based diet or 50% lupin corn-based diet had similar weight gains which were higher than pigs given the 0, 100, 75 or 50% lupin barley-based diets (P<0.05) (Table XV). While the weight gains of grower pigs given the 0, 50 or 75% lupin barley-based diets were similar, the weight gains of grower pigs given the 100% lupin diet were less than those given the 0% lupin diet. There were no significant differences in feed efficiency among grower pigs given the barley-based diets although those containing 50, 75 or 100% lupin were poorer than pigs given the 50% lupin corn-based diet (P<0.05) (Table XIV).

There were no differences in feed efficiency (Table XIV) or body weight gains (Table XV) of finisher pigs. Although there were no significant differences, the feed efficiency value obtained on the 50 or 100% lupin barley-based diet was only approximately 80% that obtained on the 0% lupin barley-based diet (Table XIV). Gains on the 50% lupin corn-based diet and the 25% lupin barley-based diet were greater than those on the 100 and 50% lupin barley-based diets (P<0.05) (Table XV). Pigs given the 50% lupin corn-based diet had similar feed efficiency as those given the 0, 25 or 75% lupin barley-based diets but had a better feed efficiency than those given the 50 and 100% lupin barley-based diets (P<0.05) (Table XIV).

Days to market

Over the entire experiment, pigs given the 50, 75 or 100% lupin barley-based diets required more days on test to reach market weight than those given the other diets (P<0.05) (Table XV).

Carcass quality

There were no significant differences in dressing percentages, lean yield class values or commercial grade indices of pigs given the 0, 25, 50, 75 or 100% lupin barley-based diets or the 50% lupin corn-based diet (Table XVI).

4.5 Discussion

Performance of pigs

The fiber concentration of the 75 or 100% lupin-barley diets (Table XI) may explain the approximate 22% reduction in feed intakes (Table XIV) resulting in reduced body weight gains of starter pigs given those diets (Table XV), relative to the 0% lupin diet (P<0.05). It is speculated that young pigs require more time to adapt to diets of higher dietary fiber content than older pigs (27). In the present study, the starter pigs given the 75 or 100% lupin diet consumed approximately half the feed of the 0% lupin-fed pigs during the first two to three weeks of the study. The level of feed intake began to increase after that time period. The

ADF content of those diets may have made the first initial mouthfuls of the diets less palatable, relative to the 0% lupin diet and may have caused the reduction in feed intake. This resulted in pigs given those diets consuming less DE and crude protein than their daily requirement (64) and, therefore, led to their reduction in growth. It is doubtful the gut capacity of pigs given the barley-based diets containing 20 or 32% lupin seeds was reduced since those pigs consumed approximately 17% less ADF than pigs given the 25% lupin diet. Fiber may have limited intake but did not reduce the energy concentration of the diet since all the diets were calculated to contain DE or metabolizable energy that met the requirements of the starter pigs. The lupin seeds used in this study were from the same source as those used in the previous study (Chapter 3). Since the alkaloid content of those lupins was 0.013%, it was unlikely that alkaloids were responsible for the reduction in intake of the 75 or 100% lupin diet. Similar to this study, Pearson and Carr (17) contributed the lower weight gain of starter pigs given lupin seeds to the low feed intake. However, the factor that caused the reduction in feed intake is unknown (17).

The fiber content of a barley-based diet containing lupins as the supplemental protein source is higher than that of a corn-based lupin diet since barley has an ADF content of 70g kg^{-1} (dry matter basis) while corn has an ADF content of only 30g kg^{-1} (dry matter basis) (2). Therefore, including lupins at levels of 50% replacement of SBM in combination with a cereal of lower fiber content, may not produce negative growth performance of starter pigs. In support of this hypothesis, pigs given the 50% corn-based diet in the present study had similar feed efficiency (Table XIV) and body weight gains (Table XV) as those given the 0 or 25% lupin barley-based diet. In addition, Barnett and Batterham (32) determined that starter pigs (6 to 20kg) were able to tolerate the high fiber content in lupins (223g kg^{-1} ADF, air dry basis) when they were given in combination with a low fiber cereal such as wheat. The lupins were included at 43% and SBM at 18% of a wheat-based diet. They found no differences in the rate of gain or feed efficiency of pigs given the lupin (L. angustifolius cultivar Unicrop) or SBM wheat-based diet when both diets contained adequate concentrations of lysine and the other essential amino acids.

On the other hand, Pearson and Carr (33) determined that L. angustifolius cultivar Uniwhite can be added at 26% of a barley-based diet for starter pigs (12-25kg) without any negative effect on the rate of body weight gain. At this concentration, the pigs had similar growth rates to those given a barley-based diet containing a mixture of fish meal and dried blood (33). There was no negative effect on weight gain in their study but this was not the case in the present study (Table XV). This may be due to the fact that the pigs given the 100 or 75% lupin diet in this study consumed less crude protein than their daily requirements.

Since the concentration of crude protein in the 50% lupin-barley diet (Table XI) was below the concentration recommended by the National Research Council (64), this may have caused the poor feed efficiency (Table XIV) and lower body weight gains (Table XV) of the starter pigs, relative to the 0% lupin diet. It is speculated that there was an error in the mixing of the 50% lupin-barley diet to have caused the lower crude protein concentration. Since the feed efficiency of the grower and finisher pigs (Table XIV) was not affected by the inclusion of lupins at 50 or 100% replacement of SBM and given that all starter diets were calculated to contain amounts of DE that met the requirements of starter pigs, it seems unlikely that the quality of protein and energy in the 50% lupin diet was the problem. The low crude protein concentration of the diet (50% lupin barley-based) explains why the feed efficiency value of starter pigs given this diet was poorer than those given the 25 or 75% lupin diet. Pearson and Carr (33) found no differences in feed efficiency between pigs (12-25kg) given a barley-based diet containing 26% L. angustifolius lupins with a crude protein content of 18.3% and those containing a mixture of fish meal and dried blood with a crude protein content of 17.7%. The calculated DE concentration of their diets was approximately 18 kJ g^{-1} of diet. Since the feed efficiency value of 2.22 recorded by Pearson and Carr (33) for the lupin-fed pigs was better than that determined for pigs given the 100% lupin-barley diet in this study (Table XIV), the difference between the results in the present study and the study conducted by Pearson and Carr (33) may be due to the difference in species of lupin, DE or crude protein concentration of the diets.

There were no differences in intake of the diets given the grower (20-50kg) and finisher (50-100kg) pigs (Table XIV) therefore, inclusion level of lupins does not reduce feed intake of these pigs. Since grower pigs given the 100% lupin diet consumed their daily requirement of protein and energy and utilized those nutrients as efficiently as those given the 0% lupin diet, the reduced growth of the 100% lupin-fed pigs (Table XV) does not appear to be the result of low availability of nutrients. Although those pigs exceeded their crude protein and DE requirement by 13% and 17%, respectively, (64) they consumed 24 grams less crude protein and 1.1 kJ less DE d^{-1} than those pigs given the 0% lupin diet. Therefore, the lower gain in body weight of the 100% lupin-fed pigs may have been attributed to less crude protein and energy available for storage in the form of body fat. However, the 100% lupin-fed grower pigs gained only approximately 87% of what they should have gained, having met their nutrient requirements (64). While Pearson and Carr (33) determined that pigs (25-85kg) given a 100% lupin (L. angustifolius cultivar Uniwhite) barley-based diet had a similar rate of gain of 0.61kg d^{-1} as those for a fish meal and meat and bone meal barley-based diet of 0.63kg d^{-1}, those weight gains were similar and in some cases lower than the ones determined in this study.

Since the finisher pigs given lupins as the sole protein supplement in a barley-based diet had a similar feed efficiency (Table XIV) and rate of body weight gain (table XV) as those given the 0% lupin diet, the protein quality in the lupin barley-based diet may equal that for a SBM barley-based diet for finisher pigs. However, even though there were no statistical differences in feed efficiency of finisher pigs, the 100% lupin barley-based diet was utilized only 80% as efficiently as the 0% lupin-barley diet. In a farm operation, this may not be acceptable. The feed efficiency value obtained for the 75% lupin diet may be a more practical alternative. Pearson and Carr (33) also determined that pigs (25-85kg) given a barley-based diet containing lupin seed (L. angustifolius cultivar Uniwhite) as the sole protein source had a similar feed efficiency as those given a mixture of meat and bone meal and fish meal as the protein source. The finisher diets in this study were not supplemented with lysine or methionine since they were formulated to contain a crude protein content that exceeded the requirements for finisher pigs (64) by 1% of the diet to meet the lysine and methionine requirements of the finisher pigs (Table XIII). King (25) determined that pigs could be given only up to 10.3% of lupins (L. albus cultivar Hamburg) in a wheat-based diet to have a similar feed efficiency as those given a SBM diet. He found that including lupins at a higher concentration resulted in a decrease in growth and poor feed efficiency. However, intake was not affected by the level of inclusion of lupins and the crude protein concentration was similar for the diets (25). King (25) suggested that the reduced performance was due to either a low availability of amino acids in the lupins or to a low utilization of synthetic lysine in the lupin diets. This does not appear to be the case with the 100% lupin barley-based finisher diet and the difference between this study and their study may be due to the difference in cultivar of lupin.

Inclusion of lupins in a corn-based diet may be a more suitable alternative to inclusion in a barley-based diet since there was a similar effect on feed efficiency and growth rate of pigs given the corn-based diet containing lupins at 50% replacement of SBM or the 0% lupin-barley diet. In addition, pigs given the 50% lupin-corn diet gained more body weight than those given the 0% lupin-barley diet during the grower phase.

Pigs remained in the barn for an average of 18 days more when given a barley-based diet containing replacement of SBM at more than 25% of the SBM with lupins, due to the slower body weight gain of the pigs during their starter phase (Table XV). When pigs were given a corn-based diet with 50% of SBM replaced with lupins they remained in the barn for the same length of time as those pigs given the 0% lupin barley-based diet.

Carcass quality

Since there were no significant differences in dressing percentages, lean yield class values or commercial grade indexes of pigs given the 0, 25, 50, 75 or 100% lupin-barley diet or the 50% lupin-corn diet (Table XVI), the level of inclusion of lupin seeds in a barley-based diet did not affect the carcass quality of pigs, relative to the 0% lupin diet. Barnett and Batterham (32) also determined that dressing percentage of pigs was unaffected by the level of inclusion of lupin seed meal in a wheat-based diet. In Chapter 3, it was suggested that the lower backfat contents of pigs given the lupin diet may have caused the lower dressing percentages resulting in the lower carcass weights of pigs. It was determined from this trial that the 100% lupin barley-based diet had the same effect on carcass weights, dressing percentages, lean yield class values and commercial grade indices as that of the SBM barley-based diet. King (25) determined that the dressing percentage decreased significantly as the level of Hamburg lupins in a wheat-based diet increased from 10 to 20.7%. Pearson and Carr (33) also determined that the dressing percentage of pigs given a 100% lupin barley-based diet was significantly lower than that for a fish meal or a meat and bone meal diet. King (25) and Pearson and Carr (33) speculated that the lower dressing percentage was due to the increased gut contents of pigs, as a result of the high fiber content in lupins. From this study, relative to the 0% lupin-barley based diet, the fiber content of the 100% lupin barley-based diet did not effect the carcass quality of pigs.

Recommended level of inclusion of lupins

The recommended level of inclusion of lupins in diets for starter, grower and finisher pigs was determined from this study after considering the feed efficiency, body weight gain and feed intakes of pigs given the diets containing different inclusion level of lupin seeds. For starter pigs, lupins can be included to replace SBM at 25% of its inclusion level (6% of the diet) in barley-based diets. At the 50, 75 or 100% replacement reduced growth rates of starter pigs resulted. For grower and finisher pigs, the 75% lupin barley-based diet resulted in growth performance of pigs similar to those given the 0% lupin barley-based diet. In a corn-based diet, replacement of SBM with lupins at 50% of the inclusion level will provide similar growth performance as the 0% lupin barley-based diet and support greater gain in body weight during the grower phase. Investigation of the effect of incremental replacement of SBM with lupins in corn-based diets on the growth performance of pigs is warranted.

4.6 Conclusions

Including lupins at 6% of the barley-based diet resulted in starter pigs having a similar growth performance as those given the 0% lupin diet. However, the high fiber concentration of the barley-based diet containing 20 or 32% lupins may have caused the reduction in feed intake and resulted in the reduced daily weight gain of starter pigs. Grower and finisher pigs were not affected by the fiber concentration of the 0, 25, 50, 75 or 100% lupin barley-based diets. Pigs given the 50% lupin-corn diet had similar growth performance and during the grower phase gained 100g more body weight per day than those given the 0% lupin barley-based diet. Lupins included at 12% of a barley-based diet (75% lupin-barley diet) for grower pigs and 9% for finisher pigs (75% lupin-barley diet) resulted in pigs having a similar growth performance as those given the 0% lupin barley-based diet. Lupin seeds have the potential to be used as a supplemental protein feedstuff in a barley or corn-based pig diet, particularly at the grower and finisher phases.

Table XI. Composition of starter diets containing increasing inclusion level of dehydrated lupins.

	0%-B	25%-B	50%-B	75%-B	100%-B	50%-C
Ingredients (%) (as fed basis)						
Dehydrated Lupins	-	5.6	12.4	21.1	32.1	15.3
SBM	20.4	16.9	12.4	7.1	-	15.3
Barley	73.0	70.6	68.0	63.9	59.4	-
Corn	-	-	-	-	-	65.4
Tallow	3.2	3.5	3.7	4.2	4.7	-
Dicalcium phosphate	1.2	1.2	1.2	1.2	1.3	1.5
Limestone	1.2	1.1	1.1	1.2	1.0	1.0
Vitamin-mineral premix[a]	0.5[b]	0.5[b]	0.5[b]	0.5[b]	0.5[b]	0.5[b]
Amino acid premix	-	0.1[c]	0.2[d]	0.3[e]	0.5[f]	0.5[g]
Iodized salt	0.5	0.5	0.5	0.5	0.5	0.5
Chemical analysis (dry matter basis)						
Dry matter (%)	89.0	88.6	89.0	89.6	90.3	88.5
Crude protein (%)	19.4	19.4	16.0	18.5	17.9	20.0
ADF (g kg^{-1})	57.0	81.0	83.0	88.0	99.0	54.0
Calculated analysis (As fed basis)[h]						
DE (kJg^{-1})	13.6	13.8	13.9	14.2	14.4	14.0
Lysine (%)	0.98	0.96	0.96	0.96	0.96	0.96
Methionine & cystine (%)	0.52	0.49	0.49	0.49	0.49	0.49

a See Chapter 3 (Table VI).
b 500 kg aureo-sp-250 and 189.6 kg wheat middlings per tonne of diet.
c 200 g lysine HCL and 800 g wheat middlings per tonne of diet.
d 700 g lysine HCL and 400 g DL methionine and 900 g wheat middlings per tonne of diet.
e 1300 g lysine HCL and 600 g DL methionine and 1100 g wheat middlings per tonne of diet.
f 2300 g lysine HCL and 1100 g DL methionine and 1600 g wheat middlings per tonne of diet.
g 2300 g lysine HCL and 500 g DL methionine and 2200 g wheat middlings per tonne of diet.
h Calculated from NRC (64) nutrient requirements for swine and the NAS. United States - Canada Tables of Feed Composition (2).

Table XII. Composition of grower diets containing increasing inclusion level of dehydrated lupins.

	0%-B	25%-B	50%-B	75%-B	100%-B	50%-C
Ingredients (%) (as fed basis)						
Dehydrated lupins	-	3.3	7.4	12.5	19.1	10.5
SBM	12.2	9.8	7.4	4.2	-	10.5
Barley	81.1	80.2	78.3	75.9	73.0	-
Corn	-	-	-	-	-	75.6
Tallow	3.7	3.7	3.9	4.3	4.7	-
Dicalcium phosphate	0.8	0.8	0.7	0.8	0.8	1.1
Limestone	1.2	1.1	1.2	1.1	1.1	1.0
Vitamin-mineral premix[a]	0.5	0.5	0.5	0.5	0.5	0.5
Amino acid premix	-	0.1[b]	0.1[c]	0.2[d]	0.3[e]	0.3[f]
Iodized salt	0.5	0.5	0.5	0.5	0.5	0.5
Chemical analysis (Dry matter basis)						
Dry matter (%)	88.5	88.3	88.2	88.3	89.0	87.3
Crude protein (%)	17.2	16.0	16.7	16.6	16.1	18.8
ADF (g kg^{-1})	56.0	58.0	60.0	63.0	76.0	42.2
Calculated analysis (As fed basis)[h]						
DE (kJg^{-1})	13.6	13.7	13.9	14.0	14.2	14.0
Lysine (%)	0.78	0.77	0.76	0.76	0.77	0.76
Methionine & cystine (%)	0.45	0.43	0.42	0.42	0.42	0.42

a See Chapter 3 (Table VI).
b 100 g lysine HCL and 900 g wheat middlings per tonne of diet.
c 300 g lysine HCL and 100 g DL methionine and 600 g wheat middlings per tonne of diet.
d 800 g lysine HCL and 200 g DL methionine and 1000 g wheat middlings per tonne of diet.
e 1300 g lysine HCL and 600 g DL methionine and 1100 g wheat middlings per tonne of diet.
f 2100 g lysine HCL and 300 g DL methionine and 600 g wheat middlings per tonne of diet.
h Calculated from NRC (64) nutrient requirements for swine and the NAS. United States - Canada Tables of Feed Composition (2).

Table XIII. Composition of finisher diets containing increasing inclusion level of dehydrated lupins.

	0%-B	25%-B	50%-B	75%-B	100%-B	50%-C
Ingredients (%) (as fed basis)						
Dehydrated Lupins	-	2.5	5.5	9.4	14.1	8.9
SBM	9.0	7.4	5.5	3.1	-	8.9
Barley	84.8	83.9	82.7	80.8	79.2	-
Corn	-	-	-	-	-	79.6
Tallon	3.7	3.7	3.8	4.2	4.2	-
Dicalcium phosphate	0.3	0.3	1.2	0.4	0.4	0.6
Limestone	1.2	1.2	0.3	1.1	1.1	1.0
Vitamin-mineral premix[a]	0.5	0.5	0.5	0.5	0.5	0.5
Iodized salt	0.5	0.5	0.5	0.5	0.5	0.5
Chemical analysis (dry matter basis)						
Dry matter (%)	88.6	88.6	90.2	89.9	89.9	88.0
Crude protein (%)	15.2	14.7	14.3	13.8	14.6	15.2
ADF (g kg^{-1})	55.0	63.0	65.0	69.0	73.0	38.0
Calculated analysis (As fed basis)[b]						
DE (kJg^{-1})	13.6	13.7	13.8	14.0	14.0	14.1
LYsine (%)	0.71	0.70	0.68	0.66	0.63	0.81
Methionine & cystine (%)	0.41	0.39	0.39	0.38	0.35	0.36

a See Chapter 3 (Table VI).

b Calculated from NRC (64) nutrient requirements for swine and the NAS. United States - Canada Tables of Feed Composition (2).

Table XIV. Feed consumption and efficiency of pigs given diets containing increasing inclusion level of lupins (as fed basis).

Diet	Starter		Grower		Finisher	
	Intake $pig^{-1}d^{-1}$ (kg)	Feed:gain	Intake $pig^{-1}d^{-1}$ (kg)	Feed:gain	Intake $pig^{-1}d^{-1}$ (kg)	Feed:gain
0%-B	1.19[c]	2.35[d]	2.31	3.36[bc]	3.39	4.16[bc]
25%-B	1.33[b]	2.54[cd]	2.46	3.33[bc]	3.79	4.34[bc]
50%-B	1.16[c]	3.54[b]	2.49	3.86[b]	3.74	5.00[b]
75%-B	0.95[de]	2.60[cd]	2.29	3.83[b]	3.61	4.51[bc]
100%-B	0.90[e]	2.83[c]	2.29	3.87[b]	3.99	5.26[b]
50%-C	1.07[cd]	2.26[d]	2.17	2.74[c]	3.11	3.59[c]
SD[a]	0.16	0.40	0.38	0.71	0.79	0.95

a Pooled standard deviation.

b-e Means within a column followed by the same letter are not significantly different; $P<0.05$

Table XV. Growth performance of pigs given diets containing increasing inclusion level of lupins.

	Starter			Grower		Finisher		
Diet	Start wt (kg)	End wt (kg)	Gain d^{-1} (kg)	End wt[a] (kg)	Gain d^{-1} (kg)	End wt[a] (kg)	Gain d^{-1} (kg)	Total test days
0%-B	11.1	22.3	0.51[c]	51.2	0.70[d]	94.0	0.83[cd]	117[d]
25%-B	11.3	22.6	0.54[c]	53.6	0.75[c]	93.5	0.88[c]	110[d]
50%-B	11.0	21.2	0.34[d]	52.7	0.66[de]	93.9	0.74[d]	136[c]
75%-B	11.4	22.0	0.38[d]	49.4	0.69[d]	94.3	0.82[cd]	131[c]
100%-B	11.7	21.7	0.33[d]	51.2	0.61[e]	93.3	0.78[d]	138[c]
50%-C	10.9	23.9	0.48[c]	53.7	0.80[c]	94.4	0.90[c]	112[d]
SD[b]	2.18	3.94	0.09	6.48	0.09	2.08	0.13	13.71

a Start weight for the grower and finisher phases were the end weights shown for the previous phase.
b Pooled standard deviation.
c-e Means within a column followed by the same letter are not significantly different; $P<0.05$.

Table XVI. Carcass characteristics of pigs given diets containing increasing inclusion level of lupins.

Diet[a]	Market wt (kg)	Carcass wt (kg)	Dressing %	Lean Yield Class	Index
0%-B	94.0	76.5	81.1	5.3	106.8
25%-B	93.5	76.5	81.9	5.8	105.9
50%-B	93.9	76.1	81.0	6.0	105.3
75%-B	94.3	76.1	80.7	5.5	106.5
100%-B	93.3	75.4	80.8	5.3	106.5
50%-C	94.4	76.7	82.1	4.8	107.5
SD[b]	2.08	2.62	2.97	1.74	3.10

a No significant differences.
b Pooled standard deviation.

5. SUMMARY OF RESULTS AND CONCLUSIONS

5.1 Nutrient Profile and Anti-Nutritional Factors of Lupins

The P. E. I. grown sweet lupin seeds contained 30 - 35% crude protein compared to roasted soybeans (37% crude protein) and soybean meal (SBM) (48% crude protein). The methionine content of lupins was approximately one-half that of roasted soybeans, while the cystine and lysine contents were slightly lower in lupins. This was due to the different amino acid profile of the lupins. This was also the reason why the content of lysine, methionine and cystine in lupins was much lower than in SBM. Since lysine and the combination of methionine plus cystine are essential amino acids for the pig and are often limited in diets for pigs, one should know the content of these amino acids in lupins or in any other feed ingredient that is to be utilized in diets for pigs to meet the requirements of pigs.

Lupins are also a source of digestible energy. While lupins do have a higher ADF content than roasted soybeans or SBM, its level of inclusion in the corn or barley-based diet did not decrease the concentration of DE below that of the requirement for growth and maintenance of the pig to negatively effect the feed conversion.

The manganese (Mn) content of lupins was approximately 40 times that of the concentration in roasted soybeans. The Agricultural Research Council (24) recommends that for pigs, the dietary concentration of Mn should not exceed 1000mg kg^{-1} of the diet to prevent reduced appetite and growth rate of pigs. The Mn concentration of the lupin diets given to rats or pigs in this study did not exceed 1000mg kg^{-1} of diet and did not appear to have an effect on feed intake or growth rate of pigs or rats.

Alkaloid concentration in lupin seeds has been implicated in past studies in limiting the feed intake and lowering the rate of body weight gain of pigs. The alkaloid content of lupins used in these studies was less than 0.015%. When included in the diet, the alkaloid concentration was less than 0.005% of the diet. At this level, alkaloids did not have an effect on feed intake or growth performance of rats or pigs.

5.2 Protein Quality of Lupins

The protein quality of sweet lupin seeds, L. albus cultivar Primorski or Ultra, improved with methionine supplementation. When supplemented with methionine, the protein quality of Primorski or Ultra was better than that of roasted soybeans (P<0.05) and similar to that of SBM. Lysine supplementation in addition to methionine improved the protein quality of Ultra, relative to supplementation with methionine alone. The protein quality of Primorski was not improved with additional supplementation of lysine. Diets containing Primorski or Ultra lupins may require supplementation with methionine for nonruminants. Pig diets containing Ultra may require supplementation with lysine in addition to methionine when the lysine content of the diet is below that of the requirements of pigs.

5.3 Growth Performance of Pigs Given Dehydrated Lupins

Since the feed efficiency of pigs (50-100kg) given the corn-based diet containing 18% lupin seeds (100% lupin-corn diet) was similar to those given the roasted soybean or SBM diet, the reduced growth and lower feed intakes of the lupin-fed pigs indicated a problem with palatability of the lupin diet. Since no adverse effects occurred when starter, grower or finisher pigs were given corn-based diets containing 15, 10 or 9% lupin seeds (50% lupin corn-based diet), respectively, relative to the 0% lupin barley-based diet (Chapter 4), these levels appear to be satisfactory in pig diets. Further investigation to determine the effect of incremental replacement of SBM with lupins in corn-based diets on the growth performance of pigs is warranted.

For starter pigs (10-20kg), the high ADF concentration of the barley-based diet containing 20 or 32% lupin seeds (75 or 100% lupin barley-based diet) may have reduced the feed intake and resulted in poor growth rate of pigs ($P<0.05$). Growth performance of starter pigs given the 25% lupin-barley diet (lupins included at 6% of the diet) was similar to that of pigs given the barley-based diet containing SBM as the sole supplemental protein source. This may be of importance to farmers when the cost of SBM is greater than the cost of lupins. Lupins included at 12% of a barley-based diet (50% lupin-barley diet) resulted in poor feed efficiency and reduced growth rates (P<0.05) but with no adverse effects on feed intake, relative to the 0% lupin-barley diet. This was because the crude protein concentration of the 50% lupin-barley diet was below the requirement of the starter pigs. Even though there may have been an error in mixing of the 50% lupin-barley diet to have caused this, lupins should not be included at this level in starter pig rations until further research is conducted to prove otherwise.

Grower (20-50kg) or finisher (50-100kg) pigs given the barley-based diet containing lupins as the sole protein source had similar feed efficiency and feed intakes as those pigs given the barley-based diet containing SBM as the sole protein source (0% lupin diet). Even though all grower pigs consumed enough crude protein to meet their requirements (64), pigs given the 100% lupin diet gained 90g less body weight per day than those given the 0% lupin diet and gained only 87% of what was expected, having met their nutrient requirements (64). Even though there were no significant differences in feed efficiency among the diets, the large numerical difference between the feed efficiency of finisher pigs obtained on the 0 and 100% lupin diets may also indicate the presence of a growth inhibitor.

5.4 Carcass Quality and Lipid Composition of Pork Carcasses

Relative to the SBM or the roasted soybean-corn diets, the slower daily gain in body weight of the lupin-fed pigs, as a result of reduced feed intake, may have lowered the dressing percentages of pigs. In addition, pigs given the lupin-corn diet may have had higher gut contents of dietary ADF that was not digested which may have played a role in reducing the dressing percentages but not the market weights of the lupin-fed pigs. Pigs given lupins or SBM in combination with barley, a cereal grain of higher ADF content than that of corn, had similar dressing percentages, lean yield class and commercial grade index values since the difference in ADF content between these two diets was not as large as that of the difference between the lupin-corn and SBM or roasted soybean-corn diets.

The backfat of pigs given the lupin diet had a greater proportion of unsaturated fatty acids than those given the roasted soybean or SBM diets ($P<0.05$). This may make consumers more receptive to including pork meat in their diet. In the backfat, a linoleic acid content of more than 12% may make the pork fat soft and unacceptable to consumers (35). However, the linoleic acid content of the pork fat of pigs given the lupin diet was less than 12% and, therefore, may be acceptable to consumers.

5.5 Overall Conclusions

Lupin seeds are a suitable feedstuff for pigs. In a barley-based diet, lupin seeds included at 6% for starter pigs (25% lupin barley-based diet), 12% for grower pigs (75% lupin barley-based diet) and 9% for finisher pigs (75% lupin barley-based diet) resulted in growth performance similar to those given the barley-based diet containing SBM as the supplemental protein source. Since pigs given the 50% lupin corn-based diet had similar growth performance and during the grower phase gained body weight at a faster rate than those given the 0% lupin barley-based diet, further research is warranted to determine the effect of incremental replacemet of SBM with lupins in corn-based diets on the growth performance of pigs. The available nutrient content in lupins, the growth performance of pigs obtained on the lupin-barley or corn diets and the growing conditions of Atlantic Canada make lupins suitable for usage in nonruminant diets on P.E.I.

7. REFERENCES

1. Lopez-Bellido L and Fuentes M. Lupin crop as an alternative source of protein. Adv Agron 1986; 38: 239-296.

2. NAS. United States-Canada Tables of Feed Composition. Washington D.C.: Nat Acad Sci, 1975.

3. Petterson DS. Lupin seed as a food for man and livestock-a literature review. Western Australian Department of Agriculture, Perth, Western Australia 1985: 37pp.

4. Gross R. First Reinhold Von Sengbusch Memorial Lecture: Lupins in the old and new world-a biological-cultural coevolution. In: Proc 4th Int Lupin Conf 1986: 33pp.

5. Hill GD. Recent developments in the use of lupins in animal and human nutrition. In: Proc 4th Int Lupin Conf 1986: 40-63.

6. Amerger N, Sommer G, Giraud JJ and Lagacherie B. Proc Third Int Lupin Conf 1984: 599-600.

7. Rhodes PJ. Proc Agron Soc 1976; 6: 69-70.

8. Henderson CWL. Lupine as a biological plough evidence for and effects on wheat growth and yield. Aust J Exp Agric 1989; 29: 99-102.

9. Church DC. Livestock feeds and feeding. New Jersey: Prentice-Hall, 1986.

10. Schoeneberger H, Gross R, Cremer HD and Elmadfa I. The protein quality of lupins (Lupinus mutabilis) alone and in combination with other protein sources. Qual Plant Plant Foods Hum Nutr 1983; 32: 133-144.

11. Lu GG. The cause of death and resusistation in sparteine poisoning. Toxicol Appl Pharmacol 1964; 6: 328-333.

12. Mazur M, Polakowski P and Szadowska A. Pharmacology of lupanine and 13-hydroxylupanine. Acta Physiol Polon 1966; 17: 299-304.

13. Keeler RF. Teratogenicity studies on non-food lupins in livestock and laboratory animals. Proc 2nd Int Lupin Conf 1982: 301-304.

14. Ballester D, Yanez E, Garcia R, Erazo S, Lopez F, Haardt E, Cornejo S, Lopez A, Pokniak J and Chichester CO. Chemical

composition, nutritive value and toxicological evaluation of two species of sweet lupine (Lupinus albus and Lupinus Luteus). J Agric Food Chem 1980; 28: 402-405.

15. Gladstones JS. Recent developments in the understanding, improvement and use of lupinus. In: Proc Int Legume Conf 1978: 8pp.

16. Erickson J. Lupines: A potential source of protein for swine. Feedstuffs 1988; 60: 15,18.

17. Pearson G and Carr JR. A comparison between meals prepared from the seeds of different varieties of lupin as protein supplements to barley-based diets for growing pigs. Anim Feed Sci Technol 1977; 2: 49-58.

18. Keeler RF. Quinolizidine alkaloids in range and grain lupins. in PR Cheeke, ed. Toxicants of Plant Origin. Boca Raton, Fl.: CRC Press, 1988.

19. Priddis CR and Harris DJ. Rapid capillary GLC analysis of the lupin alkaloids of Western Australian sweet lupin varieties. Proc Third Int Lupin Conf 1984: 584-585.

20. Van Warmelo KT, Marasas WFO, Adelaar TF, Kellerman TS, van Rensburg IBJ and Minne JA. Experimental evidence that lupinosis of sheep is a mycotoxicosis caused by the fungus Phomopsis leptostromiformis (Kuhn) Bubak. J S Afr Vet Med Assoc 1970; 41: 235-247.

21. Culvenor CCJ, Beck AB, Clark M, Cockrum PA, Edgar Ja, Fruhn JL, Jago MV, Lanigan GW, Payne AL, Peterson JE, Peterson DS, Smith LW and White RR. Isolution of toxic metabolites of Phomopsis leptostromiformis for lupinosis. Aust J Biol Sci 1977; 30: 269-277.

22. Batterham ES. Lupin-seed meal for pigs. Pig News and Info 1989; 10: 323-325.

23. Batterham ES. Lupinus albus cultivar Ultra and Lupinus angustifolius cultivar Unicrop as protein concentrates for growing pigs. Aust J Agric Res 1979; 30: 369-375.

24. Agricultural Research Council. No. 3. Nutrient Requirements of Farm Livestock. Pigs. London: 1967.

25. King RH. Lupin-seed meal (Lupinus albus cv. Hamburg) as a source of protein for growing pigs. Anim Feed Sci Technol 1981; 6: 285-296.

26. Van Soest PJ. Nutritional ecology of the ruminant. Oregon:

O and B Books, Inc., 1982.

27. Low AG. Role of dietary fiber in pigs. In: Recent Advances In Animal Nutrition. London: Butterworths, 1985.

28. Schneider BB and Flatt WP. The evaluation of feeds through digestibility experiments. Georgia: University of Georgia Press, 1975.

29. Batterham ES, Andersen LM, Lowe RF and Darnell RE. Nutritional value of lupin (Lupinus albus) seed meal for growing pigs: availability of lysine, effect of autoclaving and net energy content. Br J Nutr 1986; 56: 645-660.

30. Aguilera JF, Molina E and Prieto C. Digestibility and energy value of sweet lupin seed (Lupinus albus var. Multolupa) in pigs. Anim Feed Sci Technol 1985; 12: 171-178.

31. Halvorson JC, Shehata MA and Waibel PE. White lupins and triticale as feedstuffs in diets for turkeys. Poult Sci 1983; 62: 1038-1044.

32. Barnett CW and Batterham ES. Lupinus angustifolius cultivar Unicrop as a protein and energy source for weaner pigs. Anim Feed Sci Technol 1981; 6: 27-34.

33. Pearson G and Carr JR. Lupin-seed meal (Lupinus angustifolius cv. Uniwhite) as a protein supplement to barley-based diets for growing pigs. Anim Feed Sci Technol 1976; 1: 631-642.

34. Villegas FJ, Hedrick HB, Veum TL, McFate KL and Bailey ME. Effect of diet and breed on fatty acid composition of porcine adipose tissue. J Anim Sci 1973; 36: 663.

35. Skelley GC, Borgman RF, Handlin DL, Acton JG, McConnell JC, Wardlaw FB and Evans EJ. Influence of diet on quality, fatty acids and acceptability of pork. J Anim Sci 1975; 41: 1298-1304.

36. Barrie ED. Full fat soybeans and hog carcass quality. Pork News and Views 1989; 6.

37. Cerning-Beroard J and Filiatre A. A comparison of the carbohydrate composition of legume seeds: horsebeans, peas and lupines. Cereal Chem 1976; 53: 968-978.

38. Saini HS and Gladstones JS. Variability in the total and component galactosyl sucrose oligosaccharides of Lupinus species. Aust J Agric Res 1986; 37: 157-166.

39. Grosjean F. Conditions d'incorporation du lupin blanc doux dans les aliments pour porcs charcutiers. Proc Third Int Lupin Conf 1984: 635-636.

40. Cazes JP, Leuillet M and Seroux M. The use of lupin (Kalina) in feedstuffs for lambs, rabbits, fattening pigs and piglets. Proc 2nd Int Lupin Conf 1982: 281-285.

41. Lloyd LE, McDonald BE and Crampton EW. Fundamentals of nutrition. 2nd ed. San Francisco: Freeman and Company, 1978.

42. Pellet PL and Young VR. Nutrition evaluation of food proteins. Tokyo: The United Nations University 1980: 103-133.

43. Sarwar G, Peace RW, Botting HG and Brule D. Relationship between amino acid scores and protein quality indices based on rat growth. Plant Foods Hum Nutr 1989; 39: 33-44.

44. Camacho L, Vasquez M, Leiva M and Vargas E. Effect of processing and methionine addition on the sensory quality and nutritive value of spray-dried lupin milk. Int J Food Sci Technol 1988; 23: 233-240.

45. Prieto C and Aguilera JF. The effect of the supplementation with methionine and lysine of diets based on lupin seed (Lupinus albus var. Multolupa) on protein and energy utilization in growing rats. J Anim Physiol a Anim Nutr 1986; 55: 239-246.

46. Steel RGD and Torrie JH. Principles and procedures of statistics. A biometrical approach. New York, N Y: McGraw-Hill, 1980.

47. Statistical Analysis System Institute, Inc. SAS User's guide; Statistics. North Carolina: Sas Institute, Inc., 1987.

48. AOAC. Official Methods of Analysis. 15th ed. Washington D.C., 1985.

49. Ebeling ME. The Dumas method for nitrogen in feeds. J AOAC 1968; 51: 766-770.

50. Gehrke CW, Wall LL, Absheer JS, Kaiser FE and Zumwalt RW. Sample preparation for chromatography of amino acids: acid hydrolysis of proteins. AOAC 1985; 68: 811-821.

51. Association of Official Analytical Chemists. Official Methods of Analysis. 14th ed. Washington D.C.: AOAC, 1984.

52. Goering HK and VanSoest PJ. Forage fiber analysis (apparatus, reagents, procedures and some applications). Agricultural Handbook No. 379. Agricultural Research Service. Washington: United States Department of Agriculture, 1970.

53. Harris DJ. Determination of individual and total quinolizidine alkaloids in lupin seed and lupin feedstuffs. Western Australia: Agricultural Chemistry Laboratory. Chemistry Centre, 1989.

54. Schoeneberger H, Moron S and Gross R. Safety evaluation of water debittered Andean lupins (Lupinus mutabilis): 12-week rat feeding study. Qual Plant-Plant Foods Hum Nutr 1987; 37: 169-182.

55. Savage GP, Young JM and Hill GD. The effect of increasing levels of supplementary methionine on the biological value of New Zealand grown lupin seed. Proc 3rd Int Lupin Conf 1984: 629-630.

56. Rackis JJ. Biological and physiological factors in soybeans. J Am Oil Chemists' Soc 1974; 51: 161-174.

57. Rackis JJ. Physiological properties of soybean trypsin inhibitors and their relationships to pancreatic hypertrophy and growth inhibition of rats. Federation Proc 1965; 24: 1488-1492.

58. National Research Council. No. 10. Nutrient requirements of laboratory animals. 3rd rev ed. Washington D.C.: NAS-NRC, 1978.

59. Batterham ES, Andersen LM, Burnham BV and Taylor GA. Effect of heat on the nutritional value of lupin (Lupinus angustifolius) seed meal for growing pigs. Br J Nutr 1986; 55: 169-178.

60. Castell AC and Tsukamoto JY. Responses of growing gilts to dietary inclusion of a Manitoba lupin. Can J Anim Sci 1984; 64: 1095.

61. Wile S. Understanding cholesterol. The role of beef in the diet. Agri Sci 1990: 4-5.

62. Kies C, Lin L-S, Fox HM and Korslund M. Blood serum fatty acid patterns of adolescent boys as influenced by source of dietary fat: corn oil/butter oil, safflower oil/beef tallow. J Food Sci 1978; 43: 598-602.

63. Theunissen TJJM, Kouwenhoven T and Blauw YH. Consumers' responses to food products with increased levels of

polyunsaturated fatty acids. J Food Sci 1979; 44: 1483-1484, 1490.

64. National Research Council. No. 2. Nutrient requirements of swine. 9th rev ed. Washington D.C.: NAS-NRC, 1988.

65. Anonymous. The Canadian hog carcass grading/settlement system. Ottawa: Canadian Pork Council, 1986.

66. Bligh EG and Dryer WJ. A rapid method of total lipid extraction and purification. Can J Biochem Phys 1959; 37: 911.

67. Morrison WR and Smith LM. Preparation of fatty acid methel esters and dimethylacetals from lipids with boron triflouride in methanol. J Lipid Research 1964; 5: 600.

68. Amadi SC and Hewitt D. The digestibility and availability of lysine and methionine in isolated soya-bean protein after severe heat damage. Proc Nutr Soc 1975; 34: 26A.

69. Herkelman KL, Cromwell GL and Stahly TS. Amino acid digestibilities of conventional and low trypsin inhibitor soybeans for growing swine. J Anim Sci 1989; 67: 235.

70. Taverner MR. Nutritive value for pigs for white lupins (L. albus cv. Hamburg). Proc Austr Soc Anim Prod 1982; 14: 677.

71. Taverner MR, Curic DM and Rayner CJ. A comparison of the extent and site of energy and protein digestion of wheat, lupin and meat and bone meal by pigs. J Sci Food Agric 1983; 34: 122-128.

72. Just A, Fernandez JA and Jorgensen H. Livestock Prodn Sci 1983; 10: 171-186.

73. Cole HH and Garrett WN. Animal Agriculture. San Francisco: WH Freeman and Company, 1980.

74. Coey, WE and Robinson KL. Some effect of dietary crude fibre on live weight gains and carcass conformation of pigs. J Agric Sci 1954; 45: 41-47.

75. Wahlstrom RC, Libal GW and Berns RJ. Effect of cooked soybeans on performance, fatty acid composition and pork carcass characteristics. J Anim Sci 1971; 32: 891-894.

76. Koch DE, Pearson AM, Magee WT, Hoefer JA and Schwergert BS. Effect of diet on the fatty acid composiotion of pork fat. J Anim Sci 1968; 27: 360.