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Feeding Alpacas to Enhance Reproduction and Fleece Quality

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Feeding Alpacas to Enhance Reproduction and Fleece Quality

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Foreword

Alpacas originate from the Altiplano region of South America, an area characterised by forage of low nutritive value. In Australia, many high-value alpacas are fed diets of considerably better quality than in South America, leading to over-conditioning through over-feeding. Conversely, some alpacas are underfed as they are farmed at high stocking rates with inadequate supplementation. These problems need to be addressed to improve alpaca production, especially in terms of fibre production and reproduction.

The alpaca industry is challenged with producing an adequate quantity of quality product. This objective can only be achieved through a breeding program based on reliable assessment of the true genetic potential of the breeding animals. Fibre production in both quality and quantity is affected by not only the body condition and nutrition of the animal but also by season and sex hormones. These factors can interact with the genetic potential of each animal to such an extent that they can mask the true genetic value of an animal.

This report provides scientific data that can be used by producers, consultants to the industry, and feed manufacturers to design more appropriate diets and feeding strategies that will allow the industry to make genetic progress because these management procedures will decrease the impact of nutritional and environmental factors on the expression of the animal's genetic potential for fibre production.

The project offers the basis of strategies for the Australian alpaca industry to reduce the cost of producing quality fibre. Although some basic studies on the nutritional requirements of alpacas are still needed, policy makers should now be able to develop more appropriate guidelines for the feeding of alpacas.

This project was funded from industry revenue, which was matched by funds provided by the Australian Government through RIRDC.

This report is an addition to RIRDC's diverse range of over 200 research publications and it forms part of our Rare Natural Animal Fibres R&D program, which aims to promote industry development, commercial viability, and communication and research capacity.

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Craig Burns
Managing Director
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The authors would like to thank the producers who have helped us with this project by lending us animals. Particular thanks are given to Dr George and Jenny Jackson of Banksia Park Alpaca Stud for their help, encouragement, comments and willingness to host 2 of our experiments. We also would like to thank all the other alpaca producers who have contributed alpacas for the conduct of the project.

Abbreviations

AA: Amino acid

AAA: Australian Alpaca Association

UDP: un-degradable dietary protein

RDP: rumen-degradable protein

VFA: Volatile fatty acids

MJ: Mega Joule

MLW: metabolic live weight

N: Nitrogen

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What the report is about

In Australia, alpacas can be overweight and consequently their productivity can be compromised. We have tested a diet that with supplementation can maintain the live weight and body condition of alpacas. Our results strongly suggest that this feeding regimen could help expose the true genetic potential of alpacas for fibre production and reduce feed costs without compromising their reproductive capacity.

Who is the report targeted at?

Alpaca producers, consultants to the alpaca industry as well as the scientific community working with south-American camelids.

Where are the relevant industries located in Australia?

Over 75,000 alpacas are raised in Australia amongst over 600 alpaca breeders. The industry is present in all states, but Victoria and New South Wales have the largest number of breeders followed by Queensland and Western Australia, then South Australia and Tasmania,

The market for alpaca products is still developing. The main product is the fibre, however a number of animals are sold as guard animals to sheep and goat producers. The alpaca meat market is very small.

The research presented here should benefit alpaca breeders as well as alpaca producers because it will help them to manage a more productive flock with lower feed inputs.

Background

To develop a viable alpaca industry, seed-stock producers need to identify and breed only from animals of high genetic merit to produce large quantities of quality fibre. To do this, the animals for breeding need to be optimally fed to exhibit their genetic capacity to produce quality fibre. Thus, we needed to develop diet/s to help the alpaca industry achieve this.

Aims/objectives

Alpaca producers will be able to utilise cheaper feedstuffs that are better suited to meet the unique features of the digestive physiology and metabolism of alpacas, consequently the welfare of the alpacas is also improved.

Methods used

We tested a diet formulation with and without supplements such as canola meal, a glucose precursor and methionine in adult wether alpacas kept in individual pens. We then tested the improved formulation on juvenile and adult intact or castrated alpacas kept in a farm environment. In all experiments, we measured fibre production, body condition, live weight and some blood parameters that reflect the metabolic status of the alpacas. Using a large database, we investigated the factors in the female that could affect mating success and the length of gestation using regression models.

Results/key findings

The published energy requirements of alpacas are overestimated by at least 15%

We developed a diet that can be pelleted and fed with a small amount of cereal straw to sustain the live weight and body condition of mature wethers and intact male alpacas.

The addition of a glucose precursor or protected methionine to our balanced diet did not enhance fibre production

Feeding juvenile alpacas with rumen degradable protein as canola meal did not affect the onset of puberty, but the increased protein intake slightly increased fibre production without affecting fibre characteristics

Body condition during the 3 months preceding mating is probably the best predictor of gestation length

Implications for relevant stakeholders

Industry: The approach to formulation of alpaca diets to meet their nutrient requirements should be reviewed and modified according to the findings of this report. Genetic improvement of fibre production (both quantity and quality) will only be possible if their nutrition is optimum and does not mask the expression of the animal's genetic potential.

Recommendations

Producers and consultants formulating alpaca diets should limit the intake of protein and energy to a level that allows individual alpacas to express their true genetic potential for fibre production

Introduction

To develop a viable alpaca industry, seed-stock producers need to identify and breed only from animals with high genetic merit to produce large quantities of quality fibre.
To do this, breeding animals should be optimally fed to exhibit their genetic capacity to produce quality fibre. Thus, we needed to develop diet/s to help the alpaca industry achieve this.

In Australia, many high-value alpacas are often fed diets of much better quality than in South America. Consequently many alpacas are over-conditioned through being over-fed. Conversely, some alpacas are underfed as they are farmed at high stocking rates with inadequate supplementation. These problems needed to be addressed to avoid impacting on alpaca production, especially reproduction.

Taking advantage of the adaptation of alpacas to low quality food

In ruminants, glucose is derived mainly from propionate produced from the fermentation of feed by the micro-organisms in the rumen. However, glucose can also be derived from the deamination of amino acids (AAs) absorbed from the lower digestive tract. Alpacas eating a low quality, fibrous diet are unlikely to produce much propionate, so in order to meet their high requirement for glucose, alpacas have this unique feature whereby most of their glucose is derived from deamination of AAs in the liver (Figure 1). Most AAs in plasma are absorbed from the small intestine and the supply of AAs for absorption from the small intestine can be increased by feeding protein that cannot be degraded by the microbes in the fermentative organs. Such protein is termed un-degradable dietary protein (UDP). The other form of dietary protein can be digested by microbial fermentation and is termed rumen degradable protein (RDP). The products from the break-down of RDP can be utilised for microbial protein synthesis which is subsequently digested to AAs in the small intestine.
It is apparent from the review by Van Saun (2006c) that the amount of microbial protein reaching the small intestine of alpacas is likely to be limited by the low intake of roughage diets. With a limited supply of AAs reaching the small intestine, the deamination of AAs to meet the animal's requirement for glucose will ultimately reduce the availability of AAs for fibre growth.

It is not clear to what degree alpacas can utilise propionate to produce glucose. However, if alpacas can use propionate to produce glucose, then less AAs would need to be deaminated and more should be available for fibre growth. Thus, when alpacas are fed low quality diets with a limited amount of UDP, supplementation with propionate should lead to an increase in fibre production closer to their genetic potential.

In sheep, wool growth is often limited by the amount of protein supplied to the intestines and can be increased when low quality diets are supplemented with the sulphur AA methionine in a protected form so it is absorbed in the small intestine (Hynd and Masters, 2002). In alpacas, it is also likely that fibre production could be limited by an inadequate supply of sulphur AAs reaching the small intestine.

In most animals, there is an ideal body condition and live weight for reproduction, referred to as "metabolic comfort zone" – a concept extended from the early work of Bronson (1984). The reproductive capacity is reduced, or may be compromised, if an animal experiences metabolic stress, either by being in negative energy balance or being in a state that is "metabolically overwhelmed" - such as too fat. The response to these metabolic states depends on the genetics of the individual and the species (for example in sheep see (Blache *et al.*, 2003) and for concept (Blache *et al.*, 2007)). As a consequence of this biological regulation for alpacas adapted to a low quality diet, when overfed they will be outside their "metabolic comfort zone". Consequently, reproduction and/or the efficiency of fibre production are likely to be impacted.

Some of the factors that limit alpaca reproduction have been identified in 2 recent reviews (Tibary and Vaughan, 2006; Vaughan and Tibary, 2006). Basically, reproductive efficiency in alpacas could be improved by feeding a basal diet to maintain body condition and then supplement the animals with

energy and protein to sustain reproductive activity. Similarly adequate nutrition should also sustain fibre production.

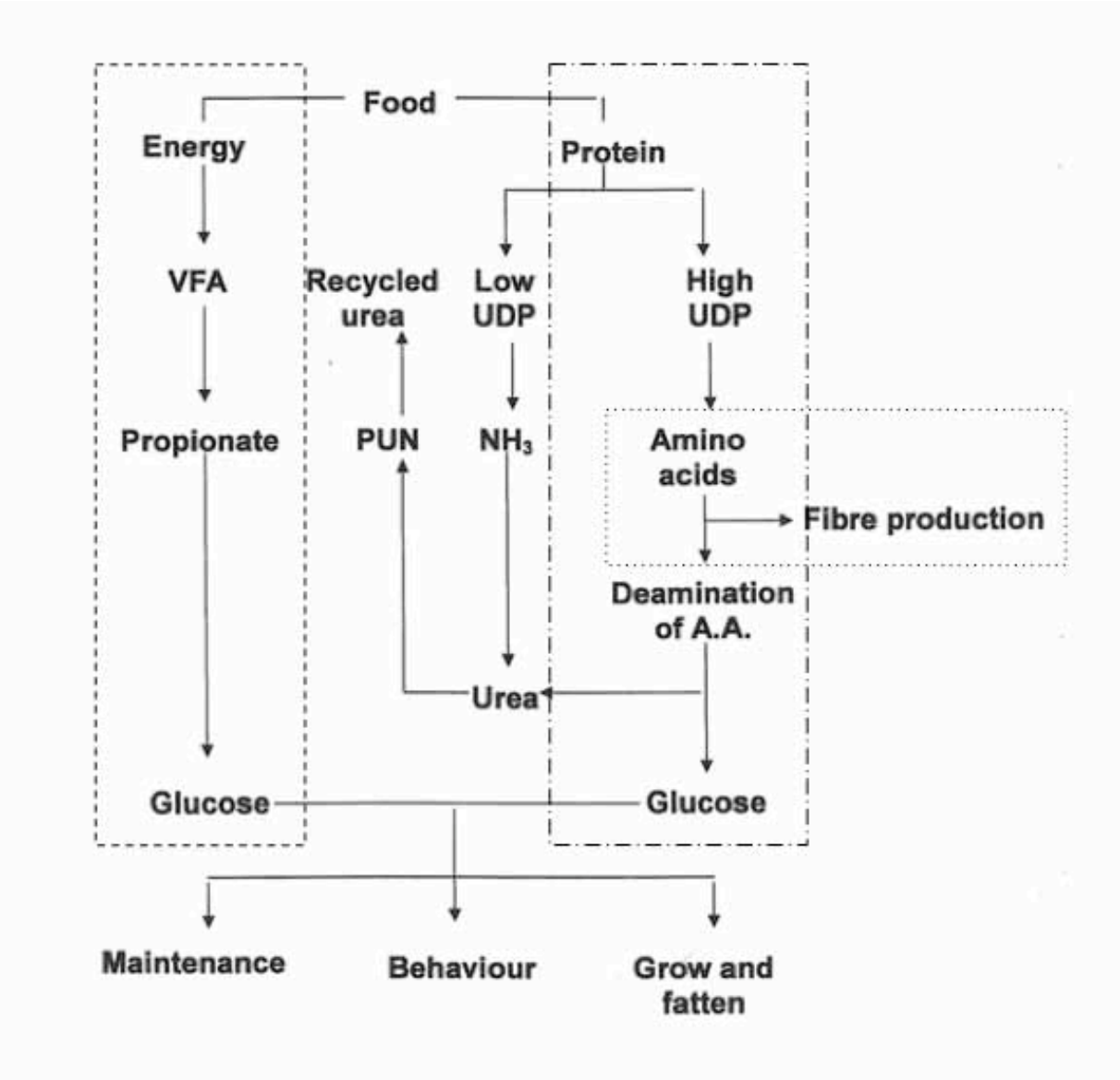

Figure 1: Potential pathways alpacas use to meet their energy requirements via either a classical glycogenic pathways (left hand side dotted panel) or deamination of AAs (right hand side dotted panel). The pool of available AAs is then used either to meet the animal's requirement for glucose or for fibre production.

In the female, fertility is not a problem as more than 85% of the females are successfully mated, but their management is made difficult because of the need for producers to join females within 2-3 weeks after parturition to avoid a decrease in conception rate as lactation progresses (Vaughan and Tibary, 2006). There are now recommendations on feeding and body condition to optimise fertility and pregnancy rate in sheep, cattle and goats. Peak lactation in cattle interferes with ovarian function mainly because of the metabolic challenge experienced by cows. Recently, it has been shown in dairy cattle that body condition and feeding before parturition are the best management strategies to reduce the length of the post-partum anoestrus in cattle (Chagas *et al.*, 2006). Therefore, it is possible that feeding to increase body condition in late gestation, or before mating could improve the conception rate in alpacas.

Alpacas are seasonal breeders and their natural history shows that nutrition can affect their reproductive performance. In their natural habitat in the highlands of southern Peru, alpacas breed from December to March (Southern hemisphere summer). These are the warmest months of the year when rainfall is sufficient and green forage is abundant (San Martin et al., 1968; Franklin 1983). In peasant farms in Peru, where male and female alpacas are run together year-round, the birth and breeding times also occur around this time of the year. However, when females are isolated from males and copulation is allowed only once a month, both sexes are sexually active during the course of the whole year, and ovulation, fertilisation rates and embryo survival do not vary across the year (Fernandez-Baca et al., 1972). Observations in various zoological parks around the world also indicate that camelids, both domestic and wild, are capable of year round breeding (Schmidt 1973). On the other hand, continuous association of females and males has been shown to inhibit sexual activity in the males (Fernandez-Baca et al., 1972). The environmental factors responsible for the onset and cessation of sexual activity under natural conditions are not clearly defined. The importance of balanced nutrition on sperm production, which can be assessed by measuring testes size, and the onset of puberty in male alpacas has never been fully examined with alpacas in Australian.

Objectives

The project aimed to develop feeding strategies to improve both fibre production and the reproductive performance of alpacas. The specific objectives were as follow:

To evaluate the impact of:

- high ratio of UDP:RDP in the diet on fibre growth and body condition
- supplementation with a glucose precursor on fibre growth and body condition
- methionine supplementation on fibre growth and body condition

To identify potential factors that could affect the length of gestation

To evaluate the impact of the ratio of UDP:RDP on

- onset of puberty in male alpacas
- seasonal variation in reproductive capacity and wool growth in mature male alpacas

Methodology

In all experiments, blood samples and fibre samples were taken to assess blood parameters and fibre production using the two procedures described below:

Blood collection and analysis

Blood samples were taken via jugular venepuncture in vacuette EDTA tubes on a weekly basis prior to feeding. The blood glucose concentration of individual alpacas was measured using a blood glucose meter (Accu-chek Advantage, Roche Diagnostics, Basel, Switzerland). After centrifugation at 3000 rpm for 10 minutes, plasma was frozen at -20ºC for future analysis. Insulin concentration in plasma was determined by double-antibody radioimmunoassay, measured on a gamma counter (Packard Cobra II, Auto Gamma) and the subsequent data were analysed using AssayZap. Plasma samples from weeks one, four, seven and ten of the experimental period were analysed for plasma urea nitrogen using a Kinetic UV test with an Olympus test kit OSR6134 on an Olympus AU400 analyser.

Fibre collection and analysis

A mid-side fibre patch of approximately 100 cm^2 was shaved from each alpaca prior to the start and at the end of the treatment period using a Laube clipper fitted with a size 40 blade (Kim Laube and Co., Oxnard, California, USA). The area of the patch was measured accurately to calculate the fibre growth (weight of dry fibre) per unit area of skin over the treatment period. The fibre samples were individually dried, weighed and analysed for several fibre characteristics using the Optical Fibre Diameter Analyser (OFDA) 2000 (BSC Electronics, Perth, Australia).

Live weight

Male alpacas were weighed to the nearest 0.5 kg before blood sampling by backing the animal onto a platform scale.

Body condition score

Body condition scoring was based on a scale of one to five with alpacas in very poor condition scored as one and obese animals scored as five. The fingers of the handler were placed on the centre of the alpacas back and the area was palpated with the fingers and thumb. Bulging indicated an over fat animal whereas the degree of concavity reflected the extent to which the animal had mobilised body fat and muscle.

The project was divided into two parts; Part 1: Understanding alpaca nutrition and metabolism to develop optimal diets and, Part 2: Determining the optimum diet to improve reproductive performance without compromising fibre production.

Part 1: Understanding alpaca nutrition and metabolism to develop optimal diets

This first series of experiments was conducted under controlled conditions at the UWA Shenton Park Research Facility (Floreat, WA), on castrated males to circumvent the influence of reproductive status and the associated hormones on metabolism and energy balance.

Experiment 1: Can fibre growth of alpacas fed a roughage diet be increased by supplementation with un-degradable dietary protein?

Alpacas were fed diets that were calculated to maintain body weight (Van Saun, 2006a) and contained various proportions of UDP protein, 0%, 30%, 60% and 100%, in the form of heat-treated canola meal as part of the total amount of canola meal protein offered. The behaviour of the alpacas in the 100% and 0% UDP groups was observed using video recording and the scan observation technique. The alpaca's fibre characteristics were analysed to determine whether fibre production was affected by the different proportions of UDP in the diet.

Animals

Castrated Huacaya male alpacas (n = 32) aged between 24 – 35 months were transported to Shenton Park Research Station at the University of Western Australia and housed in individual sand pens, approximately 3 m x 10 m. The alpacas were acclimatised to their new environment, routine, and handlers for approximately two months prior to the commencement of the treatments. Alpacas were provided with *ad libitum* water, a feed shelter and a shaded area. They were fed daily each morning to accommodate the diurnal feeding behaviour of alpacas. The feed refusals of each alpaca was weighed daily. All animals were weighed to the nearest 0.5 kg and condition scored each week and dietary adjustments were made to ensure that the animals were fed to maintain weight and body condition score.

Feed treatments and analysis

The alpacas were allocated to four treatment groups (n = 8) that were homogenous for live weight (48.0 ± 0.22 kg) and body condition (2.3 ± 0.05 units, scale 1 = emaciated, 5 = obese; Fysh, 2003). The amount of each dietary ingredient fed to each alpaca was calculated based on its metabolic live weight ($kg^{0.75}$). The alpacas received a basal diet of milled barley straw at 22 $g/kg^{0.75}$, a roughage based pellet at 9.7 $g/kg^{0.75}$ (Macco 101 pellet, Macco Feeds Australia, Williams, Western Australia), 25 g/head/day of a complete mineral mix and 25 g/head/day of dried, granulated sugar cane molasses (Palabind, Probiotic, Laverton North, Victoria, Australia). A supplement of 4.6 g/kg metabolic weight of canola meal was added to the basal diet as either untreated, flaky cold-pressed canola meal (0% UDP), the same canola meal after being finely milled and heat treated (100% escape protein), or proportions of both flaky and finely milled canola meal to achieve 30% and 60% UDP. Acid detergent insoluble nitrogen analysis was conducted on the canola meal to ensure that it was not over protected. The canola meal in the treatment groups provided about 50% of the total protein in the diets. Canola meal was deemed a suitable protein supplement for fibre growth because it has a high content of sulphur amino acids, which are known to stimulate fibre growth in sheep (Masters et al. 1999).

Behavioural observations

The behaviour of individual alpacas from the 0% and 100% RDP groups was recorded using four closed-circuit television (CCTV) cameras and digital surveillance system software (Kguard DVR7134 version 1.1, Kguard Security, 2005) over a period of five days. Each animal was recorded for an eight hour period during the day, beginning from the time of feeding in the morning. The video footage was analysed using Interact 8 software (Mangold International GmbH, 2005) to determine the total time spent in each activity by each animal.

Experiment 2: Does supplementation with propionate allow alpacas to grow more fibre when a roughage diet supplemented with UDP cannot support maximum wool growth?

Alpacas were fed diets containing a proportion of calcium propionate and UDP as treated canola meal protein in a 2x2 factorial design to determine the effect of supplementation with a glucose precursor on fibre production.

Animals

Castrated Huacaya alpacas (2-3 years old) were housed in individual outdoor pens, approximately 3 m x 10 m. The pens had sand bedding and were bare of vegetation. The alpacas were acclimatised to their environment and handled for several weeks prior to the commencement of the treatments. Each alpaca was provided with *ad libitum* water and a feed shelter and were fed in the morning on a daily basis to accommodate the feeding behaviour of alpacas. Feed refusals for individual animals were recorded daily and a 10% sample of each refusal was stored for further analysis. All animals were weighed to the nearest 0.5 kg and condition scored (scale of 1 to 5; 1 = emaciated and 5 = obese) weekly to ensure they were being fed at a maintenance level.

Feed treatments

The alpacas were allocated to four treatment groups (n = 8) that were homogenous in live body weight (46.5 kg ± 0.40 kg) and body condition score (2.52 ± 0.05). The metabolic live weight of each alpaca was used to calculate the amount of each dietary ingredient fed to the individual animal. For two months, the alpacas received a basal diet of milled barley straw at 3 g/kg$^{0.75}$, a roughage based pellet at 8 g/kg$^{0.75}$ (Macco 101 pellet, Macco Feeds Australia, Williams, Western Australia), a high fibre pellet at 20 g/kg$^{0.75}$ (Macco Feeds Australia, Williams, Western Australia), 25 g/head/day of a complete mineral mix and 25 g/head/day of dried, granulated sugar cane molasses (Palabind, Probiotec, Laverton North, Victoria, Australia). Two groups received a supplement of 4.5 g/kg$^{0.75}$ of finely milled, heat-treated canola meal, which provided a high proportion of UDP (High UDP). The other two groups received 4.5 g/kg$^{0.75}$ of untreated, flaky cold-pressed canola meal which contained a minimal amount of UDP with a high proportion of RDP. Calcium propionate (CALPRONA – C/CA, Verdugt, Netherlands) was added at 25 g/kg$^{0.75}$ to the diet of each of the high and low UDP groups. Samples of each feedstuff were ground to pass through a 0.5 mm screen using a sample grinder (Retsch, Haan, Germany). A Ballistic Bomb Calorimeter (Weiss-Gallenkamp®, Loughborough, United Kingdom) was used to determine the energy content of each feedstuff.

Data analysis

The metabolisable energy (ME) intake for each alpacas was calculated using the ME values for each feedstuff fed and the refusals for each alpaca. The ME intake for each treatment group was compared using ANOVA with pairwise comparisons using the Student-Newman-Keuls test (GenStat®, 11th edition, VSN International Ltd., 2008). Live weight and condition score were analysed using ANOVA adjusted for covariate with pairwise comparisons using the Student-Newman-Keuls test. The change in live weight and condition score over the duration of the experiment was analysed using ANOVA with pairwise comparisons also. All of the raw data from the OFDA 2000 fibre analysis were analysed using ANOVA adjusted for covariate with the initial fibre samples as a covariate. Multiple pairwise comparisons were also conducted using a Students-Newman-Keuls test ($p<0.05$) (GenStat®, 11th edition, VSN International Ltd., 2008). The same analysis was used to determine differences in the weight of fibre produced by each treatment group. An ANOVA with repeated measures and an ANOVA with pairwise comparisons using the Student-Newman-Keuls test was used to compare the plasma urea nitrogen concentration, insulin concentration and glucose concentration of the blood (GenStat®, 11th edition, VSN International Ltd., 2008).

Experiment 3: Can methionine supplementation boost fibre production when alpacas are fed a roughage diet?

To test the hypothesis that supplementation with rumen protected methionine would increase fibre growth, we supplemented two groups of alpacas with different levels of protected methionine and another group of un-supplemented alpacas were the control.

Animals and procedure

Castrated male alpacas (n=24, 2-3 years of age), with an initial mean (± SE) live-weight of 49.8 ± 1.1 kg were randomly allocated to three groups; control (MC) no methionine supplement (n=8), 2.0 g of methionine supplement/day (M2; n=8) or 4.0 g of methionine supplement/day (M4; n=8). The alpacas were maintained in a herd in a grassed paddock whilst being acclimatised to handlers and the morning feeding routine. After acclimatisation, each alpaca was moved to an individual sand-based outdoor pen, approximately 3 m x 10 m, which was equipped with feed shelters, shade and water *ad libitum* where they were fed for two weeks before the commencement of the experiment. The alpacas were fed daily each morning, to maintain their normal feeding behaviour. During the experiment each alpaca was fed for eight weeks a maintenance diet based on its live weight (Table 1), and two groups had the methionine supplement added to their feed.

Table 1: Maintenance diet of alpacas based on metabolic live weight (MLW)

Feed	Amount given
Maintenance Pellet (101)	8g/kg MLW
High Fibre Pellets	20g/kg MLW
Flaky Cold Pressed Canola Meal	4.5g/kg MLW
Barley Straw	3g/kg MLW
Mineral Mix	25g
Palabind	25g

Supplement

The methionine supplement used was a liquid form of an 88% solution of dl, 2-hydroxyl-4-(methylthio) butanoic acid, a methionine analogue feed supplement produced by Alimet (Novus International, Inc., St. Charles USA). The supplement was diluted in ratios of 2:8 (2 L of supplement to 8 L of water) for M2 and 4:6 for M4, which supplied 2.0 and 4.0 grams of methionine, with the MC treatment being water only. Ten ml of supplement or water were sprayed on the maintenance diet and mixed by hand so as all feed components were uniformly covered with the supplement.

Sampling and analysis

Live weight, body condition score and body temperature were measured and a blood sample was taken between 7 and 9 am once each week. Feed refusals were monitored daily and a 10% sub-sample of the refusals was retained. Weather data was accessed from the Department of Agriculture's Floreat Park weather station located two kilometres from the Shenton Park Field Station. Data was analysed by ANOVA followed by Student Newman-Keuls test and paired and unpaired T-tests (GenStat v.10).

Part 2: Determining the optimum diet to improve reproductive performance without compromising fibre production.

These experiments were conducted on-farm, with the investigations on males conducted at Banksia Park Alpaca stud (Serpentine, WA) and the investigation in females conducted in collaboration with Canchones Alpaca Stud (Taggerty, Victoria)

To conduct Experiments 4 and 5, feeding facilities and shelters were built on site (Photo 1) to decrease competition between the pre-pubertal males at feeding We habituated the alpacas to eat in the individual feed stalls and this minimised aggressive behaviour or a pecking order developing amongst the young alpacas at feeding time.

Photo 1: Feeding facilities and shelters were built on site at Bangsia Park. Note the feed stalls that minimised aggressive behaviour or a pecking order developing amongst the young alpacas

Experiment 4: Does canola meal supplementation increase reproductive capacity in male alpacas?

Intact and castrated male alpacas were exposed to ambient conditions while receiving a diet of canola meal for 12 months. The general hypothesis for this experiment was that reproductive capacity will increase when male alpacas are given a canola meal supplement compared to a normal diet.

Intact (n=20) and castrated alpacas (n=20) were fed a normal diet (high fibre pellets) and half of the animals in each group were supplemented with 200g/head/day canola meal.

Measures of live weight, condition score, scrotal diameter, eruption of fighting teeth were made and blood samples were taken each month over 13 months commencing in December 2009 and finishing in January 2011. Glucose and testosterone were measured in the plasma samples that were taken each month.

Libido test and sexual behaviour

The libido and sexual behaviour of each individual male was evaluated using slight modifications to the procedures described by Boyd *et al*. (1989) and Christensen *et al*. (1982). Tests were carried out by introducing a single male into a 3 m x 3 m indoor pen where there was a single receptive female. The following activities and the duration of each activity was recorded: vocalisation, chasing and attempting to mount, incomplete mount, complete mount and copulation. The test was terminated either after the male was able to copulate, after 5 minutes of intense chasing of the female, or when no interaction had occurred over a period of 5 minutes.

Testicular measurement

Scrotal length and width were measured physically using a Vernier calliper around the widest diameter of the testes after pushing the testes firmly to the bottom of the scrotum. Testicular volume was calculated using the equation to calculate the volume of an ellipsoid sphere.

Plasma testosterone

The concentration of testosterone in plasma was determined using radioimmunoassay. All samples were run in duplicate on alpaca serum.

On the first day, 25 µl of plasma were transferred to 12 x 75 mm glass tube and were extracted with 2000 µl diethyl ether. The tubes containing the mixture of plasma and diethyl ether were vortexed for 3 minutes before being allowed to freeze in a mixture of acetone, methanol and dry ice for a few seconds. The supernatant was collected in 10 x 75 mm glass tubes and stored in fume hood overnight to evaporate the diethyl ether.

On the second day, the assays were dispensed in 200 µl gelatine phosphate buffer (1 gram gelatine in 1 litre phosphate buffer solution). Then 100 µl primary antibody (diluted 1:100 in PBS) and 100 µl tracer was added. The samples were vortexed briefly and then incubated in a cool room overnight.

On the next day, 200 µl of charcoal were added to assay to separate the non-binding antibody. After addition of charcoal, the assay was incubated for 20 minutes in cool room before being centrifuged at 3000 rpm and 4^0C for 10 minutes. The supernatant was aspirated and dispensed into 6 ml scintillation vials and counted for 3 minutes in a liquid scintillation analyser (Packard Tri Carb 1500).

Experiment 5: Does canola meal supplementation advance the timing of puberty in male alpacas?

This experiment was conducted to provide information on the inter-relationships between nutrition, growth rate and the timing of puberty in male alpacas. Puberty normally occurs from as early as 10 months of age to as late as 3 years. The general hypothesis for this experiment was that canola meal supplementation would advance puberty in alpacas.

Forty pre-pubertal male alpacas (8 months old) were randomly assigned to four groups and each group received high fibre pellets and supplemented with different levels of canola meal; 0, 80, 120 and 200 g/head/day. The experiment started in September 2009 and finished in December 2010.

To estimate the onset of puberty, we used a range of indictors previously described in the literature. The separation of the foreskin of the penis (preputial separation; PPS) is an early and reliable marker for the progression of puberty. A partial separation with a thread of cartilage remaining was recorded as ‘partial’, but only the occurrence of complete separation was used to define puberty in the data analyses (Stoker et al., 2000). The concentration of testosterone in plasma was measured monthly to determine if a change in testosterone levels could be used to indicate the onset of puberty (Stoker et al., 2000). In addition, eruption of fighting teeth and testicular size were measured monthly.

Experiment 6: What are the main factors that influence gestation length?

Over 2 years, data on the live weight, body condition score, date of mating, date of parturition (and therefore gestation length) were collected from over 100 pregnant females kept at Canchones Alpaca Stud, Taggerty, Victoria. The data were entered into an excel spreadsheet and checked twice, then specific parameters such as live weight during a specific period of gestation relative to the time of mating were generated (Table 2 for details). The full data set contained records for 1037 matings. Three outliers were identified during exploratory analysis of the data and were found to be typographical errors in the data set. Consulting servicing records rectified these errors. A number of outlying data points on the lower end of the spectrum were found to be stillborn and premature births. Accurate gestation length was not available for these points because a live cria was not produced, so these females were removed from the studies on gestation length.

Table 2: Abbreviations and definitions of the parameters used in the analysis

Variable	Description
Fid	Female identification number
Mid	Male identification number
Durm	Duration of mating (minutes)
Month	Month of mating (recorded as1-12)
Year	Year of mating
Age	Age of female at mating (days)
Bwt.bef.av	Average live weight of female in the 3 months leading up to mating (kg)
Bcs.bef	Average body condition score of female in the 3 months leading up to mating (on a scale of 1-5 with 1=malnourished and 5=obese)
Success	Y= successful mating, N= unsuccessful mating
Bwtd.1	Females live weight in trimester 1 (kg)
Bwtd.2	Females live weight in trimester 2 (kg)
Bwtd.3	Females live weight in trimester 3 (kg)
Bcsd.1	Females body condition score in trimester 1
Bcsd.2	Females body condition score in trimester 2
Bcsd.3	Females body condition score in trimester 3
Gest	Gestation length (days)
Cria	Status of cria at birth (S=stillborn, N=normal, P=premature, D=dystocia)

The database was first explored and then a model was fitted to analyse the potential factors influencing length of gestation or mating success. All these analysis were done using the R statistical package (R-Cran).

Determination of which factors affect gestation length was carried out using linear regression models. For this aspect of the study, only successful matings with normal births were used. There was 329 mating records in this category. Gestation length was modelled as the dependent variable with *fid*, *mid*, *age*, *durm*, *month*, *year*, *bwt.bef.av*, *bcs.bef* and live weight and body condition at each trimester during pregnancy as the explanatory variables. The model was assessed for interactions and since none were found, all interaction terms were removed from the model.

Assessment of each factor of importance to determine if a mating was successful was carried out using logistic regression analyses. For all analyses, a significance level of $\alpha = 0.05$ was used.

Results

Experiment 1: Can fibre growth of alpacas fed a roughage diet be increased by supplementation with UDP?

All alpacas consumed their entire diet of pellets and canola meal and only a small amount of straw was not eaten by some animals. The animals in all treatment groups maintained live weight (p = 0.662) and body condition (p = 0.278) (Table 1).

The weight of fibre grown per unit skin area over the 14 week feeding period was similar between all treatment groups (p = 0.313). The mean diameter of the fibre grown by the animals in each group was less than the mean diameter of their fibre at the start of the 14 week experiment. The fibre from alpacas fed the diet with 0% UDP was of finer diameter than the alpacas fed the three diets with higher levels of UDP (p = 0.039; Table 3).

Table 3: Mean change (±SE) in live weight, body condition, fibre growth and fibre diameter of alpacas fed diets containing different proportions of UDP over 14 weeks.

	Proportion of UDP from canola meal in diet			
	0%	30%	60%	100%
Change in live weight (kg)	1.7 ± 0.28	1.5 ± 0.85	2.9 ± 1.11	1.5 ± 1.03
Change in condition score (1-5)	-0.6 ± 0.15	-0.2 ± 0.16	0.0 ± 0.19	-0.2 ± 0.16
Fibre growth (mg/cm^2)	33.8 ± 2.42	39.6 ± 3.29	42.2 ± 3.97	37.7 ± 3.10
Fibre diameter (μm)	18.1 ± 0.50^a	20.4 ± 0.93^b	21.4 ± 0.63^b	20.4 ± 0.82^{ab}

^{ab} Values within a row with different superscripts are different (p < 0.05).

There was no effect of treatment on plasma urea nitrogen (p = 0.530), however the group that received 0% UDP had the lowest plasma urea nitrogen (PUN) concentration mean of 4.2 ± 0.19 mmol/L compared to the other treatment groups (Table 4). The mean PUN concentration for all animals in the first week was significantly greater than the means for the other three weeks (p = 0.004).

There were no differences between the 0% and 100% treatment groups for any of the observed behaviours (p > 0.05; Table 5), except that the alpacas fed the diet containing 0% UDP spent a significantly greater proportion of time urinating compared to the alpacas fed the 100% UDP diet (p = 0.027).

The hypothesis that alpacas fed a diet with a high proportion of UDP would produce more quality fibre and spend less time urinating than peers fed a similar amount of canola meal protein with a low proportion of UDP was partially supported. The alpacas in all treatment groups maintained live weight throughout the experiment and there were no differences in the behavioural attributes measured for the two extreme groups, except for the time spent urinating. That the alpacas in the 0% UDP group spent more time urinating than those fed the 100% UDP treatment suggests this latter group probably retained more nitrogen. The diameter of the fibre from the alpacas fed 0% UDP was finer than those in the other groups and, although not significantly different, these animals also produced the least amount of fibre. This result is somewhat similar to those of Masters, Mata *et al*. (1999) where sheep supplemented with UDP in the form of canola meal grew more wool of greater diameter than those fed a lower proportion of UDP as lupins.

Table 4: Plasma urea nitrogen concentration of alpacas fed diets containing varying proportions of UDP. Means over the experimental period are presented.

	Proportion of UDP from canola meal in diet			
	0%	30%	60%	100%
Plasma urea nitrogen concentration (mmol/L)				
Week 1	4.6 ± 0.35	5.6 ± 0.51	5.0 ± 0.42	5.1 ± 0.57
Week 2	4.5 ± 0.36	4.8 ± 0.47	4.8 ± 0.49	4.5 ± 0.41
Week 3	4.0 ± 0.33	4.5 ± 0.23	4.6 ± 0.42	4.6 ± 0.43
Week 4	3.7 ± 0.33	4.5 ± 0.24	4.5 ± 0.32	4.3 ± 0.41
Over entire experiment	4.2 ± 0.19	4.8 ± 0.25	4.7 ± 0.12	4.6 ± 0.16

Table 5: Time budget of alpacas fed a diet containing either 0% UDP or 100% UDP for each behaviour category observed. Times for each behaviour category are expressed as percentage of total time.

	Proportion of UDP from canola meal in diet	
	0%	100%
Eating	27.1 ± 4.68	32.6 ± 3.71
Lying	20.2 ± 4.27	17.1 ± 1.65
Standing	75.5 ± 3.91	76.4 ± 2.26
Walking	4.1 ± 0.77	6.4 ± 1.79
Grooming	0.8 ± 0.10	1.6 ± 0.57
Defecating	0.4 ± 0.13	0.2 ± 0.06
Drinking	0.4 ± 0.13	0.2 ± 0.11
Urinating	0.4 ± 0.13[a]	0.1 ± 0.04[b]

[ab] Values within a row with different superscripts are different ($p < 0.05$).

The alpacas fed 0% UDP spent more time urinating and with urea being a diuretic agent it is possible that they excreted more urea in their urine with less being recycled to the fermentative organs. Under these conditions nitrogen may have limited microbial protein synthesis in the fermentative organs with the result that less amino acids were available to be absorbed and used for fibre production. This result may also indicate that alpacas have a limited ability to recycle nitrogen to the fermentative organs when fed a diet low in UDP. In contrast, llamas fed a low protein diet were found to efficiently recycle urea and utilised about 85% of it for microbial protein synthesis (Von Engelhardt and Schneider, 1977). Although similar conclusions have been drawn for alpacas, they appear to be less efficient in utilising high levels of dietary nitrogen than llamas (Davies *et al.*, 2007). In our experiment, it appears that the canola meal low in UDP was mostly degraded in the fermentative organs and ultimately excreted as urinary urea. Also, although not significantly different, the mean plasma urea nitrogen concentration of alpacas fed 0% UDP was lower compared to peers fed higher proportions of UDP. This result lends support to our view that alpacas may have a limited ability to recycle nitrogen to the fermentative organs under the conditions of our experiment. To confirm this, an experiment needs to be conducted to compare the proportion of nitrogen apparently absorbed that is excreted in the urine of alpacas fed 0% and 100% UDP from canola meal. As part of this experiment, measurements of the concentration of plasma urea nitrogen from blood taken at an appropriate interval after, rather than

before, feeding may provide a better understanding of the ability of alpacas to recycle nitrogen to the fermentative organs.

Experiment 2: Does supplementation with propionate allow alpacas to grow more fibre when a roughage diet with UDP cannot support maximum wool growth?

During the experiment, the alpacas that were fed calcium propionate (CaP) refused some of the daily portion they were offered. While there was no difference in daily metabolisable energy intake between all four groups (p = 0.278; Table 6), the nitrogen intake for alpacas not fed CaP was higher than those receiving CaP (p <0.001; Table 6)

Table 6: Metabolisable energy (ME) offered and intake from calcium propionate and other feedstuffs, N intake, mean change ±SE in live weight and condition score for alpacas fed a diet containing varying proportions of calcium propionate and either UDP or RDP canola meal protein. Means with different superscripts are different (p<0.05)

	Diet			
	+ CaP UDP	+ CaP RDP	- CaP UDP	- CaP RDP
ME offered	6.63±0.3	6.55±0.2	5.3±0.3	5.3±0.4
Total ME intake (MJ/day)	5.2 ± 0.23	4.7 ± 0.32	5.2 ± 0.15	5.2 ± 0.14
Diff between ME offered and ME intake (MJ/day)	1.4±0.3	1.7±0.4	0.1±0.0	0.1±0.0
ME intake from CaP (MJ/day)	2.62±0.2	2.24±0.2	0	0
ME intake from other feed stuff (MJ/day)	2.63±0.1	2.44±0.1	5.2±0.1	5.2±0.1
N intake (g/day)	51.3±1.8	50.3±1.7	75.4±2.2	75.4±2.1
Change in live weight (kg)	-1.5 ± 0.92[a]	-1.9 ± 0.41[a]	0.8 ± 0.52[b]	-0.9 ± 0.32[a]
Change in condition score (1-5)	-0.2 ± 0.09	-0.2 ± 0.09	-0.1 ± 0.06	-0.1 ± 0.08

All of the treatment groups, except the group of alpacas that were fed the diet of UDP and no CaP, had similar changes in live weight during the experiment. The alpacas in the group that consumed UDP and no CaP were of significantly higher live weight than the animals in the other three groups at the end of the experiment ($p = 0.005$). There was no difference in the change in the condition score between the four groups of alpacas ($p = 0.687$; Table 7).

Table 7: Mean fibre diameter at the start and end of the experiment and weight of fibre produced ± SE of alpacas fed varying proportions of CaP and either UDP or RDP. Means with different superscripts are different (p< 0.05).

	Diet			
	+ CaP UDP	+ CaP RDP	- CaP UDP	- CaP RDP
Weight of fibre (mg/cm^2)	33.1 ± 2.35^a	41.7 ± 4.67^a	44.4 ± 1.91^b	46.1 ± 2.86^b
Fibre diameter (start) (μm)	21.4 ± 0.64	22.9 ± 0.54	20.6 ± 0.62	19.3 ± 0.74
Fibre diameter (end) (μm)	21.0 ± 0.69	22.3 ± 0.62	21.0 ± 0.75	19.9 ± 0.69
Change in fibre diameter (μm)	-0.4 ± 0.17^a	-0.6 ± 0.11^a	0.3 ± 0.24^b	0.5 ± 0.22^b

The two groups of alpacas fed diets containing CaP produced significantly less fibre than those not fed CaP ($p < 0.001$). The fibre diameter of the two groups fed CaP was also significantly reduced compared to that of the other two groups ($p = 0.002$; Table 8).

Table 8: Mean ±SE blood glucose, plasma insulin and PUN concentrations of alpacas fed varying proportions of CaP with either UDP or RDP

	Diet			
	+ CaP UDP	+ CaP RDP	- CaP UDP	- CaP RDP
Blood glucose concentration (ng/mL)	4.9 ± 0.10	4.9 ± 0.10	4.8 ± 0.09	4.8 ± 0.09
Insulin concentration (uU/mL)	2.2 ± 0.13	2.0 ± 0.10	2.2 ± 0.08	2.4 ± 0.07
Plasma urea nitrogen concentration (mmol/L)				
Week 1	4.7 ± 0.59	5.3 ± 0.44	5.1 ± 0.29	4.8 ± 0.23
Week 2	4.9 ± 0.34	6.0 ± 0.74	5.5 ± 0.59	4.9 ± 0.24
Week 3	4.9 ± 0.60	5.7 ± 0.35	5.1 ± 0.38	4.9 ± 0.22
Week 4	4.4 ± 0.57	5.4 ± 0.25	4.9 ± 0.28	4.9 ± 0.22
Means for experiment	4.7 ± 0.12	5.6 ± 0.16	5.2 ± 0.13	4.9 ± 0.03

There was no effect of treatment ($p = 0.300$) or time ($p = 0.239$) on PUN concentrations for the four weeks analysed (Table 8). The concentration of blood glucose was not affected by treatment ($p = 0.300$), however, there was an effect of time ($p < 0.001$; Figure 2). There was no difference in plasma insulin concentration between the treatment groups ($p = 0.407$) however there was an effect of time ($p < 0.001$; Figure 3).

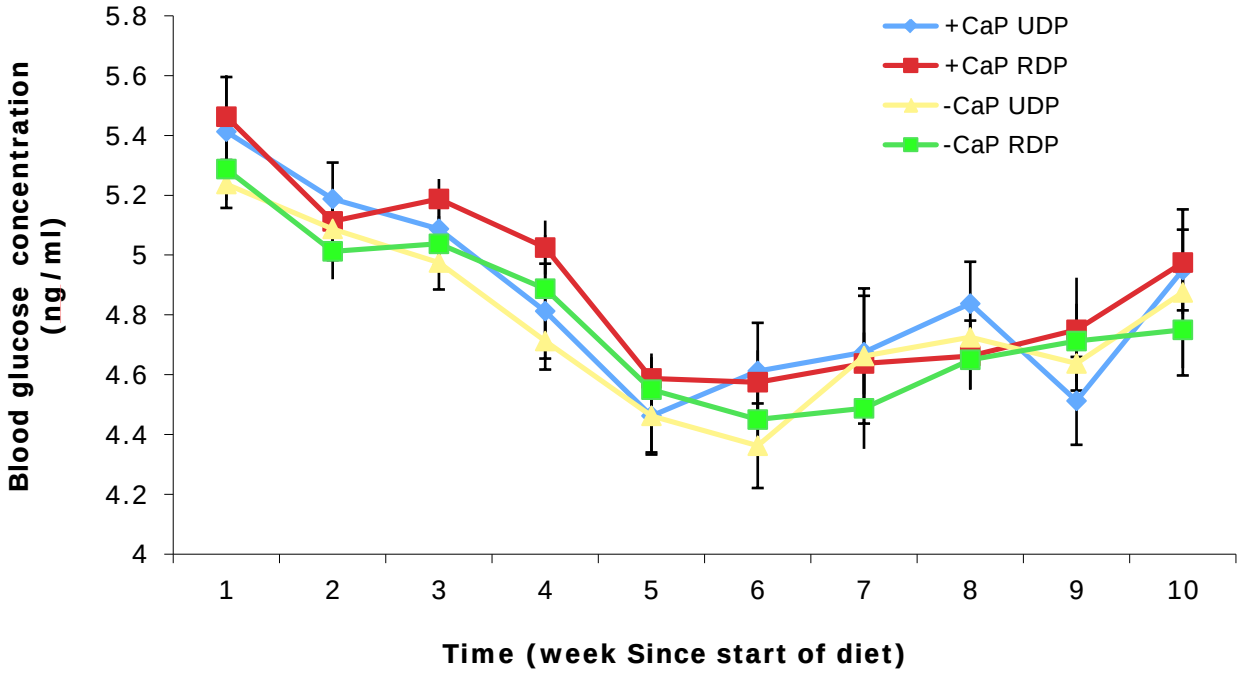

Figure 2: **Mean (±SE) blood glucose concentration (ng/mL) of alpacas fed diets containing combinations of calcium propionate and un-degradable dietary protein over the experimental period.**

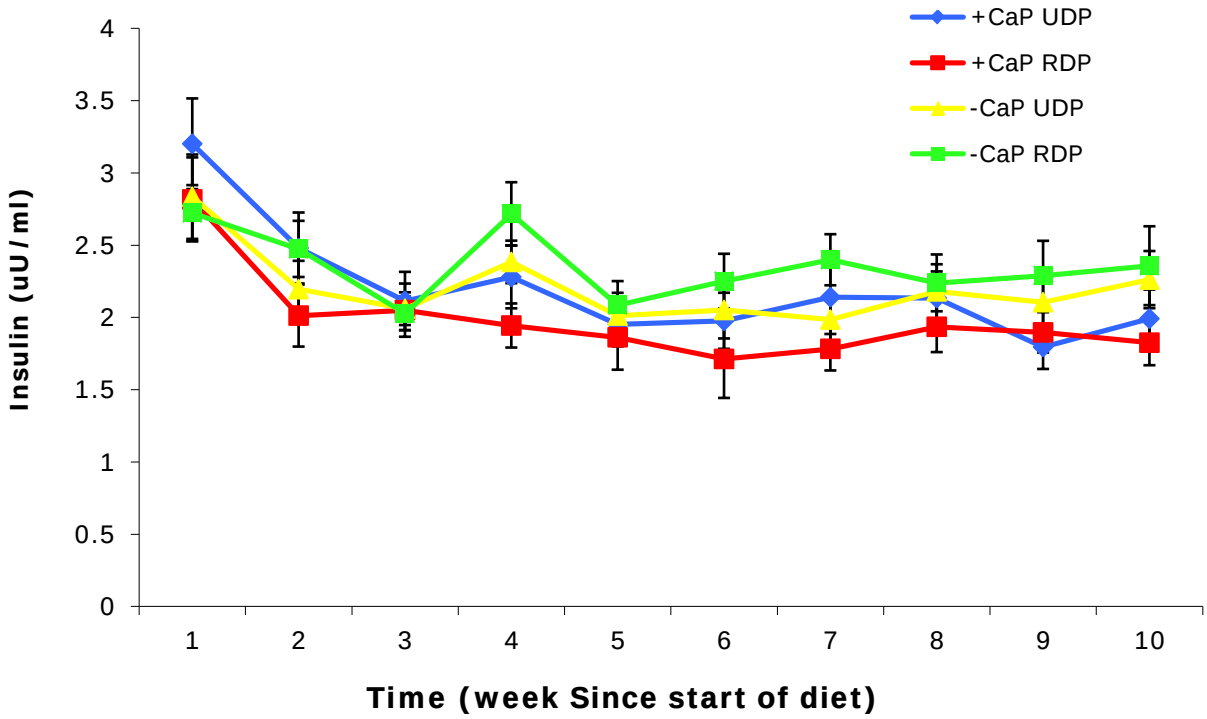

Figure 3: **Mean (±SE) insulin concentration (uU/mL) of alpacas fed diets containing portions of calcium propionate and un-degradable dietary protein (UDP) over the experimental period.**

The main impetus of this study was to determine whether alpacas fed propionate would spare amino acids from being used to supply glucose. The alpacas in this study were expected to derive glucose from propionate and therefore spare amino acids from being used for glucose production and instead use them for fibre production. This hypothesis was not supported as although the diets supplemented with calcium propionate offered more energy than the diets without calcium propionate, the amount of energy eaten by all animals was similar. It seems that rather than sparing amino acids, the alpacas regulated their energy intake and refused the additional energy offered as calcium propionate.

By regulating their energy intake, the alpacas fed diets containing calcium propionate appeared to use the protein portion of their diet to derive glucose for maintenance rather than derive glucose from the gluconeogenic precursor. The amount of protein in the diets containing calcium propionate was lower than that in the diets without calcium propionate, therefore there would have been less amino acids available for absorption from these latter diets. Fibre production is strongly influenced by the amount of amino acids available for absorption (Reis and Sahlu, 1994a). By down regulating their energy intake and using amino acids for glucose synthesis, the alpacas fed calcium propionate were likely to be starved of the amino acids required for fibre production. Consequently, they produced less fibre than peers that were not fed calcium propionate and the diameter of the fibre they produced during the experiment decreased.

Another implication arising from alpacas down regulating their energy intake from gluconeogenic precursors and relying heavily on protein as a source of glucose for maintenance energy and fibre production is the issue of obesity. Obesity is considered a prevalent nutritional disease in alpacas living in developed countries like Australia (Van Saun, 2006b). It is thought that feeding alpacas beyond their nutritional requirements, particularly with supplements, is the foremost cause of obesity. The results from our study suggest it is possible that alpacas do not regulate their protein intake because they have a strong reliance upon protein for maintenance of energy intake and fibre production. Therefore the type, rather than the quantity of food alpacas consume may be a significant underlying cause of obesity and consequently appropriate protein supplements may aid this problem.

The results show that the alpacas did not take advantage of the extra energy available from the glucose precursor, suggesting that their energy intake was tightly regulated because the alpacas offered the glucose precursors regulated their energy intake to a similar level as those not receiving the glucose precursor (about 5 MJ/Day). These results, taken in the context of the different pathways used by alpacas to synthesise glucose (Figure 1), suggest that alpacas might not regulate their protein intake and that obesity in alpacas could be the result of feeding alpacas with a diet too rich in protein.

Experiment 3: Can methionine supplementation boost fibre production when alpacas are fed a roughage diet?

There was no improvement in the quality of fibre as the fibre diameter, staple length and weight of fibre were not significantly different between groups. Similarly, the live weight (BWT) and body condition score (BCS) was not different between treatments and did not change from week 1 to week 8 (Table 9). The fibre diameter did exhibit an increase between weeks 1 and 8 (Figure 4), but as this occurred for all groups it indicates some sort of external, possibly environmental, effect which affected all animals.

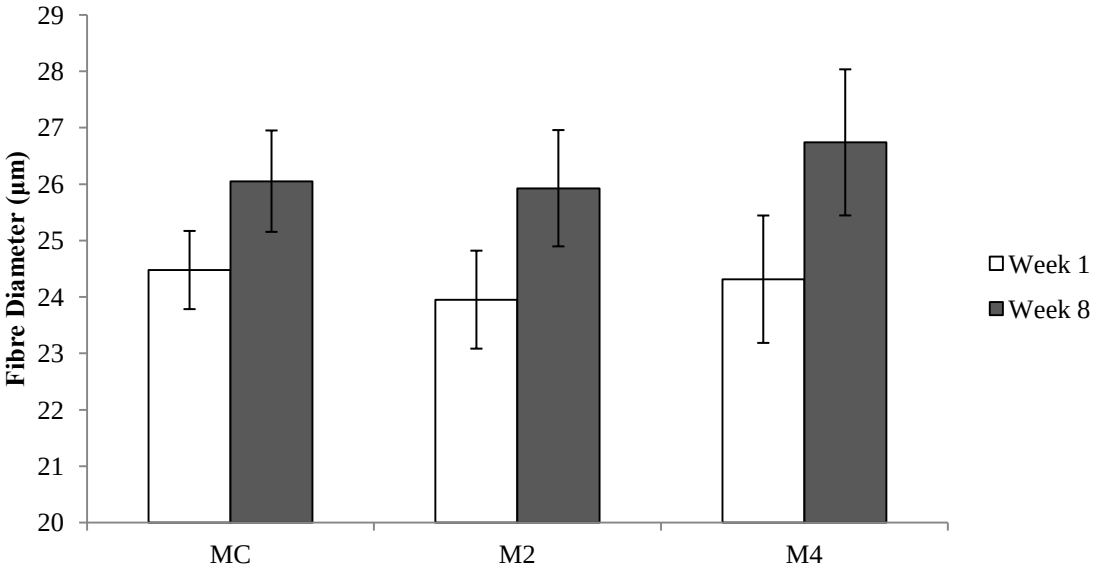

Figure 4: Fibre diameter in alpacas before (open bars - week1) and after (grey bars – week 8) 8 weeks of being fed a basic diet without the addition of protected methionine (MC), or the addition of 2.0 (M2) or 4.0 g/day of protected methionine (M4).

The plasma glucose levels changed over the experimental period, with a decrease in all groups (Figure 5) from week 1 to week 4 ($P<0.001$) and from week 4 to week 7 ($P<0.001$). Plasma urea nitrogen (PUN) levels went the opposite way with levels increasing for all groups from week 1 to week 4 ($P<0.001$) followed by no change between weeks 4 and 7 ($P=0.06$; Figure 5). Plasma leptin levels were not significantly different between MC and M2 but were significantly different between MC and M4 (Table 9) and this difference was maintained across weeks, there being no change over time; week 1 to week 4 ($P=0.65$) and week 4 to week 7 ($P=0.94$). Plasma insulin remained unchanged.

Table 9: Fibre characteristics and energy intake for alpacas fed a basic diet with 2 levels of protected methionine added. Different subscripts within a row denote differences between treatments

	Added methionine (g/day)		
	0	2	4
BWT change (kg)	-0.75±0.53 *a*	-0.81±0.30 *a*	-1.19±0.37 *a*
BCS change (unit)	-0.06±0.06 *a*	-0.06±0.11 *a*	0±0 *a*
Fibre diameter (µm)	33.88±1.65 *a*	37.89±1.84 *a*	40.94±4.12 *a*
Staple length (mm)	26.05±0.90 *a*	25.93±1.03 *a*	26.74±1.29 *a*
Weight of fibre (mg/cm^2)	48.13±3.13 *a*	46.88±2.10 *a*	46.25±2.45 *a*
Glucose (mmol/L)	5.04±0.15 *a*	4.50±0.10 *a*	4.64±0.08 *a*
Insulin (ng/ml)	3.92±0.32 *a*	3.29±0.21 *a*	4.24±0.42 *a*
Leptin (ng/ml)	0.30±0.02 *a*	0.28±0.02 *ab*	0.22±0.02 *b*
PUN (mmol/L)	5.74±0.48 *a*	5.65±0.24 *a*	5.16±0.46 *a*
Energy intake (MJ/kg/d)	5.67±0.14 *a*	5.68±0.16 *a*	5.67±0.19 *a*

The commencement of the experiment coincided with a change in the mean minimum ambient temperature as the experiment started at the end of summer and finished in the middle of autumn. The mean minimum temperature during week 8 of the experiment was significantly lower than during week 1 of the experiment ($P<0.001$). This decrease in minimum temperature, which occured with a change from summer to autumn in Perth, appeared to coincide with a decrease in glucose levels and a rise in PUN levels (Figure 5).

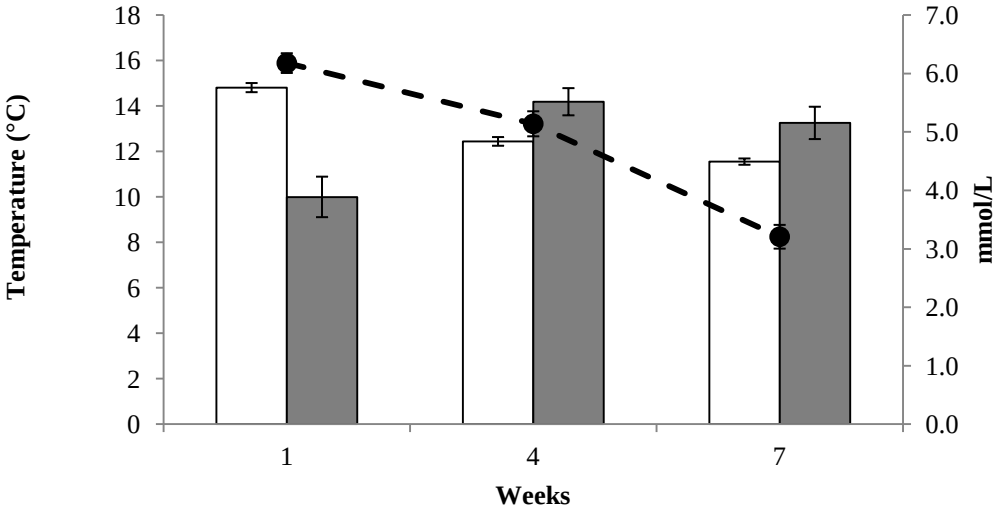

Figure 5: Mean daily minimum ambient temperature (dotted line) and concentrations of blood glucose (open bar) and PUN (shaded bar) in weeks 1, 4 and 7 of the experiment.

The results from this study demonstrate that the addition of rumen protected methionine to the diet of alpacas did not improve on the quality of alpaca fibre production, and therefore did not support the original hypothesis. In other fibre producing animals such as sheep and goats it has been found that methionine does have an effect on fibre production (Mcgregor and Hodge, 1989; Stephenson *et al.*, 1991) and has even been found to have an effect on Angora rabbits (Herrmann *et al.*, 1996). Therefore it is surprising that the addition of protected methionine did not affect fibre production in alpacas. The lack of response to methionine in the present study could be due to the diet saturating methionine requirements, the lack of genetic potential of the animals to produce quality fibre or a limit created by the absence of other amino acids essential for an increase in fibre production.

Expeller canola meal has been reported to contain a total of 1.7% methionine and cystine in the dry matter (Milton and Masters, 1998). The alpacas in our study were fed $4.5g/kg^{0.75}$ so with them weighing around 50 kg live weight they were fed around 85 g of canola meal each day, resulting in 1.4 g of methionine and cystine in the feed without the methionine supplement. Because the canola meal is lightly heat treated on exit from the expeller, this may have been enough to rumen protect the methionine and it is likely that a large percentage of the methionine and cystine would have escaped rumen degradation, partially as it was fed with barley straw as roughage (Cottle, 1988). Therefore the alpacas may have reached their methionine saturation point without needing any additional supplementation, which would help explain a lack of significance between the groups.

Furthermore, the lower levels of leptin in the M4 group indicate that a lipophilic effect was occurring as an increase in methionine levels can cause a decrease in fat depth, which has been found to reduce fat in prime lambs (Wiese *et al.*, 2003). Although there was no change in body condition score, which would usually occur with a decrease in fat deposition, the fat may have been mobilised in the visceral fat region instead of the back fat where the condition score is taken. The addition of methionine or alternatively canola meal to the diet could therefore be a useful dietary component to control obesity in alpacas.

Although the canola meal may have suppressed any distinguishable fibre quality differences between the treatment groups, the lack of significant difference may simply be due to the animal's limited genetic capacity to produce quality, long fine fibre. The animals were all wethers and would have been castrated due to their limited genetic potential for fibre production. . Future experiments on supplementation to promote fibre production in alpacas should be conducted with animals identified as being genetically superior for fibre production. Sheep that have been selected and bred over many generations to produce fine wool have been found to produce more wool with an increase in fibre diameter when supplemented with methionine (Stephenson *et al.*, 1990; Mata *et al.*, 1995). Alpacas typically produce fibre in winter that is about 25% finer diameter than that produced in summer (Newman and Paterson, 1994).Supporting the fact that these alpacas had reached their genetic potential is that the alpacas in our experiment all increased their fibre diameter from the start to the end of the experiment, when they should have been reducing their fibre diameter over the seasonal change from summer to autumn (Wuliji *et al.*, 2000). This may indicate that the alpacas in our experiment had reached their potential for fibre growth and could not respond to the supplemental methionine.

Prior to the start of the experiment the animals were kept on pasture and then were fed a diet of dry feed for two weeks before the start of the experiment. The improved nutrition from the pasture to the dry feed diet to the maintenance diet may have contributed to the increase in fibre diameter, as found by Marshall (1981) where alpacas fed on lucerne compared to alpacas fed on Peruvian native rangelands increased their fibre diameter by an average of 5 μm. Perhaps the maintenance diet that was fed to the alpacas was too nutritious for production of fine fibre, despite the possible limited genetic potential of the animals used.

It has often been commented in the literature that to promote the production of quality wool and optimise the response of protected methionine in sheep, a diet must be fed that results in a balance of other amino acids, particularly lysine (Cottle, 1988). In a review by Reis & Sahlu (1994b) it was concluded that both methionine and lysine are required in the wool follicle to influence the production of quality wool in sheep. Concurrently Sahlu & Fernandez (1992) indicated that for the production of fine mohair in goats a higher lysine to methionine ratio was required, and the percentage of medullated fibres can be decreased (Smuts-Ayers and Sahlu, 1996). Lysine is an essential amino acid meaning that it cannot be synthesised in the animal body and therefore must be ingested from plant products, predominately legumes. Canola meal does not naturally contain high quantities of lysine, in comparison to other legume meals such as soybean meal (Bell *et al.*, 1988), and the light heat treatment of the canola meal as it exits the expeller may decrease the amount of available lysine that the animal can metabolise (Bell *et al.*, 1988; Dakowski *et al.*, 1996). Therefore, if the alpacas in this study had a limited supply of lysine, then supplementing with methionine alone may not increase the production of quality fibre.

In summary, the results from this study indicate that methionine supplementation up to 4.0 g/day did not improve the quantity or quality of fibre produced by the alpacas used in this study. This may be due to the diet passing the methionine saturation point, the animals being of limited genetic potential to respond by increasing their production of finer fibre or the absence of other crucial amino acids required for the production of quality fibre. This research does highlight that canola meal in the diet is an excellent source of methionine and may offer a way to help avoid obesity in alpacas. More research into the relationship between methionine and lysine and/or other amino acids and into seasonal changes in fibre diameter in Australian alpacas is required.

Experiment 4: Does canola meal supplementation increase reproductive capacity in male alpacas?

All the alpacas used in this experiment were still growing during the experiment and gained between 15 and 20 kg live weight over the 12 months.

The addition of canola meal to the maintenance diet of intact alpacas did not affect their live weight or the body condition score over one year (Figures 6 and 7). The alpaca wethers eating the maintenance diet that was supplemented with canola meal were of similar live weight to the intact animals, which was greater than that of the castrated alpacas that were not supplemented with canola meal. Similarly, during the last six months of the experiment the wethers not fed canola meal had a lower body condition score than those in the other three groups. These results suggest that the alpaca wethers that were fed canola meal were able to deposit body mass. However the difference in live weight between the castrates receiving canola meal and those not receiving canola meal was around 10 kg at the end of the experiment and was associated with a large difference in body condition score. This suggests the wethers supplemented with canola meal were depositing fat as well as muscle or internal fat. Not surprisingly, the concentrations of blood glucose were similar between the four groups (Figure 8), a result illustrating the capacity of alpacas to regulate blood glucose levels regardless of their nutritional status (Cebra et al. 2001).

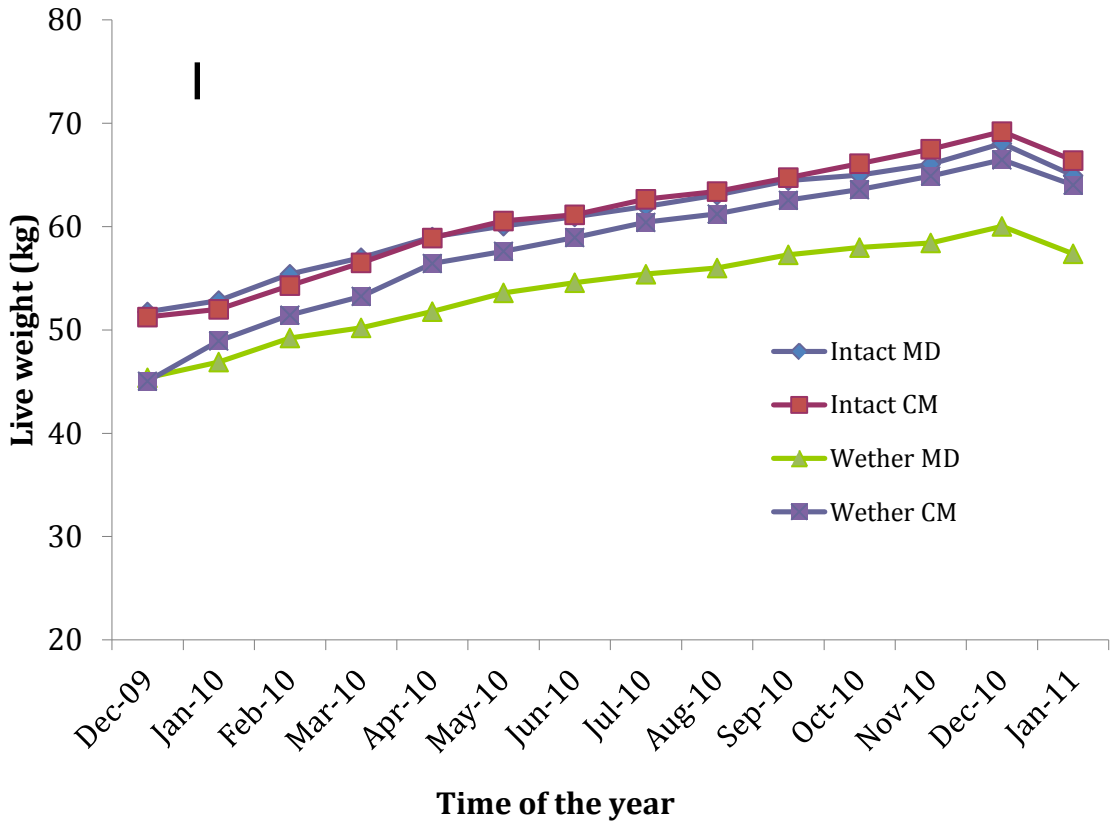

Figure 6: Live weight of castrated (Wether) and intact (Intact) alpacas fed a maintenance diet with (CM) or without (MD) the addition of canola meal. Vertical black bar represents mean SEM.

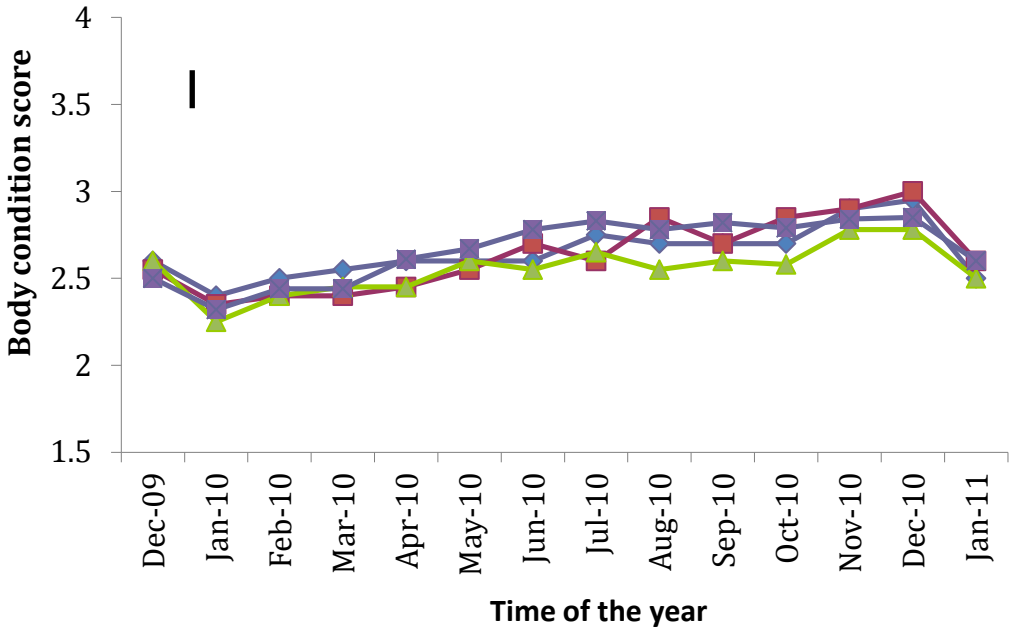

Figure 7: **Body condition score of castrated (Wether) and intact (Intact) alpacas fed a maintenance diet with (CM) or without (MD) the addition of canola meal. Vertical black bar represents mean SEM.**

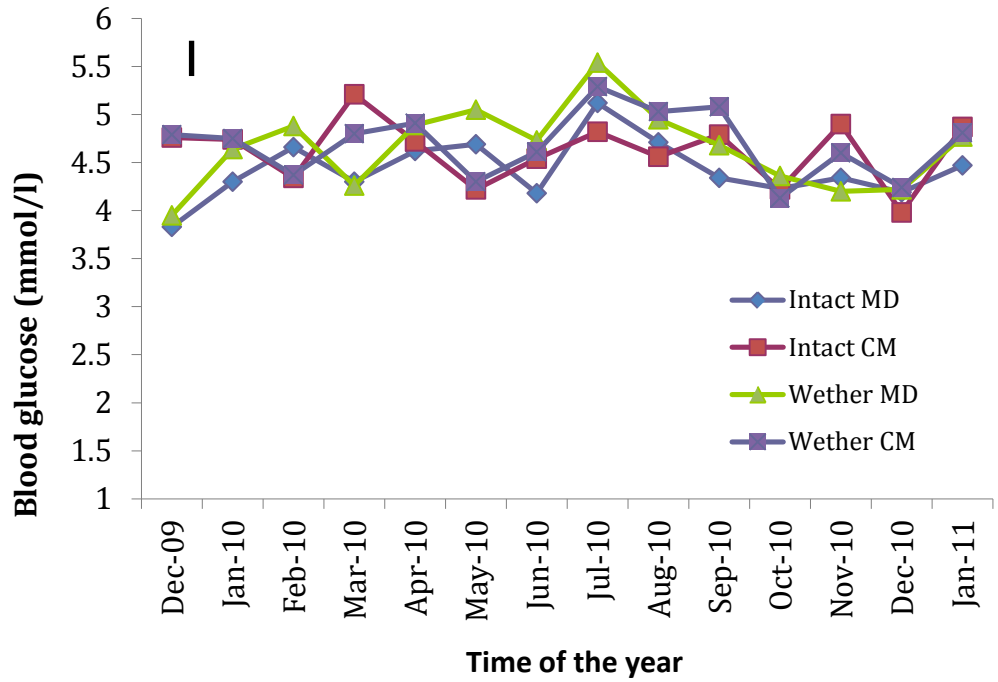

Figure 8: **Concentrations of blood glucose of castrated (Wether) and intact (Intact) alpacas fed a maintenance diet with (CM) or without (MD) the addition of canola meal. Vertical black bar represents mean SEM.**

With the intact mature males, the addition of canola meal to the diet did not affect their libido. During the first 4 months of the trial the animals on the maintenance diet were less sexually active than those receiving the supplement (Figure 9). Although the difference was marginal, it does suggest that the addition of canola meal might have facilitated in some way the expression of sexual behaviour. There was no difference in plasma concentration of testosterone between the experimental groups at the beginning or the end of the experimental period (Figure 10). Total testicular volume was not different between the 2 groups of intact male alpaca during the first 5 months of the experiment (Figure 11) but supplementation with canola increase testicular volume thereafter ($p < 0.05$).

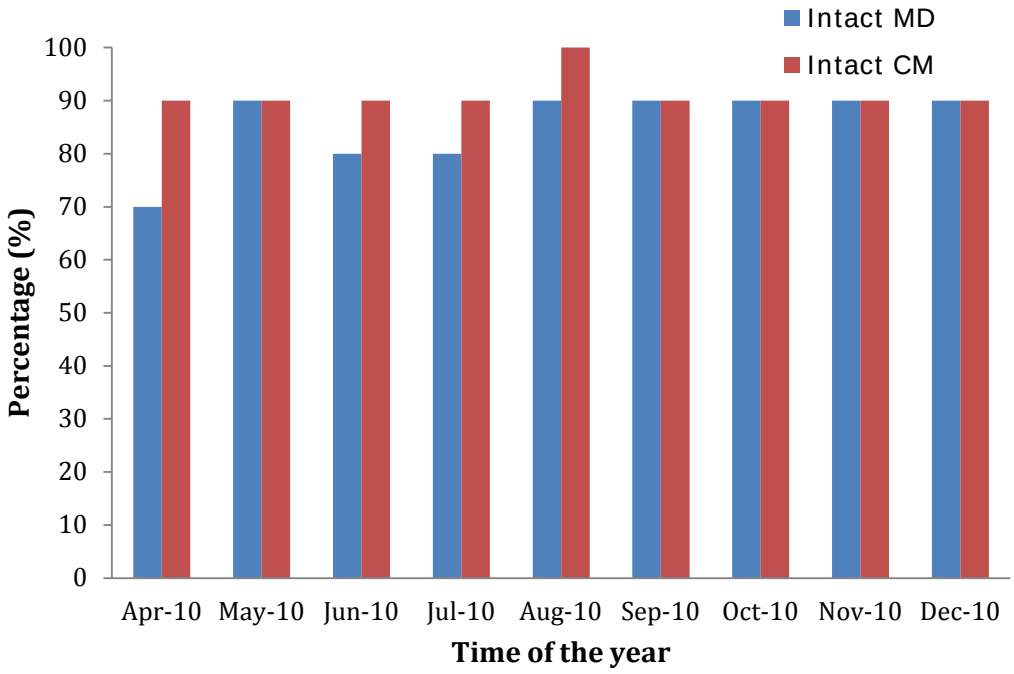

Figure 9: Percentage of adult alpacas fed maintenance diet (blue bar) or maintenance diet with canola meal added (red bar) expressing sexual behaviour when presented with a female.

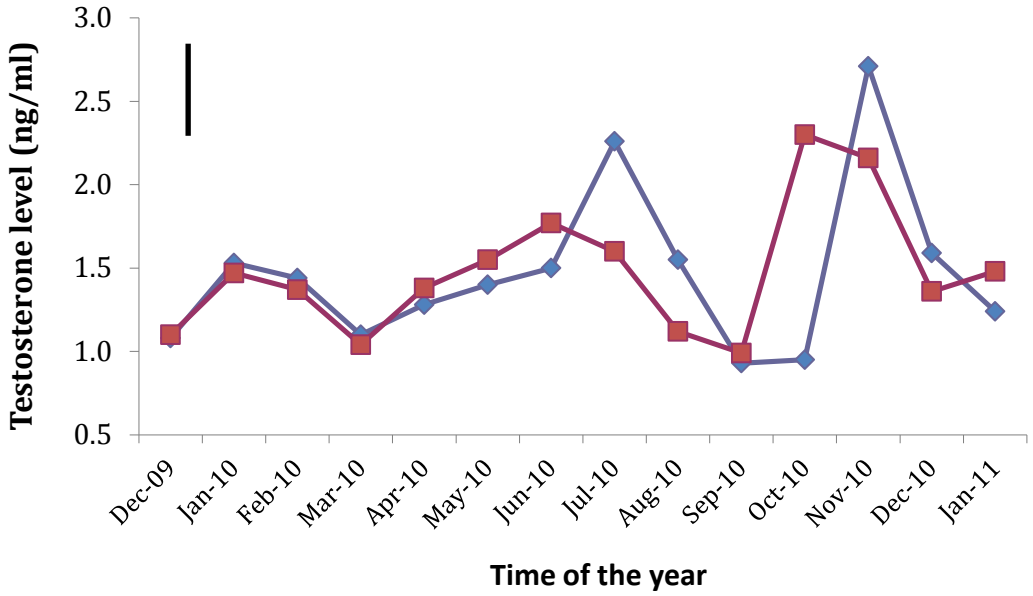

Figure 10: **Plasma concentrations of testosterone for intact alpacas fed a diet with (red line) or without (blue line) the addition of canola meal over a 1-year period. Vertical black bar represents mean SEM.**

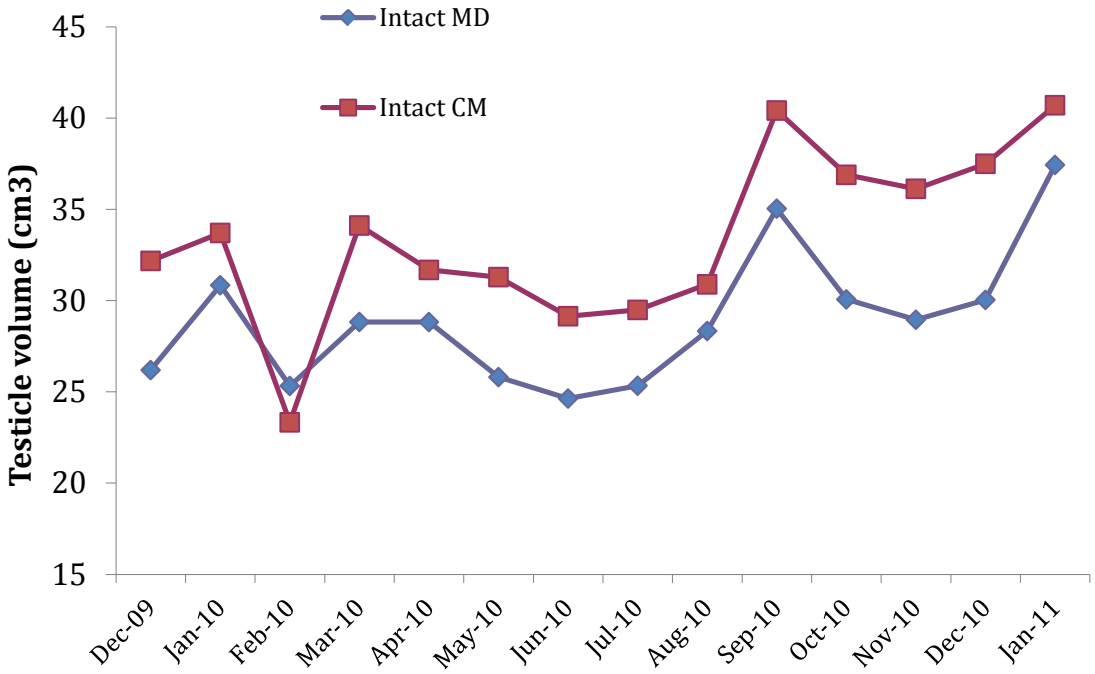

Figure 11: **Total testicular volume for intact alpacas fed a diet with (red line) or without (blue line) the addition of canola meal over a 1-year period. The third measurement was taken on a very cool day, which could partly explain the dramatic drop in testicular volume. Vertical black bar represents mean SEM.**

There was no interaction between steroid presence (castration) and nutrition on any of the fibre characteristics or production. However, fibre production on the saddle, neck and skirting, and total fleece weight (expressed in relation to body size) was higher in alpacas fed canola meal compared to those receiving only the maintenance diet ($p = 0.006$; Table 10). The increase in saddle fleece weight in response to canola was not accompanied by an increase in staple length or an increase in fibre diameter. It should be noted that the fibre diameter and several fibre characteristics (such coefficient of variation, spinning fitness, see Table 10) were higher in the castrated than in the intact animals ($p = 0.001$, Table 10) most likely because the animals were from stud producers who had selected the intact animals for their genetic potential.

In summary, the addition of canola to the diet of intact alpacas presents very little benefit to the reproduction capacity or the fibre production of mature intact male alpacas.

Table 10: Fibre production and fibre characteristics of the saddle in castrated or intact alpacas fed a basal diet with or without the addition of canola meal.

	Wethers		Intact		P value for effect of		
	+ Canola	- Canola	+ Canola	- Canola	Castration	Diet	Castration x Diet
Saddle fleece weight (mg/cm^2)	15.8 ± 4.7	13.5 ±3.5	18.3 ±5.7	13.5 ± 3.6	0.290	0.006	0.320
Neck fleece weight (mg/cm^2)	28.8 ±7.8	27.3 ±5.4	35.2 ±7.4	30.4 ± 8.2	0.828	0.189	0.923
Skirting fleece weight (mg/cm^2)	49.4 ± 20.0	44.0 ±17.5	48.8 ±12.9	42.5 ± 7.8	0.026	0.010	0.203
Total fleece weight (mg/cm^2)	23.5 ±4.6	21.5 ±4.0	27.9 ± 5.2	22.7 ± 4.4	0.314	0.089	0.513
Staple length (mm)	109 ±11	105 ±15	108 ± 11	101 ± 7	0.474	0.150	0.602
Fibre diameter (µm)	22.1 ±3.2	21.8 ±3.3	18.9 ±2.0	19.7 ±1.4	0.001	0.953	0.477
Standard deviation of fibre diameter (µm)	4.6 ±0.7	4.3 ±0.6	4.3 ±0.5	4.2 ±0.4	0.314	0.089	0.513
Coefficient of variation (%)	21.0 ±2.2	19.7 ±1.9	22.7 ±1.9	21.3 ±1.4	0.003	0.011	0.960
Coarse edge (%)	2.7 ±1.4	2.0 ±0.9	2.7 ±1.3	2.3 ±0.8	0.739	0.044	0.660
Spinning fineness (micron)	21.5 ±3.0	20.9 ±3.0	18.9 ±1.9	19.2 ±1.3	0.005	0.655	0.788
Comfort factor (%)	92.2 ±8.5	93.5 ±8.6	97.5 ±2.7	97.6 ±2.0	0.037	0.984	0.701
Fibre curvature (Deg/mm)	43.7 ±6.0	44.3 ±7.9	48.6 ±7.6	47.7 ±5.4	0.037	0.987	0.700
Standard deviation of curvature (Deg/mm)	32.6 ±5.1	33.2 ±6.2	37.5 ±5.8	35.8 ±3.5	0.018	0.901	0.442

Experiment 5: Does canola meal supplementation advance the timing of puberty in male alpacas?

The addition of increasing levels of canola meal to the basal diet of juvenile male alpacas did not affect the onset of puberty, their live weight, or their body condition score at puberty (Table 11, Figures 12 and 13). At time of puberty, testosterone concentrations and testicular volume were not affected by the addition of canola meal to the diet (Table 11, Figure 14). Similarly the proportion of juveniles with completely erupted fighting teeth and the proportion of alpacas expressing items of sexual behaviour were not different between the 4 groups (Table 11, Figures 15 and 16).

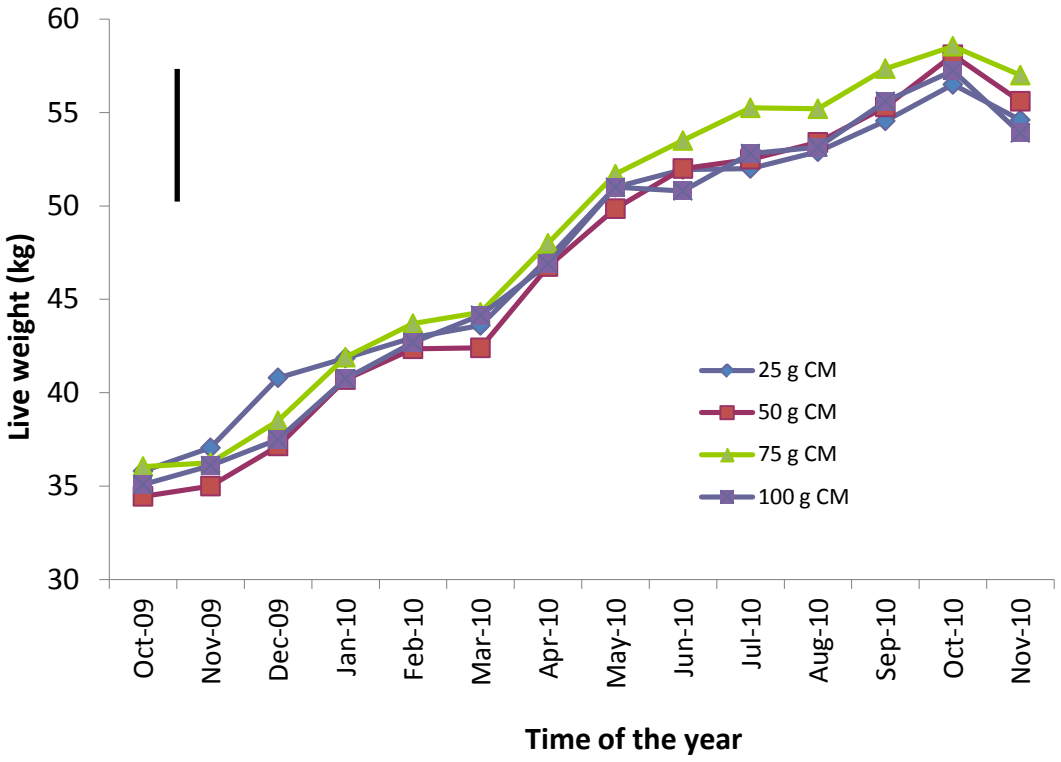

Figure 12: Live weight of juvenile alpacas fed a maintenance diet with different levels of added canola meal. Vertical black bar represents mean SEM.

Table 11: The response to adding different amounts of canola meal to the basal diet of juvenile alpacas (n = 10 per group) on indicators of puberty, live weight and body condition.

	Quantity of canola meal added to the diet (g/head/day)				
	25	50	75	100	P
Initial age (IA; month)	16.7 ± 1.5	16.1 ± 2.9	16.8 ± 2.1	15.9 ± 1.9	0.743
Age at puberty (AP; month)	23.8 ± 1.0	24.1 ± 3.3	24.1 ± 2.6	23.9 ± 3.4	0.989
(IA – AP; month)	6.9 ± 1.9	8.5 ± 1.2	7.4 ± 2.4	8.4 ± 2.1	0.285
Initial live weight (kg)	35.8 ± 7.9	34.5 ± 4.0	36.1 ± 8.4	35.1 ± 5.5	0.950
Live weight at puberty (kg)	50.9 ± 8.2	52.4 ± 3.3	51.9 ± 7.6	53.3 ± 6.6	0.920
Live weight changes (kg)	12.8 ± 6.5	17.8 ± 2.9	13.5 ± 5.1	17.3 ± 5.8	0.170
Initial BCS	2.5 ± 0.4	2.5 ± 0.3	2.3 ± 0.3	2.5 ± 0.2	0.524
At Puberty					
BCS	2.6 ± 0.4	2.7 ± 0.3	2.5 ± 0.3	2.9 ± 0.2	0.171
Right Testis Volume (cm^3)	9.8 ± 3.5	11.7 ± 5.3	11.8 ± 6.6	12.9 ± 5.6	0.642
Left Testis Volume (cm^3)	10.2 ± 3.5	11.8 ± 5.4	12.4 ± 6.4	12.4 ± 5.6	0.771
Fighting teeth					
Erupted	4	3	3	4	NS
In gum	2	3	4	2	NS
None	4	4	3	4	NS
Complete mount	8	8	7	7	NS
Complete penile detachment	8	8	7	7	NS
Intromission	8	8	7	7	NS
Deem pubertal	8	8	8	8	NS

Amongst the parameters used to assess the onset of puberty, several seemed to be more reliable than others. The presence of fighting teeth did not seem to be a good indicator of puberty in alpacas because only 50% of alpacas had erupted fighting teeth by the end of the study while more than 80% were able to mount and effect intromission (Table 11). Plasma concentrations of testosterone, taken at a single time point on a monthly basis, did not provide a reliable measure of sexual maturity as the concentrations of testosterone were not always high in the alpacas expressing sexual behaviour (Figure 15). Similarly testis size was not a reliable indicator of sexual maturity as all the animals showed an increase in testis size regardless of whether they were able to express sexual behaviour and intromission (Table 11). The testes of sexually active alpacas in the experiment was smaller than that reported in previous studies (Galloway 2000).

It has to be noted that testis size tended to increase as the amount of canola meal added to the basal diet increased (Table 11), suggesting that, as in other animal, testes size and therefore probably sperm production, could be influenced by nutritional inputs such as the addition of protein to the diet (Blache et al. 2007).

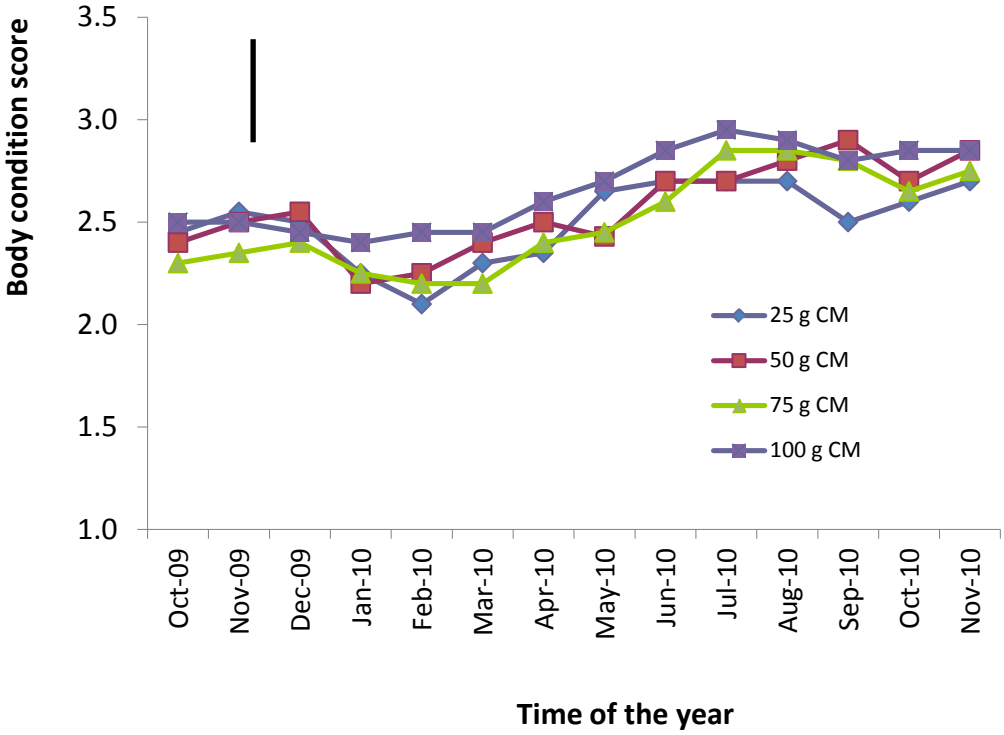

Figure 13: Body condition score of juvenile alpacas fed a maintenance diet with different levels of added canola meal. Vertical black bar represents mean SEM.

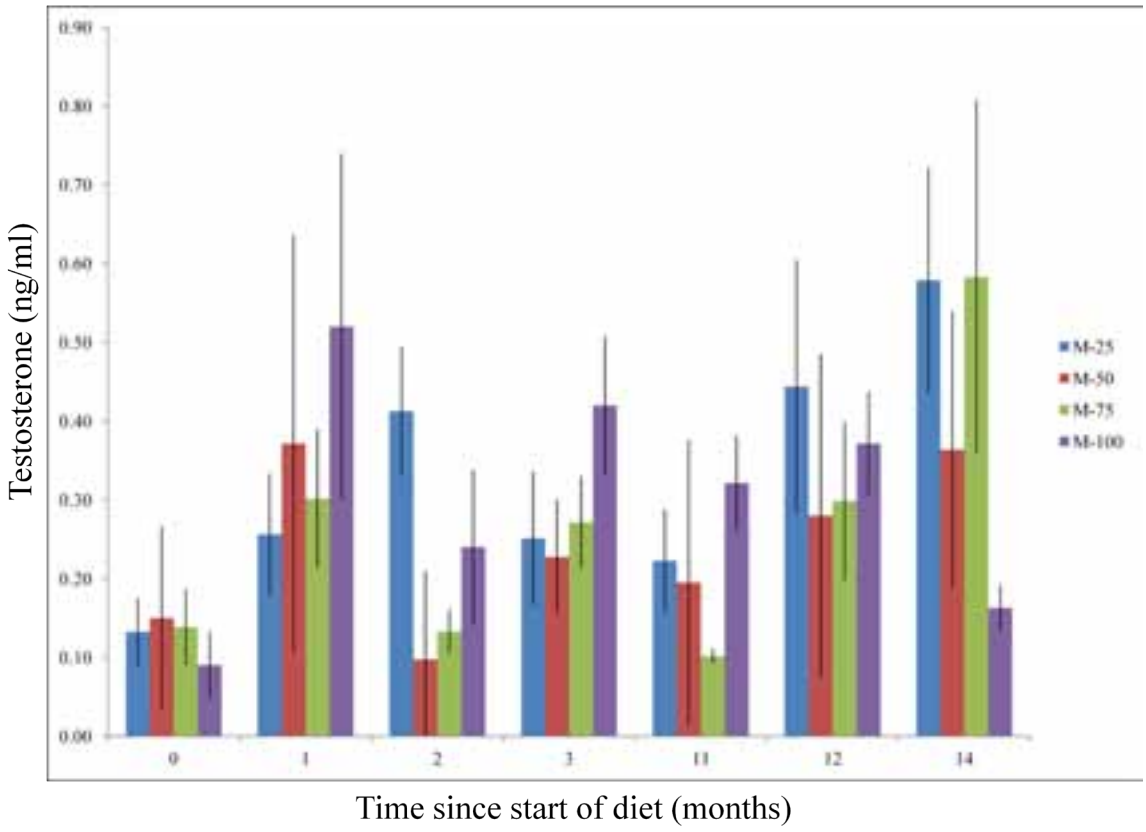

Figure 14: Plasma concentration of testosterone in juvenile alpacas fed a maintenance diet with different levels of added canola meal.

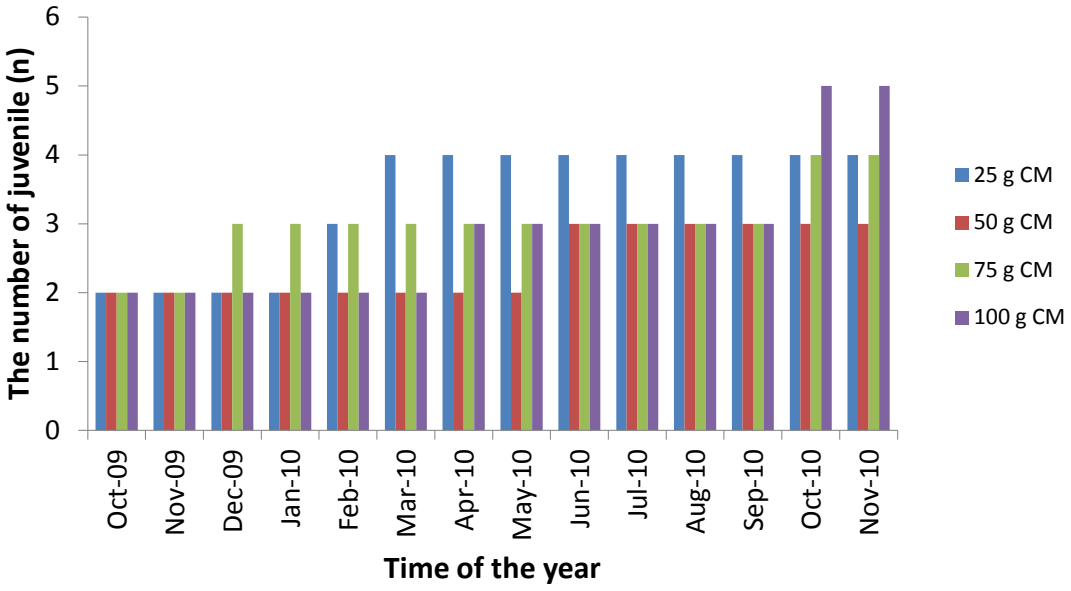

Figure 15: Number of juvenile alpacas with fighting teeth when fed a basal diet with different levels of added canola meal (n = 10 per group).

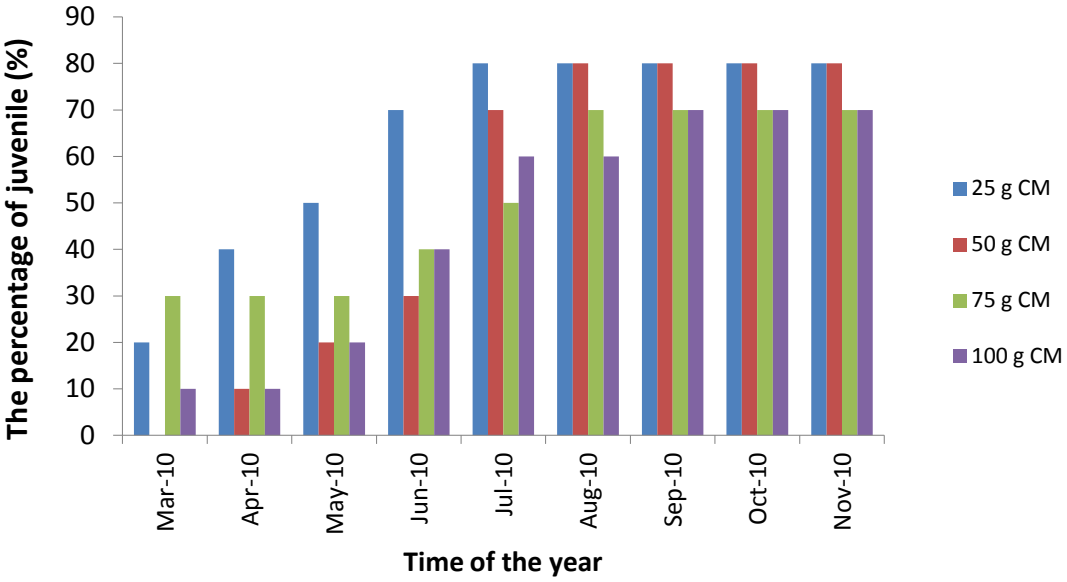

Figure 16: Percentage of juvenile alpacas with complete penile detachment when fed a basal diet with different levels of added canola meal (n = 10 per group).

We did not detect any overall response to the addition of 4 different amounts of canola meal on any of the fibre production or fibre characteristics. However fibre production was higher in the group supplemented with 100 g/head/day compared to the group supplemented with 25 g/head/day (Table 12). The amount of fibre produced was higher both as a gross weight and when calculated per unit of skin area (Table12). The fibre grown on the neck and the skirting were not different between the groups fed 25 and 100 g of canola meal. The fibre characteristics did not differ between the two groups except that the degree of curvature and its variability were lower in the alpacas fed 100 compared with those fed 25 g/day of canola meal (Table 12).

Table 12: The effect of adding canola meal to a basal diet of juvenile alpacas (n = 10 per group) on fibre production and fibre characteristics of the saddle

	Quantity of canola meal added to the diet (g/head/day)				P value	
	25	50	75	100	Overall	25 vs 100
Saddle fleece weight (kg)	0.97± 0.08	1.16 ±0.11	1.21 ±0.11	1.30 ±0.10	0.153	**0.018**
Neck and skirting fleece weight (kg)	1.87 ±0.14	2.17 ±0.16	1.75 ±0.15	2.23 ± 0.17	0.093	0.093
Total fleece weight (kg)	2.84 ±0.18	3.32 ±0.26	2.96 ±0.25	3.54 ±0.22	0.134	0.116
Saddle weight per area (g/cm^2)	13.2 ±1.2	16.1 ±1.6	15.7 ±1.2	18.5 ±1.8	0.123	**0.029**
Neck and skirting weight per area (g/cm^2)	32.1 ±2.5	35.0 ±2.6	28.9 ±2.1	34.3 ±2.8	0.339	0.579
Total fleece weight per area (g/cm^2)	19.8 ±2.0	24.8 ±1.9	21.5 ±1.5	25.9 ±1.9	0.083	**0.039**
Staple length (mm)	108 ±4	118 ±5	115 ±4	114 ±3	0.299	0.231
Fibre diameter (micron)	19.9 ±0.4	20.8 ±0.9	20.9 ±0.7	21.2 ±0.7	0.527	0.087
Standard deviation of fibre diameter (micron)	4.3 ±0.1	4.7 ±0.3	4.4 ±0.2	4.4 ±0.2	0.525	0.710
Coefficient of variation (%)	21.5 ±0.6	22.4 ±0.5	20.9 ±0.6	20.6 ±0.5	0.119	0.293
Coarse edge (%)	2.3 ±0.2	2.8 ±0.5	2.4 ±0.4	2.2 ±0.2	0.708	0.624
Spinning fineness (micron)	19.5 ±0.4	20.5 ±0.9	20.4 ±0.7	20.6 ±0.6	0.696	0.180
Comfort factor (%)	97.6 ±0.4	94.7 ±2.8	95.9 ±1.4	95.9 ±1.1	0.707	0.180
Fibre curvature (Deg/mm)	45.0 ±1.0	39.6 ±2.4	39.4 ±2.7	39.1 ±2.3	0.239	**0.040**
Standard deviation of curvature (Deg/mm)	34.5 ±1.0	31.4 ±1.9	30.5 ±2.0	28.5 ±1.5	0.116	**0.005**

The hypothesis that addition of canola meal to basal diet would advance the onset in puberty in male alpacas was not supported. However, when 100 g/head/day of canola meal was added to the basal diet the production of fibre increased, possibly because of an increase in wool growth as suggested by the numerical difference in staple length (6 mm difference between the groups fed 25 and 100 g/day of canola meal) but there was minimal difference in fibre diameter (0.3 increase in fibre diameter between the groups fed 25 and 100 g/day s). Our results show that the basal diet was balanced enough to support growth, but that the young alpacas offered extra protein were able to channel the extra amino acid towards fibre production. Therefore, it could be recommended to offer some canola meal to pre-pubertal male alpacas to sustain good fibre production. But, as pointed out earlier in this report, the genetic potential of the alpacas would have to be considered carefully so that the extra protein promotes an increase in fibre length without a significant increase in fibre diameter.

Experiment 6: What are the main factors that influence gestation length?

The database was first explored and then a model was fitted to assess the potential factors influencing the length of gestation or mating success.

Exploratory analysis

The data set contained records for 1037 mating at Canchones. There were 703 unsuccessful matings and 334 successful matings.

Exploratory analysis of the data set showed that the gestation length for normal births appeared to be approximately normally distributed with a mean of 340 days and standard deviation of 16 days (Figure 18) which is in agreement with previous studies which have found means of 330-345 days (Bravo et al 1993; Davis et al 1997).

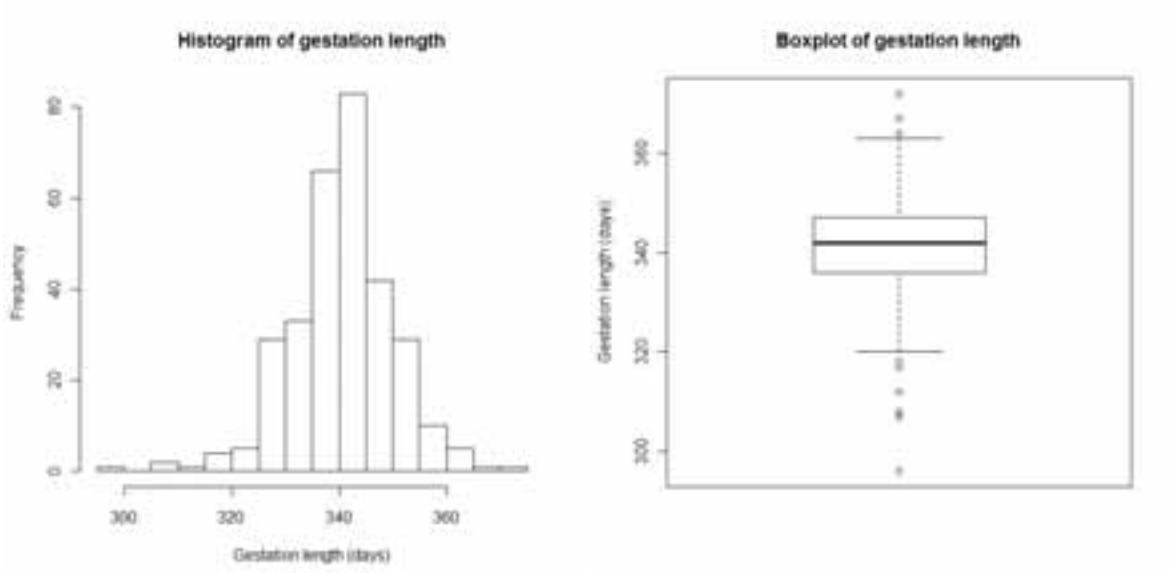

Figure 18. Histogram and boxplot of gestation length

A graph of each variable against gestation length was produced to assess any obvious trends. Month of mating appeared to be the only variable that may be significant (Figure 19).

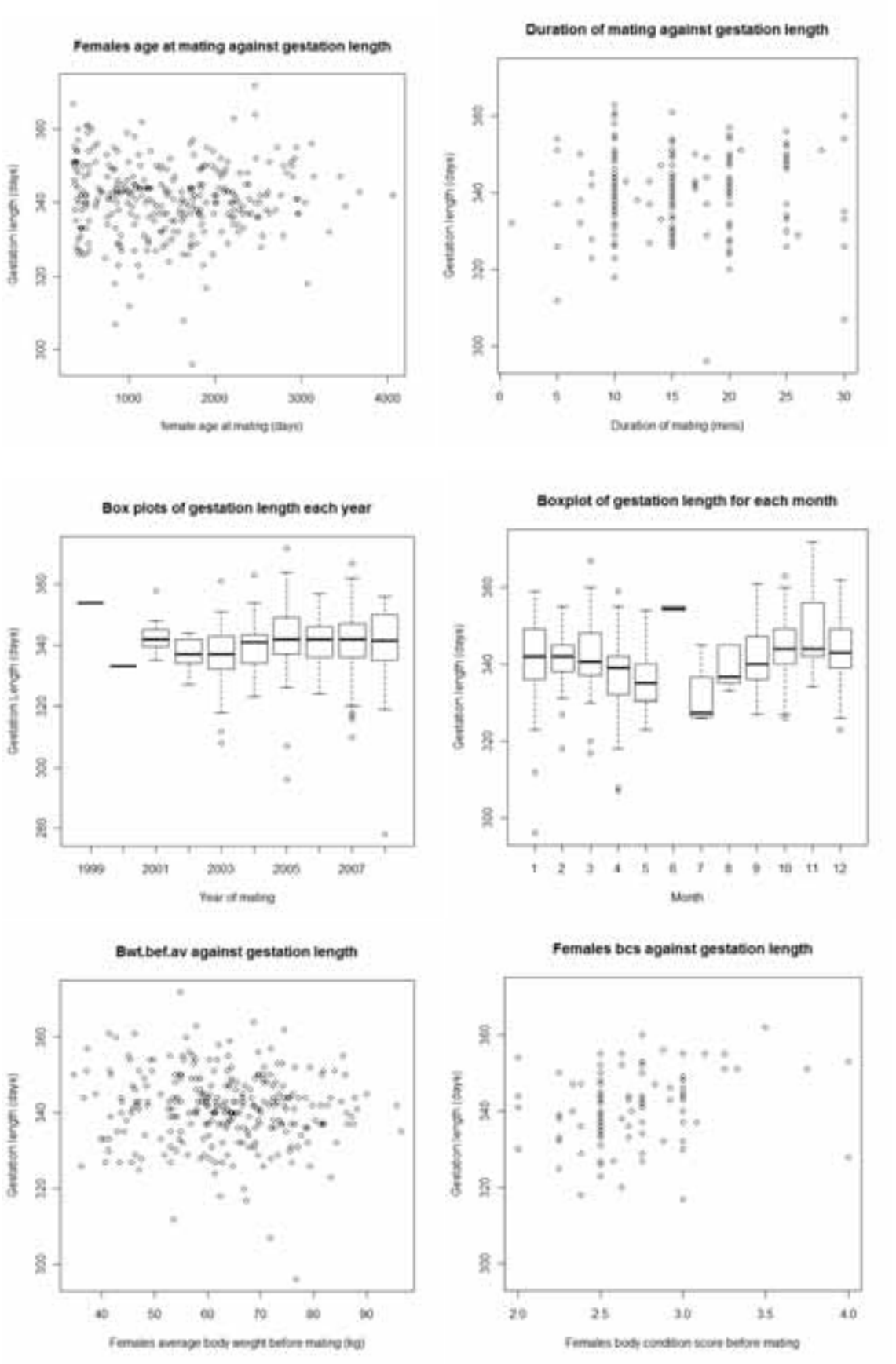

Figure 19. Plots of each independent variable against gestation length

Assessment of factors affecting gestation length

Assessment of the factors affecting gestation length was carried out beginning with the following linear model (n= 209):

$gest = \beta_0 + \beta_1 * fid + \beta_2 * mid + \beta_3 * age + \beta_4 * month + \beta_5 * year + \beta_6 * bwt.bef.av + \beta_7 * bcs.bef + \beta_8 * bwtd1 + \beta_9 * bwtd2 + \beta_{10} * bwtd3 + \beta_{11} * bcsd1 + \beta_{12} * bcsd2 + \beta_{13} * bcsd3$

This model was first fitted with interactions between *fid*, *age*, *month* and *weights* but all interactions were found to be insignificant. Backwards stepwise selection based on AIC was used to reduce the model so that only significant terms remained. The females body condition score before pregnancy was the only variable left after all insignificant terms were dropped.

The best model was as follows:

$$gest = -9413.58 + 0.6075 * month + 4.8562 * year + 8.5365 * bcs.bef$$

Table 13: P values for each coefficient

β_i	P -value
β_4 (coefficient for *month*)	0.02503
β_5 (coefficient for *year*)	0.00436
β_7 (coefficient for *bcs.bef*)	0.00328

From the boxplot of *bcs.bef*, it appeared that the data were not skewed, however there were 3 outliers above the upper quartile. These three outliers corresponded to females with very high body condition scores and from the plot of *bcs.bef* and gestation length it could be seen that these three females had longer gestation lengths than average. These three points had very high leverage (Figure 20).

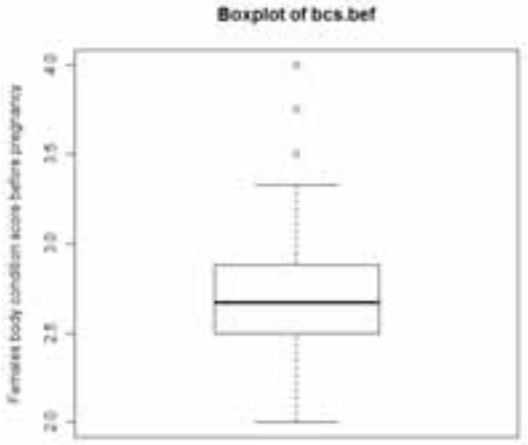

Figure 20: Boxplot of the females body condition score before mating

When the stepwise AIC was conducted again without these three points the final model didn't change, however the p-value for β_7 became 0.02129. The R^2 value was 0.05881 which indicates that bcs.bef explains only 5% of the variation in gestation length. For every 1 point increase in BCS gestation length increased by 8 days.

There was no linear relationship between gestation length and month of mating (Figure 19). Other studies have found that the season when the mating occurs has an effect on gestation length. Gestation length was 13 days longer for spring than autumn matings (Davis et al 1997). The results for this study were divided into seasons to assess if this variable may be more useful than *month* in predicting

gestation length. We created the variables ‘spring’ and ‘autumn’ and performed a t-test on the results between spring and autumn matings (Figure 31). The mean for autumn mating was 335.8 days and the mean for spring mating was 343.6 days. It was found that there was a significant difference between the mean gestation length for these seasons ($p < 0.05$).

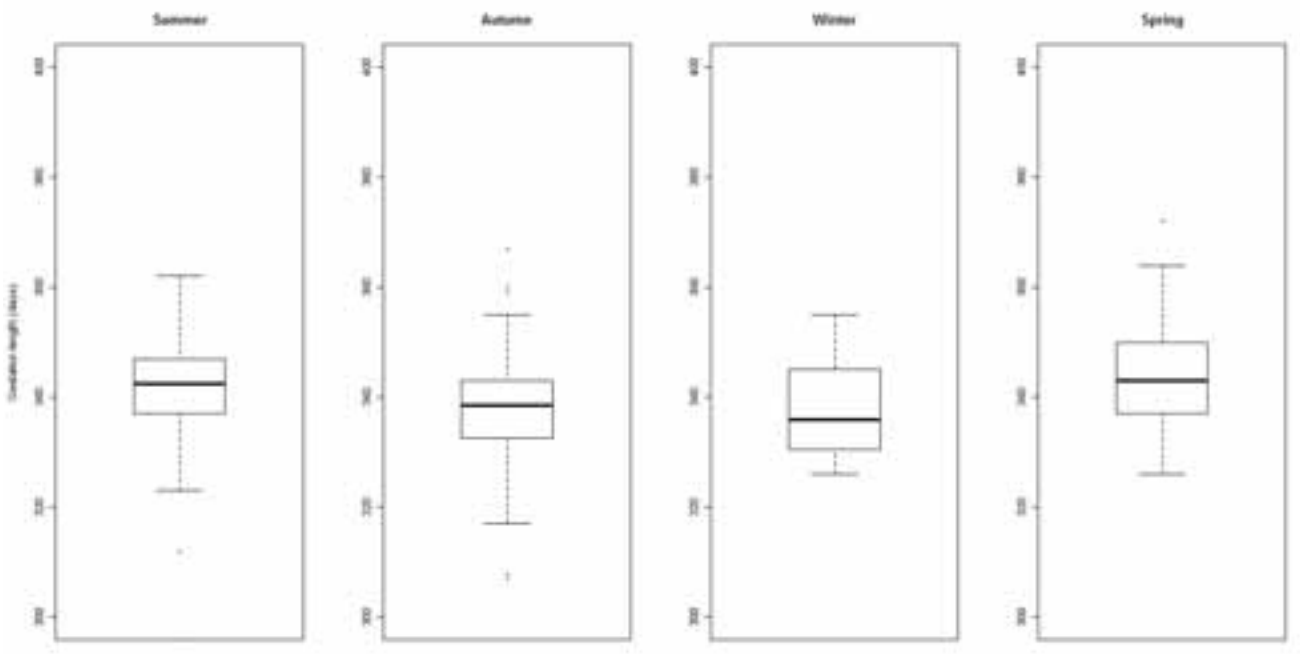

Figure 21: Boxplot of gestation length for each season

There was no linear relationship between gestation length and year as the linear model suggested (Figure 19). Gestation length appeared shorter in the early years of the study and longer in later years. Without knowing the conditions on the farm in these years it is difficult to account for this apparent difference.

Assessment of factors affecting the success of matings

Logistic regression was used to determine if any factors influenced whether a mating was successful (n=1038). An unsuccessful mating was designated 0 and a successful mating was designated 1. The regression was carried out using the formula:

$$P(x) = \frac{\exp(\beta_0 + \beta x_i)}{1 + \exp(\beta_0 + \beta x_i)}$$

To test if a factor was significant we assessed whether β for that factor was equal to zero using the following hypotheses:

$H_0 : \beta = 0$

$H_1 : \beta \neq 0$

Duration of mating, females *age* at mating, *month* and *year* of mating and *bwt.bef.av* and *bcs.bef* before mating were included in the original model. Interaction between *fid*, *age*, *month*, *year*, *bwt.bef.av* and *bcs.bef* were included but all were found to be insignificant and were removed from the model. The model was then reduced until only significant factors remained. The only factor remaining was *bwt.bef.av*, the females average body weight for the 3 months before mating. The estimate for β was 0.014 with a p-value of 0.012. and while significant, there was not a large difference in the body weight of females that had unsuccessful mating compared to those that had successful matings (Figure 22). The females that had successful matings had an average live weight of 62.7 kg while those with unsuccessful mating had an average live weight of 60.3kg.

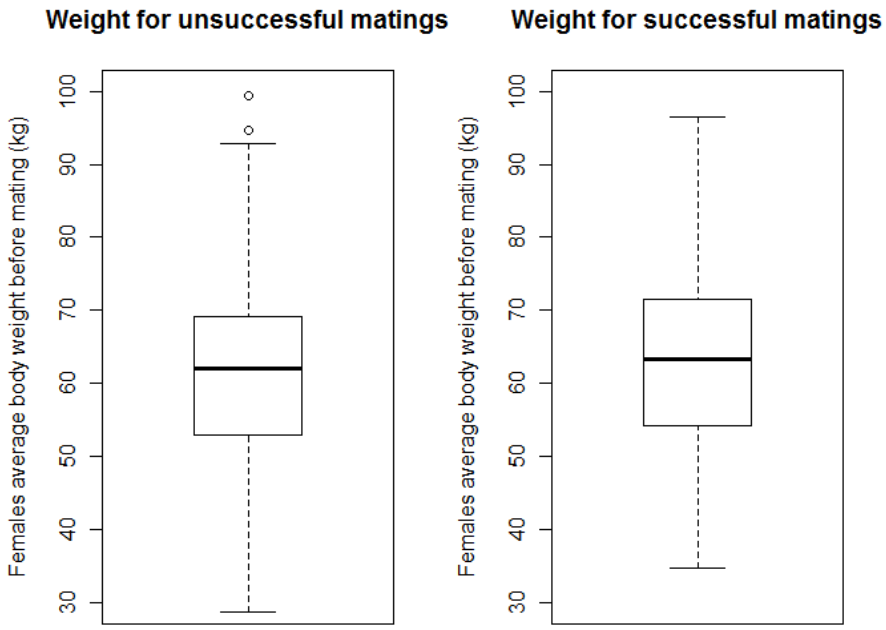

Figure 22: Box plots for the average body weight of females in the 3 months before mating for unsuccessful and successful mating.

The variable 'year of mating' was not a significant factor in determining whether a mating was successful, however some unusual trends were observed with this variable. For most years there were around twice as many failures as successes (Figure 23). However, in 2007, there was exactly the same number of successful and unsuccessful matings. Due to high level of barrenness and high embryonic loss, the chance of this occurring is very low and may indicate these records were not accurate. Only 35 of the births in 2009 were on record and all of these were failures. The recording of data ceased in February 2009, which could account for the low number of matings recorded in 2009.

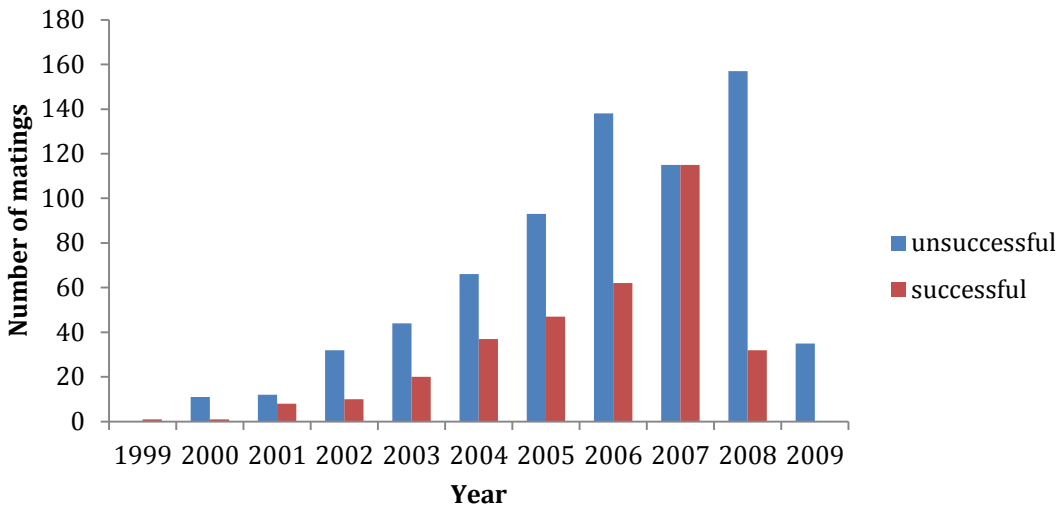

Figure 23: Number of unsuccessful and successful matings each year

The analysis indicates that the average weight of females with unsuccessful matings was lower than those with successful mating, with the cut-off appearing to be around 61 kg. The records were divided into two groups, one below 61 kg and one above 61 kg. The percentage successes were 28.8% and 32.3% respectively for females below and above 61 kg (Figure 24).

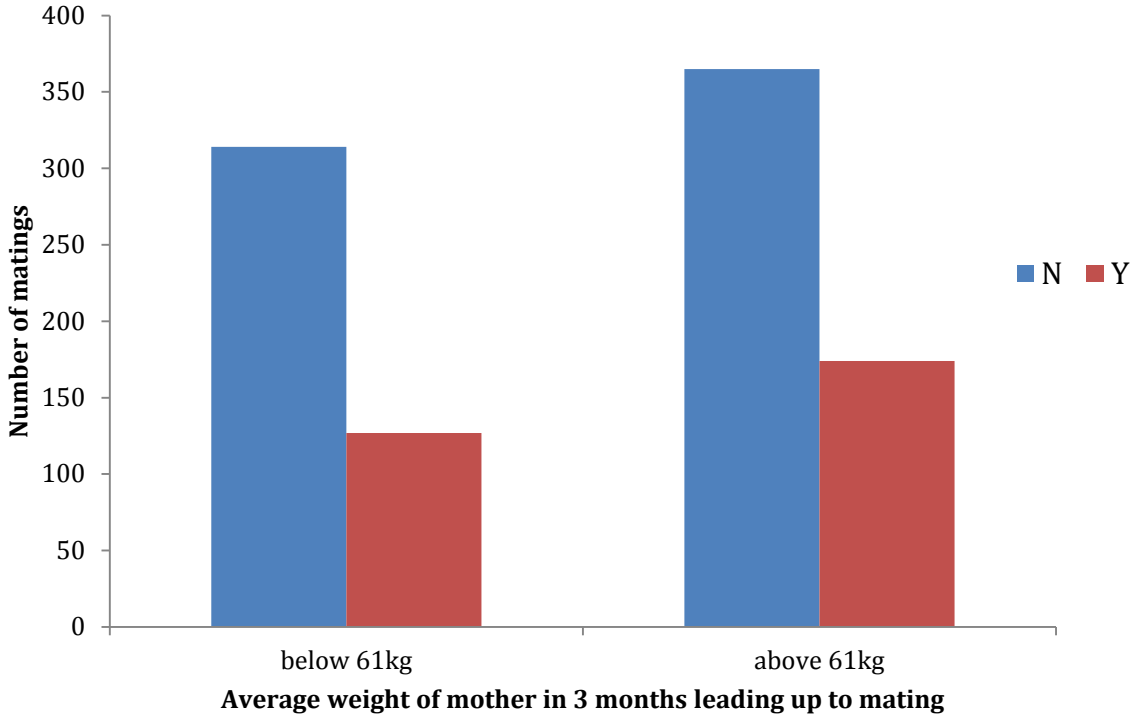

Figure 24: Number of successful (red, Y) and unsuccessful (blue, N) mating for females above and below 61 kg.

To better understand how female body weight before mating influenced success at a mating, the records were divided into seven categories of 10 kg from a 30-40 kg category up to a 90-100 kg

category (Figure 25). There was a general increase in the percentage of successful matings as the body weight of the female increased.

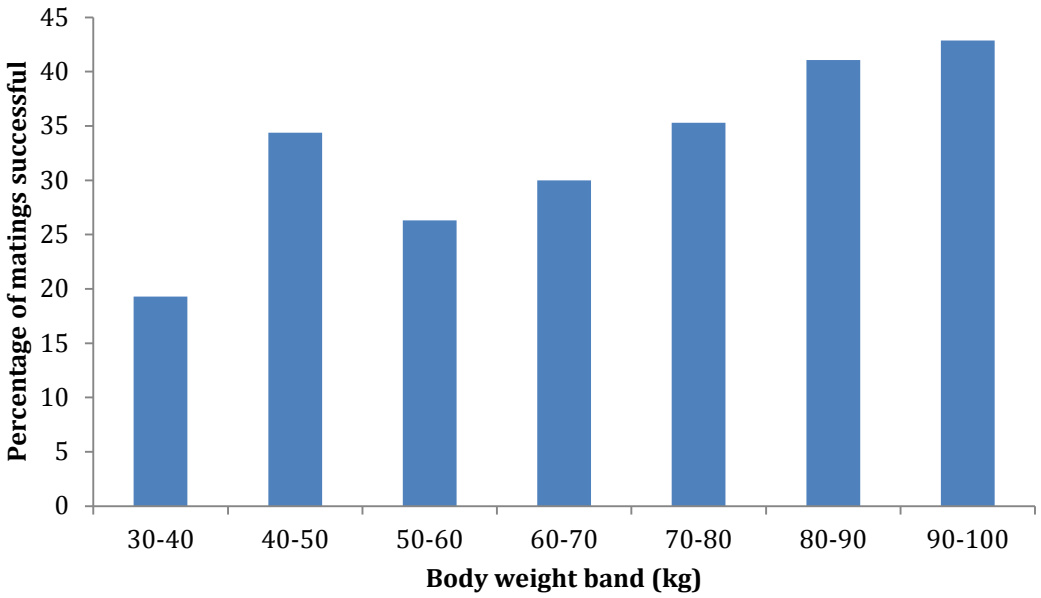

Figure 25: Percentage of successful matings for each body weight category

There were very few matings in the highest weight categories (Figure 6.9), and no records for females over 100 kg, which may be a reason for why the curve did not plateau.

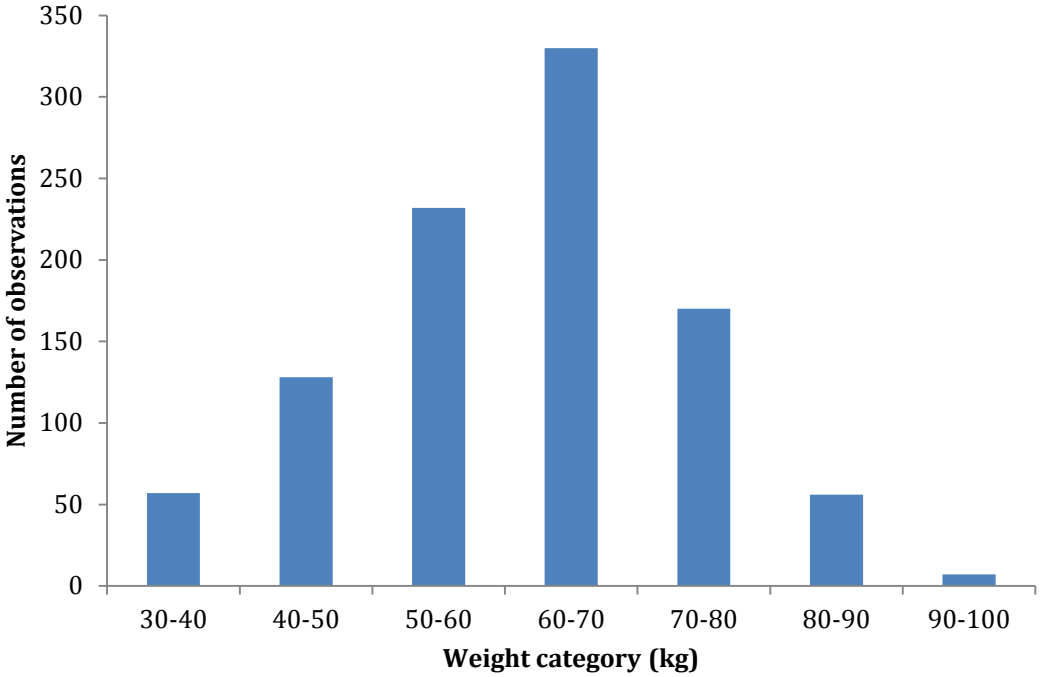

Figure 26: Number of alpacas in each weight category

Once a pregnancy progressed, it generally resulted in a normal birth. The only variable that appeared to display any obvious pattern was the month of mating. Most months had similar numbers of abnormal births except for January, where abnormal births appeared to be slightly higher (Table 14). Without further information it was not possible to say why this occurred. There was also a high percentage of abnormal births in August, but as there was only a few records for this month.

Table 14: Number of normal births, Dystocia, premature and stillborn births each month

Month	Normal Birth	Dystocia	Premature	Stillborn	% Non-normal
1	42	4	1	2	14
2	23	1	1	0	8
3	24	2	0	0	8
4	26	0	0	1	4
5	16	1	0	1	11
6	2	0	0	0	0
7	2	0	0	0	0
8	5	1	0	0	17
9	29	1	0	1	6
10	20	1	0	1	9
11	14	1	0	0	7
12	35	0	0	0	0

Conclusion

Factors influencing Gestation length

Very few of the factors examined appeared to have a major influence on the gestation length of the alpacas on Canchones farm (Latitude: 37° 19' 60 S, Longitude: 145° 43' 0 E). The only statistically significant factor was the body condition score of the female before pregnancy. There was a trend to suggest that as body condition score increased, so did gestation length. The gestation length only changed a very small amount as body condition score increased so it is not a particularly meaningful result. Most of the variation in gestation length cannot be attributed to any of the factors that were analysed, apart from the very small amount influence of body condition score. There was no significant pattern in gestation length with month of mating. However, when months were grouped into seasons, there was a significant difference of 7.8 days between the gestation lengths of spring verses autumn matings. Previous studies have found that the gestation length from spring matings is on average 13 days longer than that of autumn matings (Davis et al 1997). Although there was a difference in gestation length between seasons it was not as long as previous literature would suggest it could be. This may be because the alpacas at Canchones are kept in carefully regulated nutritional conditions throughout the year, so that the weather changes between seasons may have less of an effect. Moreover, at Canchones latitude, the amplitude of the daylength between seasons is relatively small (from 10 to 14 hours of darkness) and might not have been sufficient to induce seasonal variation in gestation length.

Gestation length was found to differ depending on year of mating. Longer gestation lengths were observed in the later years of the study, however the relationship between gestation length and year is clearly not linear. It would be reasonable to suggest that environmental conditions or changes in conditions on the farm over the years may be responsible for the changes in average gestation length between years. Without further information about differing factors between years it is difficult to speculate why gestation length differed between the years the study encompassed.

Having a different dam (mother) or sire (father) did not appear to influence gestation length The year of mating also did not influence gestation length. The mother’s age was tested for interactions with

month, year, duration of mating and body weight and condition score. No interactions were significant so all interactions were excluded from the model. Previous studies have found that the mother's age at mating did not influence gestation length (Davis et al 1997). This is consistent with the results of our study, where age was not a significant factor contributing to variation in gestation length. The duration of mating was not expected to be significant and the results supported this. The mothers average live weight leading up to the mating was also not significant. This is a little unexpected because numerous studies have found that the live weight is an important factor in determining whether pregnancy occurs and the health of the cria. It is possible that body weight before mating did not show significant effects on gestation length because there was little variation in the body weight of the females in our study. Females are sexually receptive and able to conceive at any time of the year (Sumar 1996). This was found to be true, with matings being recorded every month of the year. There was no difference in mating success between months or years. Twin births in alpacas are extremely rare (Davis et al 1997, Sumar 1996). There were no documented twin births, successful or unsuccessful, in this study.

Factors affecting mating success

Previous studies have found that 20% of females do not conceive following mating and embryonic loss is around 50% in the first month (Brown 2000). In view of this, the finding that there were over twice as many unsuccessful matings compared to successful matings is probably predictable. Studies have found that there is a relationship between the female's body weight at mating and the success or failure of a mating (Brown 2000). In Brown's study, the body weight of the female before mating was significant in determining whether a mating was successful. The females with successful pregnancies were on average 2.3 kg heavier in the 3 months leading up to mating than those with unsuccessful mating. Although we observed a general increase in successful matings as the female's body weight increased, logically this curve should level off and possibly even decrease. It was not possible to tell at what weight the successful matings would begin to decrease, but one theory is that if there were more alpacas in the +90 kg division included in the study, a decrease in mating success may have been detected. It is reported that a female alpaca needs to reach at least 33 kg live weight before she can conceive (Sumar 1996; Brown 2000). A number of records in this study were from females below this weight and they were all unsuccessful.

It was expected that the females' age at mating would be a significant factor because an animal can only conceive after they reach sexual maturity and an old animal could be expected to be less fit to carry offspring than a younger female. The age of the female at mating was not significant in determining whether a mating was successful. Female alpacas reach puberty at around 1 year old (Brown 2000). There were only a couple of females below this age in the study and they were not mated successfully. However being few in number they possibly did not influence the results. There were a few females above 10 year of age, and none of these had a successful mating. This is to be expected and it is possible that if there were more old females in the data set, age may become a significant factor in determining whether a mating results in a successful pregnancy.

To summarise, the only factors that significantly influenced gestation length were the female's body condition score before mating, year of mating and the season of mating. These results are consistent with the findings of previous studies in both Peru and New Zealand. The only factor that influenced whether mating was successful was the female's average live weight in the three months prior to mating. Females with a higher body weight tended to have more successful matings than those of lower live weight. This result is supported by previous studies in Peru.

Implications

We have shown that the maintenance requirements of wether alpacas used in our studies is about 5.0 MJ ME/day, which is about 20% less than published estimates of the energy requirement for maintenance of alpacas. Our basal diet and the inclusion of a source of protein containing degradable and un-degradable dietary protein with good levels of sulphur amino acids can sustain fibre growth and potential sperm production in growing alpacas. We have also obtained data suggesting that alpacas are better able to use protein than a glucose precursor to deposit muscle tissue. We have shown that the inclusion of methionine does not improve fibre production in alpacas. Our proposed diet should be fairly easily adapted for feeding to pregnant and lactating females, by applying similar increasing increments of maintenance as used for single-bearing ewes.

In summary, producers and alpaca feed manufacturers should design diets based on feedstuffs similar to those used in this study - with modest levels of fermentable carbohydrate and not too high in protein, but with some of the protein as UDP with good levels of sulphur amino acids. It is estimated that such diets could reduce the cost to hand-feed alpacas by as much as 30%, especially where expensive and inappropriate supplements are currently being fed.

Recommendations

Our findings have been and are being submitted for publication in national and international journals and will be presented at ruminant and camelid conferences in Australia and overseas. A fact sheet summarising our main results could also be distributed to alpaca producers. However, the most effective way to disseminate our results will be through adoption by key producers. The links we have made with the industry through this project will help achieve that objective.

Funding for research to further our understanding of the metabolic regulation and preferential use of amino acids over glucose precursors would benefit the industry because it may then be possible to use other feedstuffs to further reduce the cost of feeding alpacas.

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Feeding Alpacas to Enhance Reproduction and Fleece Quality

by D. Blache, J Vaughan, S.K Maloney and J.T.B. Milton

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The quality and quantity of alpaca fibre is affected by not only the body condition and nutrition of the animal but also by season and sex hormones. These factors can interact with the genetic potential of each animal to such an extent that they can mask the true genetic value of an animal.

This report provides scientific data that can be used by producers, consultants to the industry, and feed manufacturers to design more appropriate diets and feeding strategies that will allow the industry to make genetic progress because these management procedures will decrease the impact of nutritional and environmental factors on the expression of the animal's genetic potential for fibre production.

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