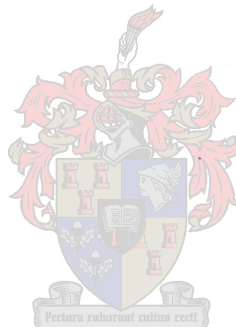
THE EFFECT OF RUMEN INERT FAT SUPPLEMENTATION AND PROTEIN DEGRADABILITY IN STARTER AND FINISHING DIETS ON VEAL CALF PERFORMANCE AND THE FATTY ACID COMPOSITION OF THE MEAT.

by

ELNA LATEGAN

THESIS PRESENTED FOR THE DEGREE OF MASTERS (AGRICULTURAL SCIENCE) AT THE UNIVERSITY OF STELLENBOSCH



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DECLARATION

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

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ABSTRACT

THE EFFECT OF RUMEN INERT FAT SUPPLEMENTATION AND PROTEIN DEGRADABILITY IN STARTER AND FINISHING DIETS ON VEAL CALF PERFORMANCE AND THE FATTY ACID COMPOSITION OF THE MEAT.

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Six groups each with six Friesian bull calves were used in this investigation and slaughtered at 20 weeks of age. Calves received a low- (LD) or high (HD) degradable protein diet, each with or without rumen inert fat supplementation. Two commercial fat sources were used, Morlac (m) and Golden Flake (gf), included at 2.5% of the diet. A commercial milk replacer (Denkavit) was fed at 4L for 42 days, followed by 2L until weaning at 49 days of age. The starter diets were fed *ad lib.* from day 14 to 10 weeks of age and finishing diets *ad lib.* from 11 to 20 weeks of age. There were no significant differences in body mass gain or dry matter intake over the entire 20 week period. The feed conversion ratio (FCR) was improved significantly (P=0.0032) when fat was supplemented to LD, but not to HD diets. The FCR (kg dry matter/ kg gain) of LD, HD, LDm, HDm, LDgf and HDgf diets were 3.45, 3.44, 3.07, 3.81, 3.02 and 3.43, respectively. All 36 calves were used in a digestibility trial, using chromium oxide (Cr_2O_3) as a marker, during week 18 of the investigation. Digestibility values (%) for the six diets (LD, HD, LDm, HDm, LDgf and HDgf) were 61.74, 65.91, 75.44, 69.00, 75.54 and 67.15 for dry matter, 61.44, 61.60, 71.33, 68.23, 75.44 and 66.12 for crude protein and 58.56, 66.45, 75.98, 70.92, 78.43 and 70.79 for fat, respectively. The dry matter (P=0.0001) and fat (P=0.0001) digestibilities were only significantly higher when fat was

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added to LD diets. The crude protein (CP) digestibilities were significantly higher when fat was added to either the LD (P=0.0001) or the HD (P=0.0488) diets.

All the calves were slaughtered at 20 weeks of age and the fatty acid content of the meat (*m. longissimus*) and subcutaneous fat layer adjacent to the 12th rib as well as the meat colour, was determined. The fatty acid composition of the longissimus muscle was changed by feeding the rumen inert fat sources. The three predominant fatty acids found were palmitic, stearic and oleic acids. The palmitic acid (C16:0) content of the muscle and diet was 24.44 & 20.47, 25.97 & 22.57, 31.06 & 33.23, 30.98 & 37.91, 34.94 & 31.77 and 29.71 & 32.88 of the total fat for the LD, HD, LDm, HDm, LDgf and HDgf diets, respectively. The C16:0 content was significantly higher in the muscle of the calves receiving the LD diets supplemented with fat (P=0.0008). There was also a significant interaction between the two fat sources and protein degradability (P=0.0065), but only in the LD diets. The stearic acid (C18:0) content of the muscle and diet was 14.35 & 5.22, 19.65 & 8.61, 17.29 & 4.68, 22.59 & 5.78, 22.27 & 15.54, and 26.48 & 20.15 of the total fat for the LD, HD, LDm, HDm, LDgf and HDgf diets, respectively. The C18:0 content was significantly higher in the muscle of calves receiving the HD (P=0.0001) compared to LD diets. The stearic acid content was also significantly higher when fat was added to LD (P=0.0042) or HD (P=0.0073) diets. The oleic acid (C18:1) content of the muscle and diet was 36.06 & 21.51, 39.99 & 21.11, 32.21 & 23.67, 29.13 & 24.59, 25.23 & 18.68 and 35.93 & 16.02 of the total fat for the LD, HD, LDm, HDm, LDgf and HDgf diets, respectively. The linolenic acid (C18:3) content of the muscle was significantly higher (P=0.0038) when fat was added to LD diets compared to no fat supplementation (0.87 vs. 0.15). The CIELAB values indicated that LD diets resulted in more pink meat. Mean values of L* = 32.61, 34.19; a* = 7.08, 7.91 and b* = 3.18 and 4.07 were observed for the LD and HD diets, respectively. Meat from the LD diets had significantly lower L*-(P=0.0252), a*-(P=0.0283) and b*-(P=0.0109) values compared to meat from the HD diets. It was concluded that there was a positive response in CP digestibility when rumen inert fats were supplemented to LD or HD diets, although a greater response was shown in the LD diets. The FCR, dry matter and fat digestibility were only increased when fat was added to the LD and not to the HD diets. Similarly, the fatty acid contents of the longissimus muscle of veal calves can be manipulated with the supplementation of rumen inert fat sources, but only when combined with a low protein degradable diet. The low degradable protein diets also produce a more attractive meat colour for the potential veal consumer.

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SAMEVATTING

DIE EFFEK VAN RUMENINERTE VETSUPPLEMENTERING EN PROTEÏEN DEGRADEERBAARHEID IN KALF-AANVANGS EN -GROEIDIEËTE OP DIE GROEI VAN KALWERS EN DIE VETSUURSAMESTELLING VAN DIE VLEIS.

deur

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Ses behandelings, lae- (LD) of hoë (HD) degradeerbare diëte, elk met of sonder rumeninerte vetsupplementering, is geëvalueer met ses kalwers in elke groep. Twee kommersiële vetbronne is gebruik, nl. Morlac (m) en Golden Flake (gf) teen 'n 2.5% insluitingspeil. 'n Kommersiële melksurrogaat (Denkavit) is aangebied teen 4L/dag tot 42 dae ouderdom, gevolg deur 2L/dag tot speenouderdom op 49 dae. Aanvangsdiëte is *ad lib.* aangebied vanaf 14 dae tot 10 weke ouderdom en die groeidiëte *ad lib.* vanaf week 11 tot 20. Daar was geen betekenisvolle verskille in die totale massatoename of die droëmateriaalinname nie. Die voeromsettingsverhouding is betekenisvol verbeter (P=0.0032) in die behandelings waarin rumeninerte vette by LD diëte ingesluit is, maar nie by die HD diëte nie. Die voeromsettingsverhouding (kg droëmateriaalinname / kg massatoename) van die LD, HD, LDm, HDm, LDgf en HDgf diëte was 3.45, 3.44, 3.07, 3.81, 3.02 en 3.43, onderskeidelik. Al 36 kalwers is in 'n verteringsproef gebruik gedurende week 18 van die proef. Chroomoksied (Cr_2O_3) is as merker gebruik. Verteerbaarheidswaardes vir die ses diëte was 61.74, 65.91, 75.44, 69.00, 75.54 en 67.15 vir droëmateriaal, 61.44, 61.60, 71.33, 68.23, 75.44 en 66.12 vir ruproteïen en 58.56, 66.45, 75.98, 70.92, 78.43 en 70.79 vir vet, onderskeilik. Die droëmateriaal- (P=0.0001) en vetverteerbaarheid (P=0.0001) was slegs betekenisvol hoër wanneer vet by LD diëte gevoeg is en nie by HD nie. Die ruproteïen (RP) verteerbaarheid

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was betekenisvol hoër (P=0.0002) by LD en HD (P=0.0488) diëte met vet supplementering, teenoor geen vet insluiting.

Die kalwers is op 20 weke ouderdom geslag en die vetsuursamestelling van die vleis (*m. longissimus*) en die subkutane vetlaag teenaan die 12de rib, asook en die vleiskleur, is bepaal. Die vetsuursamestelling van die longissimus spier is deur die supplementering van rumeninerte vet verander. Die drie primêre vetsure wat in die vleis voorgekom het, was palmitiensuur, steariensuur en oleïensuur. Die palmitensuur (C16:0) inhoud van die spier en diëte was 24.44 & 20.47, 25.97 & 22.57, 31.06 & 33.23, 30.98 & 37.91, 34.94 & 31.77 en 29.71 & 32.88 van die totale vet van die LD, HD, LDm, HDm, LDgf en HDgf diëte, onderskeilik. Die C16:0 was betekinisvol hoër in die spiere van kalwers wat die LD diëte met vet supplementering (P=0.0008) ontvang het. Die steariensuur (C18:0) inhoud van die spier en diëte was 14.35 & 5.22, 19.65 & 8.61, 17.29 & 4.68, 22.59 & 5.78, 22.27 & 15.54, en 26.48 & 20.15 van die totale vet vir die LD, HD, LDm, HDm, LDgf en HDgf diëte, onderskeidelik. Die C18:0 inhoud was betekinisvol hoër in die spiere van die kalwers wat die HD (P=0.0001), teenoor LD diëte ontvang het. Die steariensuur inhoud was ook betekenisvol hoër wanneer vet by LD (P=0.0042) of HD (P=0.0031) diëte gevoeg word. Die oleïensuur (C18:1) inhoud van die spier en diëte was 36.06 & 21.51, 39.99 & 21.11, 32.21 & 23.67, 29.13 & 24.59, 25.23 & 18.68 en 35.93 & 16.02 van die totale vet vir die LD, HD, LDm, HDm, LDgf en HDgf diëte, onderskeidelik. Die linoleensuur (C18:3) inhoud van die spier was betekinisvol hoër (P=0.0038) in die LD diëte met vet teenoor LD met geen vet supplementering (0.87 vs. 0.15). Die CIELAB waardes van die LD diëte dui op 'n pienker vleiskleur. Gemiddelde waardes van L* = 32.61 & 34.19, a* = 7.08 & 7.91 en b* = 3.18 & 4.07 is vir die LD en HD diëte, onderskeidelik, waargeneem. Die vleis van die LD diëte het 'n betekenisvol laer L*-(P=0.0252), a*-(P=0.0283) en b*-(P=0.0109) waarde in vergelyking met die HD diëte getoon. Die resultate dui daarop dat daar 'n positiewe respons in die ruproteïenverteerbaarheid by die supplementering van rumeninerte vette by LD en HD diëte voorkom, maar die response op die LD diëte is groter. Die voeromsettingsverhouding, droëmateriaal- en vetverteerbaarheid is egter net bevoordeel in die LD met vet en nie in die HD diëte nie. Die vetsuursamestelling van die longissimus spier in die kalf kan gemanipuleer word met die supplementering van rumeninerte vetbronne, maar slegs wanneer dit gekombineer word met lae degradeerbare proteïen diëte. Die lae degradeerbare proteïen diëte produseer ook die mees aanloklike vleiskleur vir die potensiële kalfsvleisverbruiker.

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This thesis is dedicated to my mother Mrs. Maggie Lategan and in memory of my father Dr. Piet Lategan.

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ABBREVIATIONS

ACP	Acyl-carrier protein
ADF	Acid-detergent fibre
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists International
ATP	Adenosine triphosphate
CF	Crude fibre
CP	Crude protein
CoA	Co-enzyme A
Cr_2O_3	Chromium oxide
Df	Degrees of freedom
DM	Dry matter
DMI	Dry matter intake
EE	Ether extract
FCR	Feed conversion ratio
GF	Golden Flake
g	grams
HDP	High degradable protein
HGRSM	High glucosinolate rapeseed meal
kg	kilogram
kJ	kilojoule
K_r	fractional outflow rates
LDP	Low degradable protein
LP	Lipids
LM	Live mass
ME	Metabolizable energy
MEm	Metabolizable energy available for mainenance
MEp	Metabolizable energy available for production
MJ	Megajoules
M	Morlac
MS	Mean square
N	Nitrogen
NAD^+	Nicotinamide adenine dinucleotide

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NADH	Reduced nicotinamide adenine dinucleotide
$NADP^+$	Nicotinamide adenine dinucleotide posphate
NADPH	Reduced nicotinamide adenine dinucleotide posphate
NDF	Neutral-detergent fibre
NFE	Nitrogen-free extractives
NPN	Non protein nitrogen
NRC	National research council
OM	Organic matter
PGE	Pregastric esterase
p	probability
RDP	Rumen degradable protein
SAS	Statistical analysis system
S.E.M.	Standard error of the means
SBM	Soyabeen Meal
SFM	Sunflower meal
TG	Triglycerides
UDP	Undegradable protein
VFA	Volatile fatty acids

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CHAPTER 1

1 GENERAL INTRODUCTION

Traditionally, in the R.S.A. Friesian bull calves are culled at 2 days of age and many tons of potensial veal goes to waste. Approximately 176 000 Friesian bull calves are born in the R.S.A. annually (Cruywagen, 2000, personal communication). The theoretical potential for veal production in the R.S.A., if the calves are slaughtered at 100 kg carcass mass, would therefore be 17600 tons. Some farmers have realized the economical potential of producing veal.

Although there is a market for pink veal in the R.S.A., it is far from its optimal potential, as the South African consumer traditionally eats beef and not veal. There is a growing public awareness of the potential harmful effects of consuming a diet containing excessive amounts of fat, saturated fat and cholesterol. The consumer desires healthier meat, and veal potentially offers the solution. Veal contains 4g of fat compared to the 8g in lamb and beef and the 9g in pork, when a 85g cooked, trimmed loin steak is compared between the various animals. Saturated fats are mainly in the depot fats and there are less of these in meats with low fat levels. Leaner meats have more polyunsaturated structural fat and less saturated depot fat. Therefore, veal is low in both total and saturated fats (Moran, 1990).

There are two types of veal, *viz.* white- and pink veal. For the production of white veal, calves receive a special milk replacer for the entire rearing period of $4^1/_2$ months. For the production of pink veal, calves are at 4-6 weeks of age and fed high energy dry feeds until slaughtered (20 weeks of age). In Australia, once the permanent incisors (front) teeth have erupted in the live animal, or it shows secondary sexual characteristics, or produces carcasses weighing more than 150 kg, it is no longer classified as veal (Moran, 1990). However, in the R.S.A., once the first premolar erupts, at approximately 20-21 weeks of age, or the carcass mass is over 100 kg, it is classified as beef and not veal.

In order to understand which protein and energy sources can be used for calves, the changes in digestive abilities from the pre-ruminant to ruminant animal must be understood. The age of the calf at which its digestive tract can manage with certain types of protein or energy sources will depend on how soon the calf had access to a dry concentrate feed. When calves are

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weaned early, dry feed should be provided from the first week, to stimulate rumen development. Calves can only ruminate at 2-3 weeks of age if they were provided with dry feed from day 4 (Wilson & Brigstoche, 1981; Moran, 1990).

There is an increased interest amongst beef producers in how to increase energy density of finishing rations, especially when feed intake may limit performance. One of the focus areas is that of protected fats which are commonly used in lactating cow diets. Recent reports have suggested that steers in the finishing stages need higher levels of fat in the diet than currently recommended, to ensure good growth and condition.

2 ANATOMICAL DEVELOPMENT OF THE DIGESTIVE TRACT

The main anatomical changes in the young calf is found in the compound stomach. At first, the reticulo-rumen is undeveloped, and the main functional chamber is the abomasum. The young ruminant has a digestive system more like a 'monogastric' animal and is known as a 'pre-ruminant', since all four parts of the compound stomach are present, even though three chambers (rumen, reticulum and omasum) are undeveloped (Wilson & Brigstocke, 1981). Although the rumen and reticulum are relatively rudimentary at birth, their special pattern of motility is already established. In Fig.1.1, the stomach of a newborn ruminant, and in Fig.1.2, the stomach of a mature ruminant is illustrated. The most noticeable feature of a mature stomach is that while the abomasum at birth is about the same size as the rumen and reticulum, at maturity, the rumen and reticulum have a volume at least 10 times greater than that of the abomasum (Orskov, 1992).

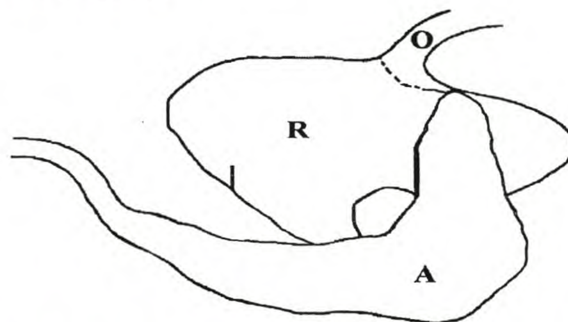

Figure 1.1 Schematic illustration of the rumen [R], oesophagus [O], and abomasum [A] in a newborn ruminant. Note the size of the abomasum relative to the rumen (Orskov, 1992).

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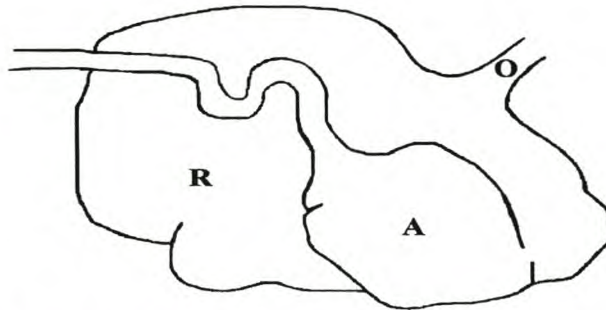

Figure 1.2 Schematic illustration of the rumen [R], oesophagus [O], and abomasum [A] in a mature ruminant. Note the size of the rumen relative to the abomasum (Orskov, 1992).

The rumen is relatively small and empty at birth. Only the abomasum, with a capacity of 60 to 70% of the total stomach volume, is functional. By contrast, in the adult ruminant, the abomasum comprises only about 8 % of the total stomach capacity (Roy, 1958). A consistent feature of prolonged and liberal milk feeding is suppressed rumen development, in size, volume, capacity and the papillary structure of the epithelium (Tamate *et al.*, 1962). If solid food is available and milk allowances are not too liberal, calves soon begin to eat and may be ruminating at two weeks of age (Waugh *et al.*, 1960).

While the unweaned animal is consuming a milk-based diet, a complicated by-pass arrangement comes into operation. This enables the milk to pass down the oesophagus and then through a temporary tube-like structure, known as the oesophageal groove - caused by the folding of the wall of the reticulo-rumen, straight through to the abomasum (Wilson & Brigstocke, 1981).

When the young ruminant eats small quantities of solid feed the oesophageal groove does not close and the material enters the rumen. It is thought that the physical texture of solid feed, especially fibrous feed like hay or straw, stimulates the development of the reticulo-rumen. In addition, dry feed stimulates the muscular movement that is an essential part of the fermentation process. The volatile fatty acids (VFA's) produced by the fermentation of this solid material also assists the reticulo-rumen to develop its full function (Wilson & Brigstocke, 1981). The normal development of rumen papillae has been attributed to the presence of VFA's. The order of effectiveness in stimulating rumen mucosal growth was found to be: butyrate, propionate and asetate (Huber, 1969). Following ingestion of dry food,

fermentation is soon established in the fore-stomachs and a wide range of foods can be utilised efficiently. For example, the digestibility of dried grass by three-week old, early-weaned calves were similar to those of fully developed ruminants (Hodgson, 1971). Early investigations showed that it was possible to have microflora in the rumen capable of breaking down cellulose at three weeks of age (Pounden & Hibbs, 1948 & 1949).

In the natural state, the very young ruminant suckles many times a day, so that many small servings of milk enter the abomasum over a twenty-four hour period. In artificial rearing systems, when the young animal is removed from its dam after the first day or so, a very different situation exists. Milk is supplied to the animal only once or twice a day, so that the process of clot formation (curd) and break-down in the abomasum is discontinuous (Wilson & Brigstocke, 1981). Gorrill & Nicolson (1972) found that the formation of a firm abomasal curd had a beneficial effect on nutrient digestibility and body mass gain, mainly due to a slower release of nutrients from the abomasum. However, other authors found that the absence of curd formation did not impair digestibility or calf performance (Bouchard *et al.*, 1973; Cruywagen *et al.*, 1990 & 1991).

When young ruminants are reared in early weaning systems, it is important that they are not moved onto a solid diet alone until two conditions are met. First, the calf must be consuming at least 1kg of solid feed per day. Secondly the animal must be actively ruminating, for which the evidence required is seeing the calves 'chew the cud'. Until rumination has started, calves are unable to digest solid food properly, because the fermentation activity of the reticulo-rumen has not yet achieved its full activity (Wilson & Brigstocke, 1981).

3 PROTEIN AND ENERGY REQUIREMENTS OF THE CALF

The total amounts of energy and protein, and the protein-to-energy ratio required by the calf, are affected by numerous factors applicable to the calf such as rate of gain, body size, age, as well as the composition of the diet (Jacobson, 1969). Several factors could cause calves to respond differently to protein supplementation. Among them are differences in growth rates, methods of feeding (*ad libitum* vs. restricted), digestible energy content of the ration, solubility of protein, palatability of the ration, balance of nutrients (e.g., sulphur), adaptation

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to urea and amount of milk consumed (Morrill & Dayton, 1978). Early growth involves primarily deposition of calcium, phosphorus, protein, and water. At high rates of gain, fat deposition is accelerated; at low rates of gain, mineral and even protein deposition may occur while fat is actually lost. In a young calf, nitrogen balance is usually positive at zero weight gain (Jacobson, 1969).

3.1 PROTEIN REQUIREMENTS

Protein nutrition in the pre-ruminant calf parallels that of the non-ruminant and the amino acid requirements can be met through milk or milk replacers (Roy & Stobo, 1983). After the rumen becomes functional, the crude protein needs for two systems must be met – the need for microbial fermentation in the reticulo-rumen and the need for post-ruminal amino acids for tissue development of the host ruminant (Kaufmann & Lüpping, 1982).

Ruminal bacteria can use various sources of nitrogen *viz*, ammonia primarily and some amino acids and peptides. Ammonia is derived from the degradation of protein or non-protein nitrogen (NPN) in the rumen. Urea is the most common source of NPN fed to ruminants (NRC, 1984). Urea can be used to replace a part of the nitrogen requirement for protein in calf starter diets, especially when urea is added to starter diets containing less than 12% total protein (Stobo *et al.*, 1967). Nelson (1970) concluded that no problems should occur from adding urea to starter diets if the urea did not supply more than 1% of the dry matter or one-fourth of the protein equivalent. Utilisation of urea in the rumen is sometimes less efficient at higher levels of crude protein (Stobo *et al., 1967*; Miron, *et al.*, 1967). Sulphur supplementation, as inorganic sulphur may be beneficial if rations fed to weaned calves contain urea and not more then 0.2% sulphur. Whey may also help increase urea use, especially under stress conditions (Morril & Dayton, 1978).

Despite numerous investigations, there is no complete agreement on the amount of protein required in calf starter diets or the extent to which urea can be used by the young calf (Morrill & Dayton, 1978). For example, in some trials calves fed rations containing only 12 to 13% protein grew as well as calves fed higher protein diets (Brown *et al.*, 1958; Brown *et al.*, 1960; Gardner, 1968; Gardner & Kunz, 1973; Morrill & Melton, 1973), but this was not found in other trials (Stobo *et al.*,1967; Leibholtz & Kang, 1973). Bartley (1973) reported

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that calves fed rations containing 20% protein gained more than those receiving 16%. Leibholz & Kang (1973) found that calves fed rations containing 15% protein gained as much as those fed 18% but that their nitrogen retention was lower. Schurman & Kesler (1974) reported similar growth and feed efficiency for calves on rations containing 14.3 or 26% protein, with a higher nitrogen balance for those on rations containing 26% protein. Akayezu *et al.* (1994) found that when calves were fed on four starter diets with a CP content of 15, 16.8, 19.6, or 22.4% (DM basis) diets containing the lower protein contents of 15 or 16.8% had only a moderate growth rate. The calves on the 19.6% CP diet showed maximum growth and there was no advantage gained from the higher protein content of 22.4%.

The digestibility of feeds that might be included in the calf's diet varies greatly. Therefore, digestible protein, is more meaningful, than total crude protein. The digestibility and utilisation of milk components by calves is high. The same applies to milk products used in milk replacers, if the processing procedures are such that the high quality is maintained. The importance of processing has been amply demonstrated by the marked reduction in nutritional value of dried skim milk resulting from overheating (Shillam & Roy, 1963).

The recommended daily protein requirements of growing large-breed calves fed milk plus a starter mix is 290 and 435 g for a 50 kg, with 500 g/day gain and 75 kg, with 800 g/day gain live mass calf respectively (NRC, 1989). Klemesrud *et al.* (1998) estimated the average metabolizable protein requirements for a growing calf as 3.8 g/kg $W^{0.75}$/day for maintenance and 305 g/kg of live mass gain.

Calves also have certain additional amino acid requirements: the methionine requirement ranges between 3.9 and 4.5 g/day for calves weighing 50 to 60 kg and growing at 0.25 kg/day (Foldager *et al.*, 1977). Campbell *et al.* (1997) estimated the methionine requirements of growing steers weighing 160 and 195 kg to be 7.9 and 8.4 g/day, respectively. The total sulphur amino acid requirement was 0.21 to 0.27 g/kg $W^{0.75}$/day. The estimated lysine requirement is 12.6 g/day or 0.78 g/kg $W^{0.75}$/day (Foldager *et al.*, 1977).

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3.2 ENERGY REQUIREMENTS

The energy requirements of the calf can be met in the starter diets by using grain supplements, but in the growing diet the energy demand for a fast growing calf is higher than what can safely be provided by the use of grains alone. Thus alternative sources like fat supplements are required. What is of particular value as an energy source, are fats that have been protected (bypass or rumen inert fats) against rumen degradation.

The metabolizable energy (ME) available for the animal is primarily used to meet its maintenance requirements. The metabolizable energy required for maintenance (ME_m) is used for sustaining primary life processes and is fully dissipated as heat (Schrama, 1995). The daily recommended metabolizable energy requirements for a 50 kg and 75 kg calf gaining 500 and 800 g live mass (LM) per day, respectively is 24.69 (493.7 kJ/kg) and 37.57 MJ (501.0 kJ/kg). The daily recommended digestible energy requirements for a 50 kg and 75 kg calf gaining 500 and 800 g LM respectively, is 26.86 (537 kJ/kg) and 40.92 MJ (545.6 kJ/kg) (NRC, 1989). During the 1st wk after transportation, ME_m values in young, newly purchased calves were found to vary between 502 kJ/kg $W^{0.75}$ /day (Arieli *et al*, 1995) and 560 kJ/kg $W^{0.75}$ /day (Schrama *et al.*, 1992). In older, growing pre-ruminant calves, the ME_m values range from 380 to 470 kJ/kg $W^{0.75}$/day with an average of about 420 kJ/kg $W^{0.75}$/day (Schrama, 1995). When the feeding level is above maintenance, the surplus to the maintanance requirements is used for growth (ME available for production = ME_p). During growth, part of the ME_p is lost as heat. When the feeding level is low the energy reserves from the body are mobilised to cover the deficit in energy for maintenance processes (Schrama, 1995).

4 DIGESTION

4.1 DIGESTION IN THE PRE-RUMINANT CALF

The protein, carbohydrate and fat metabolism in the digestive tract (mouth, rumen, reticulum, omasum, abomasum and small intestine) with the different digestive processes relevant to the pre-ruminant calf are discussed below.

4.1.1 PROTEIN DIGESTION

Abomasum

The physiology of the abomasum also differs between the young ruminant and the adult. One of the major enzymes secreted in the abomasum in the young calf is rennin, which coagulates milk protein (casein), forming a solid clot (curd) (Wilson & Brigstocke, 1981). This clot remains in the abomasum for hours, during which period it is progressively broken down by the action of both rennin and pepsin. Although the milk clot takes time to break down and pass into the duodenum, the whey fraction moves through the abomasum very quickly. Some whey has been found to be present in the duodenum five minutes after the calf has suckled milk from its dam (Wilson & Brigstocke, 1981).

Some neonatal calves produce mainly rennin, while others secrete both rennin and pepsin, but pepsin production predominates as the calves get older (Hill *et al.*, 1970). The chief or peptic cells secrete pepsinogen or pro-rennin (Hill, 1968), the same zymogen granulae may possibly contain both enzymes (Hill, 1961 & 1965). For casein coagulation, the optimum pH is 6.5 for rennin and 5.25 for pepsin, whereas for proteolysis the optimum pH is 3.5 for rennin and 2.1 for pepsin (Roy & Stobo, 1983). As the calf develops, the parietal cells secrete more and more HCl and the chief cells begin to secrete pepsinogen which is converted to pepsin in the abomasum (Orskov, 1982).

Both pepsin and rennin break down the main protein, casein, inside the clot. The essential difference between the two is that pepsin can break down most proteins whereas rennin is specific to casein. Until the HCl/pepsin system of protein digestion has been developed, casein from whole milk, or a milk replacer based on skimmed whole milk, is the only protein that can be digested properly in the abomasum. Pepsin digestion, however, is quite efficient by the time calves are 7 days old (Orskov, 1982).

Small Intestine

Pancreatic secretion contains the enzymes tripsin, chymotrypsin, protease, lipase, amylase and ribonuclease (Roy & Stobo, 1983). Feeding of skimmed milk instead of a diet containing 17-20% fat DM, reduced the total secretion of pancreatic juices (Ternouth *et al.,* 1974). The levels of pancreatic proteases were low in newborn calves and remained low up to 44 days of age. Although the total volume secreted increases with age, it remains approximately

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constant in relation to the metabolic body weight at 25 ml/kg $W^{0.75}$ in 12 hours (Huber *et al.*, 1961b).

4.1.2 CARBOHYDRATE DIGESTION

Small Intestine

During the first four weeks of life, the only carbohydrate that a pre-ruminant calf can utilize, is lactose and its component monosaccarides: glucose and galactose (Okamoto *et al.*, 1959). Fructose is absorbed poorly or not at all (Velu *et al.*, 1960) and sucrose is not utilised because of the complete lack of intestinal sucrase activity (Dollar & Porter, 1957).

Though pancreatic amylase and intestinal maltase are present in the post-ruminal digestive tract, the effective activities of these enzymes are very low. However, their activity increases with age while that of lactase in the calf decreases (Huber *et al.*, 1961a). The young calf, therefore, appears to show some adaptation to starch, but growth (Flipse *et al.*, 1950; Huber *et al.*, 1967) and glucose tolerance studies (Huber *et al.*, 1967; Larsen *et al.*, 1956) covering a wide range of ages show that post-ruminal use of starch never equals that of lactose. Though lactose and glucose are the preferable carbohydrates for inclusion in milk substitutes, diarrhoea is caused by feeding calves excessive amounts of either (Flipse *et al.*, 1950).

Hydrolysis of lactose occurs much more rapidly than the absorption of its constituent monosaccharides. Absorption of galactose is depressed in the presence of glucose and is therefore minimal in the proximal small intestine where the relative concentration of glucose is high. However, galactose was absorbed efficiently some 2 to 4m caudal to the bile duct, where the glucose concentration had fallen (Coombe & Smith, 1973).

Maltase and isomaltase activities increase during the first 1-4 weeks of life, but thereafter their activity is similar to those in adult animals (Coombe & Smith, 1973). Amylase, maltase and isomaltase activities appear to be balanced from 6 weeks of age (Coombe & Siddons, 1973).

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4.1.3 FAT DIGESTION

Some fat is essential in the diet as a source of the polyunsaturated fatty acids such as linoleic and archidonic acids that the pre-ruminant calf is unable to synthesize (Lambert, *et al.*, 1954). The dietary fat is hydrolysed in the various organs as it moves down the alimentary canal as follows:

Mouth

The initial hydrolysis of dietary fat in milk or milk substitutes occurs as a result of a lipase, pregastric esterase (PGE), secreted from the palatine glands into the saliva. This PGE acts preferentially on the triglycerides of butterfat that contain butyrate groups (C4:0) to release butyric acid (Ramsey, 1962).

Abomasum

Immediately after feed there is some passage of fat through the pylorus, but most of the fat is entrapped in the casein coagulum. Within 30 minutes of a feed, about 50% of the triglycerides in the abomasum have been hydrolysed, presumably by salivary esterase (Ramsey, 1962; Otterby, *et al.*, 1964) at an optimum pH between 4.5 and 6.0 (Siewert, 1969 cit. Roy & Stobo, 1983).

Small Intestine

The pancreatic lipase is at its lowest concentration in the pancreas of a one day old calf: it has increased threefold eight days after birth, with little further increase thereafter (Huber *et al.*, 1961a). Bile salts and pancreatic lipase are interdependent in the digestion of fat. Bile salts along with pancreatic lipase are necessary for maximum digestion of fat (Wilson 1962).

4.2 DIGESTION IN RUMINANTS

In the sense of dry food intake, calves, at five months of age, may be regarded as fully developed ruminants (Johnson & Elliott, 1969), because they consume 100 to 120 g dry matter/kg $W^{0.75}$ /day, which is similar to that found for yearling and two-year old steers (Elliott & Reed, 1968). From an anatomical point of view, Grossman (1949) concluded that the forestomachs of young cattle approached adult proportions at four to six months of age, though final proportions were not achieved until they were about 18 months of age. Church

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(1969) summarising other work, concluded that the reticulo-rumen reached its relative mature size at 12 weeks of age.

4.2.1 PROTEIN DIGESTION

The various alimentary organs perform critical roles in protein digestion (mouth, rumen, small intestine).

Mouth

Saliva is characterised by the absence of ptyalin and by the abundance of phosphate and bicarbonate with a pH of 8 to 8.5. Saliva supplies the micro-organisms with phosphates and simple nitrogenous compounds like urea. Saliva also buffers the rumen content by means of the phosphates and bicarbonates it contains thereby neutralising the acids formed during fermentation (Craplet, 1963).

Rumen

The microbial population ferments the organic matter contained in the solid feed, converting it into very simple chemical substances, such as ammonia and the various steam-volatile fatty acids (VFA's), such as acetic, propionic and butyric (Wilson & Brigstocke, 1981).

Ruminants, like monogastrics, are dependant on essential amino acids provided indirectly by their feed, although it is not necessary to feed the full requirement of these essential amino acids intact in their diet as is the case with monogastrics. This is because amino acids are provided from two radically different sources. The first is from the feed as offered to the animal. Some of the protein in this feed will escape fermentation in the rumen and will arrive in the mid-gut with its constituent amino acids intact (i.e. the undegraded protein fraction). These amino acids can then be absorbed through the gut wall into the blood stream. The second is from protein obtained from dead micro-organisms. This microbial protein is derived from nitrogenous feed material that is fermented in the rumen (i.e. the rumen degradable protein) and NPN by the same micro organisms which transform the carbohydrate fraction of feed into volatile fatty acids. The end-products of the fermentation process are simple nitrogenous compounds, especially ammonia, and various other protein break-down products such as peptides and amino acids. Having reduced part of the feed protein to ammonia and other chemicals, the micro-organisms proceed to use these simple materials as building blocks

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for their own body proteins. These micro-organisms are constantly being moved down the gut with the rest of the digesta. The microbes are killed by the acids secreted in the abomasum and the animal is able to absorb amino acids derived from the protein of the dead micro-organisms in exactly the same way as the non-degraded protein obtained from the feed itself (Wilson & Brigstocke, 1981).

Small Intestine

The dietary protein fraction, which escapes the rumen fermentation, is known as undegradable protein (UDP). This fraction together with the microbial protein formed in the rumen are then digested and absorbed in the small intestine.

4.2.2 CARBOHYDRATE DIGESTION

The ruminant secretes no salivary amylase (Kay 1966). The absence of ptyalin in the saliva of ruminants can be looked upon as fortunate, for the conversion of starch to sugar would supply the bacteria with an easy substance to break down in preference to cellulose (Craplet, 1963).

Rumen

The fermentation process which occur in the rumen involve a wide range of carbohydrates (both soluble and structural) and proteins and yield as end-products a number of short-chain (C2-C5), volatile fatty acids. The importance of the short chain acids is in supplying the energy needs of the ruminant animal (Noble, 1981).

The ability of the rumen to absorb the three major short-chain fatty acids appear to be proportional to the chain length, i.e. butyric > propionic > acetic. Extensive metabolism of butyric acid occurs within the rumen epithelium with the formation of ketone bodies. A portion of propionate does not pass through the rumen unchanged and is metabolised to lactate. Acetate passes through with little if any metabolism. Most of the short-chain fatty acids absorbed are transported into the portal vein; minimal transport occurs within the lymphatic system (Noble, 1981).

Omasum

Short-chain fatty acids that escape from the rumen can be absorbed through the omasum epithelium (contains carbonic anhydrase) which has a similar function as the rumen epithelium (Noble, 1981).

Abomasum

The abomasum has the capacity to absorb short-chain fatty acids, although the amount absorbed is quantitatively insignificant (Noble, 1981).

4.2.3 FAT DIGESTION

In the simple-stomached animal, the processes of digestion and absorption of dietary fat begin essentially when they reach the small intestine (Fig. 2); any digestive and enzymatic processes which occur anterior to the small intestine can virtually be ignored (Noble, 1981).

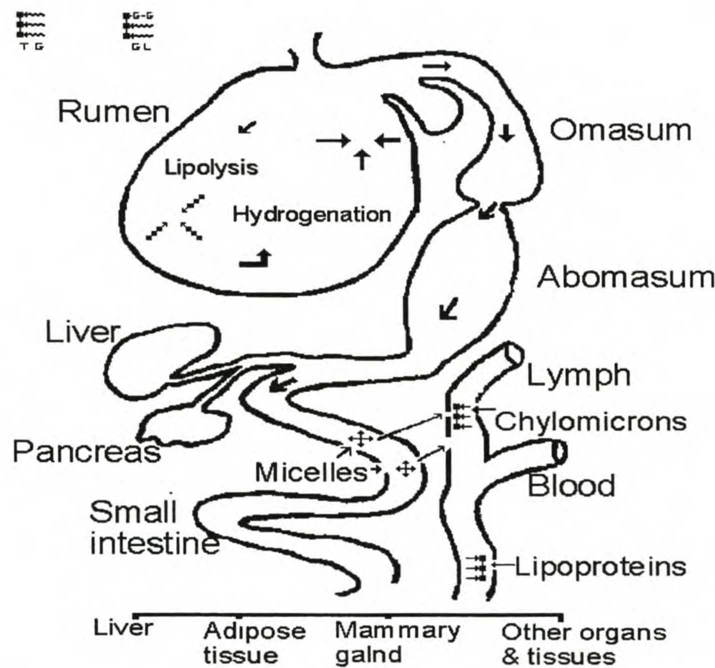

Fig. 2 Lipid digestion in the ruminant (Scott & Cook, 1975).

Rumen

Another important function carried out in the rumen is that fats and oils present in the feed are modified in their chemical composition (Fig. 2). Most unsaturated fats entering the reticulo-rumen are hydrogenated into saturated fat before they pass into the omasum. Some will be used by the microbial organisms to form microbial lipid in their bodies. A few 'protected'

unsaturated fats will escape hydrogenation and pass through unchanged (Wilson & Brigstocke, 1981).

Lipids present in forages and grains are generally in the form of triacylglycerols, galactosyl acylglycerols (Scott & Cooke, 1975) and phospholipids with C18:2 (linoleic) and C18:3 (linolenic) being the principal fatty acids (Jenkins, 1993). However, fat sources available as supplemental energy sources for cattle markedly differ in their fatty acid composition and thus the choice of lipid source can substantially alter the fatty acid profile of lipids presented to the rumen. Dietary lipids are hydrolysed by microbial lipases, as are phospholipids, to their constituent fatty acids prior to biohydrogenation of unsaturated fatty acids (Jenkins, 1993; Scott & Cook, 1975). Biohydrogenation of C18:2 and C18:3 involves an isomerization reaction which converts the cis-13 double bond to a trans -11 isomer followed by reduction to *trans*-11 C18:2 and ultimately to C18:0 (stearic acid) which is the principal end product of microbial hydrogenation of C18:1, C18:2 and C18:3 fatty acids (Jenkins,1993). A proportion of the *trans*-isomers produced in the rumen (negligible absorption of long chain fatty acids occurs across the rumen wall) escape further biohydrogenation (Jenkins, 1993) and are absorbed from the small intestine and ultimately incorporated into the glycerides of adipose tissues and milk fat (Scott & Cook, 1975).

The practical effect of hydrogenation in the rumen is to produce high yields of stearic acids and smaller amounts of positional and geometric isomers from the unsaturated C18 plant fatty acids in the feed. Hydrolysis of fatty acids from their esterified forms occurs before hydrogenation. The net effects of hydrolysis and hydrogenation are that long-chain free fatty acids constitute the major lipid class, in digesta, as they pass from the rumen to the lower digestive tract - stearic acid is the major free fatty acid (Keeney, 1970).

The fatty acids of both the bacterial and protozoal lipids, in particular of the phospholipid fractions, are characterized by high percentages of C13, C14, C15, C16 and C17 branched-chain fatty acids, together with several straight-chain fatty acids containing an odd number of carbon atoms in addition to palmitic, stearic and C18 monoenoic fatty acids (Noble, 1981). These odd and branched chain fatty acids (which are absent from the diet) are absorbed by the host animal and are incorporated into tissue lipids (Noble, 1981; Kennelly, 1996). Branched chain fatty acids arise from the substitution of isobutyrate, isovalerate and 2-methylbutyrate for acetate in the microbial synthesis of fatty acids. Similarly, odd chain fatty acids are

derived from microbial utilization of odd-chain fatty acids propionate and valetate, as precursors for fatty acid synthesis (Kennelly, 1996).

The rumen has the ability to utilise both medium- and long chain fatty acids as substrates for the production of ketone bodies (Noble, 1981).

Omasum

The omasum has the ability to utilise saturated and unsaturated medium- and long chain fatty acids as substrates for the production of ketone bodies (Noble, 1981).

Abomasum

Although the role of the abomasum is similar to that of the stomach in the monogastric animal in that it plays little part in lipid digestion, the abomasum does make an important if indirect contribution by its action upon the bacteria and protozoa passing down from the rumen. In the acid environment of the abomasum, the bacteria and protozoa disintegrate and the lipid contents are released thereby facilitating subsequent digestion further down the gastrointestinal tract (Noble, 1981).

Small Intestine

Like the rumen contents, the digesta passing into the duodenum under normal dietary conditions is mainly comprised of unesterified fatty acids together with significantly, but very much smaller amounts, of phospholipids (Noble, 1981). There are some esterified fatty acids in the bacteria lipids (McDonald *et al.*, 1995). Although some triglycerides can be detected, the rate of lipolysis in the rumen is such that, under normal dietary conditions, little unchanged dietary glyceride ever reaches the small intestine. However, when the levels of esterified fatty acids within the diet were increased greatly, elevated concentrations of triglyceride within the digesta passing into the duodenum were observed (Noble, 1981).

To cope with continuous passage of digesta into the duodenum, secretion of both bile and pancreatic juices is also continuous and not subject to large cyclic changes in output (Noble, 1981).

Only limited hydrolysis of esterified fatty acids occur in the first 2m of the upper jejenum, and 20% of the total fatty acids of the digesta entering the duodenum are absorbed, which

consists almost entirely of unesterified fatty acids. In the middle and upper jejunum, a further 60% of the total fatty acids in the digesta are absorbed and this includes fatty acids derived from hydrolysis of neutral lipids. By the time the digesta reaches the ileum, assimilation of unesterified fatty acids, together with hydrolysis and uptake of ester-bound fatty acids, is almost complete. Although the major site of lipid absorption is clearly the middle and lower jejenum, it is evident that, in spite of the conditions of very low pH that prevail, fatty acid uptake does occur in the upper jejenum (Noble, 1981).

The overall rate of fatty acid uptake and incorporation into the lymph lipids is in the order oleic > palmitic > stearic acid. Some discrimination in the rate of absorption of the geometrical and positional isomers of C18:1 fatty acid occur; *trans*-18:1 fatty acids are absorbed to a greater extent than *cis*-18:1 fatty acids. The efficiency of the absorption of long-chain (C14-C18) fatty acids increases with the introduction of a double bond or with reduction in chain length. The general rule is that there is an inverse relationship between the efficiency of absorption and the melting point of the acid; this rule is not applicable outside the range of C14-C18 fatty acids (Noble, 1981).

4.2.3.1 Metabolic consequence of feeding protected lipids.

Rumen

The extensive biohydrogenation of unsaturated fatty acids in the rumen poses a challenge to efforts targeted at altering the fatty acid composition of tissue or milk fat in cattle: in essence the unsaturated fatty acids must be fed in a form which resists biohydrogenation in the rumen. The most common approaches are to feed protected lipids which have been chemically (e.g. formaldehyde treatment or calcium salts) or physically (e.g. heat) treated to resist microbial saturation in the rumen (Palmquist & Jenkins, 1980; Ashes *et al.*, 1992). Intact oilseeds also provide a degree of protection from biohydrogenation by microbial enzymes (Smith *et al.*, 1981; Kennelly, 1996; Casper *et al.*, 1988;).

Small Intestine

The normal process of fat digestion in ruminants allows only very small amounts of unhydrolyzed lipids to pass from the rumen into the abomasum and small intestine. Most of these free fatty acids are then absorbed from the small intestine. However, when dietary lipids are protected from ruminal lipolysis and hydrogenation the amount of lipids reaching the abomasum and small intestine is substantially increased. Despite this elevated intestinal

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load of triacyglycerols there is an efficient digestion and absorption of lipid (and protein) from the small intestine. This indicates an adequate secretion of pancreatic lipase in ruminants fed protected fats (Scott & Cook, 1975).

Chylomicrons contain large proportions of triacylglycerol and this is the form in which absorbed lipids are transported from the intestine via the lymphatic system. Circulating chylomicrons, are absorbed by the liver and the triacylglycerols hydrolysed. The fatty acids so produced, along with the free fatty acids absorbed from the blood by the liver, may be catabolized for energy production or used for synthesis of triacylglycerols (McDonald *et al.*, 1995). Protected dietary C18:2 is absorbed and incorporated into the triacyglycerols of lymphatic chylomicrons (Scott & Cook, 1975). These then re-enter the blood supply in the form of lipoprotein and are carried to various organs and tissues where they may be used for lipid synthesis, for energy production and for fatty acid synthesis (McDonald *et al.*, 1995). They also serve as a source of serum lipids, which are present in association with proteins and various lipoproteins. Thus, there is an increased proportion of C18:2 in the triacyglycerols of lymphatic chylomicrons, triacylglycerols of serum lipoproteins and in other major serum lipoprotein lipid fractions (Scott & Cook, 1975).

The high proportions of C18:2 in serum cholesterol esters of ruminants on conventional rations indicate an efficient mechanism for the conservation of the polyenoic fatty acids that escape rumen hydrogenation. The incorporation of polyenoic fatty acids into serum cholesterol esters is probably mediated via the lecithin-cholesterol-acyl-transferase system. Chylomicron and serum triacylglycerols serve as a source of fatty acids for utilisation by organs and other tissues. The triacylglycerols are hydrolysed by lipoprotein lipase and the liberated fatty acids are then available for subsequent uptake and/or metabolism by the tissues. Protected polyunsaturated fats such as safflower oil tend to suppress the incorporation of [1-^{14}C] asetate into the fatty acids of subcutaneous tissue (Scott & Cook, 1975).

The extent to which absorbed triacylglycerol fatty acids are utilised for tissue lipid biosynthesis will depend largely on the total caloric intake of the animal. If caloric intake is insufficient for adequate growth or milk production, the absorbed fatty acids will be oxidised to meet the energy demands rather than be deposited in the tissue lipids (Scott & Cook, 1975).

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4.2.3.2 *Fat synthesis*

The glycerides (triacylglycerols) of the depot fat are derived from glycerides, or may be synthesized in the body from fattyacyl CoAs and L-glycerol-3-phosphate (McDonald, 1995).

Fatty acid synthesis

It is generally considered that there are three systems of fatty acid synthesis. The first, which is highly active, is centered in the cytosol and results in the production of palmitate from acetyl-coenzyme A (Fig. 3). Acetate is absorbed directly from the gut and is changed to acetyl-CoA in the presence of acetyl-CoA synthetase. The system is active in the liver, kidney, brain, lungs, mammary gland and adipose tissue. The acetyl-CoA is transformed to malonyl-CoA, which then reacts with acyl-carrier protein (ACP), to give malonyl-ACP complex. Acetyl-CoA is then coupled with ACP and this reacts with the malonyl-ACP, the chain length being increased by two carbon atoms to give the butyryl-ACP complex. The reactions involved are shown in Fig. 3. The butyryl-ACP complex then reacts with malonyl-ACP complex, resulting in further elongation of the chain by two carbon atoms to give caproyl-ACP. Chain elongation takes place by successive reactions of the fattyacyl-ACP complexes with malonyl-CoA until the palmitonyl-ACP complex is produced, when it ceases (Fig. 4). Palmitic acid is liberated by the action of a specific deacylase (McDonald, 1995).

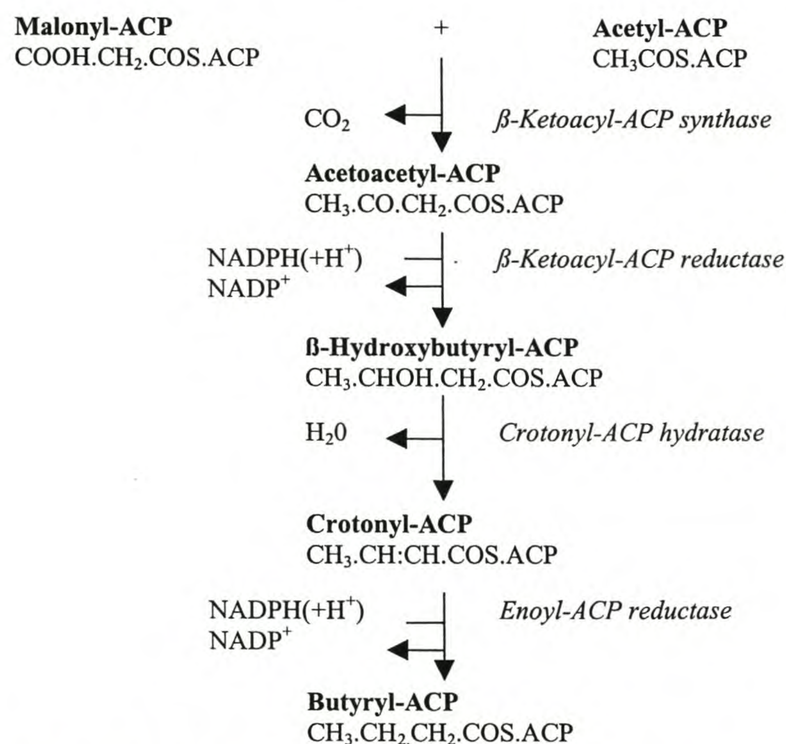

Fig. 3 The Cytosolic synthesis of fatty acids from acetyl-CoA to a butyryl-ACP complex.

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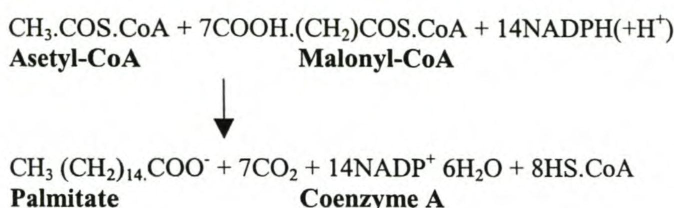

Fig. 4 The overall reaction of the production of Palmitate from Asetyl-CoA in the cytosol.

The second system of fatty acid synthesis occurs chiefly in the endoplasmic reticulum and to a minor extent in the mitochondria. It involves elongation of fatty acid chains by two-carbon addition, with malonyl-CoA as donor. It involves the incorporation of two carbon units into medium and long chain fatty acids. This system requires ATP and reduced $NADP^+$. The pathway is presented in Fig. 5. The products of the system, which is centered in the microsomes, are saturated acids with 18, 20, 22, and 24 carbon atoms usually produced from palmitic acid synthesised by the cytosolic system (McDonald, 1995).

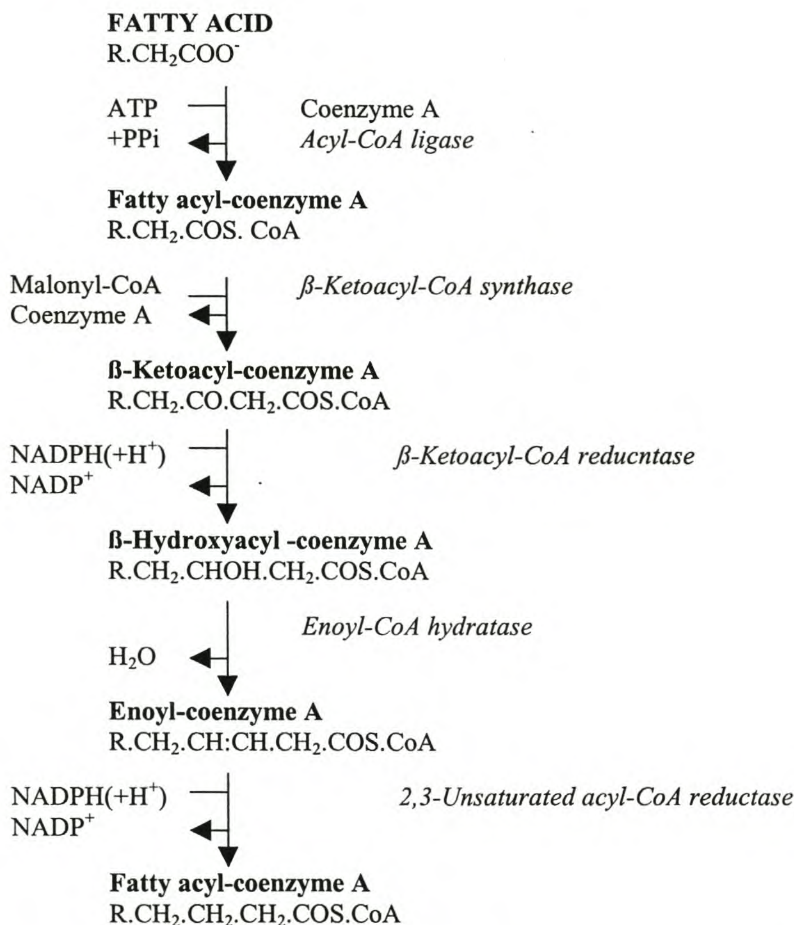

Fig. 5 Elongation of the fatty acid chain within the endoplasmic reticulum and the mitochondria.

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The third system, confined to the endoplasmic reticulum, brings about desaturation of preformed fatty acids. Double bonds may be introduced into fatty acid chains by the action of fattyacyl-CoA desaturases present in the microsomes (Fig. 6). Thus palmitoleic and oleic acids are produced from corresponding saturated acids, which introduces a double bond between carbon 9 and 10 (McDonald, 1995).

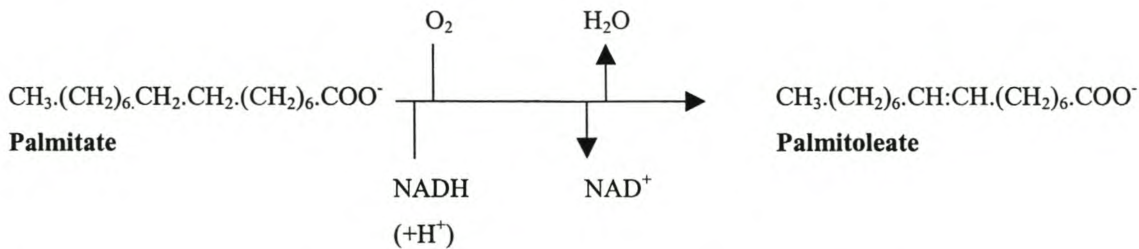

Fig. 6 Desaturation of preformed fatty acids within the endoplasmic reticulum.

Synthesis of L-glycerol-3-phosphate

The precursor in the synthesis of L-glycerol-3-phosphate is usually dihydroxyacetone phosphate produced by the aldolase reaction of the glycolytic pathway. This is reduced by the NAD-linked glycerol-3-phosphate dehydrogenase. It may also be formed from free glycerol, absorbed from the gut or arising from the catalysis of triacylglycerols, in the presence of glycerol kinase (McDonald, 1995).

Synthesis of triacylglycerols

The synthesis of triacylglycerols, starts with the acylation of the free alcohol groups of the glycerol-3-phosphate by two molecules of fattyacyl-CoA to yield a phosphatidic acid. The reaction occurs preferentially with acids containing 16 and 18 carbon atoms. The phosphatidic acid is then hydrolysed to give a diacylglycerol which reacts with a third fattyacyl-CoA to give a triacylglycerol. Direct synthesis of triacylglycerols from monoacylglycerols takes place in the intestinal mucosa of higher animals (McDonald, 1995).

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5 PROTEIN SOURCES

The nutritional quality of oilseed protein meals, or any other meal protein, will be affected by the processing conditions to which it has been exposed. Three major factors affecting the nutritional quality of protein are (a) the amino acid composition (b) the amino acid availability or digestibility and (c) anti-nutritional qualities. While heat treatment during processing may adversely affect the final quality for monogastric animals, it may have a beneficial effect for ruminant animals by reducing the extent of rumen degradability of the protein (Aherne & Kennelly, 1982).
Dietary protein sources can be divided into rumen degradable (RDP) and undegradable proteins (UDP). The RDP can be subdivided into high degradable (HD) and low degradable (LD) protein. The UDP can be naturally or artificially protected from rumen degradation. The use of proteins with low degradability can be expected to improve performance in growing animals, especially during the starting phase, when there is a relatively high rate of protein deposition and the protein requirements are high. During the finishing phases the deposition of fat becomes more dominant (Kaufmann & Lüpping, 1982).

The search for efficient veal production is for proteins, which are naturally and consistently low degradable, have a good protein quality (amino acid pattern) and are available in sufficient amounts and at acceptable prices. Some protein-rich feeds, such as maize gluten, brewer's grains, blood meal, feather meal, oil-seed cakes and fishmeal are claimed to have a low degradability. However, in most cases this has only been tested by *in vitro* methods and not by direct measurements of the flow of undegraded protein to the duodenum of cows (Kaufmann & Lüpping, 1982).

A better way to provide protein with consistently low degradability, suitable for feeding high producing animals, is to protect the protein artificially. There are mainly three methods of protecting a protein against rumen fermentation *viz*. heat treatment, with tannins and with formaldehyde (Kaufmann & Lüpping, 1982).

In the present investigation three sources of protein were used *viz.* an animal protein (fishmeal), a plant protein (sunflower oil cake) and prime gluten. Fishmeal has a low degradable protein fraction, while sunflower oil cake contains higher degradable protein.

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5.1 PROTEIN SOURCES USED IN THE PRESENT INVESTIGATION

Fishmeal contains 69.9-79.3% crude protein (CP), 14.6-17.8 MJ ME/kg and 6.0-7.5% ether extract (EE). It contains a high level of all the essential amino acids (lysine, methionine and tryptophan) as well as vitamins and minerals (McDonald *et al.,* 1995). The NRC (1989) values for fishmeal (DM basis) are 68.2%CP, 12.48 MJ ME/kg, 0.8% crude fibre (CF) and 5.1% EE. Erasmus & Prinsloo (1988) calculated the protein degradability values for local fishmeal as 52.0, 40.3 and 36.4 at different fractional outflow rates (K_r) of 0.02, 0.05 and 0.08, respectively. The local fishmeal had a CP content of 71.2%.

Sunflower oilcake contains (DM basis) 25.9% crude protein, 6.32 MJ ME/kg, 35.1% crude fibre and 1.2% EE (NRC, 1989). Erasmus & Prinsloo (1988) calculated the protein degradability values for sunflower oil cake as 93.5, 86.2 and 80.9 at different fractional outflow rates (K_r) of 0.02, 0.05 and 0.08, respectively.

The crude protein content of prepress solvent sunflower meal (SFM) ranges between 36-44%. The protein quality of SFM is regarded to be of lower value than that of soyabeen meal (SBM), with especially lysine being deficient. The amino acid profile of the meal is strongly affected by the heat treatment during processing. Prolonged heating severely depresses the availability of aspartic acid, arginine, threonine, leucine, lysine and tryptophan while increasing the content of glutamic acid, serine and ammonia. Limited amino acid availability should, therefore, be carefully considered when processed SFM is fed to fast growing calves. In contrast to some of the major oil seeds, SFM is not known to contain any growth depressing or toxic substances. Stake *et al.* (1973) compared SBM, SFM and high-glucosinolate rapeseed meal (HGRSM) as protein sources in calf starter rations. Calves were fed the test diets, to a maximum of 1.82kg per head daily, from week 0 to week 14. In addition they received whole milk until weaned at 68.2kg body weight. Daily starter dry matter intake was lower for HGRSM (0.67kg/calf) than for SFM (0.92kg) or SBM (0.99 kg) rations. Average daily gain (kg) and feed efficiencies for calves fed HGRSM, SFM or SBM rations were 0.58, 0.64, 0.65 and 3.10, 2.96 and 3.08, respectively. Similarly, no significant differences were observed in crude protein digestibility coefficients for calves fed SBM or SFM. These results indicate that SFM can effectively replace SBM as a protein supplement in calf starter rations (Aherne & Kennelly, 1982).

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Prime gluten is a by-product of the maize wet milling process and is sucessfully used in animal feeds as a protein source. Prime gluten contains (DM basis) 67.2% crude protein, 14.70 MJ ME/kg, 2.2% crude fibre and 2.4% EE (NRC, 1989). Prime gluten is also a low degradable protein source which is high in metionine. Erasmus & Prinsloo (1988) calculated the protein degradability values for prime gluten as 48.6, 31.0 and 24.5 at different fractional outflow rates (K_r) of 0.02, 0.05 and 0.08, respectively.

6 ENERGY SOURCES

6.1 GRAINS

The major grains used for ruminant diets include maize, sorghum, wheat, barley, oats and triticale. The nutritional value of grains are influenced by the location and conditions where they are grown. The choice of grains for inclusion in calf starter and finishing diets is dependent on their energy content, protein (amino acid) content, wholesomeness and price (Aherne & Kennelly, 1982).

6.2 FAT SUPPLEMENTATION

There are three main sources of fat used in animal feeds. Firstly granular fats (rumen inert fat) are used. Secondly oilseeds *viz.* whole soyabeans, cottonseeds, sunflower seeds *etc.* Lastly, rendered animal fats *viz.* tallow, poultry fats, choice white grease and yellow grease, that may be blended with vegetable oils acidulated soapstocks from the oil refining industry (Palmquist, 1984).

6.2.1 RUMEN INERT FAT

Ruminally inert fats are commonly referred to as rumen bypass, protected, escape or speciality fats. Ruminally inert is the proper descriptive terminology since fatty acids are not degraded in the rumen. These products undergo varying degrees of microbial hydrolysis and

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fatty acid hydrogenation in the rumen and were developed to minimise adverse effects of fats on ruminal fermentation and fibre digestion (Palmquist, 1984).

A Rumen inert fat should be non reactive to the rumen micro-organisms, be readily absorbed in the lower digestion tract, have an optimum fatty acid structure for metabolism and be readily incorporated into the diet (Palmquist & Cummings, 1989).

Rumen inert refers only to the lack of inhibitory effects of certain fats on the metabolism of sensitive protozoa and gram positive bacteria e.g. calcium salts have been shown to undergo biohydrogenation (Jenkins & Palmquist, 1986) even though they have no influence on fibre digestion (Jenkins & Palmquist, 1984; Chalupa *et al.*, 1986).

Lipids can be either physically or chemically protected to achieve ruminal inertness.

6.2.1.1 Chemical protection of fat by the formation of calcium salts of fatty acids

Calcium soaps are inert in the rumen (Palmquist & Jenkins, 1982; Jenkins & Palmquist, 1984; Chalupa *et al.,* 1984; Palmquist, 1984), digestible in the lower intestine (Jenkins & Palmquist, 1984; Palmquist, 1991) and have been shown to be used effectively in diet formulation for milk production (Sklan *et al.*, 1991).

The calcium soap product is rumen inert as long as the fatty acids are maintained in the calcium soap form. Calcium soaps are sensitive to pH and any tendency towards acidosis will result in some breakdown of the soaps and the liberation of long chain fatty acids and will have a negative influence on fibre digestion in the rumen (Chandler, 1988).

The pKa of calcium salts is 4 to 5 (Palmquist, 1985), therefore dietary buffers may be needed with some feeding strategies to maintain rumen pH above 6 to prevent dissociation of the salts. Estimated pKa values are 5.6, 4.6, 4.5 and 4.5 for calcium soaps of soy, palm fatty acid distillate, tallow and stearic fatty acid respectively. In the abomasum, calcium soaps are converted, by the acids present, to free fatty acids and calcium. These fatty acids are then absorbed efficiently from the small intestine where the pH is lower (Sklan, *et al.*, 1985).

Davison & Woods (1963) outlined the physiological processes required for ruminants to effectively utilise calcium soaps i.e. dissociation of the soap in the acid abomasum, absorption

of calcium in the acidic duodenum followed by absorption of fatty acids in the jejunum and ileum. If the calcium is in excess or absorbed inadequately, insoluble soaps will reform in the large intestine and be excreted in the faeces. The normal pH of the bovine duodenal contents is 2 to 2.5 which is sufficiently low to dissociate more than 99% of the calcium soaps. Properly prepared calcium soaps contain about 7% calcium. High calcium contents in the diet can affect magnesium utilisation (Chico *et al.*, 1973) in the ruminant.

Palm fatty acid distillate is very useful as a raw material for calcium soap manufacturers as it produces a soap with stearate (C18:0)) levels less than 5%. Calcium soaps have been shown to have digestibilities in excess of 90% when fed in either a pelleted or loose form (Sadler & Miller, 1982 as quoted by Stevens, 1990). Morlac (Marine Oil Refiners, Dido Valley, Simonstown, CT, RSA) is an example of a calcium salt of palm oil fatty acids.

6.2.1.2 Physical protection of fat

There are three methods in which a fat can be physically protected from rumen breakdown:

1) the formation of high melting point fats with high contents of saturated long chain fatty acids also known as dairy fat prills, saturates or hydrogenated fats,
2) protein encapsulation of oil droplets and
3) mixing fat with a non nutritive carrier (vermiculite).

1) *Fats with high melting points (dairy fat prills, saturates and hydrogenated fats)*

The physical and biological characteristics of saturated fatty acids in the rumen (high melting point, low microbial inhibition) are the basis of these commercial hard fats which are both dry and rumen inert. The high melting point refers to melting points above body temperature. The same physical characteristics which contribute inertness to this type of fat may also lower absorption from the small intestine (Palmquist, 1988). Saturated fatty acids have low solubility levels. Fatty acids with high melting points, such as stearic acid, inhibit ruminal fermentation and fibre digestion less than fatty acids with lower melting points like oleic acid (Chalupa *et al.,* 1984) and form the basis of many bypass fats. The latter has a high content of saturated fatty acids with a low solubility so as to maintain normal digestion.

Triglycerides with high melting points are also inert in the rumen. Some commercially inert fats are highly saturated triglycerides. Although these have little or no activity in the rumen this same inertness is a liability for digestion and absorption. Before absorption of

triglycerides can occur in the small intestine they must undergo emulsification (Noble, 1981). MacLeod & Buchanan-Smith (1972) and Jenkins & Jenny (1989) demonstrated that highly saturated triglycerides are at a disadvantage because of the relatively low triglycerides lipase activity in the ruminants small intestine. Thus utilisation of highly saturated triglycerides is lower than similarly saturated fatty acids in unesterified form.

Hydrogenation of fats increases the melting point, changing the fats' effect on rumen fermentation, fatty acid digestion and feed intake (Jenkins & Jenny, 1989). Hydrogenation does not greatly change the long chain fatty acid content but increases the melting point and saturated fatty acid content. Total hydrogenation appeared to increase the melting point of yellow grease beyond where reduced fat digestibility was compensated for by rumen inertness (Jenkins & Jenny, 1989). Intermediate melting points from (partial) semi-hydrogenation may provide a more acceptable balance between rumen inertness and fat digestibility.

Prilling fats involves liquefying a mixture of fatty acids high in saturated fatty acid content and spraying the mixture of fatty acids under pressure into a cooled atmosphere resulting in dried prilled fatty acid supplements that are inert in the rumen and do not alter rumen fermentation (Grummer, 1988). The fatty acids are crystallised together in a matrix. The overall effect is to produce tiny spherical beads, 0.01mm to 0.05mm in diameter.

2) *Protein encapsulated fat*

Two methods of protein encapsulation of fats exist:

(i) Formaldehyde protein protected fats and

(ii) Encapsulation of fats with sodium alginate.

3) *Protection of fat by use of a carrier*

Fats can be combined with a carrier e.g. vermiculite to prevent depression of digestibility of the fibre in ruminants. Carriers range in absorptive capability from 40 to 65%. Some nutritional carriers e.g. ground maize cobs and "bees wings" of maize cobs have been used with moderate success. As with calcium soaps, availability of the fatty acids for absorption would depend on their being dissociated from the verxite (carrier). It is not known if the association of the fatty acids with the verxite is purely one of physical coating or an interaction with the mineral structure. Detergency of bile acids is likely the major factor in removing tallow from the verxite (Chaney & Marbath, 1962).

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6.3 RUMEN INERT FAT SOURCES USED IN THE PRESENT INVESTIGATION

There are various rumen inert fat sources in the R.S.A. of which Energy Booster, Booster fat, Alifet, Dairy 80, Carolac, Morpalm II, Priplus 10 and Golden Flake are examples of fats physically protected from rumen breakdown. Three examples of chemically protected fat sources are Megalac, Ruminsol and Morlac. Golden Flake and Morlac were used as the two rumen inert fat sources in the present trial. Morlac (Marine Oil Refiners, Dido Valley, Simonstown, CT, RSA) is an example of a calcium salt of palm oil fatty acids. Golden flake (Veekon, Silverton, Pretoria, RSA) is a flaked product manufactured from palm oil fatty acids.

Morlac

Jesperson, (1993) tested Morlac *in vitro* and found that the calcium soaps are hydrogenated immediately at the start of fermentation and reached a maximum plateau at approximately 12 hours. However no digestion of the calcium soaps took place. Inert fat supplements are not excluded from being hydrolysed (if a triglyceride) or being hydrogenated (if unsaturated) in the rumen. Thus, rumen inertness simply means that the fat, or fatty acid supplement, does not get altered by rumen fermentation. Hydrolysis and hydrogenation no doubt occur in inert fats but the rates at which these processes proceed are reduced as compared to rumen active fat supplementation. Calcium soaps are known to undergo biohydrogenation (Jenkins & Palmquist, 1986) even though they have no influence on fibre digestion in ruminants (Jenkins & Palmquist, 1984). Wu *et al.* (1991) found that the net biohydrogenation of unsaturated fatty acids of calcium salts of long chain fatty acids was ±50%. This suggested that calcium soaps were only partially protected from biohydrogenation in the rumen. Supplemental animal-vegetable fat was biohydrogenated extensively in the rumen of lactating dairy cows and this was associated with a lower digestibility of total fatty acids in the intestine compared with cows fed a control diet containing no fat (Wu *et al.*, 1991). The fatty acid profile of Morlac is presented in Table 1.

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Table 1. Typical Fatty acid profiles of Morlac (M) and Golden Flake (GF).

	MORLAC	GOLDEN FLAKE
Fat content	86.0	98.4
Energy value (MJ/kg)	24.0-33.0	36.8
FATTY ACID %		
C12:0 (Lauric)	1.2	0.1
C14:0 (Myristic)	1.5	1.6
C16:0 (Palmitic)	48.0	48.6
C18:0 (Stearic)	4.5	31.0
C18:1 (Oleic)	35.0	15.2
C18:2 (Linoleic)	8.0	
C18:2 (Linoleic) +C18:3 (Linolenic)		2.8
CALCULATED:		
Saturated %	55.2	81.3
Unsaturated %	43.0	18.0

Golden Flake (GF)

The ADAS Feed Evaluation Unit at Stratford examined the solubility of Golden Flake in the rumen of sheep with the dacron bag technique. The results show that only 9% of the product was immediately soluble. The effective overall solubility, in the rumen of a high producing dairy cow, was estimated at a maximum of 39%. With this small soluble fraction containing approx. 80% long chain saturated fatty acids (C16-C18), the actual rumen protection is correspondingly estimated at ±90% and the effects on cellulose digestion is minimal. These results indicate that Golden Flake is a highly effective source of rumen protected fat (GF: Tech. Bull. A1, 1988). Similar results were obtained from a trial conducted at Barcelona University, Veterinary Division using adult heifers. The maximum solubility was found to be 24%. As 80% of this soluble fraction will be long chain fatty acids, minimum rumen protection could be estimated at 95% (GF: Tech. Bull. B1, 1989).

The ADAS Feed Evaluation Unit at Stratford examined the feeding of Golden Flake at 4.5% total ration dry matter (DM) representing 11% of the compound. The effects on the degradability of DM and neutral detergent fibre (NDF) of the forage were measured together with changes in rumen pH, lactic and volatile fatty acids (VFA) against the levels from a control ration. The results indicate that for the lactating dairy cow, there would be no significant effect on the rate of NDF degradation, rumen pH or total VFA concentration and molar percentage acetate and propionate, when GF is fed at levels up to 11% of the

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concentrate fraction. Therefore, when used in practice, GF will not adversely affect cell wall digestibility, or alter rumen fermentation, even when fed at 2 to 3 times conventional feeding levels. Most of the evidence in the literature (Van Soest, 1982) suggests that any effect of dietary unsaturated fatty acids on rumen VFA production is mediated through suppression of the methanogenic bacteria. Since methane production is reduced, the additional metabolic hydrogen is diverted into propionate production, a process that is energetically more efficient (GF: Tech. Bull. A2:1989).

The ADAS Feed Evaluation Unit at Stratford also examined the apparent digestibility of Golden Flake and its effects on the cell wall digestibility of the rest of the diet. Three diets comprising grass silage and compound feed, containing 0, 2.5 and 5% GF, were fed to adult ruminants. The effective apparent digestibility of added GF was found to be 0.95 and 0.88, when using the ether extract methods of faecal fat analysis respectively. True digestibility will lie somewhere between these values. Even at a higher rate of inclusion (5% of compound), the additional GF did not cause any significant reduction in cell wall digestibility. In fact, the apparent digestibility of the whole diet fat content increased significantly, and in a linear fashion, with increasing fat supplementation. The high digestibility seen in this trial shows how well GF is emulsified in the intestine. In the ruminant, fats are absorbed almost entirely as free fatty acids. The time duration in the duodenum and jejunum is short and phospholipid emulsification is required for absorption. Therefore, it is very important that added fat supplements (protected fats) enter the duodenum as free fatty acids as opposed to triglycerides. This means that no enzyme exposure or acid dissociation is required before absorption. The degree of absorption from the intestine is partially related to the melting point but efficiency of absorption of C16:0 and C18:0 from the diet can be improved when included in the diet in a finely divided form, or melted into a cube which will greatly improve its emulsification properties (GF: Tech. Bull. A3, 1990). An independent trial conducted on mature wether sheep at the Swiss Agricultural College, Zollikofen, looked at the digestibility of GF in sheep and gave a Metabolizable Energy value of 36.96 MJ/kg. GF was incorporated into this diet at levels above 12.5% of DM (*viz* over five times the suggested feeding rate). This very high level of GF inclusion had a small adverse effect on the apparent digestibility of DM, OM, crude fibre, NFE, ADF and NDF, the effect ranging from 2-10% (GF: Tech. Bull. B3, 1996).

An important feature of palm oil fatty acid-based products is the high content of C16:0 (palmitic acid). Animal fats and other vegetable oils have a much higher content of C18 fatty acids (stearic, oleic, linoleic, linolenic etc.). When hydrogenated, the "protected" products have a high content of C18:0 (stearic acid) which is known to have a much lower digestibility than palmitic acid (Grummer & Carroll, 1988). However, when stearic acid is fed in association with a high palmitic acid content, the digestibility is clearly enhanced as in GF. Hardened palm oil fatty acid-based products such as GF have an ideal fatty acid profile for rumen protection and subsequent digestibility in the small intestine (Grummer & Carroll, 1988; Sklan *et al.*, 1990) (GF: Tech. Bull. A4, 1996).

An independent field trial was conducted by a Veterinary Surgeon on a farm in the Pyrenees. This field trial looked at the effects of feeding two types of protected fat on the yields of adult dairy cows. The results showed clear advantages to the use of palm oil based protected fats in early lactation. All diets were the same apart from the fat treatments, which were fed in a loose form, top dressed onto fresh cut grass. The control diet had no added fat whilst the other two groups were fed 400 g Golden Flake or 400 g of a calcium salt of palm oil, respectively. When compared with those on the control diet, the Ca soap supplemented cows showed a 17% improvement in milk yield whilst the Golden Flake supplemented cows showed a 30% advantage. Some of this advantage over the Ca salt treatment, could be explained by the higher energy content of GF when fed on the same basis i.e. 400 g/day (GF: Tech. Bull. C2, 1989).

Two separate farms, in Canada, were used in another field trial. The fats were offered free-choice for 7 days in separate containers (cafeteria style). Containers were rotated daily to reduce the chances of the cows forming a "geographical" preference. The ranking in terms of palatability were as follows: Golden Flake > Booster Fat > Megalac > Energy Booster 100 > Alifet. Golden Flake was shown to be highly palatable when tested on farm (GF: Tech. Bull. C1, 1991).

A trial was conducted by the Commercial Research Unit on the effects of supplementing a major commercial beef finishing ration with Golden Flake. Three diets containing 0, 2.5 and 5.0% GF were fed to Hereford × Friesian bulls during the last 12 weeks prior to slaughter. A fourth treatment looked at feeding 2.5% GF for 28 days followed by 5.0% through until slaughter. GF improved food conversion over the control diet at higher fat inclusion, such

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that a benefit would be seen on farm. This was most significant in the first 42 days, when the GF fed bulls showed a 15% improvement in FCR over the control diet, regardless of oil level. One query that these studies have raised is that of the most effective time period over which this extra energy is required. It appears that if extra energy is given too soon, feed intake can be reduced and consequently performance will suffer. Even if performance then improves, the initial reduction in performance may delay finishing of the animal. Bulls showed a significant improvement in FCR (approx. 15%) over the control group regardless of oil level. It is possible that the metabolism adapts to the additional energy after 6-8 weeks, which is why the response in terms of growth decreases after this time. This seems to agree with previous studies, suggesting that this 'energy boost' is most successful in the final 60 days of finishing. The highest oil level did not adversely affect carcass quality in terms of fat content. In fact, carcasses from GF diets were leaner than the control (GF: Tech. Bull. C6, 1990).

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7 CONCLUSION

The major objective for the veal producer is to produce healthy animals, with optimum growth rates and feed efficiency, that will yield pink veal of acceptable carcass, meat and eating quality. In order to produce the optimum growth rates, beef producers have to increase the energy density of the finishing rations, especially when feed intake may limit growth performance. One of the areas that have enjoyed research is that of protected fats which are commonly used in lactating cow diets. Recent reports have suggested that steers in the finishing stages need higher levels of fat in the diet than that currently recommended, so as to ensure good growth and condition.

There is a great need to investigate the effect of supplementing calf starter- and finishing diets with rumen inert fat sources, for example Morlac or Golden Flake. These protected fat sources do not have a negative effect on fibre digestion in the rumen as do unprotected fat sources. This way the fat structure does not get altered in the rumen, via hydrolyses and hydrogenation, and provide the animal directly, with a high energy source. The same principal applies for the protein degradability of the diet. In the high degradable protein diets, the protein is altered by the rumen micro-organisms and microbial protein, resulting in a totally different protein structure reaching the small intestine. It is therefore difficult to predict the performance of an animal when the microbes change the protein and fat structure before it reaches the lower intestines. However, when the protein and fat is protected from rumen fermentation, a more accurate estimate of the expected performance can be calculated.

The most important factor in veal production is the end product, which the consumer wants to purchase. Thus, the fatty acid content of the muscle is an important aspect for research as customers buy for leanness (health) and the cut presented for sale (colour). Customers often first look at the colour and brightness of the meat before considering the health aspects.

One problem facing future South African veal markets is the general lack of knowledge among consumers about how to buy veal and how to cook it. Veal sales could be improved by an advertising campaign firstly, promoting its health (low fat) and quality aspects (tenderness, juiciness) and secondly, recommending better ways of cooking and presenting veal.

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CHAPTER 2

THE EFFECT OF RUMEN INERT FAT SUPPLEMENTATION AND PROTEIN DEGRADABILITY IN STARTER AND FINISHING DIETS ON VEAL CALF PERFORMANCE.

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ABSTRACT

Six groups each with six Friesian bull calves were used in this investigation and slaughtered at 20 weeks of age. Calves received a low- (LD) or high (HD) degradable protein diet, each with or without rumen inert fat supplementation. Two commercial fat sources were used, Morlac (m) and Golden Flake (gf), included at 2.5% of the diet. A commercial milk replacer (Denkavit) was fed at 4L for 42 days, followed by 2L until weaning at 49 days of age. The starter diets were fed *ad lib.* from day 14 to 10 weeks of age and finishing diets *ad lib.* from 11 to 20 weeks of age. There were no significant differences in body mass gain or dry matter intake over the entire 20 week period. The feed conversion ratio (FCR) was improved significantly (P=0.0032) when fat was supplemented to LD, but not to HD diets. The FCR (kg dry matter/ kg gain) of LD, HD, LDm, HDm, LDgf and HDgf diets were 3.45, 3.44, 3.07, 3.81, 3.02 and 3.43, respectively. All 36 calves were used in a digestibility trial, using chromium oxide (Cr_2O_3) as a marker, during week 18 of the investigation. Digestibility values (%) for the six diets (LD, HD, LDm, HDm, LDgf and HDgf) were 61.74, 65.91, 75.44, 69.00, 75.54 and 67.15 for dry matter, 61.44, 61.60, 71.33, 68.23, 75.44 and 66.12 for crude protein and 58.56, 66.45, 75.98, 70.92, 78.43 and 70.79 for fat, respectively. The dry matter (P=0.0001) and fat (P=0.0001) digestibilities were only significantly higher when fat was added to LD diets. The crude protein (CP) digestibilities were significantly higher when fat was added to either the LD (P=0.0001) or the HD (P=0.0488) diets. It was concluded that there was a positive response in CP digestibility when rumen inert fats were supplemented to LD or HD diets, although a greater response was shown in the LD diets. The FCR, dry matter and fat digestibility were only increased when fat was added to the LD and not to the HD diets.

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INTRODUCTION

The total crude protein content required in calf starter- and finishing diets (Lee & McCoy; Stiles *et al.*; 1974) and different protein sources utilised therein, have been well documented (Morrill & Dayton, 1978; Fluharty & Loerch, 1995). However, researchers are not able to reach consensus on what the crude protein levels should be. For example, in some trials calves fed diets containing only 12 to 13% protein grew as well as calves fed higher protein diets (Gardner & Kunz; Morrill & Melton, 1973). Leibholz & Kang (1973) found that calves fed diets containing 15% protein gained as much as those fed 18% but that their nitrogen retention was lower. Schurman & Kesler (1974) reported similar growth and feed efficiency for calves on diets containing 14,3 or 26% protein, with a higher nitrogen balance for those on diets containing 26% protein. However, in other trials the calves gained more when the CP content was higher (Stobo *et al.*,1967; Leibholtz & Kang, 1973). Bartley (1973) reported that calves fed diets containing 20% protein gained more than those receiving 16%. Akayezu *et al.*, (1994) found that when calves were fed starter diets which contained lower protein contents of 15 or 16.8% only a moderate growth rate was observed. Whereas the calves on the 19.6%CP diet showed maximum growth and there was no advantage gained from a higher protein content (22.4%).

There is however a need for research on the effect of dietary protein degradability in the rumen on veal calf performance. Likewise, using fat supplementation to increase the energy density in diets for feedlot steers and dairy cows have been widely documented (Fluharty & Loerch, 1997), but a lack of information exists regarding rumen inert fat supplementation in calf starter and finishing diets. The current study was designed to investigate the effect of rumen inert fat supplementation and the degradability of the protein on veal calf performance.

MATERIALS AND METHODS

Animals

Thirty-six Friesian bull calves, 2-5 days of age, were stratified according to initial mass and entered into six blocks. Calves in each block were randomly allocated to six treatments. Individual housing was provided in pens with wooden slatted floors and straw bedding. The calves were weighed weekly, during the starter and fortnightly during the finishing period, after fasting for 12 hours. The calves were slaughtered at 20 weeks of age and the carcass

mass (body without the head, feet skin and stomach) and dressing percentage (carcass mass (kg)/live mass (kg)) was determined (Table 4).

Diets

All calves received 4L of a commercial milk replacer (Denkavit, Johannesberg, RSA) until 42 days of age, and then 2L until weaning at 49 days. Starter diets were offered *ad lib*. from 14 days until 10 weeks of age, and finishing diets *ad lib*. from 11 to 20 weeks of age. Starter- and finishing diets were formulated to be iso-nitrogenous, but differed in crude protein (CP) degradability and energy content. The CP content was 18% and 14% for the starter- and finishing diets, respectively. Treatments were LD (low degradable protein) and HD (high degradable protein) each with, or without, rumen inert fat supplementation. Two rumen inert fat sources were used, *viz*. Morlac (Marine Oil Refiners, Dido Valley, Simon's Town, RSA) and Golden Flake (Veekon, Silverton, Pretoria, RSA). The total mixed diets were pelleted and their physical composition is presented in Table 1.

Table 1. Physical composition (% of ingredients) of calf starter diets to determine the effect of rumen inert fat supplementation and protein degradability on calf performance.

Item	STARTER DIETS						FINISHING DIETS					
	LD	HD	LD +m	HD +m	LD +gf	HD +gf	LD	HD	LD +m	HD +m	LD +gf	HD +gf
Maize meal	60	50	57.5	47.5	57.5	47.5	63.0	60.0	60.5	57.5	60.5	57.5
Fish meal	6	0	6	0	6	0	6	0	6	0	6	0
Prime gluten(60)	7	0	7	0	7	0	4	0	4	0	4	0
Sunflower oil cake	0	23	0	23	0	23	0	13	0	13	0	13
Molasses	5	5	5	5	5	5	5	5	5	5	5	5
Lucerne hay	15	20	15	20	15	20	0	14	0	14	0	14
Oat hulls	5	0	5	0	5	0	0	0	0	0	0	0
NaOH-wheat straw	0	0	0	0	0	0	20	6	20	6	20	6
Salt	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Mineral premix	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Romensin	0	0	0	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01
Morlac	0	0	2.5	2.5	0	0	0	0	2.5	2.5	0	0
Golden flake	0	0	0	0	2.5	2.5	0	0	0	0	2.5	2.5
CALCULATED												
Energy (MJ/kg)	12.0	11.9	12.4	12.3	12.6	12.5	11.9	12.0	12.3	12.4	12.5	12.6

LD = Low degradable protein HD = High degradable protein m = Morlac gf = Golden Flake

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Crude Protein Degradability

The dry matter content and the crude protein degradability of the six starter- and finishing diets were determined *in situ* by 24h rumen incubation in three ruminally cannulated non-lactating Friesian cows (Table 3). All the feeds were milled through a 4mm screen. Five grams (as is) of each feed were weighed into dacron bags (pore size 53µ) and the DM of each feed determined separately. Two bags per diet were placed into a netted nylon bag and then into the rumens of the three cows. To ensure that the dacron bags did not clog together in the nylon bags, each nylon bag was divided into three compartments, with only four bags in each compartment. At the end of the incubation period, the bags were removed and washed thoroughly by hand under running water. The bags were dried at 50 °C for 24h and then weighed.

Digestibility Trial

All the calves were used in a digestibility trial at 18 weeks of age. Gelatine capsules containing 2.5g of Chromic III Oxide were administered twice daily, at 8:00am and 16:00pm, with the aid of a balling gun. The administration of the Chromic III Oxide started 9 days prior to the collection period to ensure uniform excretion of the Chromic III Oxide in the faeces, and continued until the end of the faecal collection period. Faecal grab samples were collected twice daily for 7 days. Total feed intake was also determined over this period. The faecal samples were frozen directly after collection and composited at the end of the collection period. These samples were dried at 55°C in a forced draught oven, ground through a hammer mill (1mm screen) and stored in sample bottles for chemical analysis.

Chemical Analysis

Chemical analysis was performed on feed and faecal samples after passing samples through a hammer mill with a 1mm sieve. Feed and faecal samples were analysed for dry matter, organic matter, Kjeldahl nitrogen (N), crude fibre (AOAC, 1990) and lipid extraction by the acid hydrolysis procedure (AOAC No 922.06, 1996). The chemical composition of the diets is presented in Table 2.

Table 2. The chemical composition of the starter and finishing diets fed to calves.

Analysis	STARTER DIETS						FINISHING DIETS					
	LD	HD	LD +m	HD +m	LD +gf	HD +gf	LD	HD	LD +m	HD +m	LD +gf	HD +gf
DM	90.34	90.87	90.66	90.10	87.94	88.95	91.95	91.99	92.28	92.74	91.53	92.96
OM	94.69	94.53	94.03	94.06	94.74	94.54	95.74	95.63	95.26	95.40	95.35	95.54
CP	17.28	18.20	17.15	17.06	17.63	17.91	14.08	12.42	14.40	12.70	14.76	11.82
CF	7.50	11.64	8.12	13.03	8.05	13.91	11.07	12.70	10.49	12.83	9.58	12.51
LP	4.71	4.17	6.60	4.81	6.59	5.43	3.68	3.52	4.79	4.58	5.62	4.71

LD = Low degradable protein m = Morlac DM = Dry matter CP = Crude protein
HD = High degradable protein gf = Golden Flake OM = Organic matter CF = Crude fibre
LP = Lipid

In addition to the pelleted diets, all calves received lucerne hay from week 5 to10. The lucerne had the following chemical composition (%): DM=88.75, OM=87.79, CP=18.73, CF=27.89.

Determination of chromium concentration in faeces

A wet digestion using concentrated sulphuric acid, nitric acid and perchloric acid was executed, followed by a suitable dilution of 8-hydroxyquinoline to suppress the interference of iron and reduce all chrome to the trivalent form. The chromium concentration was determined by atomic absorption spectrophotometry, using calibration standards prepared similar to that for the samples. Either air/acetylene or nitrous oxide/acetylene flame can be used, but in the present data the air/acetylene flame was used (Johnson, 1999).

Statistical Analysis

The data was analysed by ANOVA using the GLM procedure of SAS (1988). Different contrasts were used to indicate the differences between treatments. These contrasts are presented in the ANOVA tables to follow. Three main contrasts were used *viz.* FAT, PROTEIN DEGRADABILITY and the interaction between fat and protein degradability (FAT*PROT.DEG.). FAT was further subdivided into two contrasts *viz.* (I) none vs. rest, i.e. no fat supplementation was compared to fat supplementation, and the protein degradability and different fat sources were ignored, and (ii) Morlac vs. Golden flake, i.e. the two fat sources, were compared and protein degradability ignored. In the second contrast, PROTEIN DEGRADABILITY, the low degradable treatments were compared to the high degradable treatments, ignoring fat supplementation. The interaction between fat and protein

degradability (FAT* PROTEIN DEGRADABILITY) was further subdivided into firstly (none vs. rest)*protein degradability, i.e. the interaction of protein degradability with no fat supplementation vs. the interaction of protein degradability with fat supplementation. The second subdivision (Morlac vs. Golden Flake)*protein degradability i.e. the interaction of each fat source with protein degradability was also compared.

RESULTS & DISCUSSION

Crude Protein Degradability

Mean CP degradability values in the starter diets were 31.3 and 73.2 % for low- and high degradable diets, respectively. Mean CP degradability values in the finishing diets were 22.47 and 56.0 % for LD and HD, respectively. The expected RDP fraction was calculated before the trial and compared to the RDP protein fraction determined *in situ* in the present investigation (Table 3). The average RDP calculated for LD starter was 8.79 and finishing diets 6.21 and the determined values 5.44 and 3.24, respectively. The average RDP calculated for HD starter diets was 12.32 and finishing diets 9.20 and the determined values 13.00 and 6.93, respectively. The RDP fraction was thus overestimated for the LD diets as well as for the HD finishing diets.

Table 3: The dry matter content and the crude protein degradability of the six starter- and finishing diets as determined *in situ* by 24h rumen incubation using non lactating Friesian cows.

Item	STARTER DIETS						FINISHING DIETS					
	LD	HD	LD +m	HD +m	LD +gf	HD +gf	LD	HD	LD +m	HD +m	LD +gf	HD +gf
DMD	71.29	75.64	64.57	70.42	72.00	75.76	59.62	66.34	65.82	69.30	65.36	66.22
CPD	31.62	70.68	26.42	63.06	35.82	85.86	23.02	48.02	18.48	73.88	25.91	46.14
CP	17.28	18.20	17.15	17.06	17.63	17.91	14.08	12.42	14.40	12.70	14.76	11.82
RDP^1	5.46	12.86	4.53	10.76	6.32	15.38	3.24	5.96	2.66	9.38	3.82	5.45
RDP^2	8.88	12.42	8.75	12.27	8.75	12.27	6.30	9.29	6.17	9.15	6.17	9.15

LD = Low degradable protein
HD = High degradable protein
m = Morlac
gf = Golden Flake
DMD = Dry matter degradability
CPD = Crude protein degradability
RDP^1 = Degradable protein content as determined *in situ*
RDP^2 = Degradable protein as calculated

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Calf performance

The results on body mass gain, feed intake, feed conversion ratios and carcass data are presented in Table 4. The data was divided into three periods: the starter period from week 0 to 10 (W0-10), the finishing period from week 11 to 20 (W11-20) and the entire trial period from week 0 to 20 (W0-20) during the investigation. Zero calf mortalities were encountered.

Table 4. Body mass gain, dry matter intake and feed conversion ratio for the different experimental periods and the carcass data for calves receiving diets differing in fat content and crude protein degradability.

Item	TREATMENTS						
	LD	HD	LD +m	HD +m	LD +gf	HD +gf	SEM
STARTER DIET W 0-10							
Body mass gain (kg)	47.55	45.35	44.60	40.00	48.30	46.18	2.45
Total DMI (kg)	114.21	108.18	102.67	98.76	111.88	110.90	4.80
FCR (DMI/kg gain)	2.43	2.38	2.31	2.49	2.32	2.43	0.07
FINISHING DIET W 11-20							
Body mass gain (kg)	90.85	96.22	97.92	82.40	97.17	94.56	5.05
Total DMI (kg)	311.02	328.33	300.38	313.93	292.82	323.66	14.95
FCR (DMI/kg gain)	3.45	3.44	3.07	3.81	3.02	3.43	0.10
TOTAL PERIOD W0-20							
Body mass gain (kg)	138.40	141.57	142.52	122.40	145.47	140.74	6.12
Total DMI (kg)	425.23	436.51	403.05	412.69	404.70	434.56	17.96
FCR (DMI/kg gain)	3.09	3.09	2.83	3.38	2.79	3.08	0.07
Carcass mass (kg)	88.42	92.75	92.25	80.80	90.33	91.00	2.88
Dressing %	49.44	50.98	50.53	48.98	48.13	49.62	0.63

Starter Diet (W0-10)

Statistical parameters for starter intake during week 0-10 are presented in Tables 5 & 6. No significant differences between the treatments were observed in total body mass gain (Table 5).

There was, however, a significant difference in the total DMI of calves on the diets containing different rumen inert fat sources (Tables 5 & 6). The calves receiving Morlac had a

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significantly lower total DMI than those receiving Golden Flake (P=0.0354) irrespective of the protein degradability. The calves receiving no fat supplementation had similar intakes than those receiving Golden Flake. The protein degradability of the diets had no significant effect on the total DMI.

Table 5. ANOVA table for the calves during the starter period (W0-10).

Source of variation	df	Mass Gain		Total DMI		F.C.R.	
		MS	P	MS	P	MS	P
Block	5	94.50	**0.0485**	366.17	**0.0471**	0.0775	0.0597
FAT	2	84.58	0.1160	447.62	**0.0562**	0.0022	0.9339
None vs. Rest	1	22.53	0.4362	211.29	0.2279	0.0017	0.8178
Morl vs. Gold	1	146.62	0.0544	683.95	**0.0354**	0.0026	0.7757
PROTEIN DEGRAD.	1	79.36	0.1500	119.36	0.3618	0.0600	0.1789
FAT*PROT DEG.	2	5.98	0.8479	19.33	0.8702	0.0387	0.3089
(None vs. Rest)*prot.deg.	1	2.70	0.7864	25.78	0.6696	0.0703	0.1470
(Morl vs. Gold)*prot.deg.	1	9.25	0.6166	12.88	0.7628	0.0070	0.6407
Error	25	35.98		138.29		0.0314	

Table 6. Mean DMI of calves receiving the different starter diets.

Protein Degradability	FAT SOURCE		Morl vs. Gold
	Morlac	Golden Flake	
Low	102.67	111.88	
High	98.76	110.90	
AVG	**100.72**	**111.39**	**P = 0.0354**

Fat supplementation has been known to have a negative effect on fibre digestion in the rumen which would result in a decrease in DMI (Palmquist, 1991). The inclusion of rumen inert fat, rather than rumen degradable fat, was intended to counteract this effect. Morlac diets showed a much lower DMI than the Golden Flake diets. An explanation could be that the calcium soaps (Morlac) have a negative effect on digestion. Jesperson (1993) tested Morlac *in vitro* and found that the calcium soups are hydrogenated immediately at the start of fermentation and reached a maximum plateau at approximately 12 hours. However, no digestion of the calcium soaps occurred. Inert fat supplements are not excluded from being hydrolysed (if a triglyceride) or being hydrogenated (if unsaturated) in the rumen. Thus, rumen inertness simply means that the fat or fatty acid supplement does not alter or affect rumen fermentation.

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Calcium soaps are known to undergo biohydrogenation (Jenkins & Palmquist, 1986) even though they have no influence on fibre digestion in ruminants (Jenkins & Palmquist, 1984). Wu *et al.* (1991) found that the net biohydrogenation of unsaturated fatty acids of calcium salts of long chain fatty acids, was ±50% and they suggested that calcium soaps were only partially protected from biohydrogenation in the rumen. When animal-vegetable fat was added to the diets of lactating dairy cows, extensive biohydrogenation took place in the rumen and this was associated with a lower digestibility of total fatty acids in the intestine compared with cows fed diets containing no fat (Wu *et al.*, 1991).

Palatability could be another explanation for the difference in DMI. Golden Flake proved to be very palatable to young calves. Two separate farms in Canada were used in a field trial where fats were offered free-choice for 7 days in separate containers (cafeteria style). Containers were rotated daily to reduce the chances of the cows forming a "geographical" preference. The ranking in terms of palatability was as follows: Golden Flake > Booster Fat > Megalac > Energy Booster 100 > Alifet. (GF: Tech. Bull. C1, 1991).

Fisher (1980) found that starter intake was similar for the two protein sources, but significantly less for the ration containing 10% protected lipid compared to either the 0 or 20% levels. Body mass gain was greater for calves fed the starter containing 20% protected lipid compared to those fed the 10% level. Efficiency of feed conversion was better for calves receiving a protected lipid. It was concluded that the inclusion of protected lipid improved feed conversion of calves from 43 to 70 days of age. Since the protein level was 22%, it was concluded that growth rate was being limited by the energy density of the starter ration and/or level of intake rather than the protein content of the diet. The efficiency of conversion, although not influenced by source of protein, was notably improved with increasing levels of protected lipid in the ration (Fisher, 1980). Waldern & Fisher (1978) added unprotected tallow to calf diets and found a lack of improvement in feed conversion. These contrasting results would indicate that the protected tallow was used more efficiently than unprotected tallow for calves (Fisher, 1980).

Doppenberg & Palmquist (1991) found that a higher dietary fat content resulted in a lowered ADG of ruminating calves and an increased ADG of liquid-fed calves. Calves fed higher fat dry diets adapted slowly to weaning, with frequent bloating. The higher fat content probably interfered with normal rumen microbial development (Palmquist & Jenkins, 1980).

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In this investigation, lucerne was fed *ad. lib.* to all six groups from W5-10 (Table 7). Lucerne was fed to counteract bloat in one LD Golden Flake calf and one LD Morlac calf. The analysis of variance (Table 7) shows that for lucerne intake, there was an interaction between rumen inert fat supplementation and the degradability of the protein (FAT*PROT.DEG.) in the diets (P=0.0046). The contrast (none vs. rest*prot.deg.) shows that there was no interaction between no fat supplementation and fat supplementation with protein degradability (P=0.0982).

Table 7. ANOVA table for the lucerne intake from W0-10.

Source of variation	df	MS	P-value
Block	5	5.81	0.0650
FAT	2	14.86	0.0067
None vs. Rest	1	24.31	0.0040
Morlac vs. Golden flake	1	5.42	0.1466
PROTEIN DEGRADABILITY	1	35.20	0.0008
FAT*PROT.DEG.	2	16.25	**0.0046**
(None vs. Rest) * prot.deg.	1	7.12	0.0982
(Morl vs. Gold) * prot.deg.	1	25.38	**0.0033**
Error	25	2.41	

The contrast (morl vs. gold*prot.deg.) shows that there was a significant interaction between the two fat sources and protein degradability (P=0.0033) (Table 8). There was a significant difference between Morlac and Golden Flake when the protein degradability was low, but not when it was high. The LD Golden Flake resulted in significantly higher lucerne intakes.

Table 8. Mean Lucerne intake of calves receiving the different treatments.

Protein Degradability		FAT SOURCE		(Morl vs. Gold) *prot.deg.
	None	Morlac	Golden Flake	
Low	1.83	**3.01**	**6.02**	**P=0.0033**
High	1.11	2.46	1.35	

The chemical analysis of the feed indicated a lower average crude fibre content for the LD diets (Table 2). The high DMI of the GF suggested a high passage rate through the rumen, which could have lead to lower fibre digestion. The lower fibre digestibility actually observed and the low fibre content of the LD diets, could explain the stimulus for higher lucerne intake. The added fat showed an even higher lucerne intake, but only in the LD diets.

The fatty acids in the LD diets, which are mostly derived from sunflower oil cake meal, are available for normal rumen fermentation. This could have a negative effect on fibre digestion. Another observation, which might explain the higher lucerne intake by the Golden Flake treatments, was that the feed pellet quality was lower. The high fat content of these diets was responsible for the poor pill quality; these diets crumbled into a powder much faster than the other diets. According to Brooks, *et al.* (1954) the addition of corn oil or lard has a depressing effect on cellulose and crude protein digestion. This effect was partially overcome by the addition of alfalfa ash in their study.

Finishing Diets (W11-20)

There were no significant differences in total body mass gain or total DMI between the treatments during the last growth phase (W11-20) of this investigation. There was, however, a significant difference in the feed conversion ratio between the treatments. The analysis of variance (Table 9) showed that there was an interaction for FCR between rumen inert fat supplementation and the degradability of the protein (FAT*PROT.DEG.) in the diets (P=0.0040). The contrast (none vs. rest*prot.deg.) further showed that there was an interaction between no fat supplementation and fat supplementation with protein degradability (P=0.0026). The contrast (morl vs. gold*prot.deg.) indicated no significant differences between the two fat sources and protein degradability (P=0.1141).

Table 9. ANOVA table for the calves receiving finishing diets (W11-20).

Source of variation	df	Mass Gain		Total DMI		F.C.R.	
		MS	P	MS	P	MS	P
Block	5	80.20	0.7563	1251.60	0.4765	0.0371	0.6894
FAT	2	98.54	0.5342	577.26	0.6550	0.1973	0.0547
None vs. Rest	1	2.20	0.9056	1147.40	0.3639	0.0975	0.2152
Morl vs. Gold	1	194.88	0.2701	7.07	0.9427	0.2970	0.0358
PROTEIN DEGRAD.	1	162.78	0.3126	3807.90	0.1045	1.3148	0.0001
FAT*PROT.DEG.	2	333.23	0.1347	247.93	0.8324	0.4182	**0.0040**
(None vs. Rest)*prot.deg.	1	416.40	0.1118	47.71	0.8519	0.6747	**0.0026**
(Morl vs. Gold)*prot.deg.	1	250.07	0.2132	448.16	0.5684	0.1617	0.1141
Error	25	153.24		1341.4		0.0603	

A further analysis of variance was done to determine whether fat supplementation was significant for both the low and high degradable protein diets (Table 10). It was found that

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there was no significant differences when the protein degradability was high (P=0.1552). There was, however a significant improvement in FCR when fat was added to the low degradable diets (P=0.0032). It appears that an increase in energy density by means of rumen inert fat supplementation, as well as a high quality protein inclusion in the diet, can be expected to result in the more favourable feed conversion ratios. This was not observed in the first 10 weeks of age and it can be speculated that rumen development was responsible for manifesting the difference observed between the HD and LD diets in the growth period. It therefore appears that by-pass protein only becomes important in calf diets after 10 weeks of age, when the rumen has become functional.

Table 10. Mean Feed Conversion Ratio for the different finishing diets.

Protein Degradability	None	FAT SOURCE Morlac	Golden Flake	REST (m&g) AVG	None vs. Rest
Low	**3.45**	3.07	3.02	**3.05**	**P=0.0032**
High	3.44	3.81	3.43	3.62	P=0.1552

Total Trial Period (W0-20)

There were no significant differences in the total body mass gain or total DMI between the treatments for the contrasts tested) over the whole investigation period. However, the feed conversion ratio showed significant differences between treatments (within the tested contrasts). The analysis of variance (Table 11) shows the same tendency as was observed during the finishing period, *viz*. an interaction between fat supplementation and protein degradability. Again, there were no significant differences in protein degradability when there was no fat supplementation, and the effect of fat was only observed when added to the low degradable protein diets. There was therefore a statistically significant interaction (FAT*PROT.DEG.) between fat supplementation and protein degradability (P=0.0043). The contrast (none vs. rest*prot.deg.) further indicated that there was an interaction between no fat supplementation and fat supplementation with protein degradability (P=0.0028). Fat source (morl vs. gold*prot.deg.) had no effect (P=0.1013).

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Table 11. ANOVA table for the TOTAL TRIAL period (W0-20).

Source of variation	df	Mass Gain		Total DMI		F.C.R.	
		MS	P	MS	P	MS	P
Block	5	274.89	0.3271	2786.0	0.2269	0.0294	0.4924
FAT	2	359.25	0.2219	1586.8	0.4387	0.1107	0.0488
None vs. Rest	1	38.81	0.6812	2343.5	0.2727	0.0411	0.2708
Morl vs. Gold	1	679.68	0.0942	830.1	0.5105	0.1803	0.0265
PROT.DEGRAD.	1	469.37	0.1607	2579.0	0.2504	0.7028	0.0001
FAT*PROT.DEG.	2	420.77	0.1745	378.3	0.8176	0.2247	**0.0040**
(None vs. Rest)*prot.deg.	1	486.41	0.1536	143.6	0.7836	0.3556	**0.0028**
(Morl vs. Gold)*prot.deg.	1	355.12	0.2202	613.0	0.5714	0.0938	0.1013
Error	25	224.54		1862.9		0.0324	

A further analysis of variance was done to determine whether fat supplementation was significant for both the low and high degradable protein diets (Table 12). When rumen inert fat was added to low degradable protein diets, a significantly lower FCR was observed (P=0.0043).

Table 12. Mean feed conversion ratio for the different diets over the total trial period (total DMI (kg)/total body mass gain (kg)).

Protein Degradability	None	FAT SOURCE Morlac	Golden flake	REST (m&g) AVG	None vs. Rest
Low	**3.09**	2.83	2.79	**2.81**	**P=0.0043**
High	3.09	3.38	3.08	3.23	P=0.1346

No data could be found in the literature where Golden Flake was included in calf diets. A trial was conducted by the Golden Flake Commercial Research Unit to determine the effect of supplementing a major commercial beef finishing ration with Golden Flake. Three diets, containing 0, 2.5 and 5.0% GF, were fed to Hereford × Friesian bulls during the last 12 weeks prior to slaughter. A fourth treatment looked at feeding 2.5% GF for 28 days, followed by 5.0% until slaughter. Golden Flake improved feed conversion ratio over the control diet at higher fat inclusion, such that a benefit would be seen on farm (GF: tech. bull. C6, 1990).

Fallon *et al.*, (1986) found that the inclusion of low levels of calcium soaps of fat in calf diets may be beneficial in allowing an increase in fibre digestibility without reducing energy intake.

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However, when the proportion of calcium soap in the concentrate was 0.10 or greater, intake was reduced and nitrogen (N) retention decreased.

Three experiments were conducted by Fluharty and Loerch (1997) to determine the effects of supplemental fat [Megalac, a calcium soap of palm fatty acids (0 vs. 2%)] and CP concentration (12 vs. 14%) and CP source [spray-dried blood meal vs. soybean meal] in diets of newly received steers. They concluded that there was no benefit in increasing the energy density of a receiving diet by the addition of calcium soaps. Also, with high crude protein concentration, or diets containing supplemental ruminal escape protein, there may be detrimental effects of calcium soaps, due to decreased dry matter intake. In feedlot steers, Brandt & Anderson (1990) found that feeding fat increased daily gain, feed efficiency and estimated diet metabolizable energy concentration.

Digestibility Trial

In the determination of the digestibility of the diets using a chromium marker, all 36 animals were fed their respective experimental diets over a 16 day period. The mean digestibilities of the dry matter- (DM), crude protein- (CP), crude fibre- (CF) and fat are presented in Table 13 and the statistical parameters calculated in Table 14.

Table 13. Mean digestibility percentages calculated from the inert marker (Chrome Oxide) used in the digestibility trial.

Digestibility	FAT SOURCE (REST)						
	NONE		MORLAC		GOLDEN FLAKE		
	LD	HD	LD	HD	LD	HD	SEM
DM	61.74	65.91	75.44	69.00	75.54	67.15	2.48
CP	61.44	61.60	71.33	68.23	75.44	66.12	2.20
CF	33.66	37.43	53.87	42.51	32.91	24.92	4.04
FAT	58.56	66.45	75.98	70.92	78.43	70.79	2.36

Table 14. ANOVA table for percentages DM-, CP-, CF- and FAT digestibility.

Source of variation	df	%Dm digest.		%CP digest.		%CF digest.		%FAT digest.	
		MS	P	MS	P	MS	P	MS	P
Block	5	38.60	0.4135	58.76	0.1090	81.59	0.5379	104.75	0.0252
FAT	2	255.36	0.0041	309.88	**0.0004**	1151.3	**0.0003**	535.43	0.0001
None vs. Rest	1	506.15	0.0011	613.78	**0.0001**	72.42	0.3977	1062.8	0.0001
Morl vs. Gold	1	4.58	0.7278	5.98	0.6534	2230.1	**0.0001**	8.10	0.6274
PROTEIN DEGRAD.	1	113.74	0.0915	150.47	**0.0314**	242.63	0.1278	23.20	0.4134
FAT*PROT.DEG.	2	137.18	**0.0387**	69.57	0.1110	189.07	0.1658	208.02	**0.0065**
(None vs. Rest)*prot.deg.	1	268.66	**0.0123**	81.24	0.1064	361.04	0.0662	406.03	**0.0019**
(Morl vs. Gold)*prot.deg.	1	5.70	0.6977	57.91	0.1696	17.09	0.6796	10.01	0.5896
Error	25	36.93		28.95		97.82		33.53	

Dry Matter (DM) Digestibility

There was an interaction (FAT*PROT) between rumen inert fat supplementation and protein degradability (P=0.0387) (Table 14). The contrast (none vs. rest*prot.deg.) showed that there was an interaction between no fat supplementation and fat supplementation with protein degradability (P=0.0123). There was no significant difference between the fat sources (morl vs. gold*prot.deg.) (P=0.6977).

A further analysis of variance was done to determine whether the rumen inert fat supplementation was significant for both the low and high degradable protein diets (Table 15). A significantly higher DM digestibility was found when rumen inert fat was added to the low degradable protein diets (P=0.0001). When fat was added to the high degradable diets there was no significant effect on the %DM digestibility (P=0.4839). The reason why fat supplementation had an effect on low protein degradable diets is not apparent.

Table 15. Dry Matter Digestibilities calculated for calves receiving different treatments.

Protein Degradability	None	FAT SOURCE		REST (m&g AVG	None vs. Rest
		Morlac	Golden flake		
Low	**61.74**	75.44	75.54	**75.49**	**P=0.0001**
High	65.91	69.00	67.15	68.07	P=0.4839

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Crude Protein (CP) Digestibility

Diets containing the low degradable protein had a significantly higher crude protein digestibility than the high degradable protein diets (P=0.0314) (Tables 14 &16). A significant amount of the protein in the LD protein diets may be expected to have escaped rumen fermentation and would presumably have arrived in the mid-gut, containing more essential amino acids than the HD diets. This could explain the higher CP digestibility of the LD diets compared to the HD diets.

Table 16. The Crude Protein digestibility (percentage) calculated for calves receiving different treatments.

Protein Degradability	None	FAT SOURCE (Rest) Morlac	Gold.Flake	NONE + REST AVG	NONE + REST (morl + gold)	REST (m&g) AVG	NONE vs. REST
Low	61.44	71.33	75.44	**69.40**	**P=0.0314**	**73.39**	**P=0.0002**
High	61.60	68.23	66.12	**65.31**		**67.18**	**P=0.0488**

The diets containing rumen inert fat supplementation had significantly higher CP digestibilities (FAT) (P=0.0004) (Tables 14 & 16). There was a significant difference between no fat supplementation and diets with fat supplementation (P=0.0001). There was a significantly higher CP digestibility in both low (P=0.0002) and high (P=0.0488) degradable protein diets when fat was added (Table 16). There was no significant difference between the fat sources (Morl. vs. Gold.) (P=0.6534). The reason for the higher apparent CP digestibility of the high fat diets was not readily apparent. Fat inclusion resulted in increased energy density of the diets. It is possible that the higher energy: protein ratio had a beneficial effect on protein digestibility.

Crude Fibre (CF) Digestibility

A significant difference was found between the two fat sources (morl vs. gold) (P=0.0001), where Morlac resulted in a higher CF digestibility than Golden Flake. (Tables 14 & 17)

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Table 17. Crude Fibre digestibility (percentage) calculated for calves receiving different treatments.

Protein Degradability	None	FAT SOURCE Morlac	Golden flake	Morl vs. Gold
Low	33.66	53.87	32.91	
High	37.43	42.51	24.92	
AVG	35.55	**48.19**	**28.92**	**P=0.0001**

Calves that received Morlac had a significantly lower DMI in the starter diets (Table 4). In the finishing diets, the LD Morlac group had a lower DMI than GF or the control (Table 4). The lower DMI suggested a slow passage rate through the rumen, thus the fibre was exposed to digestion for a longer period of time. This could explain the higher fibre digestion in the Morlac diets.

Fat Digestibility

There was an interaction (FAT*PROT.DEG.) between rumen inert fat supplementation and protein degradability (P=0.0065) (Table 14). The contrast (none vs. rest*prot.deg.) shows that there was an interaction between no fat supplementation and fat supplementation with protein degradability (P=0.0019). There was no significant difference between the fat sources (morl vs. gold*prot.deg.) (P=0.5896).

A further analysis of variance was done to determine whether the rumen inert fat supplementation was significant for both the low and high degradable protein diets (Table 18). A significantly higher %FAT digestibility was found when rumen inert fat was added to low degradable protein diets (P=0.0001), but no effect was observed when fat was added to high degradable diets. The effect of protein degradability on fat digestibility could not be explained.

Table 18. Fat digestibility (percentage) calculated for calves receiving different treatments

Protein Degradability	None	FAT SOURCE Morlac	Golden Flake	REST (m&g) AVG	None vs. Rest
Low	**58.56**	75.98	78.43	**77.21**	**P=0.0001**
High	66.45	70.92	70.79	70.86	P=0.1410

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The LD protein diets with supplemented rumen inert fat resulted in significantly higher DM-, CP- and Fat digestibilities. There appears to be a favourable interaction between the LD protein and the added fat in the diets.

Carcass mass

The mean carcass masses of the calves are presented in Table 4. The analysis of variance (Table 19) shows that there was an interaction between rumen inert fat supplementation and the degradability of the protein (FAT*PROT.DEG.) in the diets (P=0.0285). The contrast (none vs. rest*prot.deg.) shows that there was no interaction between no fat supplementation and fat supplementation with protein degradability (P=0.0624).

Table 19. The ANOVA table for the carcass masses of calves on different treatments.

Source of variation	df	MS	P-value
Block	5	89.96	0.1476
FAT	2	67.26	0.2769
None vs. Rest	1	31.60	0.4329
Morlac vs. Golden flake	1	102.92	0.1627
PROTEIN DEGRADABILITY	1	41.60	0.3691
FAT*PROT.DEG.	2	204.69	**0.0285**
(None vs. Rest) * prot.deg.	1	189.15	0.0624
(Morl vs. Gold) * prot.deg.	1	220.22	**0.0456**
Error	25	49.73	

The contrast (morl vs. gold*prot.deg.) indicated a significant interaction between the two fat sources and protein degradability (P=0.0456). The difference between the fat sources was significant in the high degradable protein diets, but not in the low (Table 20). There was a significantly lower carcass mass in the treatment containing Morlac with high protein degradability. These calves also had the lowest total body mass gain over the trial period, but this could not be explained by DMI, because their total DMI was not the lowest.

Table 20. Mean carcass masses of calves on different treatments with the dressing percentage in parentheses.

Protein Degradability	None		FAT SOURCE (REST) Morlac		Golden flake		(Morl vs. Gold *prot.deg.
Low	88.42	[49.44]	92.25	[50.53]	90.33	[48.13]	
High	92.75	[50.98]	**80.80**	[48.98]	**91.00**	[49.62]	**P=0.0456**

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Fat supplementation did not increase the dressing percentage in the present trial. Gardner and Wallentine (1972) found that tallow added to the diet had not improved dressing percentage, a conclusion also supported by the observations made in a study by Fisher (1980). In contrast to these results, Brandt & Anderson (1990) found that supplemental fats increased the carcass masses and dressing percentages of steers. In a trial previously conducted on Golden Flake diets, the highest oil levels tested did not adversely affect carcass quality. In fact, carcasses from GF diets were leaner than the control (GF: Tech. Bull. C6, 1990).

CONCLUSION

Rumen inert fat supplementation and crude protein degradability in starter- and finishing diets for veal calves appear to have no effect on body mass gain. Results from the current study would suggest a favourable effect of rumen inert fat supplementation on FCR, but only when included in diets with low protein degradability. The effect appears to manifest only after 10 weeks of age, indicating the role of rumen activity. In LD diets, the UDP fraction of the protein provides the animal with essential amino acids, by by-passing rumen fermentation and the lipids are also protected from rumen microbial lipases. With fat addition to LD diets the protein to energy ratio is probably more ideal. Either of these two systems individually had no significant effect, but together had a positive effect on FCR and the digestibilities of these diets. These results would suggest that it should be economically viable to supplement starter and finishing diets with rumen inert fats. It appears as if the starter diet may contain higher degradable protein sources that are relatively inexpensive, but that low degradable protein becomes more important in the finishing period, after 10 weeks of age. There is a need for further research into the fatty acid content of the meat of these calves fed LD diets with rumen inert fat supplementation so as to determine whether the carcass lipid composition can be manipulated by feeding theses diets.

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CHAPTER 3

THE EFFECT OF RUMEN INERT FAT SUPPLEMENTATION AND PROTEIN DEGRADABILITY ON THE FATTY ACID COMPOSITION OF VEAL.

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ABSTRACT

Six groups of six Friesian bull calves were used in this investigation. Calves received a low- (LD) and high (HD) degradable protein diets each with or without rumen inert fat supplementation. Two commercial fat sources were used Morlac (m) and Golden Flake (gf) at 2.5% of the total diets. A commercial milk replacer (Denkavit) was fed at 4L for 42 days and 2L until weaning at 49 days. An early weaning system was used, where the starter diet was fed *ad lib.* from day 14 to 10 weeks of age and finishing diets *ad lib.* from 11 to 20 weeks of age. All the calves were slaughtered at 20 weeks of age and the fatty acid content of the meat (*m. longissimus*) and subcutaneous fat layer adjacent to the 12th rib as well as the meat colour, was determined. The fatty acid composition of the longissimus muscle was changed by feeding the rumen inert fat sources. The three predominant fatty acids found were palmitic, stearic and oleic acids. The palmitic acid (C16:0) content of the muscle and diet was 24.44 & 20.47, 25.97 & 22.57, 31.06 & 33.23, 30.98 & 37.91, 34.94 & 31.77 and 29.71 & 32.88 of the total fat for the LD, HD, LDm, HDm, LDgf and HDgf diets, respectively. The C16:0 content was significantly higher in the muscle of the calves receiving the LD diets supplemented with fat (P=0.0008). There was also a significant interaction between the two fat sources and protein degradability (P=0.0065), but only in the LD diets. The stearic acid (C18:0) content of the muscle and diet was 14.35 & 5.22, 19.65 & 8.61, 17.29 & 4.68, 22.59 & 5.78, 22.27 & 15.54, and 26.48 & 20.15 of the total fat for the LD, HD, LDm, HDm, LDgf and HDgf diets, respectively. The C18:0 content was significantly higher in the muscle of calves receiving the HD (P=0.0001) compared to LD diets. The stearic acid content was also significantly higher when fat was added to LD (P=0.0042) or HD (P=0.0073) diets. The oleic acid (C18:1) content of the muscle and diet was 36.06 & 21.51, 39.99 & 21.11, 32.21 & 23.67, 29.13 & 24.59, 25.23 & 18.68 and 35.93 & 16.02 of the total fat for the LD, HD, LDm, HDm, LDgf and HDgf diets, respectively. The linolenic acid (C18:3) content of the muscle was significantly higher

(P=0.0038) when fat was added to LD diets compared to no fat supplementation (0.87 vs. 0.15). The CIELAB values indicated that LD diets resulted in more pink meat. Mean values of L* = 32.61, 34.19; a* = 7.08, 7.91 and b* = 3.18 and 4.07 were observed for the LD and HD diets, respectively. Meat from the LD diets had significantly lower L*-(P=0.0252), a*-(P=0.0283) and b*-(P=0.0109) values compared to meat from the HD diets. In conclusion, the fatty acid contents of the longissimus muscle of veal calves can be manipulated with the supplementation of rumen inert fat sources, but only when combined with a low protein degradable diet. The low degradable protein diets also produce a more attractive meat colour for the potential veal consumer.

INTRODUCTION

The general public has become increasingly aware of the potential health risks involved in eating fatty red meat because of its high saturate lipid content and the correlation thereof with cardio-vascular diseases. Conversely, monounsaturated fatty acids decrease the amount of plasma LDL-cholesterol in man without affecting the HDL-cholesterol. HDL-cholesterol is the only lipoprotein capable of removing cholesterol from the body (St. John *et al*., 1987). The 1990 Dietary Guidelines recommend that individuals avoid consuming excessive fat, saturated fat, and cholesterol, just as excessive sugar or salt must be avoided. Adequate amounts of fat are essential for health since fat supplies energy, essential fatty acids and fat-soluble vitamins (Pensel, 1997).

Researchers have attempted to change the fatty acid composition of beef. St. John *et al*, (1987) found a substantial change in the fatty acid composition of both the adipose and the muscle of swine, but not in beef. These results showed very little or no alteration in beef composition, because of the hydrogenation of unsaturated fatty acids by the rumen microbes. There were however some researchers that had positive results. Rule, *et al*., (1994) found that dietary full-fat canola altered the fatty acid composition of the lipids in adipose tissue, muscle, kidney, and liver such as that C16:0 and C16:1 were decreased and C18:0, C18:1, C18:2, C20:1 were increased. In muscle, kidney, and liver, long-chain polyunsaturated fatty acids were also affected. Brandt & Anderson, (1990) found that the portions of palmitic, stearic, oleic, linoleic and linolenic acid in longissimus muscle of steers were altered by the source of supplemental fat. Feeding protected lipids caused an increase in kidney fat (Fisher, 1980), a

result further supported by observations of Gardner and Wallentine (1972) who noted that increased consumption of protected tallow increased the percent internal fat in the body.

The purpose of this investigation was to determine the effects of supplementing rumen inert fats (to escape rumen microbial lipase action and make the fatty acids directly available) on the muscle composition of the veal. The interaction between these fats, if any, with the degradability of the protein in the diet was also measured. The meat colour was also determined as it plays a vital role in the selection of meat cuts by the consumer (Jeremiah *et al.*, 1972).

MATERIALS AND METHODS

Animals

Thirty-six Friesian bull calves, 2-5 days of age, were stratified according to initial mass and entered into six blocks. Calves in each block were then randomly allocated to six treatments. Individual housing was provided in pens with wooden slatted floors and straw bedding. All the animals were slaughtered at 20 weeks of age. Meat samples were taken from 35 of the 36 calves. Meat samples were taken from the longissimus muscle and subcutaneous fat adjacent to the 12th rib. The meat and the adjacent subcutaneous fat layer were minced together. These samples were further homogenized in a blender to ensure even fat distribution.

Diets

All calves received 4L of a commercial milk replacer (Denkavit, Johannesburg, RSA) until 42 days of age, and then 2L until weaning at 49 days. Starter diets were offered *ad lib.* from 14 days until 10 weeks of age, and finishing diets *ad lib.* from 11 to 20 weeks of age. Starter- and finishing diets were formulated to be iso-nitrogenous, but differed in crude protein (CP) degradability and energy content. The crude protein was 18% and 14% for the starter- and finishing diets respectively. Treatments were LD (low degradable protein) and HD (high degradable protein) each with, or without, rumen inert fat supplementation. Two rumen inert fat sources were used, *viz.* Morlac (Marine Oil Refiners, Dido Valley, Simon's Town) and Golden Flake (Veekon, Silverton, Pretoria, RSA). The total mixed diets were pelleted and the composition thereof is presented in Table 1.

Chemical Analysis

Chemical analysis was performed on feed samples after passing samples through a hammer mill with a 1mm sieve. Feed and meat samples were analyzed for dry matter, organic matter, Kjeldahl nitrogen (N) and the crude fibre content of the feed (AOAC, 1990). The acid hydrolysis procedure (AOAC No 922.06, 1996) was used for the lipid extraction from the feed and the meat samples (AOAC No 948.15, 1996). The Sodium Methoxide trans esterfication method was used for preparing fatty acid methyl esters (FAME). The Fatty Acid Methyl Esters (AOAC 963.22, 1996) method was used to determine the fatty acid profile. The chemical composition of the feeds used are presented in Table 2 and the fatty acid profile of the feeds are presented in Table 3. Meat colour was determined by using a Colorguard System 2000 colorimeter (Pacific Scientific, Silver Spring, MD, USA) to determine CIELAB values (Commission International de l' Elclairage, 1976), with L* indicating brightness, a* the red-green range and b* the blue-yellow range.

Table 1. Composition (% of ingredients) of finishing diets for calves to determine the effect of rumen inert fat supplementation and protein degradability on veal calf performance.

Item	FINISHING DIETS					
	LD	HD	LD +m	HD +m	LD +gf	HD +gf
Maize meal	63	60	60.5	57.5	60.5	57.5
Fish meal	6	0	6	0	6	0
Prime gluten(60)	4	0		0	4	0
Sunflower oil cake	0	13	0	13	0	13
Molasses	5	5	5	5	5	5
Lucerne hay	0	14	0	14	0	14
Oat hulls	0	0	0	0	0	0
NaOH-wheat straw	20	6	20	6	20	6
Salt	0.5	0.5	0.5	0.5	0.5	0.5
Mineral premix	1.5	1.5	1.5	1.5	1.5	1.5
Morlac	0	0	2.5	2.5	0	0
Golden Flake	0	0	0	0	2.5	2.5
Romensin	0.01	0.01	0.01	0.01	0.01	0.01

LD = Low degradable protein m = Morlac

HD = High degradable protein gf = Golden Flake

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Table 2. The chemical composition of calf finishing diets containing two levels of protein degradability and two different rumen inert fat sources.

Analysis	FINISHING DIETS					
	LD	HD	LD +m	HD +m	LD +gf	HD +gf
Dry Matter	91.95	91.99	92.28	92.74	91.53	92.96
Organic Matter	95.74	95.63	95.26	95.40	95.35	95.54
Crude Protein	14.08	12.42	14.40	12.70	14.76	11.82
Crude Fibre	11.07	12.70	10.49	12.83	9.58	12.51
Lipid	3.68	3.52	4.79	4.58	5.62	4.71

LD = Low degradable protein   m = Morlac
HD = High degradable protein   gf = Golden Flake

Table 3. The fatty acid profiles of the low and high degradable protein diets each with, or without, rumen inert fat supplementation.

Fatty Acids	LIPID SOURCES		DIETS					
	Morlac	G.F	LD	HD	LDm	HDm	LDg	HDg
C12:0			0.10	0.22	0.27	0.35	0.40	0.48
C14:0	1.5	1.6	1.26	0.60	1.69	0.91	1.35	0.85
C16:0	48.0	48.6	20.47	22.57	33.23	37.91	31.77	32.88
C16:1			1.63	0.71	2.69	1.42	1.00	0.43
C17:0			0.31	0.22	0.41	0.32	0.25	0.20
C17:1			1.08	1.07	9.48	7.43	0.90	0.55
C18:0	4.5	31.0	5.22	8.61	4.68	5.78	15.54	20.15
C18:1	35.0	15.2	21.51	21.11	23.67	24.59	18.68	16.02
C18:2	8.0	2.8	38.33	37.14	16.71	13.29	22.47	23.89
C18:3			1.59	1.84	0.62	0.92	0.91	1.35
C20:0			0.39	0.46	0.36	0.45	0.44	0.38
C20:1			0.83		0.97	0.66	0.61	0.15
C22:0				0.88	0.38	0.74	0.38	0.46
C22:6			1.97		0.76		1.36	
C24:0			1.3	1.01	0.46	1.79	0.80	0.11
Calculated								
Saturated	55.2	81.0	29.05	34.57	41.48	48.25	50.93	55.51
Unsaturated	43.0	18.0	66.94	61.87	54.90	48.31	45.93	42.39
Energy (MJ/kg)	28.5	36.6	11.93	12.03	12.18	12.36	12.49	12.56

LD = Low degradable protein   m = Morlac
HD = High degradable protein   gf = Golden Flake

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Statistical Analysis

The experimental data was analyzed by ANOVA using the GLM procedures of SAS (Statistical Analysis System, 1988). Different contrasts were used to indicate the differences between treatments. These contrasts are presented in the ANOVA tables to follow. Three main contrasts were used *viz*. FAT, PROTEIN DEGRADABILITY and the interaction between fat and protein degradability (FAT*PROT.DEG.). FAT was further subdivided into two contrasts *viz*. none vs. rest i.e. no fat supplementation was compared to fat supplementation and the protein degradability and different fat sources were ignored and Morlac vs. Golden Flake, i.e. the two fat sources, were compared and the protein degradability ignored. In the second contrast, PROTEIN DEGRADABILITY, the low degradable treatments were compared to the high degradable treatments, ignoring fat supplementation. The interaction between fat and protein degradability (FAT* PROTEIN DEGRADABILITY) was further subdivided into firstly (none vs. rest)*protein degradability i.e. the interaction of protein degradability with no fat supplementation vs. the interaction of protein degradability with fat supplementation. The second subdivision, (Morlac vs. Golden Flake)*protein degradability, i.e. the interaction of each fat source with protein degradability, was also compared.

The percentage of a specific fatty acid in a diet does not reveal the true amount received by the individuals. The total dry matter intake of each calf varies within a treatment. To ensure that the true amount of a specific fatty acid received by a specific calf is taken into account, the total fatty acid intake was calculated and used as a covariance. The total fatty acid intake was derived from the percentage fat in the feed, the specific fatty acid percentage and the feed intake in kg over the ten weeks finishing period.

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RESULTS AND DISCUSSION

FATTY ACID PROFILE IN MEAT

The mean fatty acid percentages of the meat samples derived from the investigation are presented in Table 4.

Table 4. The mean fatty acid percentages of the meat samples of calves fed low and high degradable protein diets each with, or without, rumen inert fat supplementation.

	LD	HD	LDm	HDm	LDg	HDg
C12:0	0.13	0.07	0.09	0.06	0.09	0.06
C14:0	2.68	3.19	3.41	3.41	3.69	3.09
C16:0	24.44	25.94	31.06	30.98	34.94	29.71
C16:1	2.94	4.02	3.52	3.42	3.87	3.48
C17:0	1.39	1.54	1.54	1.51	1.30	1.52
C17:1	0.85	0.82	0.59	0.57	0.46	0.67
C18:0	16.10	20.61	18.89	23.55	20.10	23.28
C18:1	34.44	38.28	34.29	31.69	26.01	34.23
C18:2	8.08	1.75	3.61	2.01	2.39	1.94
C18:3	0.22	0.61	0.73	0.37	0.68	0.40
C20:0	0.10	1.22	0.24	0.20	0.14	0.13
C20;1	0.65	0.28	0.10	0.08	0.03	0.03
Calculated						
Saturated	44.82	52.58	55.21	59.71	60.25	57.79
Unsaturated	47.17	45.76	42.84	38.15	33.43	40.75

The fatty acids in the two rumen inert fat sources were identified (Table 4) and only those fatty acids present were statistically analyzed in the meat. The mean values of the fatty acids have been adjusted according to the covariance (the total fatty acid intake) and are presented in Table 5.

Table 5. The mean fatty acid percentages of the meat which were tested for statistical significance. Mean values for mean fatty acids percentages was adjusted for covariance (total fatty acid intake).

	LD	HD	LDm	HDm	LDg	HDg
C14:0	2.84 ± 0.15	4.22 ± 0.35	2.4 ± 0.34	3.71 ± 0.18	2.92 ± 0.27	3.43 ± 0.17
C16:0	24.44 ± 1.35	25.97 ± 1.21	31.06 ± 0.78	30.98 ± 1.12	34.94 ± 0.94	29.71 ± 0.86
C18:0	14.35 ± 1.45	19.65 ± 1.00	17.29 ± 1.36	22.59 ± 1.21	22.27 ± 1.72	26.48 ± 2.41
C18:1	36.06 ± 2.32	39.99 ± 2.35	32.21 ± 2.51	29.13 ± 2.98	25.23 ± 2.07	35.93 ± 2.35
C18:2	8.35 ± 0.61	2.00 ± 0.58	3.31 ± 0.64	1.43 ± 0.84	2.47 ± 0.42	2.00 ± 0.41
C18:3	0.15 ± 0.13	0.42 ± 0.18	1.01 ± 0.23	0.46 ± 0.15	0.73 ± 0.12	0.24 ± 0.17

The C14:0 (Myristic acid) and C16:0 (Palmitic acid) composition of the meat

The analysis of variance of C14:0 (Table 6) shows that there was an interaction between rumen inert fat supplementation and the degradability of the protein (FAT*PROT.DEG.) in the diets (P=0.0085). The contrast (none vs. rest*prot.deg.) shows that there was no interaction between no fat supplementation and fat supplementation with protein degradability (P=0.0830). The contrast (morl vs. gold*prot.deg.) indicates that there was a significant difference between the two fat sources and protein degradability (P=0.0119) (Table 7).

Table 6. The ANOVA table for fatty acid analysis of the C14:0 and C16:0 percentages in the meat.

Source of variation	df	C14:0		C16:0	
		MS	P	MS	P
Tot.F.A.intake(COVAR)	1	1.60	0.0011	299.46	0.0001
Block	5	0.16	0.2529	10.59	0.0134
FAT	2	0.28	0.1126	14.24	0.0162
None vs. Rest	1	0.22	0.1804	23.57	0.0087
Morl vs. Gold	1	0.07	0.4445	10.28	0.0711
PROTEIN DEGRAD.	1	1.44	0.0018	21.64	0.0115
FAT*PROT.DEG.	2	0.68	**0.0085**	31.10	**0.0005**
(None vs. Rest)*prot.deg.	1	0.38	0.0830	34.81	**0.0020**
(Mor vs. Gold)*prot.deg.	1	0.86	**0.0119**	25.66	**0.0065**
Error	25	0.12		2.87	

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The C14:0 content of the feed was higher in the low degradable diets. Fish meal and sunflower oil cake were used as LD and HD protein sources respectively. Although the high degradable diets had lower C14:0 contents than lower degradable diets, there were higher contents in the calf meat of the calves receiving the high degradable diets. The fat sources made a small contribution the total dietary C14:0 (Table 3) which could by-pass the rumen which therefore indicates that the higher C14:0 of the meat of the calves receiving the high protein degradable diets could only come from long chained (possibly unsaturated) fatty acids that were hydrogenated and broken down by rumen micro-organism lipase.

Table 7. Mean C14:0 percentages of the meat samples of calves fed low and high degradable protein diets each with, or without, rumen inert fat supplementation. The C14:0 percentage in the different feeds are presented in brackets.

Protein Degradability	None		FAT SOURCE (REST) Morlac		Golden Flake		(Morl vs. Gold) *Prot. Deg.
Low	2.84	[1.26]	**2.40**	[1.69]	**2.92**	[1.35]	
High	4.22	[0.60]	**3.71**	[0.91]	**3.43**	[0.85]	**P = 0.0119**

The analysis of variance of C16:0 (Table 6) shows that there was an interaction between rumen inert fat supplementation and the degradability of the protein (FAT*PROT.DEG.) in the diets (P=0.0005). The contrast (none vs. rest*prot.deg.) shows that there was also an interaction between no fat supplementation and fat supplementation with protein degradability (P=0.0020).

A further analysis of variance was therefore done to determine whether fat supplementation was significant for both the low and high degradable protein diets (Table 8). It was found that there was no significant differences between the control diet (none) and the mean of the diets receiving fat supplementation (rest) when the protein degradability was high (P=0.1267). However the meat had a significantly higher C16:0 content when fat was added to the low degradable diets (P=0.0008).

The C16:0 content of the muscle (both diets) was raised by the addition of the two fat sources in the diet (Table 8). This additional C16:0 by-passes the rumen and absorption takes place in the small intestine. The low degradable protein diets with fat supplementation had a significantly higher C16:0 content in the meat than the high degradable diets.

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Table 8. Mean C16:0 percentages of the meat samples of calves fed low and high degradable protein diets each with, or without, rumen inert fat supplementation. The C16:0 percentage in the different feeds are presented in brackets.

Protein Degradability	None	FAT SOURCE (REST) Morlac	Golden Flake	REST(m+g AVG	None vs. Rest	(Morl vs. Gold *prot.deg.
Low	**24.44** [20.47]	**31.06** [33.23]	**34.94** [31.77]	**33.00**	**P = 0.0008**	
High	25.97 [22.57]	**30.98** [37.91]	**29.71** [32.88]	30.35	P = 0.1267	**P = 0.0065**

The contrast (morl vs. gold*prot.deg.) shows that there was a significant interaction between the two fat sources and protein degradability (P=0.0065). There was a significant difference between the two fat sources with low degradable protein diets, but not in the high. Both fat sources had similar C16:0 concentrations viz. 48% and 48.6% for Morlac and Golden Flake respectively (Table 3). Although for the complete feed consumed, HDm had the highest concentration C16:0, there was not a significantly higher C16:0 in the meat. There was a significantly higher C16:0 in the meat of the LDgf treatment which cannot be explained by the levels in the diet.

The C18:0 (Stearic acid), C18:1(Oleic acid), C18:2(Linoleic acid) and C18:3 (Linolenic acid) composition of the meat.

The analysed mean fatty acid values of the meat lipid are presented in Table 4. The analysis of variance (Table 9) shows that there was a significantly higher C18:0 in the high degradable protein diets (P=0.0001). Stearic acid (C18:0) is also the product of the hydrogenation of the following acids in the rumen: Oleic (C18:1) and/or linoleic (C18:2) and/or linolenic (C18:3) (McDonald, 1995). Not all the fatty acids in the sunflower oil cake diets (HD) are protected from hydrogenation in the rumen. The LD diets contained fish meal and thus more fatty acids were protected from rumen hydrogenation. Stearic acid could also be the product of elongation of palmitate acid (McDonald, 1995).

Table 9. The ANOVA table for the C18:0, C18:1 C18:2 C18:3 composition of the meat.

Source of variation	df	C18:0		C18:1		C18:2		C18:3	
		MS	P	MS	P	MS	P	MS	P
Tot.F.A. intake(COVAR)	5	48.34	0.0007	10.17	0.5189	14.63	0.0007	0.082	0.3267
Block	2	3.06	0.4609	35.77	0.2260	2.34	0.0655	0.070	0.5264
FAT	1	29.27	**0.0011**	106.29	0.0227	16.70	0.0001	0.037	0.6439
None vs. Rest	1	34.71	**0.0031**	191.47	0.0092	13.48	0.0011	0.268	0.0836
Morl vs. Gold	1	6.76	0.1580	0.026	0.9740	0.026	0.8700	0.106	0.2675
PROTEIN DEGRAD.	2	129.51	**0.0001**	93.26	0.0594	71.28	0.0001	0.070	0.3666
FAT*PROT.DEG.	1	1.10	0.7103	102.75	**0.0253**	28.19	**0.0001**	0.581	**0.0040**
(None vs. Rest)*prot.deg.	1	0.58	0.6721	0.026	0.9739	52.16	**0.0001**	1.156	**0.0010**
(Morl vs. Gold)*prot.deg.	25	1.52	0.4956	204.56	**0.0074**	2.69	0.1084	0.005	0.8127
Error		3.18		23.71		0.96		0.082	

The contrast FAT shows that there was a significant difference in muscle lipid stearic acid content when fat was added to the diet (P=0.0011). There was a significantly lower muscle C18:0 when no fat supplementation was provided (None vs. Rest) (P=0.0031) than when fat was supplemented (Table 10).

A further analysis of variance was done to determine whether muscle lipid content differs statistically for both the low and high degradable protein diets when fat was supplemented (Table 10). It was found that there were significant differences when dietary protein degradability was low (P=0.0042) and also when it was high (P=0.0073). Fat supplementation to low or high degradable protein diets therefore resulted in significantly higher meat C18:0 content. The two fat sources both contain protected C18:0 , which escapes rumen fermentation and is therefore available for absorption in the small intestine. This result would suggest that by the addition of rumen inert C18:0 in the diet, the C18:0 content in the meat can be increased.

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Table 10. Mean C18:0 percentages of the meat samples of calves fed low and high degradable protein diets each with, or without, rumen inert fat supplementation. The C18:0 percentage in the different feeds are presented in brackets.

Protein Degradability		FAT SOURCE (REST)		None + Rest	Prot.Deg.	REST	None vs. Rest
	None	Morlac	Golden Flake	AVG		AVG	
Low	**14.35** [5.22]	17.29 [4.68]	22.27 [15.54]	**17.97**	**P = 0.0001**	**19.78**	**P = 0.0042**
High	**19.65** [8.61]	22.59 [5.78]	26.48 [20.15]	**22.91**		**24.54**	**P = 0.0073**

However, it is expected that there would be a difference in the stearic acid content of the meat from the calves between receiving the two fat sources as Golden Flake has a higher C18:0 (31.0%) compared to the Morlac (4.5%). This was reflected in the complete diets, where the average percentage C18:0 in the Morlac and Golden Flake diets were 5.23% and 17.85% respectively. However, Morlac did not show any significantly lower deposition of C18:0 in the muscle (Table 10).

Due to the possible hydrogenation of the unsaturated C18 fatty acids in the rumen, stearate is the primary fatty acid available for absorption in the digestive tract. However, oleate, rather than stearate, is the predominant fatty acid derivative in bovine muscle and adipose tissue, indicating that absorbed stearate is modified before being (Table 3) deposited in ruminant tissues. Ruminants are unique in the amount of stearate presented to the small intestine for absorption; thus the contribution of stearoyl-CoA desaturase regulating the fatty acid composition of ruminant tissues is especially important. The stearoyl- CoA desaturase activities in tissues of steers fed high oleate sunflower seed, was measured by Chang (1992). Dieatary sunflower decreased the concentration of stearate in the liver. The high oleate diet significantly increased the activity of stearoyl- CoA desaturase activity in muscle, and numerical increases in desaturase activity were observed in liver, adipose and small intestine samples. The elevated oleate in the plasma and the depressed stearate in the liver of cattle fed sunflower seed may have reflected an adaptive response of stearoyl-CoA desaturase in their tissues (Chang, 1992).

The analysis of variance of muscular oleic acid content (C18:1) (Table 9) shows that there was an interaction between rumen inert fat supplementation and the degradability of the protein (FAT*PROT.DEG.) in the diets (P=0.0253). The contrast (none vs. rest*prot.deg.) indicates that there was no interaction between no fat supplementation and fat

supplementation with protein degradability (P=0.9739). However, the contrast (morl vs. gold*prot.deg.) indicates that there was a significant interaction between the two fat sources and protein degradability (P=0.0074) (Table 11). The fat source Morlac had a higher percentage C18:1 (35.0%) than the Golden Flake (15.2%) as raw materials (Table 3). This was reflected in the composition of the complete diets, where the average percentage C18:1 in the Morlac and Golden Flake diets were 24.13% and 17.35% respectively. It would therefore be expected that the Morlac diets have a higher deposition of C18:1 in the meat. However, the results are not so clear. In the low protein degradable diet, the Morlac does result in higher Oleic acid deposition (32 vs. 25%), but the opposite occurs in the high protein degradable diet where the Golden Flake results in the higher meat oleic acid content. This oleic acid could have been the result of the hydrogenation of linoleic acid (Table 12) where the Golden Flake with high protein degradability contains a much higher concentrations of this acid, when compared to the other diets. Oleic acid (C18:1) could also have been formed from the desaturation of stearic acid (C18:0). This reaction takes place in the microsomes by the action of fattyacyl-CoA desaturases which introduces a double bond between carbon atoms 9 and 10 of stearic acid (McDonald, 1995).

Table 11. Mean C18:1 percentages of the meat samples of calves fed low and high degradable protein diets each with, or without, rumen inert fat supplementation. The C18:1 percentage in the different feeds are presented in brackets.

Protein Degradability	FAT SOURCE (REST)						(Morl vs. Gold) *Prot. Deg.
	None		Morlac		Golden Flake		
Low	36.06	[21.51]	**32.21**	[23.67]	**25.23**	[18.68]	
High	39.99	[21.11]	**29.13**	[24.59]	**35.93**	[16.02]	**P = 0.0074**

Bovine adipose tissue is a major site of fatty acid elongation and desaturation, however bovine liver has an extremely limited ability to desaturase fatty acids. Further, St. John *et al.*, (1991) found that the fatty acid elongase activity was substantially higher than the desaturase activity in the adipose tissue. This suggests that, for the conversion of palmitate to oleate, the desaturation of stearate to form oleate is the limiting process, and not the elongation of palmitate to form stearate. Most of the dietary C18 is converted to stearate via biohydrogenation in the rumen. The low activity of hepatic desaturase in the liver suggests little processing of the fatty acids occur in the liver. The role of desaturating dietary fatty acids has been regulated to the target tissues. Therefore, attempts to modify the fatty acid

composition of beef should target the fatty acid elongation and/or desaturation systems of the tissues that compose beef i.e. muscle and interfascicular adipose tissue. Another option is to identify animals that exhibit hepatic desaturase activity (St. John *et al.*, 1991).

Ekeren *et al.*, (1992) fed a high-oleate sunflower seed, encapsulated by calcium alginate, to cattle and found an increase in the amount of stearate and oleate in the faeces. This suggested that greater amounts of these fatty acids were available for absorption and deposition in the muscle and adipose tissues. This data by Ekeren *et al.*, (1992) indicated that, in spite of a greater availability of stearate and oleate in the small intestine, other mechanisms influence the ultimate composition of the tissue.

Enser *et al* (1999) fed four sources of fat supplement viz Megalac (saturated) linseed (high 18:3), fish oil (high 20:5 n-3, eicosapentenoic acid and 22:6 n-3, docosahexaenoic acid) or linseed plus fish oil. They found that the increased deposition of conjugated linoleic acid (CLA) was similar for both linseed and fish oil supplements although the concentrations of total n-3 polyunsaturated fatty acids in the fish oil diet were much less than in the linseed diet. High levels of CLA and *trans*-18:1 fatty acids indicates inhibition of rectase enzymes which convert CLA to *trans* vaccenic acid and the latter to stearic acid. The increased levels of both *trans*-18:1 and CLA could result from similar proportional inhibition of both enzymes by the diet n-3 PUFA or feedback inhibition of CLA reductase by increased concentrations of *trans*-18:1 in the rumen.

The analysis of variance for muscular linoleic acid (C18:2) (Table 10) shows that there was an interaction between rumen inert fat supplementation and the degradability of the protein (FAT*PROT.DEG.) in the diets (P=0.0001). The contrast (none vs. rest*prot.deg.) shows that there was also an interaction between no fat supplementation and fat supplementation with protein degradability (P=0.0001) (Table 12).

A further analysis of variance was done to determine whether fat supplementation was significant for both the low and high degradable protein diets (Table 12). It was found that there was no significant differences when the protein degradability was high (P=0.7558). There was, however a significantly higher C18:2 when no fat was added to the low degradable diets (P=0.0001).

The diets containing the two fat sources have a higher percentage of saturated fatty acids compared to the two control groups which are high in unsaturated fatty acids (Table 3). The HD groups were subject to rumen lipases and hydrogenation and thus these fatty acids may be altered. In the LD control the C18:2 was protected from rumen hydrogenation and could stay intact to be deposited in the meat. Mammalian cells are not capable of introducing double bonds beyond carbon atom 9. As a result it is not possible for mammalian tissues to synthesize either linoleic acid (C18:2) or linolenic acid (C18:3) and these fatty acids have to be provided in the diet.

Feeding high levels of soyabean oil, which is high in linoleic acid, to cows resulted in limited deposition of linoleic acid in either the milk fat or adipose tissue, but that stearic acid was found to dramatically increases in both. These results are indicative of the efficiency and completeness of hydrogenation by the rumen microflora (Tove & Mochrie, 1963).

Table 12. Mean C18:2 percentages of the meat samples of calves fed low and high degradable protein diets each with, or without, rumen inert fat supplementation. The C18:2 percentage in the different feeds are presented in brackets.

Protein Degradability	None	FAT SOURCE (REST) Morlac	Golden Flake	REST AVG	None vs. Rest
Low	**8.35** [38.33]	3.31 [16.71]	2.47 [22.47]	**2.89**	**P = 0.0001**
High	2.00 [37.14]	1.43 [13.29]	2.00 [23.89]	1.72	P = 0.7558

The analysis of variance of muscular linolenic acid (C18:3) (Table 10) shows that there was an interaction between rumen inert fat supplementation and the degradability of the protein (FAT*PROT.DEG.) in the diets (P=0.0040). The contrast (none vs. rest*prot.deg.) indicatess that there was an interaction between no fat supplementation and fat supplementation with protein degradability (P=0.0010) (Table 13). However, the contrast (morl vs. gold*prot.deg.) shows that there was no significant difference between the two fat sources and protein degradability (P=0.8127).

A further analysis of variance was done to determine whether fat supplementation was significant for both the low and high degradable protein diets (Table 13). It was found that there was no significant differences when the protein degradability was high (P=0.6955). There was, however a significantly (P=0.0038) higher C18:3 when fat was added to the low

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degradable diets compared to no fat supplementation (0.87 vs. 0.15). The fatty acid composition of the meat can thus be altered, when LD protein diets are combined with rumen inert fat sources. In the LD diets the linolenic acid was protected from rumen hydrogenation and could stay intact to be deposited in the meat, but it can't be explained why the HD had a significantly higher C18:3 deposition than the LD diet with no fat was added. The only possible explanation is that the results are based on relative percentages and that this value is not a reflection of the true amount of C18:3. LD control was relatively high in C18:2 and low in C18:3 which could also be because of the proximity of their peak during the FAME analysis process.

Table 13. Mean C18:3 percentages of the meat samples of calves fed low and high degradable protein diets each with, or without, rumen inert fat supplementation. The C18:3 percentage in the different feeds are presented in brackets.

Protein Degradability	None	FAT SOURCE (REST) Morlac	Golden Flake	REST AVG	None vs. Rest
Low	**0.15** [1.59]	1.01 [0.62]	0.73 [0.91]	**0.87**	**P = 0.0038**
High	0.42 [1.84]	0.46 [0.92]	0.24 [1.35]	0.35	P = 0.6955

Meat colour

Consumers select meat cuts for leanness and then for appearance and freshness, with the judgements for the latter primarily being on the brightness of colour (Jeremiah *et al.*, 1972) the ANOVA of the CIELAB variables of the longissimus muscles of the claves receiving the various diets are depicted in Table 14.

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Table 14. ANOVA table for the differences in meat colour of calves receiving different diets.

Source of variation	df	L* MS	L* P	a* MS	a* P	b* MS	b* P
Block	5	1.266	0.8956	1.324	0.3406	0.226	0.9374
FAT	2	0.313	0.9241	2.232	0.1550	2.375	0.0956
None vs. Rest	1	0.139	0.8528	2.617	0.1372	2.771	0.0948
Morl vs. Gold	1	0.379	0.7593	1.571	0.2451	1.674	0.1890
PROT.DEGRAD.	1	22.51	**0.0252**	6.027	**0.0283**	6.970	**0.0109**
FAT*PROT.DEG.	2	1.38	0.7080	0.143	0.8791	0.108	0.8892
(None vs. Rest)*prot.deg.	1	0.676	0.6827	0.045	0.8419	0.005	0.9428
(Morl vs. Gold)*prot.deg.	1	2.168	0.4659	0.235	0.6494	0.209	0.6372
Error	25	3.950		1.107		0.916	

The longissimus muscles of the calves receiving the low degradable protein diets had significantly lower L* (lightness), a* (redness) and b* (yellowness) values than those receiving HD diets (Table 15).

Table 15. The CIELAB values (L*, a* and b*) to determine the colour of the longissimus muscle of the calves on the six different diets..

Protein Degradability		None	FAT SOURCE (REST) Morlac	Golden Flake	None + Rest AVG	Prot. Deg.
L*	**Low**	32.33	32.93	32.57	**32.61**	**P = 0.0252**
	High	34.30	33.70	34.58	**34.19**	
a*	**Low**	7.52	6.70	7.03	**7.08**	**P = 0.0283**
	High	8.25	7.38	8.11	**7.91**	
b*	**Low**	3.60	2.80	3.15	**3.18**	**P = 0.0109**
	High	4.45	3.52	4.25	**4.07**	

The lower a* and b* values are indicative of a lighter colour of the meat (less red, more green; less blue, more yellow) (Denoyelle &Berny, 1999). The L* (lightness or reflection) in the LD diets were lower, indicating less reflection which could be a result of water holding capacity of the meat. In pink veal production, a light pink colour rather than a dark red is in greater demand. Thus, low degradable protein diets would be more sort after by the consumer and possibly the first to be purchased. The intensity of the meat colour is very important in triggering the purchase. The aim in white veal production is to obtain a light coloured meat as this character is associated with an image of freshness and exclusively milk-based feed. The

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consumer of the 1990's, prefer a "light pink" meat as this is synonymous with a more "natural" rearing. The pink veal production is therefore more sort after in satisfying the current trend (Quilichini, 1995).

CONCLUSION

The fatty acid composition of veal can be altered by rumen inert fat supplementation, particularly when combined with low degradable protein diets. These low degradable protein diets combined with rumen inert fat sources also resulted in a higher feed conversion ratio, crude protein-and fat digestibility, as measured in another aspect of this trial. The a* and b* values of the meat were 7.52, 8.25, 6.70, 7.38, 7.03 and 8.11 and 3.60, 4.45, 2.80, 3.52, 3.15 and 4.25 for calves on LD, HD, LDm, HDm, LDgf and HDgf diets, respectively. The meat from the LD diets have a significantly lower L* (P=0.0252), a* (P=0.0283) and b* (P=0.0109) values compared to the meat from the HD diets. The LD diets with the supplementary rumen inert fat sources had a lighter pink colour and would encourage the consumer to purchase this product rather than the dark red veal, which was obtained from feeding HD diets. The consumers first have to see the meat as being appetizing before they will look at the chemical composition (health aspects). The results from the present study indicate that the fatty acid composition of veal can be changed by the supplementation of rumen inert fats. The leanness of the meat cut is very important as this product is perceived to be more heathful by the consumer and thus changing the unsaturated fatty acid composition of red meat, could have great economical value for red meat consumption.

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GENERAL CONCLUSION

Rumen inert fat supplementation can be used with great success in veal calf production. The results from the current investigation indicated that there was no advantage in including protected fat sources in the starter diets or in using protein sources with different degradabilities. This could be due to incomplete rumen development and sub-optimal rumen fermentation. The calcium soap (Morlac) fat supplement also seemed to have a negative influence on the total dry matter intake during the first ten weeks. It was therefore concluded that it was of no economical value to include rumen inert fat sources or different protein degradable sources in the starter period. There was however, an advantage to rumen inert fat supplementation and low degradable protein sources when used in the finishing diets. There was a significantly lower feed conversion ratio (FCR) when rumen inert fat was supplemented to low degradable protein diets. The crude protein and fat digestibilities, of the LD diets with added fat, were also significantly increased. There was an interaction between the by-pass protein and the protected fat, which reached the small intestine of the calf. There appears to be an optimum energy to protein ratio. There is a need for investigation into the interaction of the rumen inert fat supplementation to low degradable diets.

The fatty acid composition of the longissimus muscle can be manipulated with the supplementation of rumen inert fat sources. The low protein degradable diets also had a lighter pink colour, which is a colour more favoured by the consumer. Although this investigation proved that the fatty acid composition of veal can be changed, there is a need for further studies to investigate whether or not this would be healthier for the consumer. There is also a need to investigate the site of fatty acid deposition in the body.