# Physical form of maize grain in finishing rations of ram lambs

by

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## Declaration

I herby declare that this dissertation submitted by me to the University of the Free State for the degree, **Magister Scientia Agriculturae**, is my own independent work and has not previously been submitted for a degree to any other university. I furthermore cede copyright of this thesis in favour of the University of the Free State.

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## List of Abbreviations

| | |
|---|---|
| ADF | Acid detergent fibre |
| ADG | Average daily gain |
| ADS | Acid detergent solution |
| CGM | Coarse-ground maize |
| CP | Crude protein |
| CPD | Crude protein digestibility |
| CV | Coefficient of variation |
| DE | Digestible energy |
| DM | Dry matter |
| DMD | Dry matter digestibility |
| DMI | Dry matter intake |
| EM | Extruded maize |
| FCM | Fat corrected milk |
| FGM | Fine-grounded maize |
| FMG | Fine maize grain |
| FS | Fecal starch |
| GE | Gross energy |
| GLM | General linear models |
| GMG | Grounded maize grain |
| He | Helium |
| HM | High mosture |
| ME | Metabolisable energy |
| MEI | Metabolisable energy intake |
| MGM | Medium-ground maize |
| N | Nitrogen |
| NDF | Neutral detergent fibre |
| $NE_g$ | Net energy for growth |
| NSC | Non-structural carbohydrates |
| OM | Organic matter |
| OMD | Organic matter digestibility |
| OMI | Organic matter intake |
| $O_2$ | Oxygen |

| | |
|---|---|
| RUP | Rumen undegradable protein |
| WM | Whole maize |
| WMG | Whole maize grain |

# Chapter 1

## General introduction

Grain for livestock is processed to enhance its nutritional value. The feeding value of any feed is a function of three factors: nutrient content, intake and digestibility. Physical and chemical characteristics of a grain can alter its digestibility, its dustiness and acceptability (palatability) and its associative effects (interactions of roughage with concentrate) within the digestive tract. Processing methods are selected to economically enhance digestibility and acceptability without detrimentally affecting ruminal pH and causing digestive disfunction (Owens & Zinn, 2005). Oba & Allen (2003) are of opinion that starch is an important source of fuels for ruminants and for microbial protein production in the rumen. Although starch is potentially completely digestible, starch digestion is affected by a variety of factors, such as type of grain, processing method, conservation method and endosperm type.

Owens & Zinn, 2005 stated that grains are fed to livestock primarily to supply energy, and the major energy source in cereal grains is starch. For maximum starch digestion, maize and sorghum grain must be processed. For non-ruminants, starch from finely ground grain is fully digested, but for ruminants fed concentrate rations, finely ground grain can cause metabolic diseases. Hence, steam rolling or flaking and fermentation (high moisture storage) rather than the fine grinding are used for grains fed to ruminants to increase the extent of starch digestion. Such processing methods increase starch digestion both in the rumen (of dietary starch) and postruminally (of starch reaching the small intestine). Thus maize processing is important for improving starch fermentation in the rumen as well as starch digestion in the total gastro intestinal track. Due to the positive relationship between ruminal starch fermentation and overall starch digestion (Emeterio *et al*., 2000), any processing method that improves ruminal starch fermentation will likely increase overall starch digestibility. In addition, greater starch fermentation in the rumen will increase microbial protein synthesis, providing more microbial nitrogen to the small intestine. The first role of mechanical processing is to break the outer coat of the grain and increases microbial access to starch reserves, and consequently to increase rumen total track starch digestion. As particle size decreases, the available surface area for microbial attachment increases exponentially (Remond *et al*., 2004).

Typical grain processing methods involve particle size reduction with or without addition of water or steam. Grinding or rolling to form dry rolled or dry ground grain with or without addition of moisture is the most common method of grain processing. For more extensive processing, grain can be rolled or ground and fermented if adequate moisture (typically 24 to 35%) is present. Moisture may either be inherent in the grain due to early harvest, forming high moisture grain or added to dry grain to form reconstituted grain. To form steam rolled or "flaked" grain, dry whole grain is moistened with steam and crushed between corrugated rolls. Compared with steam flaked grain, steam rolled grain is steamed for a shorter time, crushed flakes are thicker and starch is less gelatinized (damaged). Moreover, processing methods gelatinize starch, increasing the rate of starch digestion. For less extensively processed maize, feeding value can vary with the hybrid or variety of the grain and agronomic conditions. Chewing and rumination as well as bunk management can alter site and extent of digestion and passage rate through the digestive tract; these vary with animal age and background, ration composition, feeding frequency and dietary forage or fibre (NDF) level (Owens & Zinn, 2005; Oba & Allen, 2003).

There is little evidence regarding the effect of the particle size of maize grain on the digestibility by sheep. According to Vance *et al*. (1972) in growing-finishing steers it is recommended often that maize grain should be ground or cracked for optimum performance when fed to beef cattle because it is thought that some of the maize will escape chewing and digestion if the kernels are not broken. However it has been demonstrated that when high-concentrate rations are fed *ad libitum* to growing, finishing cattle, dry whole shelled maize is as good or superior to ground, cracked or even steam flaked maize. The reason for these results is unexplained, but it has been suggested that dry whole shelled maize may serve as a source of roughage factor in the rumen. This explanation is supported by studies which have shown that gain performance was improved slightly by adding minimum amounts of roughage to all-concentrate rations containing ground maize, and also that gross rumen wall changes such as papillae clumping and hair accumulation were less severe when whole shelled maize was fed in comparison to ground or steam-flaked maize (Vance *et al*., 1970).

Wilson *et al*. (1973) is of opinion that grinding or crushing maize grain for adult sheep and cattle may not always be necessary and the extra cost incurred in processing may not be recovered in the form of improved animal production. In South Africa rations with a high maize grain content (60-70%) are often fed to weaner lambs and cattle. The physical form of the grain could however influence factors like the thoroughness of mixing with other ingredients in the ration, separation and selection of the ration components in the feed bunk and occurrence of sub-clinical acidosis. Therefore it is of utmost importance to consider the effect of physical form of maize grain on these factors and accordingly the intake, digestion and utilization of the finishing ration by these animals. McDonald *et al.* (2002) stated that sheep could often be relied upon to chew whole cereal grains, thereby obviating mechanical processing. In this regard it is important to consider the fact that lambs have not yet cut permanent teeth. Therefore their chewing ability could be hampered.

McDonald *et al*. (2002) is of opinion that if grains are given with roughage that passes rapidly through the gut they should be crushed for sheep. According to Nordin and Campling (1976) young beef cattle given whole maize grain in rations without roughage or low in roughage are apparently able to digest it well and grinding the grain before feeding did not improve its digestibility. However, in beef cattle given medium amounts of roughage and high moisture maize grain, Horton & Holmes (1975) showed that rolling improved digestibility and live-weight gain.

From the literature it seems that most research on the particle size of maize in finishing rations had been done with beef cattle. The information regarding the particle size in finishing rations for sheep and especially lambs is limiting and for beef cattle often confusing. Furthermore the roughage content and passage rate could also influence the desired maize grain particle size. Lucerne hay with a high degradability is mostly use in South Africa as roughage source in finishing rations for lambs. Therefore this study was conducted to investigate the influence of particle size of maize grain and roughage level in finishing rations on the digestibility and utilization by lambs.

## References


**Emeterio, F.S., Reis, R.B., Campos, W.E. & Satter, L.D., 2000.** Effect of coarse or fine grinding on utilization of dry or ensiled corn by lactating dairy cows. J. of Dairy Sci. 83, 2839-2848.

**Horton, G.M.J. and Homes, W., 1975.** Feeding value of whole and rolled propionic acid-treated high-moisture corn for beef cattle. J. Anim. Sci. 40, 706-713.

**McDonald, P., Edwards, R.A., Greenhalgh, J F.D. & Morgan, C.A., 2002**. Animal Nutrition. Sixth Edition. Pearson Education Limited, Prentice Hall, England.

**Nordin, M. & Campling, R.C., 1976.** Effect of the amount and form of roughage in the diet on digestibility of whole maize grain in cows and steers. J. Agric. Sci. 87, 213-219.

**Oba, M. & Allen, M.S., 2003.** Effects of corn grain conservation method on ruminal digestion kinetics for lactating dairy cows at two dietary starch concentrations. J. Dairy Sci. 86, 184-194.

**Owens, F.N. & Zinn, R.A., 2005**. Corn grain for cattle: Influence of processing on site and extent of digestion. pp. 78-85. South Nutr. Conf., Univ. of Arizona. http:/animal.cals.Arizona.edu/swnmc/2005/index.htm

**Remond, D., Cabrera-Estrada, J.I., Champion, M., Chauveau, B., Coudure, R. & Poncet, C., 2004.** Effect of corn particle size on site and extent of starch digestion in lactating dairy cows. J. Dairy Sci. 87, 1389-1399.

**Vance, R.D., Johnson, R.R., Klosterman, E.W., Dehority, B.A. & Preston, R.L., 1970.** All-concentrate rations for growing finishing cattle. Ohio Agr. Res. and Devel. Center, Res. Summary 43.

**Vance, R.D., Preston, R.L., Klosterman, E.W. & Cahill, V.R., 1972.** Utilization of whole shelled and crimped corn grain with varying proportions of corn silage by growing-finishing steers. J. Anim. Sci. 35, 598.

**Wilson, G.F., Adeer, N.N. & Campling, R.C., 1973.** The apparent digestibility of maize grain when given in various physical forms to adult sheep and cattle. J. Agric. Sci., (Camb.) 80, 259-267.

# Chapter 2

## Literature review

### 2.1 Introduction

The pericarp of the maize kernel and the protein matrix surrounding the starch granule inhibit microbial access to the starch granules. If the pericarp is not physically disrupted, several days are required for micro-organisms to penetrate the pericarp and gain access to the starch granules (Emeterio *et al*., 2000). The treatment of maize grain, ruminant species, hardness of maize kernels, starch configuration of different maize hybrids and roughage level in the rumen may influence the starch degradation in the rumen, the level of starch by-pass through the rumen, starch digestion in the small intestine, net glucose absorption and starch loss in the faeces of ruminants (Moe & Tyrrell, 1977; Welch, 1982; 1986; Lin *et al*., 1987; Flachowsky *et al*., 1992; Pascual-Reas, 1997; Knowlton et al., 1998; Rowe et al., 1999; Soe et al., 2004; Ying & Allen, 2005).

The influence of these factors and especially grain processing methods on the utilization of ruminant rations is addressed in this literature review.

### 2.2 Physical characteristics of maize grain

Although starch in cereal grain is almost completely digested in the whole digestive track, the rate and extent of ruminal fermentation vary widely with grain source and cereal processing (Huntington, 1997). The site of starch digestion also has implications for the nature and amount of nutrients delivered to the animal.

#### 2.2.1 Endosperm

The first phase of differentiation of the endosperm begin in the lower side of the kernel, where starch production, forming of protein matrix and $^{14}C$ lay down begin at the upper side and proceeds downwards (Wilson, 1978). The filling of the endosperm with starch reserves takes place in the form of starch granules that is pinched in the protein containing protoplasmatic-matrix of the endosperm cells (Kuhn, 1952). Starch granules vary in size and in shape, depending on their position in the endosperm. Big starch granules, which is loosely arranged from each other, is found in the middle powdery part of the endosperm. The starch granules have a smooth surface and this is an indication that there is less pressure in that part of the kernel. Against the outside of the kernel the cells are firmly compact, exhibit angularity and the smallest starch granule is found here (Khoo & Wolf, 1970). When most or all of the space in between are filled with protein matrix, the endosperm will be hard, invisible and hornlike. If the space in between has not been filled, the endosperm will be soft and powdery in appearance. Kernels with different degrees of hardness, thus with different softness:hardness ratios of the endosperm, is found (Wolf *et al*., 1952).

### 2.2.2 Factors affecting the breakability

Several factors could influence the breakability of the kernel and probably the rate and extent of degradation in the rumen.

Tension cracks is small channels that arise when the kernel is dried quickly (Eckhoff *et al*., 1988). If maize is grinded wet, there is a big difference in moisture content between the nucleus of the kernel and the outside of the endosperm. As a result of the tension, cracks arise (Salter & Pierce, 1988). When the kernels is dried with warm air, the outside parts heat up quicker than the inside parts, looses moisture more rapidly, the kernels experience tension and crack (Shelef & Mohsenin, 1969). The tension crack is usually noticed on the back of the kernel and the more tension it experiences, the more the cracks spread. Some of the cracks do not proceed to the surface of the kernel and is narrowed beneath the aleuronic layer, which is an indication that the crack originates in the center of the kernel and moves to the surface (Gunasekaran *et al*., 1985). Therefore gradual drying with moderate temperatures is desirable to reduce the development of pressure cracks (Vyn & Moes, 1988). It has been shown that when air at room temperature is blown over corn, pressure cracks can still be formed (Moreira *et al*., 1981). Although artificial drying of maize in South Africa occurs rarely, kernels that are dried on the cob are exposed to extreme temperatures that could range between freezing point and 40°C. Because the kernel is visco-elastic**,** the breakability is increased (Srivastava *et al*., 1974). It is recommended that breakability tests should be done at room temperature (25°C) seeing that temperatures below 5°C decrease the breakability (Miller *et al*., 1979).

The moisture content of the grain is another factor that influences breakability. Herum and Blaisdell (1981) found that if the moisture content of the grain is between 12% and

14%, small variations in the moisture content had large differences in breakability. The highest breakability is found at a moisture content of 10%. In studies of Noble et al. (2000), maize breakage susceptibility increased as moisture content decreased through the range of about 22-12% moisture.

Other characteristics related to breakability are the form and the mass of the kernel. This influences breakability because round kernels show a higher breakability than flat kernels and a low kernel mass shows high breakability, while large kernels break more readily than small round kernels (Miller *et al*., 1981; LeFord & Russell, 1985; Vyn & Moes, 1988). Low breakability is associated with high density and high breakability occurs with kernels with soft endosperms (LeFord & Russell, 1985). Improvements in mechanical handling of maize did not reduce the incidence of breakability. Breeding can reduce the problem of breakability. Determination of breakability is time consuming and there is been searched for easy measurable endosperm characteristics that are highly related to breakability.

### 2.2.3 Components of cereal grains limiting digestion

A summarization (Table 2.1) of the physical impacts of various grain processing techniques on seed components that can limit site and extent of digestion have been done by Rowe *et al*. (1999). Note that the processing methods can differ in their physical effects. How individual components limit grain digestion can explain why grains respond differently to different processing methods. Furthermore, digestion-limiting components can be modified either by genetics or environmental conditions that alter characteristics inherent to the grain.

**Table 2.1 Impact of various processing techniques on grain and its digestion (Rowe et al., 1999).**

| Grain treatment/ processing | Disrupts pericarp or exposes endosperm | Reduces particle size | Disrupts endosperm matrix | Disrupts starch granules | Increases fermentation rate | Increases intestinal digestion |
|---|---|---|---|---|---|---|
| Dry rolling | +++ | + | - | - | ++ | + |
| Grinding | +++ | +++ | - | - | ++ | + |
| Steam flaking | +++ | ++ | + | + | +++ | ++ |
| Extrusion | +++ | - | ++ | + | ++ | ++ |
| Pelleting | +++ | - | + | ? | + | ++ |
| Ensiling | + | | ++ | - | ++ | + |
| Micronization | + | + | ? | ? | ? | ++ |
| Popping | ++ | - | + | +++ | ? | +++ |
| Protease | - | - | ? | ? | ++ | ? |

The coat or pericarp of cereal grain protects the seed from moisture, insects and fungal infections that can hamper germination (Emeterio *et al*., 2000; Rowe *et al*., 1999). Furthermore Owens & Zinn (2005) pointed out that in oats, the hull can be 25% of the grain dry matter, but with sorghum and maize, the hull makes up only 3 to 6% of the weight of the grain. Although it comprises only about 4.7% of the weight of the maize kernel, the pericarp contains nearly half of the neutral detergent fibre (NDF) of the kernel (average for corn grain of about 10.0% NDF). Energy availability of a grain is roughly proportional to the amount of starch present, primarily because starch is more digestible than other components, especially NDF. The primary component that displaces starch in grain is NDF. For digestion of the starchy endosperm, the seed coat must be cracked to permit microbes and enzymes to enter. Even after being dry rolled, the pericarp of the maize kernel usually remains attached to vitreous starch and can shield the starch from localized microbial and enzyme attack. Tenacity of adherence of the pericarp to the endosperm can limit access to the endosperm for fermentation or digestion. With food-grade maize, processors desire a pericarp that is removed easily. For livestock fed coarse grains, any factor that introduces stress cracks into the pericarp (e.g., high temperature drying of grain; premature harvest) will increase starch exposure and rate and extent of starch digestion. Steam rolling or flaking and ensiling also can reduce the physical association of the pericarp with the endosperm, but even extensive processing cannot fully alleviate the negative effects of NDF on extent of digestion by ruminants and non-ruminants.

## 2.3 Grain treatment methods

Grain processing can alter the rate and extent of degradation of starch in the rumen. Whole dry maize processes a highly crystalline amylopectin matrix and a strong protein matrix surrounding the starch granule in the endosperm (Rooney & Pflugfelder, 1986). These properties increase the escape of starch from the rumen. Type and degree of processing have altered the site of starch digestion and the use of nutrients by the ruminant (Theurer *et al*., 1999). Chen *et al*. (1994) observed that increased starch degradability in the rumen increased microbial yield and total track starch digestibility, resulting in a higher milk production response.

There are at least 18 different methods of processing grain. There are however many modifications of these methods. These processing methods are listed below and classified according to dry or wet processing (Hale & Theurer, 1972):

| *Dry Processing* | *Wet processing* |
|---|---|
| Whole grain | Soaking |
| Grinding | Steam rolling |
| Dry rolling or cracking | Steam processing and flaking |
| Popping | Reconstitution |
| Extruding | Exploding |
| Micronizing | Pressure cooking |
| Roasting | Early harvesting |
| Pelleting | Earn corn silage |
| Thermalizing | Sorghum head silage |

The purpose of the next paragraphs is to describe briefly some of the most common processing methods.

### 2.3.1 High moisture maize

Maize can be harvested wet and stored as high moisture maize. For maize to be used in this manner, it should be harvested at 25 to 30% moisture for optimum storage. According to Hellevang (1995) grain moisture content affects the quality of grain, price discounts and premiums, as well grain storability, so moisture content may affect economic return. Grain moisture content is expressed as a percentage of moisture based on wet weight (wet basis) or dry matter (dry basis). Wet basis moisture content is generally used. Dry basis is used primarily in research.

$$Mw \text{ (wet basis)} = \frac{w-d}{w} \times (100)$$

$$Md \text{ (dry basis)} = \frac{w-d}{d} \times (100)$$

Where:

w = wet weight

d = dry weight

M = moisture content on a percentage basis

A representative sample must be obtained to provide a useful moisture content evaluation. Also the moisture content must be maintained from the time the sample is obtained until the determination is made by storing in a sealed container. The moisture content can be determined by an oven method, which is a direct method. The grain is weighed and dried, then weighed again according to standardized procedures. The moisture content is calculated using the moisture content equations. Moisture meters measure the electrical properties of grain, which change the moisture content. This considered an indirect method and must be calibrated by a direct method. It is important to follow moisture meter directions carefully to achieve an accurate moisture test (Hellevang, 1995).

The question occurs from the utilization of ruminants' point of view, whether the production will be better with high moist maize (25-30% moisture) or with normal maize (10-14% moisture). The utilization of high moisture maize by ruminants will be discussed later.

### 2.3.2 Grinding

Grinding is by far the most common method of feed processing and, other than soaking, is the cheapest and most simple process. A variety of equipment is available on the market and all of it allows some control of the particle size of the finished product. The hammer mill is probably the most common equipment used. Grinding generally improves digestibility of all small, hard seeds. The physical form of maize relies on the following factors: the size of the sieves, the size of the hammer mill, the speed and the power of the motor, the type of grain and the moisture content of the grain. According to the literature the physical form of maize has different implications and results in the animal production. Coarsely ground grains are preferred for ruminants because they dislike finely ground meals, particularly when the meals are dusty (Church, 1984; Pond *et al*., 1995). The question arises whether maize grain could be fed whole or would ground or finely ground maize be utilized more efficient than whole maize grain. This matter will be discussed later in this chapter.

### 2.3.3 Dry rolling or cracking

Some times grain will be rolled or cracked. The degree of fineness can vary from fine meal to coarsely grain according to the space between the rollers, the pressure, the speed and the moisture content. Grain is rolled by putting it between moving rollers that can be adjusted to permit different sized particles to pass through. Rolled grain is similar to grain coarsely ground by a hammer mill. The physical nature is attractive to most animals. Although particle size can be varied considerably, there will be quite a range in particle size unless the fines are screened out (Church, 1984; Pond *et al*., 1995).

### 2.3.4 Steam rolling

Steam rolling is a process that has been used, partly to break weed seeds. The steaming is accomplished by passing steam up through a tower above a roller mill. Grains are subjected to steam for only a short time in the usual procedure (3-5 min.) prior to rolling-usually just enough to soften the seed, but not long enough to modify the starch granules to any degree (Church, 1984; Pond *et al*., 1995). The steaming is responsible for the higher moisture content. The higher moisture content could relate to a higher intake than the original whole grain. According to Church (1984) most results indicate little if any improvement in animal performance as compared to dry rolling, but use of steam does allow production of larger particles and fewer fines, thus resulting in an improved physical texture as compared to dry rolling.

### 2.3.5 Steam processing and flaking

Based on performance of feedlot cattle, steam flaking increases the net energy (NE) value of maize by 18%, considerably more than is suggested by tabular values (Zinn *et al*., 2002). Tabular values underestimate the energy availability of flaked maize by failing to account for digestibility of the non-starch organic matter (OM) that is increased by flaking by the same magnitude (10%) as starch. Correcting for improvement in digestibility of non-starch OM increases the $NE_g$ (net energy for growth) value of steam-flaked maize to 7.12 MJ/kg, a value very close to values calculated from cattle performance trails. Digestibility of starch from maize grain is limited by the protein matrix that encapsulates starch granules and by the compact nature of starch itself. Disruption of protein matrix (by shear forces on hot grain during flaking) is the first limiting step toward optimizing starch digestion. Five critical production factors influencing the quality of steam-flaked maize: namely steam chest temperature, steaming time, roll corrugation, roll gap and roll tension. For optimal shear, it is important that rolls are hot and that kernels be hot when flaked. Steam chest should be design to allow a steaming time of at least 30 min at maximum roller mill capacity producing a flake of 0.31 kg/L. As little as 5% moisture uptake during steaming appears adequate. The rate of flaking and distribution of kernels across the rolls also are critical. Quality standards for steam-flaked maize include measurements of flake thickness, flake density, starch solubility and enzyme reactivity. Flake density, the most common quality standard, closely associated with starch solubility ($r^2$=0.87) and enzyme reactivity ($r^2$=0.79), still explains only 63% of the variability in percentage fecal starch and 52% of the variability in starch digestibility. Direct determination of fecal starch can explain 91% of the variability in starch digestion. The $NE_g$ value of maize can be predicted from fecal starch (FS) as follows: $NE_g = 1.78 - 0.0184FS$. Starch digestion is a Kappa Curve function of hot plate density, reaching a maximum at a flake density of approximately 0.31 kg/L. Flaking to a density of less than 0.31 kg/L, though increasing starch solubility may reduce dry matter intake (DMI), increase variability of weight gain among animals within a pen and predispose cattle to acidosis and bloat (Zinn *et al*., 2002). Zinn *et al*. (2002) is of opinion that the steam-flaking process must be optimized on the basis of FS analysis.

### 2.3.6 Popping and micronizing

Grain with a normal moisture content of 10-14% is exposed to a temperature of 400°C for approximately 15-30 seconds. The grain will burst, very similar to popcorn. The starch fraction is broken and gelatinized. Normally thereafter the grain will be rolled and the normal moisture content will be corrected by adding water. This treatment gives the grain more body, more storing place is needed, some times the feed intakes are negatively influenced, but the feed conversion is usually higher (Riggs *et al*., 1970; Pond *et al*., 1995). According to Sussi *et al*. (2003) heat treatment of maize grain alters starch structure and thus improves the availability to both ruminal microbial and pancreatic enzymes. Micronizing is essentially the same as popping, except that the heat is provided in the form of infrared energy. Neither method is used much in practice.

### 2.3.7 Roasting

Roasting is accomplished by passing the grain through a flame, resulting in heating and some expansion of the grain that produces a palatable product. The grain is roasted at a temperature of approximate 150°C. The feed intake has increased when the temperature, during roasting of maize grain, increased by 18°C. Body weight has increased by 11.5% and feed conversion has increased by 18% (roasting at 150°C) in contrast with unprocessed maize grain (Perry *et al*., 1973 & 1974). According to Church (1984) limited data on maize indicated a good response with cattle in terms of daily gain and feed efficiency.

### 2.3.8 Pelleting

Grinding the material and then forcing it through a thick die with the use of rollers that compress the feed into holes in the pellet die accomplish pelleting. Feedstuffs are usually, but not always, steamed to some extent prior to pelleting. Pellets can be made in different diameters, lengths and hardness and have been available commercially in many years. Pelleting finely ground portions of the ration, supplements, etc. is desirable because the animals will often refuse the finer particles of the ration (Church, 1984; Pond *et al*., 1995).

## 2.4 Processing costs

Archer & Muller (2004) used the rate of interest in 2004 namely 11.5%, to determine the costs of processing 1 ton of maize grain (Tables 2.2, 2.3, 2.4). From the calculations it seems that milling with an electrical hammer mill resulted in the highest lost of maize and processing costs. No loss of maize occurred when maize grain was crushed or rolled. The lowest processing costs were found with an electrical roll mill.

Table 2.2 Processing costs to mill 1-ton maize with an electrical hammer mill (Archer & Muller, 2004).

| Hammer mill size (Kw) | Time/ton (min) | Hammer mill cost/ton (R) | Electrical cost (R) | Total cost (R) |
|---|---|---|---|---|
| 32 | 20 | 5.48 | 6.21 | 11.69 |
| 55 | 12 | 3.92 | 5.78 | 9.72 |

Due to the cyclone, a loss of ±15% of the maize occurs.

Table 2.3 Processing costs to crush 1-ton maize with an electrical hammer mill (Archer & Muller, 2004).

| Hammer mill size (Kw) | Time/ton (min) | Hammer mill cost/ton (R) | Electrical cost (R) | Total cost (R) |
|---|---|---|---|---|
| 32 | 17 | 4.66 | 5.28 | 9.94 |
| 55 | 9 | 2.95 | 4.33 | 7.28 |

No loss of maize occurs.

Table 2.4 Processing cost to roll 1-ton maize with an electrical roll mill – single roller (Archer & Muller, 2004).

| Roll mill size (Kw) | Time/ton (min) | Total cost/ton (R) |
|---|---|---|
| 7.5 | 20 | 3.55 |

No loss of maize occurs.

## 2.5 The effect of processing on rumination and chewing

According to Knowlton *et al*. (1996a) particle size of maize did not affect frequency or chewing during meals. Particle size also had no effect on rumination time or chewing during rumination. This is in contrast with findings of Nordin & Campling (1976). They found that ground maize decreased the number or rumination contractions per day and increased water intake. Differences between cows and steers in their ability to digest whole maize grain in the diet were probably causally related to the greater extent of chewing per kg dry matter (DM) feed by steers than cows. On average the time spent ruminating per kg DM feed in steers was almost twice that of the cows (Nordin & Campling, 1976). This confirms and supports the statements made by Morrison (1956), that young animals chew their food more thoroughly than older cattle. Invariably larger quantities of whole maize grains were recovered in the faeces of cows than in steers. Fordyce & Kay (1974) showed that the rate of breakdown by chewing of plastic particles in steers weighing 170 or 250 kg was faster than in steers of 442 kg live weight. However, Horton & Holmes (1975) recovered similar amounts of whole maize grain in the faeces of 10- and 20-month old cattle. Further information is needed on the relationship between the age of animal and efficiency of rumination and of digestion of grains and forages.

Researchers in Canada (Anonymous, 2006) evaluated the effects of chewing on the digestibility of whole grains when fed to cows at one percentage of body weight. They found that chewing during ingestion and rumination resulted in extensive damage to maize kernels. The damage that occurred to the maize kernel during these processes would help support the idea that cattle supplemented with whole maize might perform similarly to cattle fed chopped corn. They also noted that the whole grain observed in the faeces appeared to be greater than what was actually present. Interestingly, 11% of the kernels that appeared to be whole in the faeces were actually empty inside, indicating minor damage to the whole kernel, which made the starch within the kernel accessible to rumen microbes and digestive enzymes.

## 2.6 The effect of processing maize on digestibility

Although the effect of physical form of maize on the digestibility of finishing rations for lambs was investigated in this study, a literature review including different species and physiological stages was executed. Results obtained with other species could probably help to explain some results observed with sheep and ruminants in general.

### 2.6.1 Beef cattle

Maize grain is approximately 72% starch (Huntington, 1997). Thus, the starch content of maize is primarily responsible for the ability of maize to promote high levels of production. With starch being the major energy content of maize, optimal starch utilization is critical to improving the efficiency of conversion of maize to an animal product. The underlying goal is to increase the amount of energy (starch) available to the animal, thereby, increasing gain efficiency.

Maize is one of the most commonly used grains for supplementing energy in beef cattle rations. Whole maize is generally cheaper per ton than cracked, rolled or ground maize, because of the added cost associated with grain processing. In addition, some cattle producers have the opportunity to purchase maize directly from farmers after harvest or purchase bulk loads of whole maize or maize screenings (Anonymous, 2006).

Most cow-calf operations do not have grain processing and mixing equipment. For this reason, the question often arises as to whether certain grains can be fed whole or do they need to be processed. This question arises from the fact that whole grains can be seen in the fecal patties, alerting the producer that the animal may not be getting the nutrients out of the grain.

In theory, processing grain should improve the digestibility and feed conversion of a feed by (1) reducing particle size that allows for more sites of attachment for rumen microbes and (2) some processing methods change the structure of starch rendering the feed grain more digestible. However, as previously stated, further processing always comes with additional costs and the improvement in grain digestibility and feed conversion must outweigh the cost for additional processing.

In studies of Van der Merwe *et al*. (1978), the substitution of whole maize grain for maize meal in high concentrate rations (±20% silage on dry basis) for young beef cattle did not significantly lower intake, digestible energy content of ration, mass gain and feed efficiency (2-5%). The milling of whole grain was not economical justified when milling and handling costs amounted to more than approximately 7% the price of grain. Various researchers (Hixton *et al*., 1969; White *et al*., 1972) did not found any increase in digestibility when maize meal was fed in high-energy rations. A study of Vance *et al*. (1972) showed that whole maize resulted in the same and even better results than maize meal in finishing rations for beef cattle. These researchers speculated that whole grain has a roughage effect in the rumen. Wilson *et al*. (1973) and Nordin & Campling (1976) reckoned that whole maize kernels stimulate rumination.

### 2.6.2 Site and extent of starch digestion by cattle

To evaluate site and extent of starch digestion, the factors of primary concern are: (1) percentage of dietary starch apparently digested in the rumen, (2) percentage of starch flowing out of the rumen that was digested in the intestines, (3) total tract starch digestion and (4) site of starch digestion (fraction of total tract starch digested that disappeared in the rumen).

Total tract digestion of starch from grain ranged from 90 to 96% for lactating cows and from 87 to 99% for feedlot cattle (Owens & Zinn, 2005). With grain being approximately 70% starch, feeding value differences due to processing from starch alone should be about 4% for lactating cows and 9% for feedlot cattle. These must be balanced against the expenses of handling and processing grain (Table 2.1). Additional benefits from processing can occur from increased digestion at a more efficient site of digestion. If starch is fermented in the rumen, ruminal microbes use the energy to synthesize protein for the animal to digest and deposit or secrete. However, if starch digested in the small intestine, energy loss during ruminal fermentation as methane and heat of metabolism is avoided (Owens & Zinn, 2005). This makes site of digestion (rumen versus intestines) of interest.

In contrary with the results of Mitzner *et al*. (1994) and Knowlton et al. (1996a; 1998), Yu *et al*. (1998) observed an increased total tract non-structural carbohydrate (NSC) digestibility with smaller particle size maize grain in dairy cow rations. Studies of Callison *et al*. (2001) indicated that ruminal NSC digestibility was apparently affected quadratically by particle size of maize with a twofold increase for fine grinding. In contrast to ruminal digestibility, apparent NSC digestibility in the small intestine (percentage of total NSC digestibility) largely compensated (quadratic increase) for medium-ground maize (MGM) and coarse-ground maize (CGM), resulting in a small but highly significant linear increase in total tract NSC digestibility as maize particle size decreased. The large compensatory effect of digestion in the small intestine could be a result of fermentation in the distal small intestine (Knowlton *et al*., 1998; Mills *et al*., 1999b). Cows fed MGC digested about 3,1 kg/d of NSC postruminally, with about 2,9 kg/d digestion occurring in the small intestine. These data support the conclusions of Reynolds *et al*. 1997) and Mills *et al*. (1999b) that apparent no limit exists in intestinal digestion of starch by dairy cows adapted to their rations for a sufficient period.

Low ruminal digestibility of starch (≤50%) has often been reported for lactating dairy cows at high DMI of rations containing forage and maize grain (Mills *et al*., 1999a). Although average ruminal starch digestibilities varied from 44,6% for dry cracked maize to 86,8% for high-moisture maize, average total tract digestibility was affected considerably less (85,0 to 98,8%), as determined by regression analyses (Firkins *et al*., 2001).

According to Owens & Zinn (2005), total tract digestibility of starch from high moisture, steam rolled (or flaked), dry rolled and whole maize average 98, 97, 90 and 84% respectively of starch intake in studies done with both dairy cows and feedlot cattle. Furthermore Owens & Zinn (2005) showed that the extent of ruminal disappearance of dietary starch from high moisture, steam rolled (or flaked), dry rolled and whole maize was 85, 77, 55 and 77%, respectively. In the case of flaked and rolled maize the values for lactating cows fell consistently below the regression lines for all cattle. This confirms the idea that ruminal starch digestion is lower for cows. Welch (1982; 1986) attributed this to a faster particle passage rate from the rumen associated with a higher feed intake or a greatly enlarge size (500%) of the opening of the reticulo-omasal orifice. This larger opening will allow larger, less digested and dense maize particles to flow from the rumen.

Several past reviews have suggested that intestinal starch digestibility decreases as starch flow to the intestines increases. However, when calculated within a processing method (Owens & Zinn, 2005), post-ruminal digestion did not decline as passage of starch to the small intestine (abomasal supply) increased. Post-ruminal disappearance of abomasal starch for high moisture, steam rolled (or flaked), dry rolled and whole maize grain average 84, 82, 80 and 29%. Abomasal flow of starch as high as 6000g daily caused no decrease in the fraction of starch digested post-ruminally. However, very low postruminal digestion of starch from whole maize (29%) indicates that very large particles are poorly digested in the intestines. Starch from whole dry maize that is not chewed but escapes ruminal digestion has virtually no value for ruminants.

### 2.6.3 Rate of passage

In addition to the effect of chewing and ruminating, rumen fermentation plays an important role in particle size reduction. Thus factors limiting reduction of particle size or microbial degradation will generally reduce the voluntary feed intake. For maximum feed intake, the rate of disappearance of digesta from the rumen has to be optimized. Important factors in this respect are feed particle size and rate of degradation in the rumen (Haresign & Cole, 1988). An increase in the quantity of a food eaten by an animal generally causes a faster rate of passage of digesta. The food is then exposed to the action of digestive enzymes for a shorter period and there may be a reduction in its digestibility. The reductions in digestibility due to increased rates of passage are the greatest for the slowly digested components of foods like cell walls (McDonald *et al*., 2002).

Intake generally increases after reduction of particle size by chopping, wafering, grinding or pelleting of forages. These smaller particles, due to their increased surface area, allow a more rapid microbial attack and an increased rate of passage (Haresign & Cole, 1988). The activity of the microbes in the rumen depends upon sufficient substrate and nitrogen supply in the rumen contents and its intensity is important for the fermentation and the rate of degradation. Feed factors involved in the rate of degradation and type and extent of microbial fermentation includes the forage-to-concentrate ratio, the proportion of fibrous roughages in long form in the ration and supplementation of the ration with fats or fatty acids (Tamminga, 1982). Besides these factors, level of feeding, changing the feeding procedure, processing such as grinding, pelleting, chemical or heat treatment, coating, inclusion of active agents (e.g. monensin), salts and mineral buffers may also affect microbial degradation (Haresign & Cole, 1988). Rate of fermentation varies between different sources of carbohydrates (Johnson, 1976; Sutton, 1980). The highest rate is found with soluble sugars, starch has an intermediate rate varying with type of starch, but cell-wall constituents (hemicellulose, cellulose, lignin) have the lowest rate of fermentation.

### 2.6.4 Dry matter degradability in sheep

Studies with sheep by Flachowsky *et al*. (1992) showed that the *in sacco* dry matter digestibility (DMD) of maize grain was mainly influenced by processing of the kernels and incubation time. Whole kernels were degraded more quickly ($P<0.05$) when a high concentrate ration was fed. The *in sacco* DMD increased faster within the sequences whole <halved <broken <ground maize grain. Without any mechanical treatment or chewing by the animals, rumen microbes need a long time to start degrading whole kernels. In this case the DM content increased in the bags because of microbial adhesion during the first hours of incubation. Feeding whole grain or maize silage with whole kernels high in DM to cattle resulted in the kernels passing through the rumen and digestive tract with subsequent losses in the faeces (Honig & Rohr, 1982; Richter *et al*., 1987; Schwarz *et al*., 1988, as cited by Flachowsky *et al*., 1992). Starch losses in cattle were also reported with halved and broken maize grain or coarse ground maize.

Another way to manipulate the rate of starch degradation is by selecting cultivars. Sorghum grain variety (Streeter *et al*., 1990a) and hybrid (Streeter *et al*., 1990b) altered the site and extent of starch digestion. In a comparison of *in vitro* ruminal starch disappearance rates of sorghum cultivars, Kotarski *et al*. (1992) reported a faster disappearance rate for cultivars with a floury compared to a horny endosperm. The texture of the grain seems to play a major role in ruminal starch degradation, as Philippeau & Michalet-Doreau (1997) showed *in situ* with maize grains.

## 2.7 The effects of processing maize on production

### 2.7.1 Cattle

Grains should be processed as thoroughly as possible for maximum digestibility by feedlot cattle. However, fine particles often decrease ration acceptability and increase the incidence of acidosis. Thus, maximum ration digestibility may not yield maximum feed efficiency (Owens *et al*., 1986; Secrist *et al*., 1995). Method of maize processing method (rolling *vs* grinding) also may affect ration digestibility, rate and efficiency of grain (Secrist *et al*., 1995). Ensiling high moisture maize also affects digestion by increasing the grain surface area and starch solubility in the rumen (Theurer, 1986). Smaller particles of high moisture maize have faster rates of starch digestion in the rumen

(Galyean *et al*., 1981). A mixture of dry maize with different particle sizes and mixtures of high-moisture and dry maize have been showed to improve feedlot performance compared with feeding one type of maize only (Turgeon *et al*., 1983; Stock *et al*., 1987).

A review (Anonymous, 2006) of processing methods on average daily gain and feed conversion revealed that cattle gained at similar rate (1.45kg per day) among studies where whole maize was fed as compared to dry rolled maize. Feed conversion (kilogram of feed require per kilogram of gain) were significantly lower with whole maize (5.95kg) as compared to dry rolled maize (6.57kg) as a result of cattle fed whole maize consuming nearly 1kg less per day than cattle consuming dry rolled maize. However, the authors (Anonymous, 2006) noted that this may also be an artifact of finishing rations with whole maize generally contains less roughage as compared to finishing rations with processed maize.

Processing maize may become necessary when small amounts of additional ingredients such as protein feeds (e.g. soybean meal), mineral and vitamin premixes or feed additives are going to be blended with the maize. Mixing large quantities of whole maize with minute amounts of other feedstuffs or feed additives will result in the blend becoming unevenly distributed due to sifting of the smaller feed particles during shipping and handling.

Although maize can be fed whole as a supplement, this concept cannot be applied to all feed grains. Some feed grains contain a hard external coat. Feed grains that benefit from processing before feeding include rice, sorghum and wheat (Anonymous, 2006).

### 2.7.2 Dairy cows

#### 2.7.2.1 Milk production and composition

According to Wilkerson *et al*. (1997) the milk yield of cows fed rations containing high moist (HM) maize was 2.0 kg/d higher than that of cows fed rations containing whole dry maize. Milk yield was higher (2.2 kg/d) for cows fed rations containing ground maize than for cows fed rations containing rolled maize. The effects of maize processing indicated that cows fed rations with ground dry maize yielded amounts of milk similar to those of cows fed rations with rolled HM maize when both rations were fed with equal amounts of lucerne silage. The response in milk yield observed in cows fed rations containing HM maize or ground maize suggested a more efficient use of dietary starch and energy. Clark *et al*. (1973) observed no difference in milk yield when lactating cows were offered a concentrate of dry maize or HM maize in combination with a forage ration of lucerne hay or lucerne haylage. Clark *et al*. (1975) observed increased milk yield when the concentrate ration consisted of rolled maize rather than whole maize. Further, McCaffree & Merrill (1968) observed no difference in milk yield when early lactating cows were fed a concentrate ration with either HM maize or whole dry maize. Cows in their study were allowed *ad libitum* access to a forage ration, and total DMI was greater when the concentrate contained dry maize compared to HM maize. The results suggested that more digestible energy (DE) was available from the HM maize, which compensated for the decrease in total intake.

Furthermore researchers have reported decreased milk yield (McCarthy *et al*., 1989; Robinson & Kennelly, 1989) or decreased fat corrected milk (FCM) as ruminally degraded starch increased (Aldrich *et al*., 1993). However Knowlton *et al*. (1996a) found that milk yield increased with finely ground maize grain relative to cracked maize grain. This effect was likely due to the increased total tract starch digestibility with ground maize.

The decrease in milk fat with ground maize treatment agreed with results of other studies (Aldrich *et al*., 1993; Moore *et al*., 1992) in which higher percentages of ruminally fermented starch decreased milk fat, which was commonly explained by a decrease in the ratio of acetate to propionate. Propionate increased with ground maize, but acetate concentrations were not affected (Knowlton *et al*., 1996b). The increase in milk protein with ground maize agreed with results of other studies (Aldrich *et al*., 1993; Oliviera *et al*., 1993). One possible mechanism was that increased propionate might spare AA for gluconeogenesis (Dye *et al*., 1988). However, the response of lactating cows that were isocalorically infused with glucose in the rumen or propionate in the duodenum suggested that the increase in milk protein observed with increased ruminal starch degradability was due to altered ruminal metabolism of glucose and increased propionate absorption (Wu *et al*., 1994). Another possibility was that rumen undegradable protein (RUP) increased because of an increased rate of nutrient passage.

### 2.7.3 Sheep

The uterus and accompanying fetuses utilize a major part of the glucose produced by prolific pregnant ewes (Prior & Christenson, 1978). Poor nutrition of ewes decreases glucose entry rate and impairs fetal development, but glucose infusion to fetuses may restore fetal development to normal (Bell *et al*., 1988). Birth weight of lambs is positively correlated with glucose entry rate of their mothers at late pregnancy (Barry & Manley, 1985; Landau, 1994), and is positively related with perinatal survival if litter size is high (Hinch *et al*., 1985). Another component of lamb survival is the immediate availability to newborn lambs of adequate amounts of colostrums, which is also positively related with glucose entry rate (Barry & Manley, 1985) and negatively affected by under nutrition (Mellor & Murray, 1985). Glucose entry rate is positively correlated with the level of energy supplies to sheep (Barry & Manley, 1985; Landau, 1994). High ruminal degradability of dietary starch negatively affects glucose entry rate in non-pregnant (Landau *et al*., 1992) but not in 115-day pregnant ewes (Landau, 1994). An increase in ruminal degradability of starch from corn grain may be obtained by processing the grain (Landau *et al*., 1992).

Studies of Landau *et al*. (1997) provides evidence that energy intake is not the only factor affecting litter weight in prolific ewes, since physical treatment of the grains affected litter weight with little effect on maternal energy intake. This may be explained by the enhanced glucose metabolism in ewes fed extruded maize (EM), compared with whole maize (WM). Feeding EM generates higher amounts of ruminal propionate, compared with those fed WM (Landau *et al*., 1992). Also, pregnant ewes fed EM had greater glucose entry rates than their WM-fed counterparts (Landau, 1994). On the other hand, feeding WM elicited higher glucose entry rates in non-pregnant ewes (Landau *et al*., 1992) and more ovulations in prolific ewes (Landau *et al*., 1995) than feeding EM. The discrepancy in results obtained with pregnant and non-pregnant sheep can be explained by the greater ability of pregnant sheep to synthesize glucose from propionate (Wilson *et al*., 1983). Supporting evidence for this theory is that insulin levels were not significantly higher in EM-fed sheep than in WM-fed pregnant sheep (Landau *et al*., 1997), in contrast to their previous finding in non-pregnant sheep fed at a maintenance level where plasma insulin levels were higher in EM-fed sheep (Landau *et al*., 1992). In conclusion, dietary starch degradability in the diet of pregnant ewes affects the birth weight of twin-lamb litters, but not colostrums accumulation prepartum. Extruding the maize in rations resulted in a 25% greater lamb birth weight to maternal body weight ratio (Landau *et al*., 1997).

## 2.8 Conclusion

A lack of information in the available literature occurred regarding the influence of physical form of maize grain on the utilization of sheep rations. Sheep masticate their food more than cattle and probably do not benefit as much as cattle from processed maize. This may be the reason for the absence of information on the physical form of maize grain in finishing diets of sheep and warrants this aspect further investigation.

## References

**Aldrich, J.M., Muller, L.D., Varga G.A. & Griel, L.C., *Jr*., 1993.** Nonstructural carbohydrates and protein effects on rumen fermentation, nutrient flow and performance of dairy cows. J. Dairy Sci. 76, 1091.

**Anonymous, 2006.** Beef cattle nutrition and feeding. Frequently asked questions. Whole versus chopped or ground corn as an energy source. University of Arkansas. http://www.aragriculture.org

**Archer, G. & Muller, G.S., 2004.** Guide to Machinery Costs. Directorate of Agricultural Economics.

**Barry, T.N. & Manley, T.R., 1985.** Glucose and protein metabolism during late pregnancy in triplet-bearing ewes given fresh gorage *ad lib*. Br. J. Nutr. 54, 521-533.

**Bell, A.W., Slepetis, R., Schoknecht, P.A. & Vatnick, I., 1988.** Nutritional and placental influences on prenatal growth, p.p. 103-108. Proc. Cornell Nutr.Conf. Fd. Manuf., 25-27, Oct 1988, Syracuse, NY.

**Callison, S.L., Firkins, J.L., Eastridge, M.L. & Hull, B.L., 2001.** Site of nutrient digestion by dairy cows fed corn of different particle size or steam-rolled. J. Dairy Sci. 84, 1458-1467.

**Chen, K.H., Huber, J.T., Theurer, C.B., Swingle, R.S., Simas, J., Chan, S.C., Wu, Z. & Sullivan, J.L., 1994.** Effect of steam flaking of corn and sorghum grains on performance of lactating cows. J. Dairy Sci. 77, 1038-1043.

**Church, D.C., 1984.** Livestock feeds and feeding. Second edition. O & B Books, Inc. Corvallis, Oregon.

**Clark, J.H., Frobish, R.A., Harshbarger, K.E. & Derrig, R.G., 1973.** Feeding value of dry corn, ensiled high moisture corn and propionic acid treated high moisture corn fed with hay or haylage for lactating dairy cows. J. Dairy Sci. 56, 1531-1539.

**Clark, J.H., Croom, W.J. & Harshbarger, K.E., 1975.** Feeding value of dry, ensiled and acid treated high moisture corn fed whole or rolled to lactating cows. J. Dairy Sci. 58, 907.

**Dye, B.E., Amos, H.E. & Froetschel., 1988.** Influence of lasalocid on rumen metabolites, milk yield, milk composition and digestibility in lactating cows. Nutr. Rep. Int. 38, 101-115.

**Eckhoff, S.R., Wu, P.C., Chung, D.S. & Converse, H.H., 1988.** Moisture content and temperature effects on Wisconsin Breakage Tester results. Trans ASAE 31(4), 1246-1246.

**Emeterio, F.S., Reis, R.B., Campos, W.E. & Satter, L.D., 2000.** Effect of coarse or fine grinding on utilization of dry or ensiled corn by lactating dairy cows. J. Dairy Sci. 83, 2839-2848.

**Firkins, J.L., Eastridge, M.L., St-Pierre, N.R. & Noftsger, S.M., 2001.** Effects of grain variability and processing on starch utilization by lactating dairy cattle. J. Anim. Sci. 79, E218-E238.

**Flachowsky, G., Baldeweg, P. & Schein, G., 1992.** A note on in sacco dry matter degradability of variously processed maize grains and of different maize varieties in sheep. Anim. Feed Sci. and Technology. 39, 173-181.

**Fordyce, J. & Kay, M., 1974.** A note on the effect of polyethylene particles on rumen metabolism of steers. Anim. Prod. 18, 105-108.

**Galyean, M.L., Wagner, D.G. & Owens, F.N., 1981.** Dry matter and starch disappearance from corn and sorghum as influenced by particle size and processing. J. Anim. Sci. 64, 1804-1812.

**Gunasekaran, S., Deshpande, S., Paulsen, M.R. & Shove, G.C., 1985.** Size characterization of stress cracks in corn kernels. Trans ASAE 28(5), 1668-1672.

**Hale, W.H. & Theurer, B.C., 1972.** In D.C. Church (Ed.) Digestive physiology and nutrition of ruminants. Vol. 3, Oregon State Univ., Corvallis.

**Haresign, W. & Cole, D.J.A., 1988.** Recent developments in ruminant nutrition 2. London: Butterworths.

**Hellevang, K.J., 1995.** Grain moisture content effects and management. NDSU Extension Service. AE-905.

**Herum, F.L. & Blaisdell, J.L., 1981.** Effects of moisture content, temperature and test variables on results with grain breakage testers. ASAE Paper No. 81-3030. ASAE, St. Joseph, MI 49085.

**Hinch, G.N., Crosbie, S.F., Kelly, R.W., Owens, J.L. & Davis, G.H., 1985.** Influence of birth weight and litter size on lamb survival in high fecundity Booroola-Merino crossbred flocks. N.Z. J. Agric. Res. 28, 31-38.

**Hixton, D.H., Hatfield, E.E. & Lamb, P.E., 1969.** Comparison of whole shelled corn with cracked corn in cattle finishing diets. J. Anim. Sci. 29, 161.

**Horton, G.M.J. & Holmes, W., 1975.** Feeding value of whole and rolled propionic acid-treated high-moisture corn for beef cattle. J. Anim. Sci. 40, 706-716.

**Huntington, G.B., 1997.** Starch utilization by ruminants: From basic to the bunk. J. Anim. Sci. 75, 852-867.

**Johnson, R.R., 1976.** Influence of carbohydrate solubility on non-protein nitrogen utilization in the Ruminant. J. Anim. Sci. 43, 184-191.

**Khoo, U. & Wolf, M.J., 1970.** Origin and development of protein granules in maize endosperm. Amer. J. Bot. 57(9), 1042-1050.

**Knowlton, K.F., Allen, M.S. & Erickson, P.S., 1996a.** Lasalocid and particle size of corn grain for dairy cows in early lactation. 1. Effect on performance, serum metabolities and nutrient digestibility. J. Dairy Sci. 79, 557-564.

**Knowlton, K.F., Allen, M.S. & Erickson, 1996b.** Lasalocid and particle size of corn grain for dairy cows in early lactation. 2. Effect on ruminal measurements and feeding behaviour. J. Dairy Sci. 79, 565-574.

**Knowlton, K.F., Glenn, B.P. & Erdman, R.A., 1998.** Performance, ruminal fermentation and site of starch digestion in early lactation cows fed corn grain harvested and processed differently. J. Dairy Sci. 81, 1972-1984.

**Kotarski, S.F., Waniska, R.D. & Thurn, K.K., 1992.** Starch hydrolysis by the ruminal microflora. J. Nutr. 122, 178-190.

**Kuhn, H.C., 1952.** 'n Vergelykende studie van resiproke Ronde-xDuikpitkruisings by mielies. MSc (Agric.) verhandeling, Univ. Stellenbosch.

**Landau, S., Nitsan, Z., Zoref, Z. & Madar, Z., 1992.** The effect of processing corn grain on glucose metabolism in ewes. Reprod. Nutr. Dev. 32, 231-240.

**Landau, S., 1994.** Increasing glucose metabolism in dry and pregnant ewes by nutritional means. Ph.D. Thesis, the Hebrew University of Jerusalem, Israel.

**Landau, S., Bor, A., Leibovich, H., Zoref, Z., Nitsan, Z. & Madar, Z., 1995.** The effect of ruminal starch degradability in the diet of Booroola crossbred ewes on induced ovulation rate and prolificacy. Anim. Reprod. Sci. 38, 97-108.

**Landau, S., Zoret, S., Nitsan, Z. & Madar, S., 1997.** The influence of extruding corn grain in diets fed to Finn X Awassi crossbred ewes during late pregnancy on birth weight of lambs. Can. J. Anim. Sci. 77, 141-147.

**LeFord, D.R. & Russel, W.A., 1985.** Evaluation of physical grain quality in the BS17 and BS1(HS)C1 synthetics of maize. Crop Sci. 25, 471-476.

**Lin, F.D., Knabe, D.A. & Tanksley, T.D., Jr., 1987.** Apparent digestibility of amino acids, gross energy and starch in corn, sorghum, barley, oat groats and wheat middlings for growing pigs. J. Anim. Sci. 64, 1655-1663.

**McDonald, P., Edwards, R.A., Greenhalgh, J F.D. & Morgan, C.A., 2002.** Animal Nutrition. Sixth Edition. Pearson Education Limited, Prentice Hall, England.

**McCaffree, J.D. & Merrill, W.G., 1968.** High moisture corn for dairy cows in early lactation. J. Dairy Sci. 51, 553-560.

**McCarthy, R.D.,Jr., Klusmeyer, T.H., Vicini, J.L., Clark, J.H. & Nelson, D.R., 1989.** Effects of source of protein and carbohydrate on rumen fermentation and passage of nutrients to the small intestine of lactating cows. J. Dairy Sci. 72, 2002-2016.

**Mellor, D.J. & Murray, L., 1985.** Effects of maternal undernutrition on udder development during late pregnancy and on colostrums production in Scottish Blackface ewes with twin lambs. Res. Vet. Sci. 39, 230-234.

**Miller, B.S., Hughes, J.W., Rousser, R. & Pomeranz, Y., 1979.** A standard method for measuring breakage susceptibility of shelled corn. ASAE Paper No. 79-3087, ASAE St. Joseph, MI 49085.

**Miller, B.S., Hughes, J.W., Rousser, R. & Pomeranz, Y., 1981.** Measuring the breakage susceptibility of shelled corn. Cereal Foods World 26(2), 75-80.

**Mills, J.A.N., France, J. & Dijkstra, J., 1999a.** A review of starch digestion in the lactating dairy cow and proposals for a mechanistic model: 1. Dietary starch characterisation and ruminal starch digestion. J. Anim. Feed Sci. 8, 291-339.

**Mills, J.A.N., France, J. & Dijkstra, J., 1999b.** A review of starch digestion in the lactating dairy cow and proposals for a mechanistic model: 2. Postruminal starch digestion and small intestinal glucose absorption. J. Anim. Feed Sci. 8, 451-481.

**Mitzner, K.C., Owen, F.G. & Grant, R.J., 1994.** Comparison of sorghum and corn grains in early and midlactation diets for dairy cows. J. Dairy Sci. 77, 1044-1051.

**Moe, P.W. & Tyrrell, H.F., 1977.** Effects of feed intake and physical form on energy value of corn in timothy hay diets for lactating cows. J. Dairy Sci. 60, 752-758.

**Moore, J.A., Poore, M.H.,Eck, T.P., Swingle, R.S. Huber, J.T. & Arana, M.J., 1992.** Sorgum grain processing and buffer addition for early lactation cows. J. Dairy Sci. 75, 3465-3472.

**Moreira, S.M., Krutz, G.W. & Foster, H.H., 1981.** Crack formation in corn kernels subject to impact. Trans ASAE 24(4), 889-892.

**Morrison, F.B., 1956.** Feeds and Feeding. 22$^{nd}$ ed. Clinton, Iowa: The Morrison Publ. Co.

**Noble, S.D., Brown, R.B. & Davidson, V.J., 2000.** Development of a maize breakage test method using a commercial food processor. J. Agric. Engng. Res. 77(4), 385-390.

**Nordin, M. & Campling, R.C., 1976.** Effect of the amount and form of roughage in the diet on digestibility of whole maize grain in cows and steers. J. Agric. Sci., (Camb.) 87, 213-219.

**Oliviera, J.S., Huber, J.T., Ben-Ghedalia, D., Swingle, R.S., Theurer, C.B. & Pessarakli, M., 1993.** Influence of sorghum grain processing on performance of lactating dairy cows. J. Dairy Sci. 76, 575-581.

**Owens, F.N., Zinn, R.A. & Kim, Y.K., 1986.** Limits to starch digestion in the ruminant small intestine. J. Anim. Sci. 63, 1634-1648.

**Owens, F.N. & Zinn, R.A., 2005.** Corn grain for cattle: Influence of processing on site and extent of digestion. pp. 78-85. South Nutr. Conf., Univ. of Arizona. http://www.animal.cals.Arizona.edu/swnmc/2005/index.htm.

**Pascual-Reas, B., 1997.** A comparative study on the digestibility of cassava, maize, sorghum and barley in various segments of the digestive tract of growing pigs. Livestock Research for Rural Development 9: Volume 5. http://www.cipav.org.co/lrrd/index.html.

**Perry, T.W., Peterson, R.C. & Beeson, W.M., 1973.** Value of roasting corn for finishing cattle. Annual Indiana Cattle Feeders Day, Purdue Univ. Indiana.

**Perry, T.W., Peterson, R.C. & Beeson, W.M., 1974.** The comparative nutritional value of regular and waxy corn for beef cattle. Purdue Univ. Cattle Feeders Day, March 1974, 13-14.

**Philippeau, C. & Michalet-Doreau, B., 1997.** Influence of genotype and stage of maturity on rate of ruminal starch degradation. Anim. Feed Sci. Technol. 68, 25-35.

**Pond, W.G., Church, D.C. & Pond, K.R., 1995.** Basic Animal Nutrition and Feeding. Fourth Edition. New York, John Wiley & Sons.

**Prior, R.L. & Christenson, R.K., 1978.** Insulin and glucose effects on glucose metabolism in pregnant and non-pregnant ewes. J. Anim. Sci. 46, 201-210.

**Reynolds, C.K., Stutton, J.D. & Beever, D.E., 1997.** Effects of feeding starch to dairy cattle on nutrient availability and production. Pages 105 – 134 in Recent Advances in Animal Nutrition. P.C. Garnsworthy and J. Wiseman, eds. Nottingham Univ. Press, Nottingham, UK.

**Riggs, J.K., Sorenson, J.W. & Hobgood, P., 1970.** Dry heat processing of sorghum grain for beef cattle. Texas A&M Univ. Agric. Exp. Sta.

**Robbinson, P.H. & Kennelly, J.J., 1989.** Influence of ammoniation of high moisture barley on digestibility, kinetics of rumen ingesta turnover and milk yield in dairy cows. Can. J. Anim. Sci. 69, 195-203.

**Rooney, L.W. & Pflugfelder, H.R., 1986.** Factors effecting starch digestibility with special emphasis sorghum and corn. J. Anim. Sci. 63, 1607-1623.

**Rowe, J.B., Choct, M. & Pethick, D.W., 1999.** Processing cereal grains for animal feeding. Aust J. Agric. Res. 50, 721-736.

**Salter, K.L. & Pierce, R.O., 1988.** Reducing corn breakage susceptibility through rehydration. Trans ASAE 31(3), 947-951.

**Secrist, D.S., Hill, W.J., Owens, F.N., Strasia, C.A., Gill, D.R. & Duggan, J.B., 1995.** Effects of particle size and distribution of high moisture corn on performance and carcass characteristics of feedlot steers. Olka. Agr. Exp. Sta. MP-943, 99-104.

**Seo, S., Tedeschi, L., Schwab, C. & Fox, D.G., 2004.** Predicting feed passage rate in dairy cattle. J. Anim. Sci. 82(Suppl 1), 462.

**Shelef, Leora & Mohsenin, N.N., 1969.** Effect of moisture on mechanical properties of shelled corn. Cereal Chem. 46, 242-253.

**Srivastava, A.K., Herum, F.L. & Balastreire, L.A., 1974.** Effect of freezing temperatures treatment on rapture strength of corn kernels. Trans ASAE 17(6), 1182-1184.

**Stock, R.A., Brink, D.R., Brandt, R.T., Merrill, J.K. & Smith K., 1987.** Feeding combinations of high moisture corn and dry corn to finishing cattle. J. Anim. Sci. 65, 282-289.

**Streeter, M.N., Wagner, D.G., Hibberd, C.A. & Owens, F.N., 1990a.** Comparison of corn with four sorghum grain hybrids: Site and extent of digestion in steers. J. Anim. Sci. 68, 3429-3440.

**Streeter, M.N., Wagner, D.G., Hibberd, C.A. & Owens, F.N., 1990b.** The effect of sorghum grain variety on the site and extent of digestion in beef heifers. J. Anim. Sci. 68, 1121-1132.

**Sussi, C., Superchi, P., Bonomi, A. & Bani, P., 2003.** Effect of corn grain popping temperature on lamb productive performance. Ital. J. Anim. Sci. 2(Suppl.), 497-499.

**Sutton, J.D., 1980.** Influence of nutritional factors on the yield and content of milk fat: dietary components other than fat. IDF-Bulletin, 125, 126-134.

**Tamminga, S., 1982.** In Protein and energy supply for high production of milk and meat, pp. 15-31. Pergamon; Oxford.

**Theurer, B.C., 1986.** Grain processing effects on starch utilization by ruminants. J. Anim. Sci. 63, 1649-1662.

**Theurer, C.B., Huber, J.T., Delgrado-Elorduy, A. & Wanderley,R., 1999.** Invited review: Summary of steam-flaking corn or sorghum grain for lactating dairy cows. J. Dairy Sci. 82, 1950-1959.

**Turgeon, O.A., Brink, Jr., D.R. & Britton, R.A., 1983.** Corn particle size mixtures, roughage level and starch utilization in finishing steer diets. J. Anim. Sci. 57, 739-749.

**Van der Merwe, H.J., Van Schalkwyk, A.P. & Van Rensburg, L.J.J., 1978.** Invloed van fisiese form van mieliegraan en aanvullende proteïenvoeding op die benutting van hoë kragvoerrantsoene deur vleisbeeste. S. Afr. Tydskrif. Veek. 8, 131-136.

**Vance, R.P., Preston, R.L., Klosterman, E.W. & Cahill, V.R., 1972.** Utilization of whole shelled and crimped corn grain with varying proportions of corn silage by growing-finishing steers. J. Anim. Sci. 35, 598-605.

**Vyn, T.J. & Moes, J., 1988.** Breakage susceptibility of corn kernels in relation to crob management under long growing season conditions. Agron. J. 80, 915-920.

**Welch, J.G., 1982.** Rumination, particle size and passage from the rumen. J. Anim. Sci. 54, 885-894.

**Welch, J.G., 1986.** Physical parameters of fibre effecting passage from the rumen. J. Dairy Sci. 69, 2750-2754.

**White, T.W., Hembry, F.G. & Reynolds, W.L., 1972.** Influence of grinding, supplemental nitrogen source and roughage on the digestibility of corn. J. Anim. Sci. 34, 672-676.

**Wilkerson, V.A., Glenn, B.P. & McLeod, K.R**., **1997.** Energy and nitrogen balance in lactating cows fed diets containing dry or high moisture corn in either rolled or ground form. J. Dairy Sci. 80, 2387-2496.

**Wilson, G.F., Adeeb, N.N. & Campling, R.C., 1973.** The apparent digestibility of maize grain when given in various physical forms to sheep and goats. J. Agric. Sci., (Camb.) 80, 259-267.

**Wilson, C.M., 1978.** Some biochemical indicators of genetics and developmental controls in endosperm. In D.B. Walden (ed). Maize breeding and Genetics. John Wiley & Sons, New York. Pp 405-419.

**Wilson, S., MacRae, J.C. & Buttery, P.J., 1983.** Glucose production and utilization in non-pregnant, pregnant and lactating ewes. Br. J. Nutr. 50, 303-316.

**Wolf, M.J., Buzan, C.L., Macmasters, M.M. & Rist, C.E., 1952.** Structure of the mature corn kernel. III Microscopic structure of the endosperm of dent corn. Cereal Chem. 29(5), 349-361.

**Wu, Z., Sleiman, F.T., Treurer, C.B., Santos, F., Simas, J.M., Francolin, M. & Huber, J.T., 1994.** Effect of isocaloric infusion of glucose in the rumen or propionate in the duodenum. J. Dairy Sci. *77*, 1556-1562.

**Ying, Y. & Allen, M.S., 2005.** Effects of corn grain endosperm type and conservation method on site of digestion, ruminal digestion kinetics and microbial nitrogen production of lactating cows. J. Dairy Sci. 88(suppl.1), 393.

**Yu, P., Huber, J.T., Santos, F.A.P., Simas, J.M. & Theurer, C.B., 1998.** Effects of ground, steam-flaked and steam-rolled corn grains on performance of lactating cows. J. Dairy Sci. 81, 777-782.

**Zinn, R.A., Owens, F.N. & Ware, R.A., 2002.** Flaking corn: Processing mechanics, quality standards and impacts on energy availability and performance of feedlot cattle. J. Anim. Sci. 80, 1145-1156.

## Chapter 3

## Influence of the physical form of maize grain and roughage level on the digestibility of finishing rations for lambs.

### 3.1 Introduction

Grain sources and processing have been researched for many years. Substantial portions of grain production have been marketed through beef, sheep or dairy products (Huntington, 1997). The basic drive for feeding high-grain rations to ruminants is the price of grain relative to forage. Furthermore grains increase the energetic density of the ration, which will optimize production in well-managed, intensive systems. Because starch is the major energy component of grains, improvements in the intensive systems will depend upon improved conversion of starch to animal product. One of the main factors influencing the utilization of starch is the physical form of grain.

Several authors have investigated the physical form of maize grain, mostly on cattle (Knowlton *et al*., 1996, Emeterio *et al*., 2000, Callison *et al*., 2001, Reis *et al*., 2001, Remond *et al*., 2004). Research on sheep is however very limited. Some research has been done on *in sacco* dry matter degradability of different processed maize grains (Flaschowsky *et al*., 1992). Very little research has been done specifically on the physical form of maize grain in high concentrate rations of growing sheep. Thus, research on sheep in this matter needs urgent attention.

The extent to which maize grain is digested in the rumen depends largely on the physical form in which it occurs in the rumen. Campher & Hofmeyr (1986) pointed out that both Mehrez & Orskov (1977) and Liebenberg *et al*. (1979) clearly demonstrated that virtually no whole maize grain (WMG) organic matter disappeared from dacron bags suspended in the rumen for periods of up to 96 hours. These authors concluded that, at normal digesta passage rates, microbes are unable to penetrate the testae of whole grain. The animal is therefore dependent on chewing and rumination to release the readily available carbohydrates. Sheep masticate their feed more completely than cattle. As a result, sheep do not benefit as much as cattle from grain processing (Hale, 1973). The question however arises whether this would apply for lambs with no permanent cut teeth. Other factors such as thorough mixing of the ration ingredients and the occurrence of selective intake could however also influence ration digestibility and utilization.

Type and level of roughage in the ration could have opposing effects on starch digestion. If added roughage increases mastication and rumination of the grain, it should increase digestibility in both the rumen and small intestine. On the other hand if added roughage elevates passage rate and more large particles are flushed out of the rumen, ruminal and total tract digestibility of starch from less well-processed grains will be compromised (Teeter *et al*., 1981). The interaction between grain processing and roughage level is most apparent with rations of whole shelled maize. With a whole shelled maize ration, levels of roughage above 6% depress starch digestion in the total track of beef cattle and depress efficiency of feed utilization. In the case of a processed maize ration, roughage levels as low as 6% will also result in poor efficiency, possibly due to ruminal acidosis. Further research of these interactions between grain processing and source and level of roughage are needed to optimize the efficiency with which grain can be used by finishing lambs.

The objective of this study was to investigate the influence of physical form of maize grain and level of roughage inclusion on the digestion of finishing rations for ram lambs.

## 3.2 Materials and Methods

### 3.2.1 Materials

#### 3.2.1.1 Experimental animals

Thirty Mutton Merino ram lambs, 2-3 months of age, with an average weight of 27.61kg (SD±2.13) were used. All the animals were dewormed and vaccinated against pulpy kidney and pasteurella before the start of the experiment. The animals were fed the experimental rations for 4 weeks before the start of a 7-day collection period.

#### 3.2.1.2 Metabolic cages

The lambs were housed individually in metabolic cages (Figure 3.1). The cages were designed to effectively separate the faeces and urine. Accordingly the cages were designed as such that the contamination of feed with water and faeces with urine was virtually eliminated. The width of each cage was adjusted according to the animals' size, preventing the sheep from turning around. Eventually they could only face towards the feed and water troughs. Each cage had an appropriate container (metal) to collect the faeces of the sheep. Urine was collected in 5l glass bottles to ensure clean, dry and hygienic conditions.


**Figure 3.1 – Individual metabolic cages**

### 3.2.1.3 Housing and management

The animals were housed in a well–ventilated room equipped with a cemented floor. Individual feeding (metabolic cages) and watering arrangement throughout the experimental period was easily managed. The finishing rations were offered to individual animals twice a day. Fresh water was freely available.

### 3.2.1.4 Experimental rations

a) Composition

The composition of the experimental rations is set out in Table 3.1. A high and lower energy ration containing 20% and 40% lucerne hay respectively was formulated to investigate a possible roughage level x grain physical form interaction. The ration was composed to provide in the crude protein (±13.5%), calcium (±0.5%) and phosphorus (±0.3%) requirements of finishing lambs on an air-dry basis (NRC, 1985). All the rations were formulated on a crude protein, degradable protein, calcium and phosphorus equivalent basis. The mean values of the feeds as indicated by Van der Merwe and Smith (1991) and Erasmus *et al*. (1988; 1990) were used to formulate the experimental rations.

**Table 3.1 – Physical and chemical composition of the finishing rations on an air-dry basis.**

| | **Rations** | |
|---|---|---|
| | **Roughage inclusion (%)** | |
| **Physical composition (%)** | **20** | **40** |
| Maize grain[1] | 48.5 | 46.5 |
| Lucerne hay | 20 | 40 |
| Molasses meal | 5 | 5 |
| Wheat bran | 15 | - |
| Cottonseed oilcake | 10 | 8 |
| Calcium-carbonate | 1 | - |
| Salt | 0.5 | 0.5 |
| **Chemical composition[2] (%)** | **20** | **40** |
| Moisture | 10.34 | 10.23 |
| Crude protein | 13.57 | 13.46 |
| Acid detergent fibre | 12.09 | 16.72 |
| Calcium | 0.65 | 0.47 |
| Phosphorus | 0.38 | 0.26 |

1 Three types: Whole, ground and fine

2 According to the feed values of Van der Merwe & Smith (1991) and Erasmus *et al*. (1988; 1990)

Furthermore the effect of physical form of maize grain on the digestibility of the rations namely whole (WMG), grounded (GMG) and fine (FMG) was investigated for each energy level (roughage inclusion). The maize cultivar was Phb 32AO5B (Pioneer). The experimental rations was thoroughly mixed with a paddle type feed mixer (Figure 3.2).

**Figure 3.2 – Paddle type feed mixer**

b) Physical form

GMG was obtained by using a ROFF MK1S MILL 419 SERIES 5 groove roller (5grooves per 25mm) machine without any sieves. The FMG was obtained with a ROFF MK6D 319 SERIES machine. This machine was equipped with three sets of sieves. Only the first two sets were used. The third set was left out to collect the total ingredients of the maize grain. The first set consisted of two sieves with 10 holes per 25mm and 28 holes per 25mm respectively. The second set also has two sieves namely 14 holes per 25mm and 28 holes per 25mm respectively. Furthermore the machine consisted of three sets of rollers. The first set included 8 grooves per 25mm, the second 20 grooves per 25mm and the third 24 grooves per 25mm.

The lucerne hay (Medicago sativa) was milled with a Drotsky hammer mill through a 12.5 mm grid.

### 3.2.2 Methods

#### 3.2.2.1 Digestibility study

a) Animals

Thirty Mutton Merino ram lambs with legible ear tags were randomly allocated to 6 treatments (5 per group). Lambs were weighed at the beginning and end of the feeding period after an overnight fasting period. The sheep were also randomly allocated to individual metabolic cages. All the cages were clearly identified with the respective tag numbers of the sheep. Apart from a 3-week adaptation period to the experimental rations outside in pens, they were adapted to the metabolic cages for 7 days, before the commencement of a 7-day collection period.

b) Feed

Fresh feed (rations) was weighed accurately for each sheep in appropriate containers twice a day and fed at 08:00 and 16:00. During the digestibility study the constant refusal method of Blaxter *et al*. (1961) was applied which defines that the experimental animals received 15% more feed than consumed the previous day. A composite feed sample was collected daily for each experimental ration and stored in a plastic bag. At the end of the seven-day collection period a smaller representative sample obtained by the quartering method for each experimental ration was composed, milled with a laboratory mill (1mm sieve) and stored in sealed sample bottles for later chemical analysis.

c) Feed refusals

Daily feed refusals for each sheep were collected separately. The total feed refusals of each sheep at the end of the seven days period were mixed and a smaller representative sample was composed (quartering method) for chemical analysis at a later stage. The same milling and storing procedures described for feed was used.

d) Faeces

The faeces of the sheep were collected separately on an appropriate sieve plate. Any uncontaminated faeces which might have been in the feed troughs or on the collection plates under the feed troughs, was collected later with the rest of the faeces for a specific sheep. The total daily faeces excretion for each sheep was immediately dried in an oven at 100°C. At the end of the collection period the total dry matter excretion of faeces for each sheep was determined. Sampling, milling and storing procedures of faeces for later chemical analysis was the same as for feed and feed refusals.

e) Urine

As already mentioned before, urine was collected in glass bottles, which was cleaned out daily to ensure clean, dry and hygienic conditions.

f) Water

Fresh water was freely available. The water troughs were cleaned and refilled at 10:00 and 17:00 daily.

### 3.2.2.2 Chemical analysis

Milled feed samples, refused feed and dried faeces were analyzed in duplicate for dry matter (DM) and organic matter (OM) (AOAC, 2000), crude protein (CP) (Randall, 1993), acid detergent fibre (ADF) (Van Soest, 1963) and gross energy (GE) (adiabatic bomb calorimeter).

a) Dry matter (DM)

Approximately 2g of each sample (ration, refused feed and oven dried faeces) was weighed accurately in a 30ml porcelain crucible and dried in an oven at 100 °C for a minimum period of 16 hours (overnight) to a constant mass (AOAC, 2000).

Calculation:

$$\% \text{ DM} = \frac{\text{MCDS-CM}}{\text{MOCS-CM}} \times \frac{100}{1}$$

Where:

CM = crucible mass

MOCS = crucible mass plus air dry sample

MCDS = crucible mass plus dried sample

b) Crude protein (CP)

Crude protein was determined using the Dumas method of combustion with a LECO FP 2000 machine (Randall, 1993). A sample was combusted in an atmosphere of oxygen to produce the oxide of nitrogen and other gasses.

An oven-dried sample (feed, refusal or faeces) of approximately 1g was accurately weighed into a re-usable boat and placed into a purge chamber of the horizontal furnace. The boat was placed into the furnace, oxygen ($O_2$) allowed to flow directly onto the sample and combustion initiated at 950°C. The resulting gaseous products were passed through a thermo-electric cooler, removing most of the moisture and the gasses collected in a ballast chamber. Nitrogen (N) was measured using a thermal conductivity detector against a background of pure helium (He). The detector signal was transmitted to a computer via microprocessor and the data analyzed to determine the nitrogen content of the sample. Crude protein (g/100g DM) was calculated as N (g/100g DM) x 6.25.

c) Gross energy (GE)

Gross energy was determined using a Gallencamp adiabatic bomb calorimeter. The bomb was standardized using benzonic acid. A sample of approximately 0.5g of feed, refusals or faeces was accurately weighed and approximately 10cm platinum wire was connected to the electrodes of the bomb. The bomb was tightly closed and filled with oxygen to 3000 Kpa and placed into a calorimeter to equilibrate the temperature between the outer container and the internal calorimeter container and then ignited. An automatic heating unit and the circulation of cold water created an adiabatic environment. The final temperature was determined by an electronic microprocessor (CP 400: Digital Data Systems).

Calculation:

$$\text{Gross energy (MJ/kg)} = \frac{A}{B}$$

Where:

A = Micro-processor reading

B = Weight of sample

d) Acid detergent fibre (ADF)

The method of determination of ADF was used as described by Van Soest (1963). A sample of approximately 1g was accurately weighed and put over night in oven at 100°C. Oven dried sintered glass crucibles were accurately weighed. The dry sample was transferred from the small tubes to sintered glass crucibles and weighed again accurately. The sintered glass crucibles with the sample were placed into the hot extraction unit (Tecator Fibertec System M 1020 Hot Extractor) ensuring that all the crucibles fit snugly i.e. cannot easily be turned by hand. All the valves were put in the closed position and the condenser was turned on (cooling water). Each crucible received 100ml of cold acid detergent solution (ADS). Leakage was checked and the cover was fitted on the front of the heating section. The heating element was now turned on high in order to bring the solution to boil. The heat was adjusted and then boiled for approximately 60 minutes.

The residue in the crucible was filtered with suction, washed 3 times with hot water and then rinsed twice with acetone. Each sample was dried over night, weighed and ashed at 500°C for a minimum of 4 hours. The furnace was allowed to cool over night before the crucibles were removed and weighed.

Calculation:

$$\% \text{ ADF} = \frac{\text{RCD} - \text{RCA}}{\text{Original sample mass}} \times 100$$

Where:

RCD = residue in crucible after drying.

RCA = residue in crucible after ashing.

e) Ash

Percentage ash was obtained by the incineration of the fodder (AOAC, 2000). The part of the dry material that incinerates in the presence of air is known as organic material.

A silica dish was dried for one hour at 525°C in an incineration oven, cooled in a dessicator to room temperature and weighed accurately. Approximately 2g of sample (feed, feed refusals or faeces) were weighed into the dried and already weighed dish. The sample was subsequently carbonized on a hot plate and incinerated overnight at 525°C in an incineration oven. After incineration the dish and ash were cooled in a dessicator and weighed accurately.

Calculation:

$$\text{Percentage ash} = \frac{W_1 - W_2}{\text{Sample mass}} \times 100$$

Where:

$W_1$ = dish mass plus ash

$W_2$ = dish mass

Percentage organic matter was calculated by subtracting the percentage ash from 100.

f) Apparent digestibility coefficients

The following formula was used to calculate apparent digestibility coefficients:

$$\text{Apparent digestibility (\%)} = \frac{\text{(dry matter or nutrient intake)} - \text{(dry matter or nutrient excreted in feaces)}}{\text{dry matter or nutrient intake}} \times \frac{100}{1}$$

Where dry matter intake = dry matter or nutrient presented – dry matter or nutrient refused.

g) Apparent digestible protein and -energy

The crude protein figure provides a measure of the nitrogen present in the food but gives little indication of its value to the animal. The digestible protein in the feed was determined by the digestible trail in which nitrogen intake was measured along with the nitrogen voided in the faeces.

The following formula was used to calculate apparent digestible protein coefficient:

$$\text{Digestible protein (\%)} = \frac{\text{(crude protein intake)} - \text{(crude protein excreted in faeces)}}{\text{dry matter intake}} \times \frac{100}{1}$$

The apparent digestible energy of a food is the gross energy content of a unit weight of the food less the gross energy content of the faeces (digestion study) resulting from the consumption of unit weight of that food. Digestible energy was calculated from a similar formula as digestible protein. Metabolisable energy was calculated from digestible energy values by multiplying by 0.8 (McDonald *et al*., 2002).

### 3.2.2.3 Statistical analysis

Data was statistically analyzed as a 2 x 3 factorial block design (effect of 2 roughages and 3 physical forms of maize grain) in which data from individual lambs served as replicates. Data were subjected to PROC ANOVA using the General Linear Models

(GLM) procedure of SAS® (SAS Institute, 1996) (version 6.12) to assess the effect of dietary treatment on response variables. The differences between means were separated using Tukey's studentised range (HSD) test.

## 3.3 Results and Discussion

### 3.3.1 Chemical composition

The chemical composition of the experimental rations is summarized in Table 3.2. It is clear that the DM- OM- and CP-content was similar in all the rations. The higher ADF content of the 40 compared to the 20% roughage rations is to be expected. These higher ADF content in the rations could result in lower DM and OM digestibility coefficients. The GE-content of the rations varied from 17.46 to 19.55 MJ/kg. The values agreed with the statement of McDonald *et al*., (2002) that most common foods contain about 18.5MJ GE/kg DM. Furthermore the actual CP and ADF values compared in general well with the calculated values in Table 3.1 on a dry matter basis.

### 3.3.2 Intake

An increase in the quantity of a food eaten by an animal generally causes a faster rate of passage of digesta. The food is then exposed to the action of digestive enzymes for a shorter period and there may be a reduction in its digestibility. Thus dry matter intake (DMI) should be considered in the interpretation of digestibility results.

From the results in Table 3.3 it is evident that the DMI and organic matter intake (OMI) of lambs consuming the ration with WMG was significantly (P=0.0052) lower than those fed FMG. This higher intake level of the lambs consuming the FMG-ration could result in a reduction of digestibility of the nutrients in the ration. According to McDonald *et al*. (2002) the reductions in digestibility due to increased rates of passage is the greatest for the slowly digested components of foods, namely the cell-wall components. In the current study relative high concentrate rations were fed and could the effect of DMI on digestibility probably be less prominent.

**Table 3.2 – The chemical composition of the experimental rations on a dry matter basis**

| Parameters | Lucerne hay (%) | Particle size WMG | GMG | FMG |
|---|---|---|---|---|
| Dry matter (%) | 20 | 89.82 | 89.93 | 89.79 |
| | 40 | 90.01 | 89.71 | 90.05 |
| Organic matter (%) | 20 | 92.93 | 93.86 | 93.84 |
| | 40 | 93.26 | 93.30 | 92.25 |
| Crude protein (%) | 20 | 15.71 | 15.04 | 15.19 |
| | 40 | 16.35 | 15.04 | 15.27 |
| Acid detergent fibre (%) | 20 | 14.34 | 14.03 | 13.44 |
| | 40 | 19.37 | 19.21 | 16.83 |
| Gross energy (%) | 20 | 18.59 | 17.74 | 17.66 |
| | 40 | 19.55 | 17.71 | 17.46 |

WMG – Whole maize grain
GMG – Grounded maize grain
FMG – Fine maize grain

The results of DMI are in contrary with findings of Owens *et al*. (1997). These researchers found reduced DMI of a rapidly fermented grain source and extensively processed grain. This has been attributed to excessive rates of acid production in the rumen and subclinical acidosis, which increases day-to-day variation in DMI (Stock *et al*., 1995). In the case of the current study subclinical acidosis probably did not occur. The higher DMI of the FMG lambs could be attributed to a faster fermentation rate and therefore a faster passage rate of digesta. DMI results over a relative short period of 7 days is however less accurate and should be interpreted with caution.

It further seems from Table 3.3 that lucerne hay content (20% v. 40%) of the finishing ration did not significantly (P=0.7181) influence DMI by lambs. Galyean and Defoor (2003) pointed out that roughage source and level can have substantial effects on DMI by cattle fed high-concentrate rations. Effects of larger changes in roughage level (e.g. greater than 5% of DM) on DMI might simply reflect energy dilution, such that cattle increase DMI presumably in an attempt to maintain energy intake. It is however, doubtful whether small changes in roughage level or changes in roughage source could affect energy density enough to account for relatively large differences in DMI. This was clearly not the case in the present study with sheep.

**Table 3.3 – Influence of physical form of maize grain and roughage level on the intake of lamb finishing rations**

| Parameters | Lucerne hay (%) | WMG | GMG (Particle size) | FMG | Average | Roughage | Form (Significance (P)) | Interaction | CV(%) |
|---|---|---|---|---|---|---|---|---|---|
| Dry matter intake (kg/lamb/day) | 20 | 1.06 | 1.10 | 1.30 | 1.15 | 0.7181 | 0.0052 | 0.6721 | 16.54 |
| | 40 | 0.95 | 1.13 | 1.31 | 1.13 | | | | |
| | Average | 1.01[b] | 1.12[ab] | 1.31[a] | | | | | |
| Organic matter intake (kg/lamb/day) | 20 | 0.98 | 1.04 | 1.22 | 1.08 | 0.6916 | 0.0057 | 0.7934 | 16.45 |
| | 40 | 0.89 | 1.06 | 1.21 | 1.05 | | | | |
| | Average | 0.94[b] | 1.05[ab] | 1.22[a] | | | | | |
| Dry matter refusal (kg/lamb/7days) | 20 | 1.78 | 1.38 | 1.31 | 1.49[a] | 0.8679 | 0.0230 | 0.6789 | 35.34 |
| | 40 | 2.05 | 1.22 | 1.29 | 1.52[a] | | | | |
| | Average | 1.92[a] | 1.30[b] | 1.30[bc] | | | | | |
| Acid detergent fibre refusal (kg/lamb/7days) | 20 | 0.16 | 0.18 | 0.13 | 0.16[a] | 0.0094 | 0.2625 | 0.3647 | 44.98 |
| | 40 | 0.32 | 0.23 | 0.21 | 0.25[b] | | | | |
| | Average | 0.24 | 0.21 | 0.17 | | | | | |
| Acid detergent fibre intake (kg/lamb/7days) | 20 | 1.16 | 1.09 | 1.27 | 1.17[a] | 0.0008 | 0.2957 | 0.4885 | 16.38 |
| | 40 | 1.36 | 1.52 | 1.55 | 1.48[b] | | | | |
| | Average | 1.26 | 1.31 | 1.41 | | | | | |

WMG – whole maize grain
GMG – grounded maize grain
FMG – fine maize grain
CV – coefficient of variation

[a,b,c] Means in rows or column with different superscripts differ significantly (P<0.05)

Roughage-rich rations are more bulky and limit the feed intake. According to Haresign & Cole (1988) the ruminant can utilize the major part of bulky, fibrous materials only via microbes. Voluntary intake of rations rich in roughages is generally restricted by the limited capacity of the digestive track, the reticulorumen in particular. Disappearance of the digesta from the reticulorumen is possible either by microbial degradation and absorption of end products (VFA, ect.) or by passage to the lower digestive track of undigested residues, after sufficient reduction of particle size and of microbial mass. According to the results of the current study rumen capacity did not restrict DMI where 40% roughage (lucerne hay) was included in the finishing ration. In this regard Van Soest *et al*. (1987) mentioned that lucerne hay used in the present study as roughage source has a moderately fast rate of fermentation in the rumen. Therefore rumen capacity plays a minor role compared to roughage with a slow fermentation rate.

To achieve maximum energy intake in ruminants it is important to know which factors limit feed intake and their interactions. Feed intake regulation in ruminants is complex and not fully understood. The traditional opinion that the main physical factors on limitation of feed intake from roughage-rich rations are rumen capacity and rate of disappearance of digesta from the digestive tract is well known (Conrad *et al*., 1964). Metabolic factors are said (Baumgardt, 1970; Baile & Forbes, 1974) to play a more important role in the regulation of intake of highly digestible forages and rations rich in concentrates like in this present study.

Studies of Hadjipanayiotou & Hadjidemetriou (1990) showed that DMI decreased with a decreasing proportion of roughage in the ration, using three diets of varying barley grain to barley hay ratios (75:25, 55:45, 35:65). This is in accordance with the findings of Hejazi *et al*. (1999). DMI was greater for the lambs fed rations containing supplemented fibre than for those fed rations that lacked supplemented fibre. The different results observed in the present study are probably because of different grain- and roughage types used in the various studies and also fibre levels, -composition and -digestibility. The experimental period of DMI measurements could also play a role.

### 3.3.3 Dry and organic matter digestibility (DMD, OMD)

The digestibility of a food is most accurately defined as that proportion which is not excreted in the faeces and which is, therefore, assumed to be absorbed by the animal

(Bondi & Drori, 1987; McDonald *et al*., 2002). The apparent DMD and OMD of rations with FMG were significantly (P=0.008) lower than those containing WMG (Table 3.4). This could be partially due to the higher (P=0.0052) DMI and to the fact that the food was exposed to the action of digestive enzymes for a shorter period (McDonald *et al*., 2002). However as already mentioned a higher DMI and therefore increase in passage rate of digesta has a smaller influence on the reduction in digestibility of high concentrate ration (less cell-wall components). Therefore other factors could have contributed to the lower DMD of the FMG ration by lambs. Blaxter (1973) and Van der Honing (1975) are of opinion that although intake increases, digestibility of grounded and pelleted materials compared to the unprocessed materials tends to be lower. These effects on intake and digestibility are mainly attributed to an increased rate of passage through the fore stomachs and the reduced time for the microbial fermentation. In most cases the lower digestibility is compensated for by an improved utilization of digestible energy. As already stated sub-clinical acidosis that might occur during the digestion of the FMG (Stock *et al*., 1995), probably had no influence on digestibility results.

A factor that could contribute to the differences in DMD is the selection behaviour of lambs. The selection of WMG and less lucerne hay could result in a higher DMD. From Table 3.3 it is evident that the DM refusal from lambs, which consume WMG rations, is significantly higher (P<0.05) than those which consumed the FMG rations. No statistical significant (P=0.2625) differences occurred, however in the refusal and intake of ADF by lambs on the different physical form treatments. The WMG rations only tend to cause a lower ADF intake (Table 3.3) by lambs, indicating that selection plays a minor role in this study.

Furthermore Camper & Hofmeyr (1986) are of opinion that a positive relationship has been well established between roughage inclusion and rumination on meal type of rations. Nicholson *et al*. (1971) confirmed this relationship in the case of WMG rations. However in spite of this, they found no increase in apparent grain or DMD and it would therefore seem that a significant amount of time is spent on the mastication and rumination of roughage, rather than WMG. In studies of Fimbres *et al*. (2002) rumination time varied from 2.4 h per day in lambs fed the ration without hay to 6.9 h per day in lambs fed the ration with 30% hay. In the present study physical form of grain had the same effect on DMD irrespective of roughage level. Therefore roughage level accordingly did not seem to influence the mastication and rumination of WMG.

It further seems from Table 3.3 that in contrast with DMI, the level of lucerne hay in the ration had a statistical significant (P=0.0025) influence on apparent DMD. The DMD of the ration with 20% roughage was higher (P=0.0025) than the 40% roughage inclusion level. McDonald *et al*. (2002) mention that modern methods of food analysis attempt to distinguish between fractions of cell walls and cell contents. Cell contents are almost completely digested. The digestibility of cell walls is more variable and depends on the degree of lignification. Roughages are less digestible than concentrates because they contain more cell walls and vascular bundles, hence more lignin, and because they have dense masses of cells that resist invasion by microorganisms. This explains the lower DMD of the 40% lucerne hay ration.

### 3.3.4 Apparent digestibility of crude protein (CP)

Proteins are an essential part of all living tissue. There is no other nutrient that can replace protein in the ration. The degradative and synthetic processes taking place in the rumen are of major importance in the nitrogen economy of the host animal since they determine the nature of the amino acid mix made available for protein synthesis at tissue level (McDonald *et al*., 2002).

From the results in Table 3.4 it seems that the processing of maize grain resulted in a reduction (P=0.0547) of apparent crude protein digestibility (CPD). The lower intake level of the WMG ration by the lambs could again contribute to these higher observed CP-digestibility values. Furthermore processing of grain could influence site of digestion of both starch and protein and it can also alter urea utilization (Owens *et al*., 1986). The lower apparent digestibility of CP in the FMG-ration could be due to a higher passage rate and site of digestion.

**Table 3.4 – Influence of physical form of maize grain and roughage level on the apparent digestibility of lamb finishing rations**

| Parameters | Roughage Level(%) | Particle size WMG[1] | GMG[2] | FMG[3] | Average | Significance Roughage | Form | Interaction | CV(%)[4] |
|---|---|---|---|---|---|---|---|---|---|
| Dry matter (%) | 20 | 71.83 | 73.13 | 68.38 | 71.11[a] | 0.0025 | 0.0008 | 0.2430 | 5.24 |
| | 40 | 70.20 | 68.62 | 61.15 | 66.65[b] | | | | |
| | Average | 71.01[a] | 70.87[a] | 64.76[b] | | | | | |
| Organic Matter (%) | 20 | 73.90 | 75.24 | 70.32 | 73.16[a] | 0.0064 | 0.0005 | 0.2777 | 4.73 |
| | 40 | 72.83 | 71.31 | 64.31 | 69.48[b] | | | | |
| | Average | 73.36[a] | 73.28[a] | 67.32[b] | | | | | |
| Crude protein(%) | 20 | 69.29 | 65.76 | 64.82 | 66.63[a] | 0.0005 | 0.0547 | 0.4951 | 8.84 |
| | 40 | 61.61 | 60.36 | 53.51 | 58.49[b] | | | | |
| | Average | 65.45[a] | 63.06[ab] | 59.17[b] | | | | | |
| Acid Detergent fibre (%) | 20 | 40.15 | 34.58 | 18.99 | 32.68[a] | 0.5989 | 0.0001 | 0.2732 | 23.22 |
| | 40 | 47.38 | 35.39 | 15.28 | 31.24[a] | | | | |
| | Average | 43.77[a] | 34.99[b] | 17.13[c] | | | | | |
| Gross Energy(%) | 20 | 71.96 | 71.84 | 67.16 | 70.32[a] | 0.0211 | 0.0001 | 0.1443 | 5.37 |
| | 40 | 72.19 | 68.16 | 60.65 | 67.00[b] | | | | |
| | Average | 72.08[a] | 70.00[a] | 63.91[b] | | | | | |

WMG – whole maize grain
GMG – grounded maize grain
FMG – fine maize grain
CV – coefficient of variation

[a,b,c] Means in rows or column with different superscripts differ significantly (P<0.05)

From the results in Table 3.4 it is evident that the apparent digestibility of CP was significantly (P=0.0005) higher where 20% compared to 40% lucerne hay was included into the ration. The forage-to-concentrate ratio plays a big role in the rate of degradation and the type and extent of microbial fermentation, thus the digestibility of crude protein (Haresign & Cole, 1988). In studies of Sahlu *et al*. (1993) crude protein digestibility was significantly (P<0.05) higher with an inclusion of higher proportion of concentrate in the ration. Digestibility of protein depends primarily on protein content of the ration and intake. According to Chandramoni *et al*. (1999) the digestibility of a ration increase with the increase of concentrate proportion in the ration. Furthermore the ration with 20% lucerne hay contained more cottonseed oilcake (Table 3.1) to rectify the CP-content of the ration because of a lower lucerne hay content. This could also attribute to a higher CP digestibility because of differences in CP-digestibility of cottonseed oilcake and lucerne hay.

### 3.3.5 Apparent digestibility of acid-detergent fibre (ADF)

The ADF represents the crude lignin and cellulose fractions of plant material but also includes silica. The determination of ADF is particularly useful for forages as there is a good statistical correlation between it and the extent to which the food is digested (digestibility). The fibre fraction of a food has the greatest influence on its digestibility and both the amount and chemical composition of the fibre are important. The digestibility of cell walls is variable and depends on the degree of lignification, which in chemical terms is expressed as the lignin content of acid-detergent fibre (Bondi & Drori, 1987; MacDonald *et al*., 2002).

It is clear from Table 3.4 that a smaller particle size maize grain in the ration had a negative (P=0.0001) influence on the apparent digestibility of ADF. This could be partially due to a more rapid fermentation rate of FMG and lower rumen pH. The lower pH inhibits cellulolytic microorganisms and accordingly fibre (ADF) digestibility is depressed. McDonald *et al*. (2002) is of opinion that in addition to its "pH effect" rapid starch fermentation seems to have a direct effect on cellulolysis. A higher DMI, faster rate of passage and shorter exposure of the food to the digestive enzymes could also contributed to these lower apparent digestibility values for ADF in the FMG ration.

Koenig *et al*. (2003) found that ruminal starch digestibility and fibre digestibility (NDF and ADF) in the rumen was lower (P<0.05) when fed a more extensively processed barley grain combined with 5% barley silage to beef cattle. In contrast with results of the current study grain processing had no effect (P>0.05) on ruminal fibre digestion when combined with 20% barley silage (more roughage). More extensive grain processing reduced (P<0.05) total-track ADF digestibility when combined with 5% barley silage and was a reflection of the reduction in ruminal ADF digestibility. This was in contrast to findings of Beauchemin *et al*. (2001) with feedlot cattle. They found that there was more ADF digested in the intestine with increased processing and hence digestibility of ADF in the total track tended (P=0.07) to increase with increased grain processing. Factors like species, age, ration composition, grain and roughage type could contribute to these variation in results.

The level of lucerne hay in the ration had no effect (P=0.5989) on the apparent digestibility of ADF. According to these results the inclusion of 40 compared to 20% lucerne hay in the ration seems not to influence pH and therefore cellulolytic fermentation in the rumen.

### 3.3.6 Apparent digestibility of gross energy (GE)

The animal obtains energy from its food, converting it into heat energy. The quantity of chemical energy present in a food is measured by converting it into heat energy and determining the heat produced. This conversion is carried out by oxidizing the food by burning it; the quantity of heat resulting from the complete oxidation of unit weight of a food is known as the GE or heat of combustion of that food. Not all of the GE of foods is available and useful to the animal. Some energy is lost from the animal in the form of the solid, liquid and gaseous excretions; another fraction is lost as heat. Their deduction from the GE content of the food gives rise to further descriptive categories of food energy; for example, GE less the energy content of faeces gives the category known as the digestible energy (DE) of the food (Church, 1984; Bondi & Drori, 1987; Gillespie, 1987; McDonald *et al*., 2002).

From the results in Table 3.4 it is evident that the apparent digestibility of GE of rations with WMG and GMG were both significantly (P=0.0001) higher than those with FMG.

As discussed before the higher intake of rations and passage rate of digesta in the case of FMG, resulted in a shorter exposure to microorganisms and therefore an increased faecal energy loss.

It further seems from the Table 3.3 that the apparent digestibility of GE decreased significantly (P=0.0211) when 40% roughage was included in the ration. This was expected because of the lower concentrate level. This is also in agreement with the DMD and OM digestibility findings (par. 3.3.3).

### 3.3.7 Digestible crude protein (DCP)

The crude protein figure provides a measure of the nitrogen present in the food but gives little indication of its value to the animal. Before the food becomes available to the animal it must undergo digestion, during which it is broken down to simpler substances, which are absorbed into the body (McDonald *et al*., 2002). The digestible protein in the rations is expressed as a percentage of the DMI.

From the results in Table 3.5, it is clear that the digestible crude protein of rations fed with both GMG and FMG were significantly (P=0.0150) lower than rations with WMG. This could also be due to the fact than processed grain has a higher rate of passage and the food was exposed to the action of digestive enzymes for a shorter period of time. The lower digestible crude protein in rations as a result of processing maize grain (GMG and FMG) should be considered when formulating finishing rations for lambs.

In accordance with crude protein digestibility, the rations with 20% roughage had a significantly (P>0.05) higher digestible crude protein than the ration with a 40% roughage inclusion (Table 3.4). The digestibility of cell walls is more variable and depends on the degree of lignification. Roughages are less digestible than concentrates because they contain more cell walls and vascular bundles, hence more lignin, and because they have dense masses of cells that resist invasion by microorganisms (McDonald *et al*., 2002). Furthermore the same factors that influenced apparent CP digestibility as discussed in paragraph 3.3.4 could influence the digestible CP results.

**Table 3.5 – Influence of physical form of maize grain and roughage level on the digestible crude protein and energy of lamb finishing rations**

| Parameters | Roughage level(%) | Particle size WMG[1] | GMG[2] | FMG[3] | Average | Significance Roughage | Form | Interaction | CV(%)[4] |
|---|---|---|---|---|---|---|---|---|---|
| Digestible | 20 | 11.48 | 9.64 | 9.87 | 10.33[a] | 0.0130 | 0.0150 | 0.7246 | 13.80 |
| crude | 40 | 10.05 | 8.87 | 8.16 | 9.02[b] | | | | |
| protein(%) | Average | 10.76[a] | 9.26[b] | 9.01[b] | | | | | |
| Metabolisable | 20 | 10.82[a] | 10.20[ab] | 9.50[b] | - | 0.3123 | 0.0001 | 0.0069 | 6.10 |
| energy(MJ/kg) | 40 | 11.66[a] | 9.69[b] | 8.48[c] | - | | | | |

WMG – whole maize grain
GMG – grounded maize grain
FMG – fine maize grain
CV – coefficient of variation

[a,b,c] Means in rows or column with different superscripts differ significantly (P<0.05)

### 3.3.8 Metabolisable energy (ME)

The apparent digestible energy of a food is the gross energy content of a unit weight of the food less the gross energy content of the faeces resulting from the consumption of a unit weight of that food. The animal suffers however further losses of energy-containing substances in the urine and particularly if it is a ruminant, in the combustible gasses leaving the digestive tract. The metabolisable energy of a food is the digestible energy less the energy lost in the urine and combustible gasses. The metabolisable energy values can be calculated from digestible energy by multiplying it by 0.8 (McDonald *et al*., 2002).

According to Table 3.5 and Figure 3.3 a significant (P=0.0069) physical form x roughage level interaction occurred, indicating that the influence of physical form on ME varied within roughage level. Processing of grain seems to have a more detrimental effect (P<0.05) on the ME content of the ration when a higher level of lucerne hay was included. It is however clear that in accordance with DMD and OMD, processing of maize grain result in a lower ME-content in the ration. This decline was more obvious when more roughage was included in the ration.

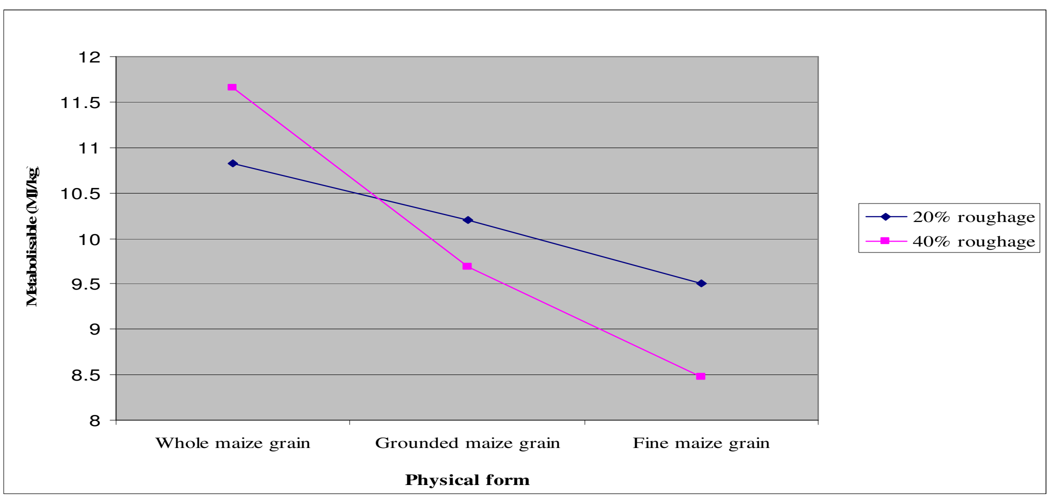


**Figure 3.3 – Physical form x roughage level interaction for metabolisable energy**

According to Table 3.5 lucerne hay level however, did not influence ME-content of the finishing rations within a specific physical form. This is in contrast with the DMD and gross energy digestibility results as already discussed. These different results are difficult to explain as DMI was not statistical significant (P>0.05) influenced by roughage level in the ration. Roughage may decrease the energetic efficiency of the entire ration by increasing the passage rate of the ration (Vance et al., 1972).

### 3.4 Conclusions

It is evident from the results of the present study that rations containing WMG delivered better digestible results. Lambs consuming the WMG ration had lower DM intakes, which could lead to the higher apparent DMD, CPD, digestibility of GE, and a higher digestible CP and ME content. These effects on intake of the FMG rations by lambs could increase the rate of passage of food through the rumen and reduced the time for microbial fermentation. It is also probably an indication that sheep masticate their feed more completely than cattle.

Furthermore, the rations with a 20% compared to a 40% roughage inclusion delivered throughout significantly ($P<0.05$) better results regarding DMD and the apparent digestibility of CP and GE. In contrary with these results the ME-content of the rations was not influenced by the mentioned roughage levels.

## References

**AOAC, 2000.** Official Methods of Analysis of the Association of Official Agricultural Chemists, 17th Edn. Washington: AOAC.

**Baile, C.A., & Forbes, J.M., 1974.** Control of feed intake and regulation of energy balance in ruminants. Physiological Review. 54, 160-214.

**Baumgardt, B.R., 1970.** Regulation of feed intake and energy balance. In physiology of digestion and metabolism in the ruminant, pp. 235-253. Ed. A.T. Philipson. Oriel Press Ltd; Newcastle-upon-Tyne.

**Beauchemin, K.A., Yang, W.Z. & Rode, L.M., 2001.** Effects of barley grain processing on the site and extent of digestion of beef feedlot finishing diets. J. Anim. Sci. 79, 1925-936.

**Blaxter, K.L., Wainman, F.W. & Wilson, R.S., 1961.** The regulation of the food intake by sheep. Anim. Prod. 3, 51-61.

**Blaxter, K.L., 1973.** In Proceedings of the first international green crop drying congress, pp. 64-72. Ed. C.L. Skidmore. E. and E. Plumridge; Cambridge.

**Bondi, A.A. & Drori, D., 1987.** Animal nutrition. John Wiley & Sons, Chichester, Great Britain, pp 499-506.

**Callison, S.L., Firkins, J.L., Eastridge, M.L. & Hull, B.L., 2001.** Site of nutrient digestion by dairy cows fed corn of different particle size or steam-rolled. J. Dairy Sci. 84, 1458-1467.

**Campher, J.P., & Hofmeyr, H.S., 1986.** The influence of roughage on the digestibility of whole maize grain diets. S. Afr. J. Anim. Sci. 16, 54-56.

**Chandramoni, X.X., Jadhao, S.B., Tiwari, C.M. & Khan, M.Y., 1999.** Carbon and nitrogen balance studies in Muzaffarnagari sheep fed diets varying in roughage and concentrate ratio. Small Rumin. Res. 31, 221-227.

**Church, D.C., 1984.** Livestock feeds and feeding. Second edition. O & B Books, Inc. Corvallis, Oregon.

**Conrad, H.R., Pratt, A.D. & Hibbs, J.W., 1964.** Regulation of feed intake in dairy cows. I. Change in importance of physical and physiological factors with increasing digestibility. J. of Dairy Sci. 47, 54-62.

**Emeterio, F.S., Reis, R.B., Campos, W.E. & Satter, L.D., 2000.** Effect of coarse or fine grinding on utilization of dry or ensiled corn by lactating dairy cows. J. of Dairy Sci. 83, 2839-2848.

**Erasmus, L.J., Prinsloo, J., Botha, P.M. & Meissner, H.H., 1988.** The establishment of protein degradability database for dairy cattle using the nylon bag technique. I. Protein Sources. S. Afr. J. Anim. Sci. 18, 23-31.

**Erasmus, L.J., Prinsloo, J., Botha, P.M. & Meissner, H.H., 1990.** Establishment of protein degradability data base for dairy cattle using the *in situ* polyester bag technique. Roughages. S. Afr. J. Anim. Sci. 20, 124-134.

**Fimbres, H., Kawas, J.R., Hernández-Vidal, G., Picón-Rubio, J.F. & Lu, C.D., 2002.** Nutrient intake, digestibility, mastication and ruminal fermentation of lambs fed finishing ration with various forage levels. Small Rumin. Res. 43, 275-281.

**Flachowsky, G., Baldeweg, P. & Schein, G., 1992.** A note on in sacco dry matterdegradability of variously processed maize grains and of different maize varieties in sheep. Anim. Feed Sci. Techn. 39, 173-181.

**Galyean, M.L. & Defoor, P.J., 2003.** Effects of roughage source and level on intake by feedlot cattle. J. Anim. Sci. 81(E. Suppl. 2), E8-E16.

**Gillespie, J. R., 1987.** Animal Nutrition and Feeding. By Delmar Publishers Inc. Clifton Park, New York.

**Hadjipanayiotou, M. & Hadjidemetriou, D., 1990.** Effect of lactation and of roughage to concentrate rations on outflow rates of protein supplements from the rumen of sheep and goats. Livestock Prod. Sci. 24, 37-46.

**Hale, W.H. 1973.** Influence of processing on the utilization of grains (starch) by ruminants. J. Anim. Sci. 37, 1075-1080.

**Haresign, W. & Cole, D.J.A., 1988.** Recent developments in ruminant nutrition 2. Second edition. London; Boston: Butterworths.

**Hejazi, S., Fluharty, F.L., Perley, J.E., Loerch, S.C. & Lowe, G.D., 1999.** Effects of corn processing and dietary fiber source on feedlot performance, visceral organ weight, diet digestibility, and nitrogen metabolism in lambs. J. Anim. Sci. 77, 507-515.

**Huntington, G.B., 1997.** Starch utilization by ruminants: From basic to the bunk. J. Anim. Sci. 75, 852-867.

**Knowlton, K.F., Allen, M.S. & Erickson, P.S., 1996.** Lasalocid and particle size of corn grain for dairy cows in early lactation. 1. Effect on performance, serum metabolities and nutrient digestibility. J. Dairy Sci. 79, 557-564.

**Koenig, K.M., Beauchemin, K.A. & Rode, L.M., 2003.** Effect of grain processing and silage on microbial protein synthesis and nutrient digestibility in beef cattle fed barley-based diets. J. Anim. Sci. 81, 1057-1067.

**Liebenberg, L.H.P., Meissner, H.H. & Pienaar, J.P., 1979.** Disappearance of processed maize grain in the rumen. S. Afr. J. Anim. Sci. 9, 227.

**McDonald, P., Edwards, R.A., Greenhalgh, J F.D. & Morgan, C.A., 2002.** Animal Nutrition. Sixth Edition. Pearson Eduction Limited, Prentice Hall, England.

**Mehrez, A.Z. & Orskov, E.R., 1977.** A study of the artificial fibre bag technique for determining the digestibility of feeds in the rumen. J. Agric. Sci., Camb. 88, 645-650.

**Nicholson, J.W.G., Gorrill, A.D. & Burgess, P.L., 1971.** Loss in digestible nutrients when ensiled barley is fed whole. Can. J. Anim. Sci. 51, 697-700.

**NRC, 1985.** Nutrients Requirement of sheep, National Research Council, National Academy of Sciences, Washington, D.C.

**Owens, F.N., Zinn, R.A. & Kim, Y.K., 1986.** Limits to starch digestion in the ruminant small intestine. J. Anim. Sci. 63, 1634-1648.

**Owens, F.N., Secrist, D.S., Hill, W.J. & Gill, D.R., 1997.** The effect of grain source and grain processing on performance of feedlot cattle: A Review. J. Anim. Sci. 75, 868-879.

**Randall, G.P., 1993.** An evaluation of the Dumas technique for the termination of protein wheat and barley. Project 137, December. South Africa Wheat Board, SA.

**Reis, R.B., San Emeterio, F., Combs, D.K., Satter, L.D. & Costa, H.N., 2001.** Effects of corn particle size and source on performance of lactating cows fed direct-cut grass-legume forage. J. Dairy Sci. 84, 429-442.

**Remond, D., Cabrera-Estrada, J.I., Champion, M., Chauveau, B., Coudure, R. & Poncet, C., 2004.** Effect of corn particle size on site and extent of starch digestion in lactating dairy cows. J. Dairy Sci. 87, 1389-1399.

**Sahlu, T., Hart, S.P. & Fernandez, J.M., 1993.** Nitrogen metabolism and blood metabolites in three goat breeds fed increase amounts of protein. Small Rumin. Res. 10, 281-292.

**SAS Institute, 1996.** SAS® User's Guide. Version 6.12. SAS Institute Inc., Raleigh, NC.

**Stock, R., Klopfenstein, T. & Shain, D., 1995.** Feed intake variation. Okla. Agric. Exp. Sta. Misc. Publ. P-942, 56.

**Teeter, R.G., Owens, F.N. & Gill, D.R., 1981.** Roughage-concentrate associative effects. Okla. Agric. Exp. Sta. Misc. Publ. P-108, 161.

**Van der Honing, Y., 1975.** Agriculture Research Reports, 836, pp 1-156. Centre for Agricultural Publishing and Documentation; Wageningen.

**Van der Merwe, F.J. & Smith, W.A., 1991.** Dierevoeding. Anim. Sci. Pty. Ltd., Pinelands.

**Van Soest, P.J., Robertson, J.B. & Lewis, B.A., 1987.** Methods of dietary fibre, neutral detergent fibre, and non-starch polysaccharides in relation to animal nutrition. J. Anim. Sci. 74, 3583-3597.

**Van Soest , P.J., 1963.** Use of detergents in the analysis of fibrous feeds **2.** A rapid method for the determination of fibre and lignin. J. Assoc. Off. Anal. Chem. 46, 829.

**Vance, R.D., Preston, R.L., Klosterman, E.W. & Cahill, V.R., 1972.** Utilization of whole shelled and crimped corn grain with varying proportions of corn silage by growing-finishing steers. J. Anim. Sci. 35, 598-605.

# Chapter 4

## Influence of the physical form of maize grain and roughage level in finishing rations on the performance of lambs.

### 4.1 Introduction

Although grain may be processed to simplify mixing with other ration ingredients and reduce separation of ration components during feed preparation and in the feed bunk, the primary reason for processing grain for livestock is to enhance nutritional value. Feeding value of a cereal grain is a function of its nutrient content, physical and chemical characteristics that effect digestibility, acceptability (palatability) and associative interactions with the digestive process. Processing methods must be selected that will most economically enhance digestibility and acceptability without detrimentally affecting ruminal pH and causing digestive dysfunction (Owens & Zinn, 2005).

Modern day intensive production systems involve feeding high levels of concentrates (mostly non-fibrous carbohydrates such as starch in feed grains) to ruminants. The research regarding the physical form of maize grain in finishing rations is confined to beef cattle. Contrary results occurred in the literature on the effect of physical form of maize grain in finishing rations for beef cattle on digestibility and performance (Van der Merwe *et al*., 1989). It seems as if the quantity of roughage (Vance *et al*., 1972), the physical form (Pitzen *et al*., 1971) and the type of roughage (Meissner *et al*., 1982) could influence the utilization of whole grain by beef cattle. In the case of sheep McDonald *et al.* (2002) is of opinion that sheep can often be relied upon to chew whole cereal grains thereby obviating mechanical processing. However if grains are given with a roughage that passes rapidly through the digestive tract, they should be crushed for sheep. Theurer (1986) also mentioned years back that processing methods do not appear to be as important with sheep and goats (as with cattle), due to their ability to utilize effectively whole grains. In this regard it is however important to remember that the absence of permanent cut teeth in lambs could hamper their chewing ability.

It seems as if the performance regarding physical form of maize grain in finishing rations for lambs is limiting. Furthermore the quantity, physical form and type of roughage could also influence the results with different grain particle sizes in the finishing ration.

In South Africa lucerne hay is the most common roughage source in finishing rations for lambs. Therefore a study was done to investigate the influence of particle size of maize grain and lucerne hay level in finishing rations on the growth performance of lambs.

## 4.2 Materials and Methods

### 4.2.1 Materials

#### 4.2.1.1 Experimental animals

Thirty approximately 3 months old South African Mutton Merino lambs with an average weight of 27.76kg (SD±1.67) were used in a finishing study. All the animals were dewormed with a broad-spectrum vermicide and vaccinated against pulpy kidney and pasteurella before the start of the experiment. The lambs were gradually adapted to the finishing ration during a 14-day period.

#### 4.2.1.2 Housing

The lambs were housed individually in experimental pens (Figure 4.1) with slatted floors in a well-ventilated building. The animals were randomly spread among the pens and the slatted floor ensured a clean and hygienic environment. Each pen was equipped with its own food bucket and water trough. It was designed to prevent any contamination of water and feed (Figure 4.2). All pens were clearly identified with the respective tag numbers of the sheep (Figure 4.2).

**Figure 4.1 – Individual experimental pens**


**Figure 4.2 – Food bucket and water trough**

Each pen was cleaned once a week to ensure and maintain a good hygienic environment (Figure 4.3). The finishing ration was offered to individual animals twice a day. Fresh clean water was freely available.

**Figure 4.3 – Cleaning**

#### 4.2.1.3 Experimental rations

The composition and physical form of the rations were exactly the same that were used in the digestibility study (see par. 3.2.1.4).

#### 4.2.2 Methods

##### 4.2.2.1 Performance study

a) Animals

Thirty South African Mutton Merino ram lambs with legible ear tags were randomly allocated to 6 treatments (5 per group). Lambs were weighed at the beginning of the feeding period after an overnight fasting period. Thereafter, they were weighed weekly without fasting. At the end of a 74-day feeding period the weight after an overnight fasting period of the lambs were again determined. Facilities to weigh the lambs are shown in Figure 4.4. This was to ensure to determine the exact amount of weight gained.

b) Feed

As mentioned before, an adaptation period of 14 days was applied. Fresh feed was weighed accurately for each sheep in appropriate containers twice a day and fed at 08:00 and 16:00. The feed consisted of 1000g lucerne and 200g of the finishing ration at the first two days of the adaptation period. Thereafter the ration increased with 200g increments every two days, whereas the lucerne decreased with 200g. After 14 days all the ram lambs received the final experimental rations as described in Chapter 3. Once the adaptation period was completed, the rations were provided *ad libitum*. Feed intake of each lamb was determined on a weekly basis by subtracting the refusal weight from the feed provided. At the same time a composite feed sample was collected for each experimental ration and stored in a plastic bag. At the end of the 74-day feeding period a smaller representative sample obtained by the quartering method for each experimental ration was taken, milled with a laboratory mill (1mm sieve) and stored in sealed bottles for later chemical analysis.


**Figure 4.4 – Facilities to weigh lambs**

c) Water

Fresh and clean water was freely available. The water troughs were cleaned and refilled at 10:00 and 17:00 daily.

d) Faeces

The faeces of each sheep were scored (1-5) weekly according to the physical form as indicated in Figure 4.5. This gave a good indication of the adaptation of lambs on the different rations as well as general health.

**1**

**2**

**3**

**4**

**5 Diaree**

**Figure 4.5 – Physical score card for faeces of lambs**

e) Slaughtering, grading and carcass evaluation of the lambs

At the end of the 74-day feeding period all the ram lambs were slaughtered at a commercial abattoir and their carcass characteristics were evaluated and recorded. The body weight of each lamb was determined the morning prior to slaughter after an overnight fasting period. Following slaughtering, the carcasses were skinned and eviscerated. The warm carcass weight and the carcass grades were recorded according to the official methods practiced in South Africa (SAMIC, 2004). According to this grading system a code of 1 represents a very lean carcass, while 6 represents an over-fat carcass, as summarized in Table 4.1. These carcasses were then preserved by means of refrigeration (4 to 5ºC) for 24 hours and then weighed.

Table 4.1 – Official sheep carcass classification system used in South Africa

| Age description (Teeth) | Age class code | Fat description | Grade | Back fat (mm) |
|---|---|---|---|---|
| 0 | A | No fat | 0 | 0 |
| 1-2 | AB | Very lean | 1 | <1 |
| 3-6 | B | Lean | 2 | 1-3 |
| >6 | C | Lean | 3 | 3-5 |
| | | Fat | 4 | 5-7 |
| | | Over fat | 5 | 7-10 |
| | | Excessively over fat | 6 | >10 |

Source: Government notice no. R 1748, 26 June 1992.

Carcass measurements were taken 24h after refrigeration according to the methods described by Fisher & De Boer (1993) and Ramsay *et al*., (1991). The external length of the carcass, the circumference of the shoulders and the circumference of the buttock were measured after 24h of refrigeration. The back fat thickness was measured on the left half of the carcass between the 12$^{th}$ and 13$^{th}$ rib of the *M. longissimus thoracis* (at 3 points) (Edwards *et al*., 1989).

Calculation:

$$\text{Slaughter percentage} = \frac{\text{Carcass mass cold (kg)}}{\text{Live weight}} \times \frac{100}{1}$$

#### 4.2.2.2 Chemical analysis

Chemical analysis was done on the representative samples of each experimental ration as described in Chapter 3.

#### 4.2.2.3 Statistical analysis

Data was statistically analyzed as a 2 x 3 factorial block design (effect of 2 roughages and 3 physical forms of maize grain) in which data from individual lambs served as replicates. Data were subjected to PROC ANOVA using the General Linear Models (GLM) procedure of SAS® (SAS Institute, 1996) to assess the effect of dietary treatment on response variables. The differences between means were separated using Tukey's studentised range (HSD) test.

### 4.3 Results and Discussion

#### 4.3.1 Intake and feed efficiency

The influence of rations with different roughage levels and physical form of maize grain on feed intake and weight gain is shown in Table 4.2. A significant ($P<0.05$) physical form x roughage level interaction for dry matter intake (DMI), organic matter intake (OMI) and metabolisable energy intake (MEI) by lambs occurred, indicating that the effect of dietary physical form of maize grain on intake varied at different roughage levels. However no significant ($P>0.05$) differences were found in the DMI of lambs on the various treatments. The DMI of lambs consuming the 20% lucerne hay ration only tended to be higher ($P=0.0774$) as the degree of grain processing increased. In contrast a significant ($P<0.05$) influence of grain processing on DMI of lambs was observed in the digestible study. The differences in length of the experimental periods, average weight of the lambs and environment of the two studies, could contribute to these different results. The longer experimental period of the finishing period should however result in more accurate DMI results. Furthermore the metabolisable energy (ME) values of the experimental rations determined in the digestibility study (Chapter 3) are most likely not completely representative for those of the finishing study. As mentioned before feeding level could influence digestibility and therefore ME values. This should be kept in mind when interpreting the ME-results. In contrary with DMI, the MEI of lambs in the fine maize grain (FMG) treatment with 40% lucerne hay was significantly ($P=0.0013$) lower compared to the whole maize grain (WMG) and grounded maize grain (GMG) treatments. These differences in ME-intake were however not reflected in the weight gain results of the lambs. This could be attributed to the fact that the ME-values of the digestibility study used for calculation purposes, was not representative as already discussed. Furthermore the ME-content of the experimental rations does not include heat losses.

It is clear from the Table 4.2 that no significant ($P>0.05$) particle size x roughage level interaction occurred for the weight gain, feed- and energy efficiency results. Therefore the effect of grain processing on these results was the same, irrespective of roughage level. According to the weight gain and energy conversion results the inclusion of WMG in finishing rations for lambs, resulted in statistical significant poorer results.

**Table 4.2 – Influence of physical form of maize grain and roughage level on dry matter intake, growth and feed conversion of lamb finishing rations.**

| Parameters | Roughage Level(%) | Particle size WMG | GMG | FMG | Average | Significance (P) Roughage | Form | Interaction | CV(%) |
|---|---|---|---|---|---|---|---|---|---|
| Dry matter intake (kg/lamb/d) | 20 | 1.30 | 1.48 | 1.55 | - | 0.2918 | 0.0774 | 0.0256 | 8.80 |
| | 40 | 1.39 | 1.49 | 1.32 | - | | | | |
| Metabolisable energy intake (MJ/lamb/d) | 20 | 14.02[a] | 15.10[a] | 14.76[a] | - | 0.1471 | 0.0013 | 0.0002 | 8.66 |
| | 40 | 16.24[a] | 14.47[a] | 11.22[b] | - | | | | |
| Initial weight (kg) | 20 | 28.65 | 28.80 | 28.52 | 28.81 | 0.8037 | 0.36477 | 0.5495 | 5.97 |
| | 40 | 29.40 | 29.36 | 27.68 | 28.66 | | | | |
| | Average | 29.03 | 29.08 | 28.10 | | | | | |
| End weight (kg) | 20 | 45.65 | 51.52 | 50.28 | 49.40 | 0.1918 | 0.0389 | 0.2018 | 7.38 |
| | 40 | 47.16 | 50.20 | 45.48 | 47.61 | | | | |
| | Average | 46.41[a] | 50.86[b] | 47.88[ab] | | | | | |
| Weight gain (kg/lamb/d) | 20 | 0.230 | 0.307 | 0.294 | 0.280 | 0.1415 | 0.0371 | 0.4081 | 17.40 |
| | 40 | 0.240 | 0.282 | 0.241 | 0.254 | | | | |
| | Average | 0.235[a] | 0.295[b] | 0.268[ab] | | | | | |
| Kg DM/kg life weight gain | 20 | 5.75 | 4.84 | 5.31 | 5.69 | 0.1504 | 0.1064 | 0.9955 | 13.88 |
| | 40 | 5.93 | 5.33 | 5.80 | 5.27 | | | | |
| | Average | 5.84 | 5.09 | 5.56 | | | | | |
| MJ ME/kg life weight gain | 20 | 62.25 | 49.40 | 50.39 | 56.67 | 0.2660 | 0.0001 | 0.6806 | 13.92 |
| | 40 | 69.18 | 51.62 | 49.22 | 53.42 | | | | |
| | Average | 65.72[a] | 50.51[b] | 49.81[bc] | | | | | |

WMG – whole maize grain
GMG – grounded maize grain
FMG – fine maize grain
CV – coefficient of variation

[a,b,c] Row means with different superscripts differ significantly (P<0.05)
[1,2] Column means with different superscripts differ significantly (P<0.05)

This lower weight gain of the WMG rations can be observed in Figure 4.6. With the exception of the end weight no significant (P>0.05) differences between treatments on a weekly basis were observed. This was confirmed by the energy efficiency (P=0.0001), but not feed efficiency results (P=0.1064).

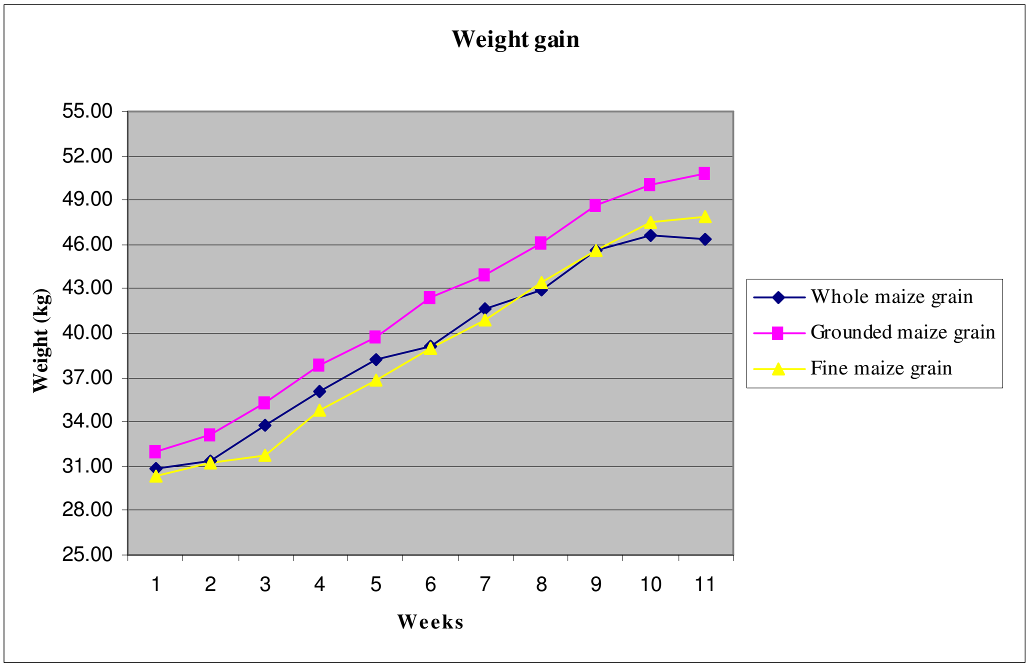


**Figure 4.6 – Average live weight gain of the lambs on a weekly basis**

According to Owens & Zinn (2005) improves grain processing feed efficiency while decreasing flow of starch to the abomasum due to an increased extent of ruminal fermentation. This has led to the concept that enhancing ruminal starch digestion is beneficial and that postruminal starch digestion is incomplete, inefficient or both. Base on these precepts, the ideal site for starch digestion must be the rumen. The same results were found in trials of Scott *et al*. (2003) who reported that feed efficiency was improved as the degree of processing of maize was increased in finishing rations of steers. These studies with cattle are in contrary with findings of Fluharty *et al*. (1999) with sheep. They found that lambs fed whole maize had a higher average daily gain (ADG) (P<0.001)(345 *vs*. 267 g/day) and better feed efficiency (P<0.05)(4.29kg dry matter (DM) *vs.* 4.83kg DM/kg life weight gain) compared with lambs fed ground/pelleted maize. According to these researchers this could be due to the fact that feeding ground/pelleted maize rations to lambs limits feed intake compared with whole-shelled maize rations. The results of Fluharty *et al*. (1999) are however in contrast with those in the current study. These contrary results could be *inter alia* attributed to the type of grain fed.

Braman *et al*. (1973) reported that steers fed dry-rolled waxy maize had increased daily gains and improved feed efficiency compared with steers fed normal maize. A possible physical form x grain type (softness) interaction warrants further investigation.

It is further evident from Table 4.2 that the different levels of lucerne hay in the finishing rations did not statistical influence the DMI of lambs. This is in agreement with the results of the digestibility study (Chapter 3). Accordingly ME-intake, weight gain, feed and energy efficiency of lambs were not statistically (P>0.05) influenced by the inclusion of 20 or 40% lucerne hay in the ration. It is widely accepted that the addition of roughage to high-energy feedlot rations will increase the DM consumed, but the effects on rate of gain and efficiency have been inconsistent (Traxler *et al*., 1995). A study performed by Turgeon *et al*. (1983) with various forms and mixtures of dry maize indicated that increasing the level of roughage (from 5 to 15%) in the ration had no effect on daily rate of gain and resulted in greater intakes and poorer feed conversion rations. Stock *et al*. (1990) however observed inconsistent effects on gain when roughage was added to rations of dry maize and grain sorghum. A reduction in the extent of starch digestion, due to a greater intake of roughage rations, was suggested as being responsible for the decrease in concentrate efficiency in many of the dry grain rations. Differences in fermentation and passage rate of different roughage sources could however have an influence on the results.

### 4.3.2 Carcass data

Carcass parameters collected in this study are presented in Table 4.3. With the exception of shoulder circumference, no significant influence of physical form of maize grain on carcass characteristics could be detected. Carcass classification scores were similar for all treatment groups (Government notice no. R 1748, 1992). These results are in contrast with findings of Van der Merwe *et al*. (1978). They found a significantly (P<0.01) higher carcass mass for steers consumed maize meal compared to whole maize. In studies of Van der Merwe *et al*. (1989) no significant (P>0.05) differences were found in carcass mass, dressing percentage and grading among treatments where maize meal was substituted with rolled and whole maize respectively in steer rations. Factors like species, age, ration composition, roughage level, roughage source and grain type could influence the results with different physical forms of grain.

**Table 4.3 – Influence of physical form of maize grain and roughage level on the carcass characteristics of lamb finishing rations**

| Parameters | Roughage Level(%) | Particle size WMG | GMG | FMG | Average | Significance (P) Roughage | Form | Interaction | CV(%) |
|---|---|---|---|---|---|---|---|---|---|
| Carcass weight(kg) | 20 | 22.75 | 24.60 | 24.48 | 24.03[1] | 0.0232 | 0.1724 | 0.1369 | 7.31 |
| | 40 | 22.72 | 23.56 | 21.20 | 22.49[2] | | | | |
| | Average | 22.74 | 24.08 | 22.84 | | | | | |
| Dressing % | 20 | 49.81 | 47.82 | 48.74 | 48.72[1] | 0.0142 | 0.0922 | 0.4824 | 3.14 |
| | 40 | 48.16 | 46.93 | 46.62 | 47.24[2] | | | | |
| | Average | 48.99 | 47.38 | 47.68 | | | | | |
| Fat thickness (mm) 1 | 20 | 4.50 | 4.70 | 3.70 | 4.29 | 0.2759 | 0.8090 | 0.6551 | 39.84 |
| | 40 | 3.40 | 3.70 | 3.80 | 3.63 | | | | |
| | Average | 3.95 | 4.20 | 3.75 | | | | | |
| Fat thickness (mm) 2 | 20 | 3.50 | 3.40 | 3.70 | 3.54 | 0.2039 | 0.6512 | 0.7302 | 43.17 |
| | 40 | 2.30 | 3.30 | 3.00 | 2.87 | | | | |
| | Average | 2.90 | 3.35 | 3.35 | | | | | |
| Fat thickness (mm) 3 | 20 | 3.38 | 3.30 | 3.30 | 3.32 | 0.3310 | 0.7069 | 0.7197 | 44.40 |
| | 40 | 2.30 | 3.30 | 2.80 | 2.80 | | | | |
| | Average | 2.84 | 3.30 | 3.05 | | | | | |
| Carcass length (cm) | 20 | 57.75 | 59.00 | 57.80 | 58.21 | 0.2579 | 0.3214 | 0.9721 | 2.86 |
| | 40 | 57.30 | 58.00 | 57.20 | 57.50 | | | | |
| | Average | 57.53 | 58.50 | 57.50 | | | | | |
| Shoulder Circumference (cm) | 20 | 76.88 | 79.00 | 78.50 | 78.21[1] | 0.0359 | 0.0144 | 0.0987 | 1.94 |
| | 40 | 76.80 | 78.60 | 75.50 | 76.97[2] | | | | |
| | Average | 76.84[a] | 78.80[b] | 77.00[ac] | | | | | |
| Buttock circumference (cm) | 20 | 64.88 | 67.90 | 67.30 | - | 0.0674 | 0.2865 | 0.0345 | 3.16 |
| | 40 | 66.50 | 65.90 | 63.60 | - | | | | |

WMG – whole maize grain
GMG – grounded maize grain
FMG – fine maize grain
CV – coefficient of variation

[a,b,c] Row means with different superscripts differ significantly (P<0.05)
[1,2] Column means with different superscripts differ significantly (P<0.05)

The results in Table 4.3 clearly indicated that lambs fed the 20% lucerne hay rations were significantly (P<0.05) higher in carcass weight, dressing percentage and shoulder circumference than lambs fed the 40% lucenre hay rations. In many feeding situations intake seems to be restricted by the capacity of the rumen, with stretch and tension receptors in the rumen wall signaling the degree of 'fill' to the brain, but what constitutes the maximum – and hence critical – 'fill' of the rumen is uncertain (McDonald *et al*., 2002). The motion that voluminous, 'bulky' foods, such as this lucerne hay, will fill the rumen to a greater degree than concentrates, although after being chewed, the voluminous foods are not as 'bulky' as they are in the trough. Apart from the heavier carcass weight, this could contribute to the significantly (P<0.05) higher dressing percentage for lambs consuming the 20% lucerne hay rations over the 40% lucerne hay rations.

## 4.4 Conclusions

It seems from the results of the present study that physical form of maize grain did not influence the DMI of lambs. Although MEI of lambs fed FMG in a ration with 40% lucerne hay was lower than the WMG and GMG treatments, this was not reflected in the weight gain results. In fact the weight gain results of lambs were poorer when WMG was included in the finishing rations. These conflicting results between MEI and weight gain could be partly attributed to the ME-values of the digestibility study used for calculation purposes. The feeding level differed between the digestibility and production studies. Accordingly the actual ME-values of the similar ration (same composition) fed in the digestibility and production studies could differ. Furthermore heat losses not measured in the current study could also influence the weight gain results. Therefore feed conversion ratios seem to be an important indication of the effect of physical form in finishing rations of lambs. It seems that the physical form of grain did not influence feed efficiency. These results were supported by the carcass characteristic results.

According to the DMI feed efficiency and carcass characteristic results, processing of maize grain in finishing rations of lambs seems to be unnecessary. A roughage level of 20 to 40% (lucerne hay) seems not to influence the results with different physical forms of maize grain. The influence of type of grain (softness) on the effect of physical form of grain in finishing rations for lambs warrants however further investigation.

The influence of 20 and 40% lucerne hay in finishing rations of lambs respectively seems not to influence DMI, MEI and weight gain as well as feed and energy efficiency. However, a higher carcass weight and dressing percentage were observed when a lower level of roughage (20 *vs*. 40%) was included in the finishing ration. The quality of lucerne hay (fibre and energy content) could however influence the results with different roughage levels. Therefore further research is needed to quantify the effect of fibre level in finishing rations containing lucerne hay or other roughage sources, on the performance of lambs.

## References

**Braman, W.L., Hatfield, E.E., Owens, F.N. & Rincker, J.D., 1973.** Waxy corn and nitrogen sources for finishing lambs and steers fed all-concentrated rations. J. Anim. Sci. 37, 1010-1017.

**Edwards, J.W., Cannell, R.C., Garret, R.P., Savell, J.W., Cross, H.R & Longnecker, M.T., 1989.** Using ultrasound, linear measurements and live fat thickness estimates to determine the carcass composision of market lambs. J. Anim. Sci. 67, 3322-3330.

**Fisher, A.V. & De Boer, H., 1993.** The EAAP standard method of sheep carcass assessment. Carcass measurement and dissection procedures. Live. Prod. Sci. 38, 149-159.

**Fluharty, F.L., Lowe, G.D. & Clevenger, D.D., 1999.** Effects of feed-delivery system and corn processing on lamb growth and carcass characteristics. Special
Circular Ohio Agric. Research and Development Centre. pp 99-106.

**Government Notice No. R 1748, 26 June 1992.** Regulation Gazette of South Africa No. 4890, Government Gazette No. 14060 of South Africa, Vol. 3245, 8.

**McDonald, P., Edwards, R.A., Greenhalgh, J F.D. & Morgan, C.A., 2002.** Animal Nutrition. Sixth Edition. Pearson Education Limited, Prentice Hall, England.

**Meissner, H.H., Liebenberg, L.H.P., Pienaar, J.P., Van Zyl, A.B. & Botha, Brenda, 1982.** Effects of physical form and alkali treatment of maize grain supplements on hay intake and utilization by steers. S. Afr. J. Anim. Sci. 12, 119.

**Owens, F.N. & Zinn, R.A., 2005.** Corn grain for cattle: Influence of processing on site and extent of digestion. Proc. Southwest. Nutr. Conf. pp 86-112.

**Pitzen, D.F., Cooper, C.C. & Burrough, W., 1971.** Starch digestion, whole *vs* rolled corn for cattle. J. Anim. Sci. 33, 1169 (Abstr.).

**Ramsay, C.B., Kirton, A.H., Hogg, B. & Dobbie, J.L., 1991.** Ultrasonic, needle and carcass measurements for predicting chemical composition of lamb carcasses. J. Anim. Sci. 69, 3655-3664.

**SAMIC, 2004.** Classification of red meat in RSA. [Web]: http://www.samic.co.za

**SAS Institute, 1996.** SAS® User's Guide. Version 6.12. SAS Institute Inc., Raleigh, NC.

**Scott, T.L., Milton, C.T., Erickson, G.E., Klopfenstein, T.J. & Stock, R.A., 2003.** Corn processing method in finishing diets containing wet corn gluten feed. J. Anim. Sci. 81, 3182-3190.

**Stock, R.A., Sindt, M.H., Parrott, J.C. & Goedeken, F.K., 1990.** Effects of grain type, roughage level and monensin level on finishing cattle performance. J. Anim. Sci. 68, 3441-3455.

**Theurer, C.B., 1986.** Grain processing effects on starch utilization by ruminants. J. Anim. Sci. 63,1649-1662.

**Traxler, M.J., Fox, D.G., Perry, T.C., Dickerson, R.L. & Williams, D.L., 1995.** Influence of roughage and grain processing in high-concentrate diets on the performance of long-fed Holstein steers. J. Anim. Sci. 73, 1888-1900.

**Turgeon, O.A., Brink, Jr., D.R. & Britton, R.A., 1983.** Corn particle size mixtures, roughage level and starch utilization in finishing steer diets. J. Anim. Sci. 57, 739-749.

**Van der Merwe, H.J., Van Schalkwyk, A.P. & Van Rensburg, L.J.J., 1978.** Invloed van fisiese vorm van mieliegraan en aanvullende proteïenvoeding op die benutting van hoë kragvoerrantsoene deur vleisbeeste. S.-Afr. Tydskr. Veek. 8, 131-136.

**Van der Merwe, H.J., Jordaan, G., Kotter, W.A. & Swart, J.N., 1989.** Invloed van fisiese vorm van mielies en kuilvoer op benutting van afrondingsdiëte deur vleisbeeste. S. Afr. Tydskr. Veek. 19(2), 62-66.

**Vance, R.P., Preston, R.L., Klosterman, E.W. & Cahill, V.R., 1972.** Utilization of whole shelled and crimped corn grain with varying proportions of corn silage by growing-finishing steers. J. Anim. Sci. 35, 598-605.

# Chapter 5

## General conclusions

Maize grain is an important energy source in high-grain finishing rations for lambs. The physical form of the grain could however influence factors like the thorough mixing with other ingredients in the ration, separation and selection of the ration components in the feed bunk, occurrence of sub-clinical acidosis, intake, rate of passage, digestibility, growth rate, feed efficiency and carcass characteristics. Research regarding the physical form of maize grain in finishing rations was up to now mostly confined to beef cattle. In the case of sheep it is generally assumed that sheep is able to chew whole cereal grains to such an extent that mechanical processing becomes unnecessary. In this regard it is however important to consider, apart from the factors mentioned above, the fact that the chewing ability of lambs could be hampered by the absence of permanent cut teeth. Furthermore the quantity, physical form and type of roughage could also influence the results. Lucerne hay is an important roughage source in finishing rations for lambs and was accordingly used in the present study. Hence the effects of physical form of maize grain at two levels of lucerne hay (specific particle size) inclusion in finishing rations of lambs have been addressed in the current study.

It seems from the results of the digestibility study that grain processing and especially fine maize grain (FMG) resulted in lower apparent digestibility for dry matter, crude protein and gross energy in the ration as well as digestible crude protein and metabolisable energy (ME) content. A higher dry matter intake (DMI) of the lambs consuming the FMG ration could contribute to these results. It could be speculated that the higher DMI of lambs consuming the FMG ration, increased the rate of passage of food through the rumen and reduced the time for microbial fermentation.

Another factor that could contribute to the higher digestibility and ME-content of the whole maize grain (WMG) ration is the selection behaviour of the lambs. Physical form of maize grain in the ration however did not influence the acid detergent fibre (ADF) intake and -refusal by lambs. Therefore selection of WMG by lambs seems not to occur.

The higher digestibility and ME-values of the WMG ration could also be an indication of the chewing ability of the lambs. Furthermore physical form of maize grain had the same effect on digestibility, irrespective of roughage level. Accordingly roughage level (20 to 40% lucerne hay) seems not to influence the mastication and rumination of WMG by lambs.

The apparent digestibility of fibre (ADF) was negatively influenced by a smaller particle size maize grain in the ration. A higher DMI, more rapid fermentation rate, lower rumen pH, less cellulotic activity and faster rate of food passage could contribute to these findings.

From the results of the production study, it seems that physical form of maize grain in finishing rations for lambs did not influence DMI, feed conversion and carcass characteristics results. On the other hand, the ME-intake of lambs consuming the FMG ration with 40% lucerne hay was the lowest, while weight gain revealed the opposite results. These contrary results between ME-intake and weight gain could probably partly attributed to differences observed in DMI between the digestibility and production studies. Accordingly the actual ME-values of the similar rations fed in these two studies could differ and should the ME-intake and -conversion results be interpreted with caution. Heat losses not measured in this study could also contribute to the differences in ME-intake and weight gain results. Therefore DMI, feed conversion and carcass characteristics seems to be the most reliable indicators of the effect of physical form of maize grain on the utilization of finishing rations by lambs. According to these measurements physical form of maize grain in finishing rations has no influence on the performance of lambs. Accordingly no physical x roughage level (20 to 40% lucerne hay) interaction exist in finishing rations for lambs. The influence of type of grain (softness) on the effect of physical form of grain in finishing rations for lambs warrants however further investigation.

It was further evident from the results of the current study that the inclusion of 20 and 40% lucerne hay in finishing rations of lambs respectively did not influence ME-content, DMI, ME-intake and weight gain as well as feed and energy efficiency. These results were obtained despite a higher apparent digestibility observed for dry matter, crude protein and gross energy at the lower roughage level. Accordingly a higher carcass weight and dressing percentage occurred at the lower roughage level. A smaller rumen fill of lambs consuming the rations with a lower roughage level could explain the higher dressing percentage.

The quality of lucerne hay (fibre and energy content) could influence the results obtained with different roughage levels in finishing rations of lambs. Therefore further research is needed to quantify the effect of different fibre levels in finishing rations for lambs containing different roughage sources.

## Abstract

The effect of whole (WMG), ground (GMG) and fine (FMG) maize grain in finishing rations for lambs containing 20 and 40% lucerne hay respectively was investigated. Thirty 3-month-old SA Mutton Merino lambs were randomly allocated to 6 treatments of 5 animals each. A digestibility and production study was carried out (60 lambs in total). All lambs were kept in individual pens for the duration of the various studies.

The dry matter intake (DMI) of the lambs in the digestibility study consuming the ration with WMG was significantly (P=0.0052) lower than those fed FMG. Processing of maize grain resulted a significant (P<0.05) reduction in the apparent digestibility of dry matter, crude protein, acid detergent fibre and gross energy as well as digestible crude protein and metabolisable energy (ME).

In contrast with DMI (P>0.05) the apparent digestibility of dry matter, crude protein and gross energy were significantly (P<0.05) decreased with an increase in roughage level to 40%. Acid detergent fibre digestibility showed no statistical significant (P>0.05) differences between dietary roughage levels. Lucerne hay level did not influence (P>0.05) the ME-content of the finishing rations within a specific physical form.

Physical form of maize grain in finishing rations for lambs did not significantly (P>0.05) influence DMI, feed conversion and carcass characteristics. The inclusion of FMG in a finishing ration with 40% lucerne hay resulted in a significant (P=0.0013) lower ME-intake. A significantly (P<0.05) poorer weight gain and energy efficiency were observed for lambs fed WMG in the ration.

The inclusion of 20 and 40% lucerne hay in finishing rations of lambs did not significantly (P>0.05) influence DMI, ME-intake and weight gain as well as feed and energy efficiency. A higher (P<0.05) carcass weight and dressing percentage occurred when 20% compared to 40% lucerne hay was included in the lamb-finishing ration.

It was concluded that the physical form of maize grain in finishing rations has no influence on the performance of lambs. Accordingly no physical form x roughage level (20 to 40% lucerne hay) interaction exists in finishing rations for lambs.

## Opsomming

Die effek van heel (HMG), gruis (GMG) en fyn (FMG) mieliegraan in die afrondrantsoene vir lammers, bevattende 20 en 40% lusernhooi onderskeidelik, is ondersoek. Dertig 3 maande oud SA Vleismerino lammers is ewekansig ingedeel in 6 behandelings met 5 diere elk. ʼn Vertering- sowel as ʼn produksiestudie is uitgevoer (60 lammers in totaal). Alle lammers is gehuisves in individuele kratte gedurende die onderskeie studies.

Die droëmateriaalinname (DMI) van die lammers in die verteringstudie wat die rantsoen met HMG gevoer is, was betekenisvol ($P=0.0052$) laer as die van die FMG rantsoene. Prosessering van mieliegraan het ʼn betekenisvolle ($P<0.05$) verlaging in skynbare verteerbaarheid van droëmateriaal, ruproteïen, suurbestande vesel en bruto-energie sowel as verteerbare ruproteïen en metaboliseerbare energie (ME) teweeggebring.

In teenstelling met DMI ($P>0.05$), het die skynbare verteerbaarheid van droëmateriaal, ruproteïen en bruto-energie betekenisvol ($P<0.05$) verlaag ʼn die verhoging van die ruvoerpeil na 40%. Verteerbaarheid van suurbestande vesel het geen statistiese betekenisvolle ($P>0.05$) verskille tussen ruvoerpeile getoon nie. Lusernhooi het nie die ME-inhoud van afrondrantsoene binne ʼn spesifieke fisiese vorm betekenisvol ($P>0.05$) beïnvloed nie.

Fisiese vorm van mieliegraan in afrondrantsoene vir lammers het nie DMI, voeromset, en karkaseienskappe betekenisvol ($P>0.05$) beïnvloed nie. Die insluiting van FMG in ʼn afrondrantsoen met 40% lusernhooi het ʼn betekenisvolle ($P<0.05$) laer ME-inname tot gevolg gehad. ʼn Betekenisvolle ($P<0.05$) swakker massatoename en energie-omset is waargeneem by lammers wat die HMG rantsoene ontvang het.

Die insluiting van 20 en 40% lusernhooi in afrondrantsoene van lammers het nie DMI, ME-inname en massatoename sowel as voer- en energie-omset betekenisvol ($P>0.05$) beïnvloed nie. ʼn Hoër ($P<0.05$) karkasmassa en uitslagpersentasie het voorgekom wanneer 20% in vergelyking met 40% lusernhooi in afrondingsrantsoene vir lammers ingesluit is.

Daar is tot die slotsom gekom dat die fisiese vorm van mieliegraan in afrondrantsoene geen invloed op die prestasie van lammers gehad het nie. Dienooreenkomstig het geen fisiese vorm x ruvoerpeil (20 na 40% lusernhooi) interaksie voorgekom in afrondrantsoene vir lammers nie.