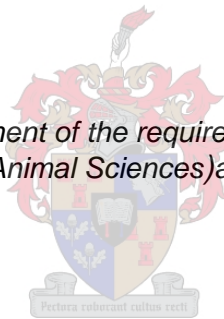


**THE EVALUATION OF THE EFFECT OF ACID BUF™ ON STOMACH  
ULCER OCCURRENCE, GROWTH PERFORMANCE AND HISTOLOGICAL  
PARAMETERS OF GROWER - FINISHER PIGS**

*by*

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*Thesis presented in partial fulfilment of the requirements for the degree of Master of  
Science in Agriculture (Animal Sciences) at Stellenbosch University*



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**Date: April 201(**

## **DECLARATION**

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## SUMMARY

The objective of this study was to determine the effect of the inclusion of Acid Buf™ at 4g.kg<sup>-1</sup> to a maize-soya bean diet in both pelleted and meal form, on the occurrence of stomach ulcers, performance parameters, carcass characteristics and histological parameters of the small intestine of growing finisher pigs. The trial was done on 320 growing finisher pigs fed for 8 weeks. The four treatments (Tr) were as follows: Tr1 – pelleted, Tr2 – meal, Tr3-pelleted with Acid Buf™ at 4g.kg<sup>-1</sup>, Tr4 –meal with Acid Buf™ at 4g.kg<sup>-1</sup>.

No significant differences ( $P>0.05$ ) were observed for cumulative feed intake between the different treatments. The feed conversion ratio (FCR) showed significant differences with the pigs on the meal diet faring significantly ( $P<0.05$ ) worse than those the pelleted diet containing Acid Buf™. The average daily gain (ADG) on Tr3 was significantly better ( $P<0.05$ ) than those on the meal diets. Overall the performance parameters showed a positive response to the inclusion of Acid Buf™.

With regards to changes in the intestinal pH, significant differences ( $P<0.05$ ) were observed between the different treatments for pH in the stomach, duodenum and colon. The pH in the stomach was closest to optimal with Tr3m and Tr4. The pH in the duodenum was highest and closest to optimum with Tr4.

Scoring of stomachs revealed that the highest percentage of normal stomachs was found in pigs on Tr4, with 64.1% of the stomachs being normal, 57.1% was the second highest percentage of normal stomachs and was found with Tr3, pelleted with AB. Carcass scoring showed no significant differences ( $P>0.05$ ) between the different treatments.

The mean villi height to crypt depth ratio (VH: CD) in the jejunum showed a significant difference ( $P<0.05$ ) between Tr1 and Tr3. The pigs on the pelleted diet had VH: CD of 0.89 while those on the pelleted diet with AB a VH: CD of 1.28. The average villi height measured in both the duodenum and the jejunum was higher in both of the pelleted diets compared to the meal diet and the meal with AB diet. The results of the different experiments conducted to evaluate the effect of AB all showed improved results with the inclusion of AB to the diet.

## OPSOMMING

Die doel van hierdie studie was om die effek van die insluiting van Acid Buf™(AB) teen  $4\text{g}\cdot\text{kg}^{-1}$  in 'n mielie-sojaboondieët in beide verpilde- en meelvorm, op die voorkoms van maagsere, groei parameters, karkaseienskappe en histologiese parameters van die dunderm in groeivarke te bepaal. Die studie is vir agt weke op 320 groei varke uitgevoer. Die vier behandelings (Tr) was soos volg: Tr1 -verpil, Tr2 - meel, Tr3-verpil met Acid Buf™ teen 0,4% ingesluit, Tr4 – meel met Acid Buf™ teen 0,4%ingesluit.

Daar was geen beduidende verskille ( $P > 0.05$ ) in die kumulatiewe voerinnamte tussen die verskillende behandelings waargeneem nie. Voeromsetverhouding (VOV) op die meel diet (Tr4) het beduidend swakker gevaar ( $P < 0.05$ ) as die varke op Tr3. Die gemiddelde daaglikse toename (GDT) van die varke op Tr3 was aansienlik beter ( $P < 0.05$ ) as die van die varke op Tr2.

Met betrekking tot die pH van die spysverteringskanaal was daar beduidende verskille ( $P > 0.05$ ) opgemerk tussen die verskillende behandelings vir pH in die maag, duodenum en kolon. Die pH in die maag was die laagste en naaste aanoptimaal vir die AB diëte. Die pH in die duodenum was die hoogste en naaste aan optimaal met Tr4.

Gradering van die mae toon die hoogste persentasie van normale, met 64.1 % van die mae met Tr4 normaal. Die tweede hoogste persentasie was 57.1 % normale mae en was gevind met Tr3, verpil met AB. Karkasgradering het geen beduidende verskille ( $P > 0.05$ ) tussen die verskillende behandelinge getoon nie.

Die gemiddelde villi hoogte kryptdiepte verhouding (VH: KD) in die jejenum het beduidende verskille ( $P < 0.05$ ) getoon tussen Tr1 en Tr3. Die verpilde diet (Tr1) het n (VH: KD) van 0.89 getoon en Tr3, die varke op die verpilde diët met AB 1.28. Die gemiddeldie villi hoogte gemeet in beide die duodenum en jejenum was hoër in die beide die verpilde diëte as in die meel diëte. Die resultate van die verskillende eksperimente uitgevoerom die effek van AB te evalueer, toon verbetering met die insluiting van AB in die diët.

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## NOTES

The language and style used in this thesis are in accordance with the requirements of the *South African Journal of Animal Science*. This thesis represents a compilation of manuscripts where each chapter is an individual entity and some repetition between chapters has been unavoidable.

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## CHAPTER 1

### General introduction

*Pars oesophaga* ulceration is a common, widespread condition in finishing and growing pigs worldwide. Incidence as high as 50% have been reported by abattoirs. It can be a significant cause of death in certain herds. The cause of *pars oesophaga* ulceration is not fully understood, but some of the important risk factors have been identified, which include management and nutritional factors such as the physical aspects of the feed, especially when in pelleted form (Chamberlain *et al.*, 1967). Despite the fairly good level of understanding of these factors, the occurrence of gastric lesions at slaughter and the mortality due to gastric ulceration has increased over the past few decades. Only a limited, often contradictory, number of reports on the effects of gastric ulcers on pig performance are available.

Feeding pelleted feed to pigs has been shown to increase nutrient digestibility and improve feed to gain ratio from 5% to 8% in finishing pigs fed a maize-soya bean meal diet under university research conditions (Potter *et al.*, 2009). Other advantages of pelleted diets include the ability to grind grain to a smaller micron size and use high percentages of alternative ingredients in the diets and still maintain feed flow ability. However, the improved feed to gain ratio may not be as large under field conditions because of poor pellet quality (Mahan *et al.*, 1966; Maxwell *et al.*, 1970). Increased fines build-up in feed pans and feed wastage are outcomes of poor quality pellets. Besides the cost of pelleting, another disadvantage to feeding pelleted diets is a mortality increase as a result of gastric ulcers. The occurrence of ulcers can range from sub clinical where efficiency of production can be decreased or per acute where animals can be found dead in pens. The cause is possibly multi factorial and the management of environmental and dietary factors in a manner to attempt to decrease the incidence could be beneficial. The use of Acid Buf<sup>TM</sup> could be beneficial in this regard as the recent increase in feed cost has led producers to re-evaluate the economics of feeding pelleted diets to growing and finishing pigs.

Acid Buf<sup>TM</sup> is a product from Celtic Sea Minerals (Strand farm, Currabinny, Co. Cork. Ireland, Phone +35321 4378377) and is manufactured from calcareous marine algae which are harvested from the clean waters off the coasts of Ireland and Iceland. Acid Buf<sup>TM</sup> is conventionally used as a highly effective rumen buffer and also a pure source of bio-available minerals, especially calcium and magnesium (Calitz, 2009).

Therefore the objective of this study was to determine the effects of pelleting and the addition of Acid Buf<sup>TM</sup> to a maize-soya bean based diet on:

- Performance parameters including feed conversion ratio and average daily gain
- Stomach ulcer occurrence and carcass damage
- Histological parameters of the small intestine

in growing finisher pigs.

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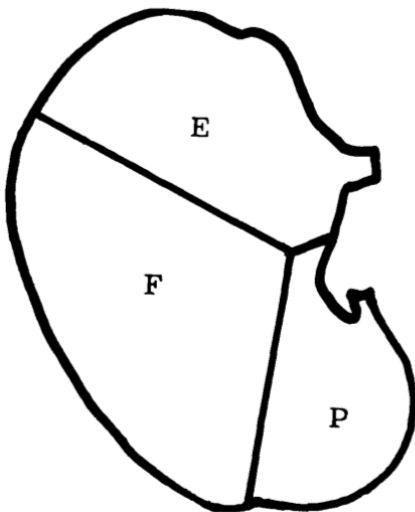
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## CHAPTER 2

### Literature review

#### Introduction

Gastric ulceration in swine is a common problem throughout the world and was first described by Bullard, (1951) as the cause of death in an adult boar. The stomach is divided into three main regions, *oesophageal*, *fundic* and *pyloric* regions (Figure 2.1). Ulceration of the non-glandular part or *oesophageal* region is more common than ulceration in the glandular or peptic region in the stomach and is an important cause of deaths in especially finisher pigs and sows (Mahan *et al.*, 1966; Friendship, 1999). The non-glandular part of the stomach is called the *pars oesophaga* and is covered with a stratified squamous epithelium that does not secrete mucus. This part consequently offers limited protection against the low pH in the lumen (Friendship, 1999).



**Figure 1.1** Diagram of the division of the stomach into *oesophageal* (E), *fundic* (F) and *pyloric* (P) regions

Hyperplasia and hyperkeratosis area result of any abuse to the epithelium in the stomach. Hyperplasia is characterized by an increase in number of cells or proliferation of cells and is considered to be a physiological response to a specific stimulus. Hyperkeratosis is characterized by the thickening of the stratum corneum often associated with qualitative abnormality of keratin. As hyperplasia continues, insufficient nutrients reach the cells leading

to the weakening of junctions between the cells. Gastric juices can then penetrate the underlying tissue which leads to the development of erosions and ulcers (Lang *et al.*, 1998).

The cause of gastric ulceration is not fully understood but some of the important risk factors have been identified. The main predisposing factors include feeding of fine dietary particle feeds and feeding feed in a pelleted form (Maxwell *et al.*, 1970; Wondra *et al.*, 1995b). Previously the association of fine particle feed on gastric ulcers frequency has also been described by other investigators (Reimann *et al.*, 1968; Reimann *et al.*, 1968; Flatlandsmo & Slagsvold, 1971a; Millet *et al.*, 2012a) did not find a consistent effect of dietary particle size on pH of the gastric contents. Although this does not rule out the possibility that the occurrence of gastric lesions is related to gastric pH, since the mixed gastric contents obtained from slaughter may not be indicative of the pH in the *oesophageal* region of the stomach. Fine dietary particle size did however increase the fluidity as well as pepsin activity in the stomach. Increased mixing and higher pepsin activity can be responsible for the development of ulcers. Feeding a coarse diet is thought to decrease fluidity within the stomach, and restore the pH gradient between the *oesophageal* area and the pyloric area. Decreased fluidity and mixing within the stomach prevent contact of HCl, pepsin and bile acids with the *pars oesophageal* area (Ayles *et al.*, 1996).

With regards to pelleting, Reese *et al.* (1966b) found no significant detrimental effect on ulcer formation, although some epithelial changes were observed; while other workers indicated an increased incidence of ulceration caused by feeding pelleted diets (Chamberlain *et al.*, 1967; Pocock *et al.*, 1968). The differences in results between authors can be due to differences in the particle size of the pellets and experimental design. Chamberlain *et al.* (1967), Pocock *et al.* (1968) and Reese *et al.* (1966b) all concluded that fluidity of the stomach content was associated with abnormal stomachs. Fluidity of stomach contents depends on contents and the type of diet consumed (Maxwell *et al.*, 1970). The latter also found that animals consuming a coarse diet had a greater amount of dry matter in their stomach contents when compared with animals consuming a finely ground diet. This leads to the conclusion that the main difference between stomach contents of pigs consuming these diets is the degree of fluidity. It was suggested by Reiman *et al.* (1968) that decreased particle size of maize increased the incidence of ulcers via the increase in pepsin activity and the fluidity of the stomach. Apparently the fluid nature of the stomach contents of pigs fed finely ground diets, allowed the acid and pepsin to come into contact with the relatively unprotected *oesophageal* area.

Other factors include feed nutrient contents, feed processing methods (Mahan *et al.*, 1966), bacterial infection (Argenzio & Eisemann, 1996), environmental factors (Amory *et al.*,

2006b), genetics (Berruecos & Robison, 1972) and management practices (Reese *et al.*, 1966a; Chamberlain *et al.*, 1967).

### **Prevalence and severity of gastric ulcers**

Paralleling the intensification of the pig industry, the incidence of gastric ulcers has increased substantially over the past few decades (Guise *et al.*, 1997). In-house slaughter surveys typically found over 80% of market ready pigs with some type of lesion involving the *pars oesophaga* (Friendship, 1999). The *pars oesophaga* regularly has a normal opening of the oesophagus into the stomach (*pars oesophaga*) with a smooth white lining (squamous epithelium). It may be a roughened appearance and is often yellow in colour as an effect of bile staining. The most frequent location for early erosion to take place is along the border between the *pars oesophaga* and the cardiac region of the stomach. Frequently, small erosions can be observed between the ridges when parakeratosis is present or hyperkeratinisation of the squamous area leading to yellow discolouration. Also there may be sloughing of the thickened yellow epithelium. Mortalities attributable to gastro-*oesophageal* ulcers have been estimated to be between 0.5% and 0.75% (Deen, 1993). Ulceration of the gastric *pars oesophaga* is a common problem in intensive pig production and is often only detected at slaughter. Gastric ulcers are dynamic, occurring swiftly and perhaps healing almost just as fast. In addition to assessing the severity of an ulcer, it would be beneficial to be able to estimate the age of a lesion or ulcer at slaughter, but this is very difficult (Makinde & Gous, 1998). A survey carried out at the Pietersburg (now Polokwane) abattoir in the Northern Province (now Limpopo), South Africa, during a 6-month period, examined 4320 pig stomachs. Gastro-*oesophageal* ulcers were observed in 5.1% of the stomachs, gastric erosion in 15.2%, and hyperkeratosis in 18.9%. Time of slaughter since last meal was found to affect the prevalence of gastric lesions (Makinde & Gous, 1998). This agrees with Lawrence *et al.* (1998) who conducted an experiment to determine if pigs fasted for 24 hours before slaughter showed an increase in *pars oesophageal* abnormalities. In their study it was concluded that there was a significant increase ( $P < 0.05$ ) in the number of abnormal stomachs in the fasted pigs.

The prevalence and severity of gastric ulcers were investigated by Amory *et al.* (2006a) in a sample of 50 slaughter pigs from each of 16 commercial farms in the UK. The mean prevalence of ulcers was 19.1% and the mean severity score on the 16 farms was 2.2 on a scale from 0 (normal) to 6 (severe). On examination of 1000 stomachs from a Norwegian slaughter house a rather high frequency (55%), of epithelial alterations and ulcers were found (Teige, 1967). It is difficult to assess the severity of lesions on gross inspection alone. A small but deep erosive lesion could result in severe blood loss, whereas extensive lesions

covering almost the entire area of the *pars oesophaga* may be shallow and insignificant (Friendship, 2003). Embaye *et al.* (1990) classified lesions using a scoring system where 0 indicated no lesions indicating a shiny white squamous epithelium over the oesophago-gastric area; score 1 lesions were limited in extent, occurring mainly near the *oesophageal* opening or at the margin adjacent to the cardiac portion. Lesions designated as score 3 severely affected the entire non-glandular area whilst score 2 lesions had intermediate severity.

## **Effect of dietary particle size and pelleting on gastric ulcers**

### **Reducing particle size**

Reducing diet particle size improves efficiency of growth in growing and finishing pigs, (Gieseemann *et al.*, 1990) and lactation performance in sows due to increased nutrient digestibility (Wondra *et al.*, 1995b). Dietary particle size has been implicated as a contributing factor to *oesophageal* ulcers where increasing particle size in a diet showed a marked decrease in the incidence of gastric lesions and cornification (Mahan *et al.*, 1966). Cornification is the process of forming an epidermal barrier in stratified squamous epithelial tissue. At the cellular level, cornification is characterized by the production of keratin following damage, in this case damage from HCl, pepsin and bile acids. Feeding a coarse diet is thought to decrease fluidity within the stomach, and restore the pH gradient between the *oesophageal* area and the pyloric area. Fluidity of stomach contents depends on contents and the type of diet consumed (Maxwell *et al.*, 1970). Animals consuming a coarse diet had greater amount of dry matter in their stomach contents when compared with animals consuming a finely ground diet. This leads to the conclusion that the main difference between stomach contents of pigs consuming these diets is the degree of fluidity. It was suggested by Reiman *et al.* (1968) that decreased particle size of maize increased the incidence of ulcers via the increase in pepsin activity and the fluidity of the stomach. Decreased fluidity and mixing within the stomach prevent contact of HCl, pepsin and bile acids with the *pars oesophageal* area (Ayles *et al.*, 1996). However the mechanism whereby fluidity increases in the stomach of pigs fed finely ground and pelleted diets is not clear. Previous measurements of stomach contents in the proximal stomach showed a decrease in pH and an increased concentration of bile acids after having fed pigs finely and pelleted diets (Lang *et al.*, 1998). This might lead to greater exposure to refluxed secretions from the distal stomach that may lead to the formation of lesions in the *oesophageal* area of the stomach if stomach contents are very fluid.

The objective of an experiment by Dirkzwager *et al.* (1998) was to study the optimal particle size distribution in a complete pelleted diet for pig performance and the influence of particle size on the number and severity of gastric lesions, and the influence of gastric lesions on pig performance. The three diets used, fine, mixed and coarse had the same composition but the fine diet was ground on a 2.5 mm screen in the hammer mill at 1500 rpm. The coarse diet was ground through a 4.0 mm screen at 750 rpm. The mixed diet was composed by mixing 50% of the fine and 50% of the coarse diet. Mixed and coarse diets showed a higher average daily gain than the fine diet in the early stages of growth (from 25kg to 45kg live weight) after which no differences in growth between treatments was observed. The proportion of pigs with lesions in the *pars oesophaga* was less for the coarse diet ( $P < 0.03$ ) compared to the fine diet. Pigs with no lesions did perform better in this study.

Wondra *et al.* (1995b) studied the effect of particle size and pelleting on growth performance in finishing pigs. A maize soya bean meal-based diet was used, with the maize milled to particle sizes of 1000 $\mu\text{m}$ , 800 $\mu\text{m}$ , 600 $\mu\text{m}$  and 400  $\mu\text{m}$ . The diet was fed in both meal and pelleted form. Pelleting the diet resulted in 5% greater average daily gain (ADG) ( $P < 0.01$ ) and 7% greater feed to gain ratio ( $P < 0.01$ ) for each of the different particle sizes. Reducing particle size from 1000 $\mu\text{m}$  to 400  $\mu\text{m}$  increased gain to feed ratio by 8% ( $P < 0.01$ ) and digestibility of gross energy (GE) by 7% ( $P < 0.03$ ). Improved nutrient digestibility and lower average daily feed intake (ADFI) resulted in 26% less daily excretion of nitrogen when particle size was reduced from 1000 $\mu\text{m}$  to 400  $\mu\text{m}$ .

Hedde *et al.* (1985) allocated a hundred and sixty crossbred pigs to either a fine or coarse particle treatment, in twenty different pens. The pigs receiving the fine particle diet grew more rapidly and had better feed utilization efficiency. Ulcers were more prevalent in pigs receiving the fine particle diet and more pigs died or were culled in this treatment. Within the group fed the fine particle feed, pigs with higher ulcer scores had lower daily gains compared to those having lower ulcer scores. This agrees with a study by Ayles *et al.* (1996) which showed that pigs with either moderate or severe gastric ulcers had lower ADG than pigs without ulcers and those pigs without ulcers ate more than those with ulcers. Again indicating that dietary particle size has been implicated as a contributing factor to *oesophageal* ulcers where increasing particle size in a diet showed a marked decrease in the incidence of gastric lesions and cornification (Mahan *et al.*, 1966).

Maxwell *et al.* (1970) fed a cracked maize diet and a finely ground maize diet to different groups of pigs and found that pigs fed the cracked maize diet had a higher percentage of normal stomachs ( $P < 0.05$ ) than pigs fed the finely ground maize diet. This is confirmed by



Wondra et al. (1995c) who found that there was an increase in pigs showing severe stomach ulcers when maize particle size in a diet was reduced from 1000 µm to 400 µm.

In the same study, Maxwell *et al.* (1970) found that the pH of the samples obtained by means of gastric fistulas was consistently lower when cracked maize was fed than when finely ground maize was fed, although this differed in the different regions of the stomach. Pepsin activity in the *oesophageal* region was consistently less in pigs fed a cracked maize vs. the finely ground maize diet. This resulted in a lower pH in the *oesophageal* region when finely ground maize diet vs. a cracked maize diet was fed: 4.3 vs. 4.6, 3.9 vs. 4.5, and 3.5 vs. 4.5 for four, eight and thirteen hours after feeding, respectively.

In a study by Flatlandsmo & Slagsvold, (1971); only eight of the 341 pigs in the study developed erosions and ulcers of the stomach epithelium. No pigs died due to ulcers although the physical form of the diet had a significant ( $P<0.01$ ) effect on the incidence of gastric defects. The results can be seen in Table 2.1 The effect of finely ground and coarsely ground diets in pelleted and meal form on the performance of pigs and findings of epithelial change at autopsy (Adapted from Flatlandsmo & Slagsvold, (1971b). When comparing the finely ground and coarsely ground meal, the finely ground meal resulted in a significantly ( $P<0.01$ ) higher frequencies of both epithelial changes and the occurrence of ulcers. This occurred when the finely ground meal was given in a meal or in the pelleted form. When only meal and pelleted diets were compared the pelleted diets had a significantly higher ( $P<0.01$ ) ADG than the meal diets. Pigs fed pellets of the finely ground meal made more rapid and efficient gains ( $P<0.01$ ) than pigs fed the non-pelleted diet.

**Table 2.1** The effect of finely ground and coarsely ground diets in pelleted and meal form on the performance of pigs and findings of epithelial change at autopsy (Adapted from Flatlandsmo & Slagsvold, (1971b))

Diet form	No. of pigs	Normal Stomachs	Epithelial Changes ( $P<0.01$ )	Erosion and ulcers count	Average daily gain (g) ( $P<0.01$ )
Finely ground meal	85	65	19 <sup>a</sup>	1	601 <sup>d</sup>
Pellets of finely ground meal	86	14	66 <sup>c</sup>	6	635 <sup>e</sup>
Coarse ground meal	85	80	5 <sup>b</sup>	0	584 <sup>d</sup>
Pellets of coarsely ground meal	85	67	17 <sup>a</sup>	1	621 <sup>e</sup>

<sup>a, b, c, d, e</sup> means in the same column with different superscripts differs significantly ( $P<0.01$ )

Mößeler *et al.* (2010) evaluated the physical form of feed and its effect on the integrity of the gastric mucosa. The four different diets used in this study were identical in chemical and botanical composition, but differed in grinding intensity (fine/course) and physical form (pelleted/meal). Marked effects were found in the *pars oesophaga*. The finely ground pelleted diet resulted in a more liquid chyme with a significantly higher  $\text{Cl}^-$  concentration in the non-glandular area (*pars oesophaga*), when compared to the meal diets. Although there was no distinct pH gradient between the regions after feeding the finely ground pelleted diet, the coarsely ground meal resulted in the highest pH value in the *oesophageal* region and a low pH value in the *fundic* region. In the pigs fed the finely ground pelleted diet, a significantly higher  $\text{Cl}^-$  secretion rate of the upper gastrointestinal tract was found. This study clearly indicates effects of grinding intensity and physical form of the diet on the composition and quality of gastric chyme within different regions of the pig stomach.

The stomach contents of pigs fed finely ground diets were found to be more liquid in appearance and to have higher moisture content (Maxwell *et al.*, 1970). Reimann *et al.* (1968) suggested that the liquid nature of the stomach contents when pigs are fed a finely ground diet leads to more mixing and distribution of pepsin and acid to the relatively unprotected *oesophageal* region which can lead to the formation of ulcers. A similar study by Regina *et al.* (1999) who recorded the changes in gastric contents of pigs fed either a finely ground and pelleted diet or a coarsely ground meal diet noted that increased fluidity caused by the finely ground pelleted diet leads to the mixing of the proximal and distal stomach contents. Components secreted in the distal region of the stomach, such as acid and pepsin can play a role in initiating damage to the stratified squamous mucosa. Thus the composition of the stomach contents may be related to ulceration of the *oesophageal* mucosa.

Organic acids produced in the stomach of the pig such as acetic acid and ammonia; a by-product of microbial activity, may also play a role in the formation of lesions (Argenzio & Southworth, 1975). Acetate can be produced by microorganisms at high concentrations in the stomach which can damage stratified squamous mucosal tissue (Argenzio & Eisemann, 1996). Ammonia impairs cellular energy metabolism by inhibiting mitochondrial respiration, which leads to decreased mucosal cell viability (Tsuji *et al.*, 1995). Regina *et al.* (1999) found that there was significantly more ( $P < 0.01$ ) ammonia in the stomach contents of pigs consuming a finely ground and pelleted diet compared to pigs consuming the coarsely ground meal diet. The stratified squamous mucosa of the pigs consuming the coarsely ground meal diet had white, smooth and healthy looking tissue. Conversely pigs consuming the finely ground and pelleted diet showed varying degrees of epithelial damage.

## Pelleting

Pelleting is a process which reduces dustiness of feed and segregation of ingredients, increases the bulk density and eliminates bridging problems for diets (Wondra *et al.*, 1995b). Wondra *et al.* (1995b) and Baird, (1973) reported improved average daily gain (ADG) in pigs when the feed was pelleted although a number of other scientists found no effect of pelleting on growth (Hanke *et al.*, 1972; Skoch *et al.*, 1983).

The differences in results by Wondra *et al.* (1995b) and Skoch *et al.* (1983) can be attributed to the difference in particle size of the ingredients of the pellets. Although in both of the experiments by Wondra *et al.* (1995b) and Skoch *et al.* (1983), pelleting was done through a 4.8mm diameter hole and the mash conditioned at about the same temperature (80°C and 75°C, respectively), the particle size, however, differed. In the study by Wondra *et al.* (1995b) particles were ground to between 1000µm and 400µm and in the study of Skoch *et al.* (1983) particles were ground through a 3.2mm screen. From this result it can be concluded that the size of the particles before pelleting plays an important role in growth performance of the pigs, as well as ulcer formation, as discussed in the previous section.

All of the researchers however reported that pelleting improved the efficiency of gain, thus improving growth performance (Mahan *et al.*, 1966; Maxwell *et al.*, 1970). The improvement in the feed to gain ratio may not be as large under field conditions because of poor pellet quality (Potter *et al.*, 2009). Increased fines build-up in feed pans and feed wastage are outcomes of poor pellet quality. Besides the cost of pelleting, another disadvantage of feeding pelleted diets is the increase in mortality rates due to the occurrence of gastric ulcers (Ayles *et al.*, 1996; Potter *et al.*, 2009).

The objective of a study by Potter *et al.* (2009) was to determine the effects of feeding a pelleted maize-soya bean diet or a maize-soya bean meal based diet on the performance of commercial finishing pigs. Pigs fed the pelleted diet had an increased average daily gain compared with pigs fed the same diet in meal form, but the magnitude of the response was gender dependent ( $P < 0.03$ ). Though back fat thickness was unaffected ( $P = 0.19$ ) by diet form, there was a trend for pigs fed pelleted diets to be less ( $P < 0.07$ ) lean and have decreased ( $P = 0.09$ ) loin depth. In summary, pigs fed the pelleted diet had an increased ADG compared with pigs fed the same diet in meal form, but the magnitude of the response was gender dependent. From day 0 to day 90, barrows fed pelleted diets gained 0.08kg per day more than barrows fed meal diets, and gilts fed pelleted diets gained 0.05kg per day more than gilts fed the meal diet. Regardless of gender pigs fed pelleted diets had improved feed to gain ratio and heavier market and carcass weights than pigs fed meal diets

In a study by Wondra *et al.* (1995c) 160 crossbred finishing pigs were fed diets with particle size ranging between 1000  $\mu\text{m}$  to 400  $\mu\text{m}$ , both in meal and pelleted forms. Pelleting the diet resulted in 5% greater average daily gain (ADG) ( $P < 0.01$ ) and 7% improved feed to gain ratio ( $P < 0.01$ ). This was also reported by Baird, (1973) although without any statistical difference: only two of the eighty pigs fed the meal had severe gastric lesions where seven of the eighty pigs fed the pelleted form had severe gastric lesions. The number of pigs having ulcers or severe ulcers increased with decreased particle size. These findings were also reported by Mahan *et al.* (1966) and Maxwell *et al.* (1970). Thus the incidence and severity of gastric ulcers were increased by pelleting and particle size reduction. Chamberlain *et al.* (1967) showed the effect that pelleting has on the incidence and severity of gastric ulcers. Different diet forms including a meal mixed on a University farm (1), a commercial meal (2), commercial pellet (3) and a commercial pellet reground (4) were fed to the pigs; the data is summarized in Table 2.2

**Table 2.2** Effect of pelleted feed on the performance and incidence of ulcers in swine. (Adapted from Chamberlain *et al.* (1967) ( $P < 0.05$ ))

	Treatment			
	1 University mixed meal	2 Commercial meal	3 Commercial pellet	4 Commercial pellet reground
<b>Average daily gain (kg)</b>	0.65 <sup>a</sup>	0.68 <sup>a</sup>	0.77 <sup>b</sup>	0.69 <sup>a</sup>
<b>Feed/kg.gain (kg)</b>	3.25 <sup>a</sup>	3.2 <sup>a</sup>	2.91 <sup>b</sup>	3.06 <sup>b</sup>
<b>No. of pigs</b>	8	8	8	8
<b>No. of ulcers</b>	0	1	4	3
<b>Ulcer severity</b>	Heavily Kertinized	Medium Kertinized	Medium Ulcer	Heavily Kertinized to slight ulcer

<sup>a,b</sup> means in the same row bearing different superscripts differ significantly ( $P < 0.05$ )

Pigs receiving the pelleted diets had a significantly better ( $P < 0.05$ ) average daily gain when a pelleted diet was fed than any of the other diets. Feed conversion ratio was significantly better in the pelleted and pelleted reground feed than the meal diets. However, the number and severity of ulcers were significantly ( $P < 0.05$ ) higher in pigs fed the pelleted feed. These findings are the same as that of Griffing, (1963) who reported an increase in the incidence of gastric ulcers in pigs from 4% when a meal was fed to 13.8% when a pelleted diet was fed.

The objective of a study by Cappai *et al.* (2013) was to adopt the latest laboratory tests and thresholds for the ulcerogenic risk assessment of diets. This study also verified class of risk

in relation to gastric prevalence in finisher pigs. Forty one pigs, 21 fed a pelleted diet and 20 fed a mixed meal were inspected at an abattoir for gastric lesions. The pelleted diet resulted in 13/21 macroscopic lesions. The breakdown in severity showed 13/13 hyperkeratosis, 11/13 mucosal erosion and 2/13 bleeding ulcers. This occurrence was compared to the morphology of the stomach mucosa of the pigs fed the mixed meal diet, and no gastric lesions were observed. The diets fed were analysed and the particle size distribution between the two diets determined and the following were found: the pelleted diet: 14.1% coarse (1.4-3.15 mm), 27.8% medium (1.0-1.4mm), 15.5% fine (0.4-0.8mm) and 42.6% very fine (0.2-0.4mm). The mixed meal diet: 60.8% coarse, 15.8% medium, 13.3% fine and 10.1% very fine. On a basis of particle size distribution and gastric mucosa integrity, three classes of ulcerogenic risk of diets were identified: Class1, high risk (very fine particles >36%); Class2, moderate risk (29% < very fine particles <36%); Class3, low risk (very fine particles <29%). With these findings Cappai *et al.* (2013) concluded that proper sieving analysis is necessary to define the very fine particle portion of a diet with certainty, as this can be an adequate measure to assess the ulcerogenic risk of a diet.

### **Effect of heat expansion on the incidence of gastric ulcers**

Most swine pelleted diets make use of an extrusion process that involves using heat to expand and bind the pellet. The procedure of expansion involves grinding of the grains and steam heating to soften the grain. Pressure and heat are then increased where after the softened grain is extruded through holes in the expander. The sudden loss of pressure and escaping steam causes the expansion of the grain (Riker *et al.*, 1967).

Expanded or heat treated maize have been reported by Perry *et al.* (1963) and Nuwer *et al.* (1965) to cause *oesophageal* gastric ulcers, however Reese *et al.* (1966a) was unable to report an increase in ulcers when heat treated maize was fed.

In a study by Riker *et al.* (1967) expanded grains were compared to raw grains to establish which grains were more ulcerogenic. Barley, maize, sorghum and wheat in raw and expanded form were tested (Table 2.3). Forty eight stomachs were collected in total. Six stomachs of each of the raw form of the grain and six of each of the expanded grains were then examined. Ulcers were found in one of each of the expanded grain fed pigs' stomachs. Only wheat in raw form showed an ulcer in one of the stomachs and two of the stomachs showed ulcers in the expanded form. The results also showed a highly significant ( $P < 0.01$ ) increase in the number and severity of gastric lesions when expanded maize was fed.

**Table 2.3** Effect of raw vs. expanded grain on average daily gain (ADG), feed to gain ratio and ulcer scores. Adapted from Riker *et al.* (1967).

	Barley		Maize		Sorghum		Wheat	
	Raw	Exp.	Raw	Exp.	Raw	Exp.	Raw	Exp.
<b>ADG (kg)</b>	0.56	0.57	0.59	0.55	0.46	0.47	0.49	0.43
<b>Feed/kg gain kg</b>	3.15	3.62	3.23	3.24	2.99	3.14	2.82	2.99
<b>No. of stomachs Examined</b>	6	6	6	6	6	6	6	6
<b>Mean ulcerogenic index</b>	9 <sup>a</sup>	7.5 <sup>a</sup>	8.5 <sup>b</sup>	5 <sup>c</sup>	8.3 <sup>b</sup>	4.5 <sup>c</sup>	6.7 <sup>d</sup>	5 <sup>d</sup>

<sup>a b c d</sup> means in the same row per grain type with different superscripts differ significantly (P<0.01) from each other. Exp = (Expanded)

When the results in

Table 2.3 of the stomach examinations were scored for lesion severity as explained above, a highly significant (P<0.01) increase in the number and severity of esophagogastric lesions in the expanded maize and sorghum diets vs. the raw maize and sorghum diets was found, despite the relatively few animals tested.

This agrees with a study by Mahan *et al.* (1966) which found that stomach lesions were most severe when pigs were fed expanded maize rations. This study also showed that 27.8% of pigs had stomach ulcers when fed expanded maize compared to 5.6% of pigs fed finely ground maize and none fed a coarse maize diet. Although Pocock *et al.* (1968) did not find an increase in ulceration when comparing heat expanded maize and raw maize, there was an increase in the number of abnormal stomachs, showing hyper keratinization of the epithelium of the stomach when expanded maize was fed.

Nuwer *et al.* (1967) found expanded maize to be more ulcerogenic than raw maize and that it produced up to 50% esophagogastric ulcers as well as other lesions in animals tested. Nuwer *et al.* (1967) concluded that expanded endosperm and bran contained ulcerogenic activity associated with expanded maize but expanded germ did not. It appears that neither heat nor gelatinization of starch are responsible for the ulcerogenic activity of expanded maize, however these conditions in some way play a role in the unknown physical chemical change of maize during expansion that leads to ulcerogenic activity.

In a more recent study by Millet *et al.* (2012b) the effect of high temperature expansion on the performances of pigs were examined. The trial started from 1 week after weaning until

slaughter. Performance parameters as well as the gastric mucosa integrity of growing-finishing pigs at slaughter were inspected. Millet *et al.* (2012b) compared a diet expanded at high pressure and temperature (expanded) with a diet expanded under milder conditions that was subsequently pelleted and crumbled (crumble) and an untreated control diet (meal). The expanded and the crumbled feed were utilised more efficiently ( $P=0.003$ ), and feed intake was considerably higher on the meal feed ( $P=0.003$ ) between start and slaughter, this led to a similar growth in the three groups ( $P=0.898$ ). The feed structure affected the ulcer score significantly ( $P<0.001$ ). Pigs on the meal diet had the lowest ulcer score, those on the expanded an intermediate score and those on the crumbled diet the highest score. All of the diets differed significantly from each other ( $P<0.05$ ). Assessing the microbiology of the gut, the number of *Helicobacter suis* bacteria per gram of mucus was lower on the meal than on the expanded or the crumbled feed. It can be concluded that expanding and pelleting improved feed efficiency of growing-finishing pigs. However, these technological treatments had a negative impact on gastric mucosa integrity and were associated with an increased *H. suis* colonisation.

## **Effect of various nutritional factors on gastric ulcers**

### **Dietary buffers**

Maxwell *et al.* (1970) observed a relationship between decreased pH in the *oesophagal* region when finely ground maize diet vs. a cracked maize diet was fed: 4.3 vs. 4.6, 3.9 vs. 4.5, and 3.5 vs. 4.5 for four, eight and thirteen hours after feeding respectively, as well as increased ulcerations of the stomach when a fine particle diet was fed. It is thus possible that alkaline salts could help to neutralize the acidity of the stomach and improve the morphology of the stomach as Patience *et al.* (1986) indicated that pH of the gastrointestinal tract may be changed by adding buffers to the diet. In a study by Wondra *et al.* (1995a) it was found that there is a trend for bicarbonate sources to reduce the incidence of ulcers in finishing pigs (

Table 2.4).



**Table 2.4** Effects of sodium bicarbonate and potassium bicarbonate on ulcer formation (Adapted from Wondra *et al.* (1995a))

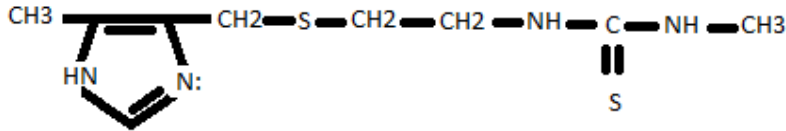
	Control	1% NaHCO <sub>3</sub>	1% KHCO <sub>3</sub>
<b>ADG (kg/day)</b>	0.92	0.91	0.91
<b>No of observations</b>	24	25	25
<b>Normal</b>	11	14	14
<b>Erosions</b>	3	4	5
<b>Ulcers</b>	7	5	3
<b>Severe ulcers</b>	3	2	3

The average daily gain was not affected by the addition of either 1% NaHCO<sub>3</sub> or 1% KHCO<sub>3</sub> to the diet. Pigs fed the bicarbonate sources showed a trend for reduced stomach ulcer scores, with a higher number of normal stomachs as well as a decrease in ulcers when bicarbonate sources was fed (Wondra *et al.* (1995a)).

#### Feeding Histamine receptors agonists

Histamine receptor antagonists (H<sub>2</sub>-antagonists) are a class of physiologically active compounds that block the effect of histamine on parietal cells (Black *et al.*, 1972).

Histamine stimulated gastric acid secretion can be antagonized in animals by burimamide given intravenously (Black *et al.*, 1972; Wyllie *et al.* (1972)). This effect seems to be related to the specific blockade of histamine H<sub>2</sub>-receptors by burimamide which was demonstrated on certain tissues *in vitro* (Black *et al.*, 1972). Interest was aroused by findings that burimamide also inhibited gastric acid secretion evoked by pentagastrin or gastrin. Because of difficulties in studying the oral effectiveness, no proposal for its clinical evaluation was made (Black *et al.*, 1973). A new compound metiamide has been developed from burimamide by replacing a methylene group (-CH<sub>2</sub>-) with an isosteric thioether (-S-) link in the side chain and by the addition of a methyl group in the imidazole ring (Figure 2.2). The changes give metiamide a high specific activity, low toxicity and good oral availability (Black *et al.*, 1973).



**Figure 2.2** Chemical structure of metiamide

Metiamide (Black *et al.*, 1973) and cimetidine (Brimblecombe *et al.*, 1975) are two of the original H<sub>2</sub>-antagonists synthesized, and both compounds inhibit gastric acid secretion stimulated by histamine, pentagastrin, hypoglycaemia and feed. Recently Anderson *et al.* (1981) reported that cimetidine, an H<sub>2</sub>-antagonist, decreases the incidence of stress induced ulcers in laboratory pigs.

SK&F 93479 is a newer H<sub>2</sub>-antagonist which is more potent and longer acting than what has been available on the market. In a study by Hedde *et al.* (1985) four experiments were conducted to evaluate the effect of diet and the administration of the H<sub>2</sub>-antagonists' metiamide and SK&F 93479 in feed on gastric ulcer formation and performance of growing pigs. Pigs receiving a finely ground diet grew faster ( $P < 0.01$ ), had better feed utilization ( $P < 0.01$ ) but a greater incidence of ulcers ( $P < 0.01$ ) than pigs receiving a cracked maize diet. The addition of metiamide and SK&F 93479 in different concentrations added to the finely ground feed did not improve performance or affect the incidence of ulcers. The addition of SK&F 93479 to a maize soya based diet containing 4.5% lucerne meal caused a reduction in gastric ulceration ( $P < 0.05$ ) and improved feed utilization by 3.2% ( $P < 0.05$ ). Feeding H<sub>2</sub>-antagonists in maize-soya bean diets seems to improve feed utilization and reduces ulceration. Although feeding H<sub>2</sub>-antagonists did not reduce the ulcerogenic properties of finely ground feed, suggesting that other factors than gastric acid secretion are also involved in ulcerogenesis.

### **Effect of microbial flora associated with gastric ulcers in pigs**

Kowalczyk, (1969) reviewed the factors related to gastric ulceration in pigs, and it has become apparent that little information is available on the microbial flora of the pig stomach. Tannock and Smith, (1970) examined the microbial flora of stomachs of a number of pigs to detect possible association of microbial flora with gastric ulceration. The yeasts *Candida albicans* and *C. slooffii* was isolated from ulcerations in the stomach and seem to be the main yeasts that causes erosion that can lead to ulcerations. This seems only to be true if previous damage occurred in the region and keratinization has taken place. This agrees with Kadel *et al.* (1969) who stated that there is no question that *C. albicans* and other *Candida* spp. are more common in the gastric contents of pigs showing ulceration of the *pars oesophaga* than in normal stomachs.

Research on causes of ulcers in humans, using *Helicobacter pylori*, showed that the urease activity of these microbes could produce ammonia from urea present in the stomach contents (Lichtenberger, 1995). Helicobacter-like organisms are often found in the glandular region of the stomach but it seems unlikely that these bacteria play a major role in the development of lesions in the *pars oesophagi* (Friendship, 2003). Although a spiral bacterium identified as *H. heilmannii* Type I was found with greater incidence in the stomach of pigs with ulcers than pigs without stomach ulcers (Queiroz *et al.*, 1996).

According to Haesebrouck *et al.* (2009) the main Helicobacter species colonizing the stomachs of pigs is *H. suis*. Its prevalence at slaughter age in most reports is 60% or more and causes gastritis in experimentally and naturally infected pigs (Grasso *et al.*, 1996; Hellemans *et al.*, 2007a). It has also been associated with ulcers of the non-glandular part of the stomach (Barbosa *et al.*, 1995; Choi *et al.*, 2001).

In a study by Haesebrouck *et al.* (2009) 6-week-old piglets that were free of *H. suis* were used. All the piglets were fed a finely ground diet, but nine piglets were intra gastrically inoculated with a pure culture of *H. suis*, while five piglets were given a sham-inoculation. Hyperkeratosis and ulcer formation were clearly present in the gastric non glandular mucosa of all the *H. suis* inoculated pigs, while none of the sham-inoculated pigs developed gastric lesions. According to Hellemans *et al.* (2007b) an infection with *H. suis* may result in the excessive secretion of gastric acid, leading to increased contact of the non-glandular part of the stomach with hydrochloric acid. In the fundic gland region of pigs infected with *H. suis*, these microorganisms were found in close contact with parietal cells, which might indicate that the bacterium may have an impact on the hydrochloric acid producing cells itself.

### **Genetic basis of gastric ulcers**

The occurrence of gastric ulcers and the differences in susceptibility to ulceration between pig breeds have been recognized by Curtin *et al.* (1963) and Mahan *et al.* (1966) but rankings among breeds have not been conclusive. Other than breed differences there is little information available concerning the importance of genetics in ulcer formation.

In a study by Berruecos and Robison, (1972) the inheritance of gastric ulcers in swine was tested using 98 Duroc and 155 Yorkshire barrows, representing 51 sires. After a subjective scoring of ulcers the data was analysed. Year, season and breed effects on ulcer scores were significant ( $P < 0.01$ ). Duroc's showed a greater incidence of ulcers (29%) compared to Yorkshires (12%). Similar results were found by Curtin *et al.* (1963), although 166 Yorkshires were used and only six Durocs. Heritability estimates for ulcer scores were high (0.52), indicating that it may be possible to reduce the incidence of ulcers by means of

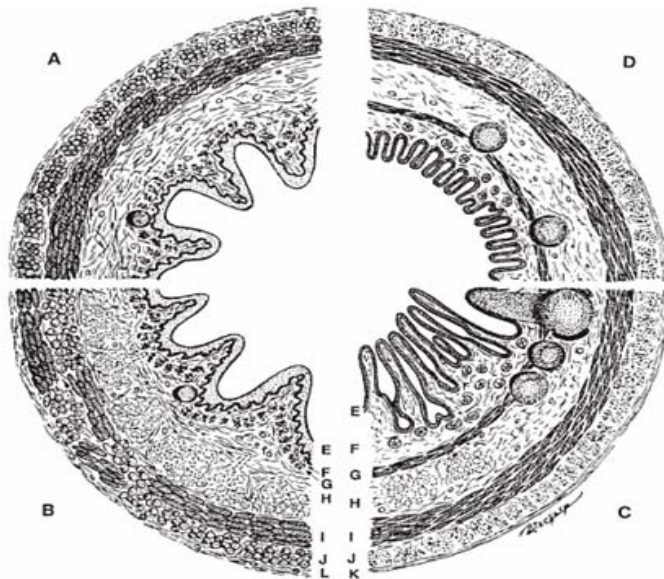
selection. This is in contrast with the findings of Conley, Kratzer and Bicknell (1967) which reported a low heritability (0.04) for the incidence of ulcers. This may be because little to no correction was made for seasonal effects in the latter study.

### **Small intestine**

The eight major functions of the digestive system are (Akers & Denbow, 2008):

- (1) Ingestion - material brought into the oral cavity,
- (2) Propulsion - ingested material moved through the digestive tract by swallowing and peristalsis,
- (3) Mechanical processing - reduction of size increases surface area and facilitating enzymatic digestion,
- (4) Digestion - chemical breakdown into particles small enough for absorption,
- (5) Secretion - water, mucous, acids, enzymes, buffers, and salts are released into the lumen,
- (6) Absorption – nutrients including organic substrates, electrolytes, vitamins and water pass from the lumen into the body,
- (7) Excretion – elimination of waste products and
- (8) Immunity – provide a substantial barrier to prevent the entry of pathogens into the body

The small intestine is a long convoluted tube approximately 5-7m long and is the longest section of the digestive tract. The small intestine extends from the junction with the stomach at the pylorus to join with the large intestine or colon (Di Fiore, 2012). With the aid of accessory organs that produce the necessary enzymes, buffers and other secretions, most of the digestion and 90% of the absorption occurs in the small intestine (Akers & Denbow, 2008).



**Figure 2.3** Cross section through the various segments of the digestive tract. A and B, Oesophagus with stratified squamous epithelium. C, Small intestine with columnar epithelium and sub mucosal glands and aggregated lymphatic nodules in some segments. D, Large intestine. E, tunica mucosa: epithelium; F, lamina propria; G, lamina muscularis; H, tela submucosa; I, túnica muscularis: circular layer; J, longitudinal layer; K, tunica serosa; L, túnica adventitia (Dellmann & Eurell, 1998).

The anatomic and functional characteristics of the mucosa and its epithelia vary greatly among the segments of the intestine as seen in Figure 3 (Frandsen *et al.*, 2009).

The interior of the small intestine contains transvers folds called plicae, which increase the surface area. The mucosa has finger like projections called intestinal villi, and are covered with simple columnar epithelium that have microvilli on the surface. Each villus contains a central lymph vessel (lacteal) and around this is a plexus of capillaries, connective tissue and smooth muscle fibres. Villi are one of the most important agents in the absorption of the contents of the intestine (Getty, 1975). The micro villi make up the brush border and are cytoplasmic extensions that cover the apices of the intestinal absorptive cells. The combination of plicae, villi and brush border increase the surface of the small intestine by up to 600 fold (Akers & Denbow, 2008). There are various cells, glands and lymphatic nodules lining the surface of the small intestine. These include absorptive cells, goblet cells, entero endocrine cells, intestinal glands, Brunner's glands, Paneth cells, Peyer's patches and M cells each with different functions (Di Fiore, 2012).

There are several factors influencing the structure and function of the small intestine that can be divided into histological and biochemical factors. Most of these factors influence the structure and function after weaning but can also have an influence in growing pigs.

The first factor that influences the structure and function of the small intestine is the withdrawal of sows' milk at weaning. Several bioactive compounds in sows' milk that affects the development of gut structure and cell growth have been studied. Epidermal growth factor supports gut growth and development (Kelly *et al.*, 1992). Polyamines are critical for postnatal cellular proliferation and differentiation (Kelly, 1994). Insulin growth factor is another biological active compound in sow's milk and the importance has been described by Odle *et al.* (1996).

It is recognized that the indigenous micro flora exerts a profound influence on the digestive and absorptive capabilities as well as the morphological structure of the gastro intestinal tract (Kelly *et al.*, 1992a). The effect of entero pathogenic bacteria in the small intestine can be best illustrated by comparison between gnonobiotic (pathogen free) pigs and conventional animals (Kelly *et al.*, 1992b). According to Kelly *et al.* (1992b) the intestinal wall and *lamina propria* of conventional animals are thicker, the villi shorter and the crypts deeper than their gnonobiotic counterparts. A study by Nabuurs *et al.* (1993) reported that herds of pigs with a long history of post weaning diarrhoea had shorter villi and deeper crypts than specific pathogen free counterparts.

Although there is little information relating the effects of physiological stress such as mixing and moving of pigs on the gut structure, maladaptation to the stressors at weaning has been described by Hall *et al.* (1990). The study reported gut atrophy and declines in the brush border activity in unthrifty pigs after weaning, but stated that five weeks later the gut structure and function were comparable to normal pigs of the same age. In this regard a study by Pluske *et al.* (1996) showed that changes in gut function and structure during physiological stress are most likely confounded with the low levels of voluntary feed intake at the time.

## **Conclusion**

The effects of gastric ulceration on performance and health seem to be negative, although some authors are inconclusive on this. Gastric ulceration is a problem worldwide and more research should be conducted to conclude on the prevalence of gastric ulcers. Gastric ulceration has increased over the past few decades following the intensification of pig production in terms of the stress of housing and the feeding of fine particle or pelleted feeds. Care must be taken when altering factors that may contribute to gastric ulceration, especially the feeding, as this may negatively influence the performance of the piggery. A better understanding of the pathogenesis of ulceration, the risk factors associated with ulceration as well as methods to reduce the incidence of ulceration is needed to solve this problem.

The inclusion of buffers in the diet to minimise the incidences of ulceration in growing pigs may hold potential – in this study, the inclusion of commercially available buffer (Acid Buf™) in a maize-soyabean based diet in meal or pelleted form will be evaluated on the growth performance and degree of ulceration of pigs grown under South African conditions.

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## CHAPTER 3

### Evaluation of the effect of feeding a pelleted and meal diet with or without Acid Buf<sup>TM</sup> on the production parameters of growing-finishing pigs

#### Abstract

This experiment evaluated the effect of adding Acid Buf<sup>TM</sup> at 4g.kg<sup>-1</sup> to a maize-soya based diet in a pelleted and meal form on growth performance and production parameters of growing-finishing pigs. The four treatments (Tr) were: Tr1 – pelleted, Tr2 – meal, Tr3-pelleted with Acid Buf<sup>TM</sup> at 4g.kg<sup>-1</sup>, Tr4 –meal with Acid Buf<sup>TM</sup> at 4g.kg<sup>-1</sup>. No significant differences ( $P>0.05$ ) were observed for cumulative feed intake. Feed conversion ratio (FCR) showed significant differences with pigs on Tr2 performing significantly ( $P<0.05$ ) worse than those on Tr3 with Acid Buf<sup>TM</sup> whilst the performance on the other diets were intermediary. Average daily gain (ADG) was estimated by fitting a linear model to live weight over time ( $R^2= 0.89$ ). The ADG of pigs on Tr3 was significantly better ( $P<0.05$ ) than that of pigs on Tr2 and Tr4, Tr1 was found to be intermediary and equal to all other treatments. It would thus seem that a pelleted diet containing Acid Buf<sup>TM</sup> proved to be the most efficient as pertaining to production performance.

#### Introduction

Pigs raised in commercial conditions are normally penned in groups. Growth performance is usually greater when pigs are penned individually than when they are penned in groups (De Haer & De Vries, 1993; Hacker *et al.*, 1994). Competition at the feeder, social facilitation and social stress are all factors that may be responsible for the difference in feeding behaviour, production parameters and the occurrence of gastric ulcers between group housed and individually housed pigs.

The prevalence of gastric ulcers in growing finishing pigs that has been published varies from 2 to 100% (Palomo *et al.*, 1996). The large variations in prevalence are, at least in part, due to the objective assessment methods of the ulcer condition. In Germany, Frerking *et al.* (1996) have reported an increase in gastric ulcers from 1.1% in 1965 – 1975 to 7.5%. Ayles *et al.* (1996) showed that pigs with either moderate or severe gastric ulcers had lower ADG

than pigs without ulcers and those pigs without ulcers ate more than those with ulcers. The pelleting process has been discussed as one of the causes of the increasing incidence of ulcers. Although Reese *et al.* (1966) found no detrimental effect; other studies indicated an increasing incidence of gastric ulceration caused by feeding pelleted diets (Pocock *et al.*, 1968; Chamberlain *et al.*, 1967). Feeding pelleted diets to pigs has been shown to increase nutrient digestibility and improve feed to gain ratio from five to eight percent under university research conditions (Potter *et al.*, 2009). Wondra *et al.* (1995b) indicated that pelleting the diets increased average daily gain ( $P < 0.01$ ) and gain to feed ( $P < 0.01$ ) by 5% and 7%, respectively.

Other advantages of pelleted diets include the ability to grind grain to a smaller micron size and use high percentages of alternative ingredients in the diets and still maintain feed flow ability (Potter *et al.*, 2009). However, the improved feed to gain ratio may not be as large under field conditions because of poor pellet quality (Myers *et al.*, 2012). The recent increase in feed costs has led producers to re-evaluate the economics of feeding pelleted diets to growing finishing pigs (Potter *et al.*, 2009).

A study by Wondra *et al.* (1995a) investigated the effect of dietary buffers on growth performance, nutrient digestibility, and stomach morphology in finishing pigs. The two buffers investigated was  $\text{NaHCO}_3$  (sodium bicarbonate) and  $\text{KHCO}_3$  (potassium bicarbonate). Pigs fed the bicarbonate sources showed a trend for reduced stomach ulcer scores, with a higher number of normal stomachs as well as a decrease in ulcers when bicarbonate sources was fed.

Therefore the objective of this part of the study was to determine the effect of feeding a maize-soyabean based diet in meal or pelleted form, with or without the inclusion of Acid Buf<sup>TM</sup>, on the growth performance of growing-finishing pigs.

## **Materials and methods**

### **Experimental design**

A total of 320 commercial crossbred grower pigs were used and entered the trail at 10 weeks of age ( $27.7 \pm 3$  kg). Sows (Landrace X Large White) were crossed terminally with Duroc boars to produce the commercial growing pigs. In this design there were eighty pigs per treatment on four different treatments. Each treatment was randomly allocated to each of the different pens. The four treatments were as follows:



Tr1 – Pelleted feed

Tr2 – Meal feed

Tr3 – Pelleted feed with Acid Buf<sup>TM</sup> included at 4g.kg<sup>-1</sup>

Tr4 – Meal feed with Acid Buf<sup>TM</sup> included at 4g.kg<sup>-1</sup>

Ten pigs were placed (chosen randomly) per pen in an open sided commercial type grower house with full concrete floors and flushable slurry channels at the back of the pens, to give a total of 32 pens. Water was supplied by nipple drinkers and feed in manually filled automatic feeders. Mechanical ventilation by means of fans was used to increase airspeed and cool the house.

The pigs were tagged for identification and their individual live weights were recorded at the onset of the trail, as well as weekly thereafter until slaughter weight ( $70 \pm 4$ kg) was reached eight weeks later. Feed intake was recorded weekly on a per pen basis. At each weighing period, injuries were recorded and chronically sick pigs removed from the trail to a hospital area where they were treated. These pigs did not return to the trail. Sick pigs were treated according to their ailment and remained in the trail.

### **Diet composition and feed characteristics**

The feeding program consisted of a single diet only. A maize and soya based 16% protein grower feed which is normally used on Sweetwell farm was used in this trail (Table 3.1). The different treatments were mixed on the farm using a pancake hammer mill and a 2 ton fountain mixer. Feed was mixed weekly to provide fresh feed and to prevent spoilage of feed during storage. Alterations was made to the standard feed formula using Winfeed to standardize Calcium (Ca) and Magnesium (Mg) levels in the two treatments where Acid Buf<sup>TM</sup> was used (Table 3.2). Pelleting was done at University Stellenbosch, Mariendahl Experimental farm, Stellenbosch, using a pelleting machine with a 3mm die.

**Table 3.1** Calculated nutrient composition of the experimental feed

<b>Nutrient</b>	<b>Units</b>	<b>Total</b>	<b>Available</b>
Metabolisable Energy (pig)	MJ/kg	13.28	
Digestible Energy (pig)	MJ/kg	13.77	
Crude protein	%	16.63	14.19
Ether Extract	MJ/kg	10.12	
Organic Matter	%	83.8	
Crude Fat	%	3.25	2.79
Crude Fibre	%	3.5	
Dry Matter	%	87.64	
Methionine	%	0.27	0.24
Lysine	%	0.97	0.85
Arginine	%	1.07	0.98
Cysteine	%	0.33	
Histidine	%	0.47	0.41
Isoleucine	%	0.7	0.61
Leucine	%	1.56	1.4
Methionine+cystine	%	0.6	0.51
Phenylalanine+tyrosine	%	1.39	1.24
Phenylalanine	%	0.76	0.67
Threonine	%	0.62	0.52
Tryptophan	%	0.19	0.16
Valine	%	0.84	0.73
Calcium	%	0.67	0.67
Chloride	%	0.4	0.4
Phosphorous	%	0.62	0.62
Available phosphorous	%	0.31	0.31
Sodium	%	0.21	0.21
Ash	%	3.84	

**Table 3.2** Ingredient composition of the experimental feed with and without Acid Buf™

Ingredient	Without Acid Buf™		With Acid Buf™ included	
	(%)	Weight (kg)	(%)	Weight (kg)
Maize	66.67	666.7	66.67	666.7
Wheat bran	10.38	103.8	10.38	103.8
Soybean46	20	200	20	200
L-Lysine HCL	0.2	2	0.2	2
Vitamin and mineral premix	0.25	2.5	0.25	2.5
Limestone	1.3	13	0.9	9
Salt	0.5	5	0.5	5
Monocalcium phosphate	0.7	7	0.7	7
Acid Buf™	0	0	0.4	4

## Results and discussion

The trial was conducted during the summer of 2010 at a commercial pig production farm Sweetwell, Somerset West, South Africa. The housing was naturally ventilated open sided houses, with two 36 inch stirring fans to create air movement during the hottest time of the day. The average temperature for the three months was 28°C with relative humidity of 65%, with the lowest temperature measured being 14°C and the highest 36°C. The variation between the minimum and maximum temperature may have had a negative effect on animal performance. All the animals was subjected to the same environmental conditions so environmental factors did not differ between different treatments. A stressor such as hot weather negatively influences feed intake and growth. The optimum temperature range for finishing pigs is between 10 and 23.9°C (Myer and Bucklin, 2009) and temperatures above 23.9°C decrease voluntary feed intake and pig growth (Kouba *et al.*, 2001). Inferior growth performance of animals in summer may be due to the redirection of more energy into their maintenance requirements. Animals in warm conditions have increased physical activities, such as respiratory hyperventilation, which are consistent with additional energy costs and higher maintenance requirements. Animals in cold weather have increased basal metabolic rates to maintain their core temperature. Feed conversion ratio met and even exceeded the standards set by Carr (1998) but the cumulative feed intake of the trail pigs did not meet the standards set (FCR=3.2; cumulative feed intake 179kg) by 18 weeks of age.

Production parameter results are shown in Table . No differences ( $P>0.05$ ) were observed for cumulative feed intake. This is consistent with findings of Potter *et al.* (2009) who found no significant difference ( $P=0.69$ ) in feed intake among pigs fed meal and pelleted diets. Flatlandsmo & Slagsvold, (1971) who studied the performance of pigs fed either a finely

ground or coarse diet, both in meal and pelleted form did not find significant differences in feed intake. Skoch *et al.* (1983) suggested that pelleting increases the bulk density of the diet and reduced dustiness, making the diet more palatable. However improved palatability would be contradictory with the decreased average daily feed intake usually observed for pigs fed pelleted diets reported by Gamble *et al.* (1967). Although average daily feed intake did not differ significantly ( $P>0.05$ ) in their study, a decreased feed intake were observed for their pigs fed a pelleted diet (2.18 kg vs. 2.32 kg).

Skoch *et al.* (2010) used 146 pigs to study the effects of steam pelleting a maize-soya bean meal diet on pig performance. Treatments included ground meal, meal steam conditioned to 80°C before pelleting, meal pelleted without steam conditioning, and a meal diet with 2% molasses replacing maize. Steam-conditioning the meal before pelleting resulted in less starch damage, and less electrical energy was required for pelleting. Pellet durability was considerably increased with steam conditioning. None of the processing methods studied caused significant ( $P<0.05$ ) improvement in daily gain, feed efficiency, or digestibility of energy for weanling pigs. An improvement ( $P<0.05$ ) over the control diet in feed efficiency and energy digestibility, was found with the pelleting treatment for grower-finisher pigs. However, daily gain was not ( $P<0.05$ ) improved.

The results of the performance parameters measured in the current study can be seen in Table 3.3.

**Table 3.3** Cumulative feed intake (kg), feed conversion ratio (FCR) and average daily gain (ADG) ( $\pm$  standard deviation) of grower pigs receiving either pelleted or mash diets with or without Acid Buf™ from 70 days of age until slaughter eight weeks later.

	Cumulative feed intake (kg)		Feed conversion ratio		Average daily gain (g/day)	
<b>Pelleted</b>	117.05	$\pm$ 8.62	2.52 <sup>ab</sup>	$\pm$ 0.26	844.30 <sup>ab</sup>	$\pm$ 25.77
<b>Meal</b>	116.49	$\pm$ 11.20	2.78 <sup>a</sup>	$\pm$ 0.11	772.03 <sup>a</sup>	$\pm$ 25.09
<b>Pelleted AB</b>	116.59	$\pm$ 13.39	2.42 <sup>b</sup>	$\pm$ 0.12	876.07 <sup>b</sup>	$\pm$ 24.66
<b>Meal AB</b>	111.96	$\pm$ 9.40	2.65 <sup>ab</sup>	$\pm$ 0.20	762.03 <sup>a</sup>	$\pm$ 25.08

<sup>a, b</sup> means values in the same column with different superscripts differ significantly ( $P<0.05$ )

AB=Acid Buf™

The ADG as well as the FCR of the pigs on pelleted feed (Tr3) containing Acid Buf™ was significantly better ( $P<0.05$ ) than that of meal diet (Tr2). The ADG and FCR of pigs on the pelleted feed without Acid Buf™ were found to be intermediary and equal to all other treatments. It would thus seem that a pelleted diet containing Acid Buf™ proved the most efficient as pertaining to production performance. These data support findings previously

reported in the literature for improvements in feed efficiency achievable with feeding maize-soyabean meal based pelleted diets. Wondra *et al.* (1995b) reported that pelleting the diets increased the gain: feed ( $P < 0.001$ ) by 7%. Potter *et al.* (2009) reported that pigs fed pelleted diets had a 5.3% improvement (2.68 vs. 2.83;  $P < 0.01$ ) in overall feed: gain compared with pigs fed meal diets. The findings of both of these studies are consistent with results of a study conducted by Gamble *et al.* (1967) that showed significant improvement ( $P < 0.05$ ) in FCR (3.18 vs. 2.95) when a pelleted instead of a meal diet was fed.

Average daily gain (ADG) was estimated by fitting a linear model to live weight over time ( $R^2 = 0.89$ ). The ADG on pelleted feed containing Acid Buf<sup>TM</sup> was significantly better ( $P < 0.05$ ) than that of meal diets, the pelleted feed without Acid Buf<sup>TM</sup> was found to be intermediary and equal to all other treatments. These data supports finding by Baird, (1973) as well as Wondra *et al.* (1995a) who reported that pelleting a maize-soya bean meal diet significantly ( $P < 0.05$ ) improved ADG of growing pigs by 5%. These findings also support that of Seerley *et al.* (1962), that indicated a significant ( $P < 0.05$ ) increase in average daily gain (1.47kg vs. 1.58kg) when comparing a meal to a pelleted diet. However, several experiments, including that of the NCR-42 Committee on Swine nutrition and that of Nielsen & Ingvarsten, (2000), failed to demonstrate constant improvements in ADG because of pelleting. Because of inconsistent improvement to ADG and a tendency for decreased daily feed intake with pelleted diets, researchers have tended to attribute improvements in performance to decreased feed wastage and increased nutrient digestibility with pelleted diets.

## Conclusion

The results reported in this study revealed that the pigs on the pelleted maize soya based (16% protein) diet had significantly better performance than the pigs on the meal diet. This corresponds with most of the literature cited. When Acid Buf<sup>TM</sup> was included at a level of  $4\text{g}\cdot\text{kg}^{-1}$  to the pelleted diet the cumulative feed intake did not change significantly but the feed conversion ratio as well as ADG was significantly better compared to a pelleted diet without Acid Buf<sup>TM</sup> as well as to the meal with and without Acid Buf<sup>TM</sup> in the diet. The positive results of the inclusion of Acid Buf<sup>TM</sup> obtained from this study may be linked to the alteration or improvements to factors that affect the digestion and absorption of nutrients as discussed in Chapter 4 and Chapter 5. Results of the study revealed that at a  $4\text{g}\cdot\text{kg}^{-1}$  Acid Buf<sup>TM</sup> supplementation to the pelleted increased growth performance without any visible or measurable negative effects. Average daily gain was not significantly improved when Acid

Buf<sup>TM</sup> was added to the meal diet. It is thus concluded that the inclusion of Acid Buf<sup>TM</sup> to both pelleted and meal based maize soya diets for growing finishing pigs had a positive effect on efficiency of production.

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## CHAPTER 4

### **Evaluation of the effect of feeding a pelleted and meal diet with or without Acid Buf<sup>TM</sup> on the occurrence of stomach ulcers and carcass damage of growing-finishing pigs**

#### **Abstract**

This experiment evaluated the effect of feeding a maize-soya based diet in a pelleted and meal form with or without adding Acid Buf<sup>TM</sup> at 4g.kg<sup>-1</sup> to the diet on the occurrence of stomach ulcers, changes in intestinal pH at slaughter and the occurrence of carcass injuries on growing-finishing pigs. The four treatments (Tr) were: Tr1 – pelleted, Tr2 – meal, Tr3 – Pelleted with Acid Buf<sup>TM</sup> at 4g.kg<sup>-1</sup>, Tr4 –meal with Acid Buf<sup>TM</sup> at 4g.kg<sup>-1</sup>. Significant differences ( $P < 0.05$ ) were observed for pH in the stomach, duodenum and colon. The pH in the stomach was highest for pigs on the meal diet and the lowest, and closest to optimal, for those on the Acid Buf<sup>TM</sup> (AB) diets with the pelleted diet being intermediary and equal to all other treatments. The pH in the duodenum was highest and closest to optimum with the meal Acid Buf<sup>TM</sup> diet and lowest in the pelleted Acid Buf<sup>TM</sup> diet with the control diets being intermediary and equal to the Acid Buf<sup>TM</sup> diets. No pH differences ( $P > 0.05$ ) were observed for diet in the jejunum and ileum. With regards to the occurrence of stomach ulcers, the highest percentage (64.1%) of normal stomachs was found in the pigs fed meal with AB. The second highest percentage (57.1%) of normal stomachs was found in the pelleted with AB feed group. The results also indicate that there were no differences ( $P > 0.05$ ) between the effects of the dietary treatments on carcass damage scoring.

#### **Introduction**

In monogastric animals the gastro intestinal tract (GIT) is simply composed of the stomach, small intestine, large intestine and colon. The GIT performs two primary functions. Firstly it is the critical interface between the digested food and the blood circulation that sends nutrients to the cells for productive purposes (Kim *et al.*, 2012). Secondly it houses intestinal flora which is essential to gut health, although when potential pathogenic bacteria gain the upper hand over beneficial bacteria by some means such as a drastic change in the environment (pH), it can become problematic (Merchant *et al.*, 2011). The efficiency of the digestive function can be modified by changes in gastric pH, enzyme production and various

gastric secretions (Phillis, 1976). The measurement of the pH of the different components of the digestive tract is beneficial to the understanding of the efficiency of digestion.

In pigs, behavioural reactions to stress can affect the health of the recipient pig directly, as for example in the case of tail biting (Fraser, 1975). Individual differences in behaviour are pronounced in pigs. Behavioural observations therefore may be useful as early predictors of how likely pigs are to develop subclinical and clinical pathological conditions that are influenced by dietary stress. Carcass (lesion) scoring can therefore be used to observe if there were changes in behaviour in different treatment groups of pigs and if aggression levels were aggravated by a stress factor such as stomach ulcers.

According to Hessing *et al.* (1994) acute stress can give rise to conflict behaviour such as fighting. Acute stress arises when the pig's immediate environment changes unexpectedly. Chronic stress on the other hand can be recognized when disturbed behaviours are performed (Hessing *et al.*, 1994). Chronic stress occurs if animals experience long-lasting stresses of their environment. Behavioural indicators of stress were identified by Dybkjaer, (1992) on the basis of an experiment where pigs were exposed, simultaneously to three stress factors i.e. mixing, crowding and a lack of food, which have been associated with increased pituitary-adrenocortical activity. Hessing *et al.* (1992) reported cortisol levels to increase the severity of lesions in the *pars oesophaga* in pigs. From these studies it can be concluded that any factor causing increased pituitary-adrenocortical activity such as fighting, seen on carcass lesion scoring, is a potential risk factor for stomach ulceration in pigs.

In assessing the value of the different treatments in this study, stomachs were taken from the slaughtered animals and the appearance of the different areas of the stomach were scored to determine the effect of Acid Buf<sup>TM</sup> and pelleting on the occurrence of ulcers. Currently, a number of scoring systems have been applied in the analyses of surveys and experimental ulceration evaluations (Elbers *et al.*, 1995). Previous work has shown that the gross appearance of ulcerated stomachs is directly related to the histological appearance of various degrees of parakeratosis, erosions and ulcerations (Embaye *et al.*, 1990).

## **Materials and methods**

On the day of slaughter, pigs were loaded onto a truck at 06:00 in the morning, and transported 20 km to Winelands Pork abattoir, La Belle Road, Stikland, Bellville, South Africa. Pigs from different dietary treatments were not kept separately and randomly combined on the truck and transported in one truckload to the abattoir. The pigs were randomly assigned to lairage pens and maintained in lairage for two hours prior to slaughter. In lairage the pigs were provided with water but no feed.

Pigs were herded into a stunning cage, where they were stunned using an electrical stunner set at 220 Volts, with a current flow of 1.4 Amps for a period of four seconds. The electrodes were positioned at the base of each ear. After five seconds the pig was shackled and hoisted, and bleeding was performed with a thoracic stick within ten seconds after cessation of stunning. Bath scalding commenced five minutes after stunning. The same commercial abattoir and practices were used for all the slaughter groups. Thereafter the standard commercial dressing procedures were followed.

### **Carcass lesion scoring**

Carcass lesion scoring was done on the moving line after epilation and washing of the carcass before evisceration. For the purpose of scoring the body of animal was divided into four areas i.e. head, front quarter, rump and back quarter. Injuries was noted and scored on a scale of 0 to 3 with 0 being a minor injury with no or little visible bruising/scratch marks and 3 being a heavy bruise/laceration. The area covered by the injury was recorded on a scale of 1 to 3, with 1 meaning 33% of an area is affected and 3 meaning the whole area is affected. This represents categorical data and the incidence of the presence of injuries as well as the variation in the scale will largely determine the statistical value of the data.

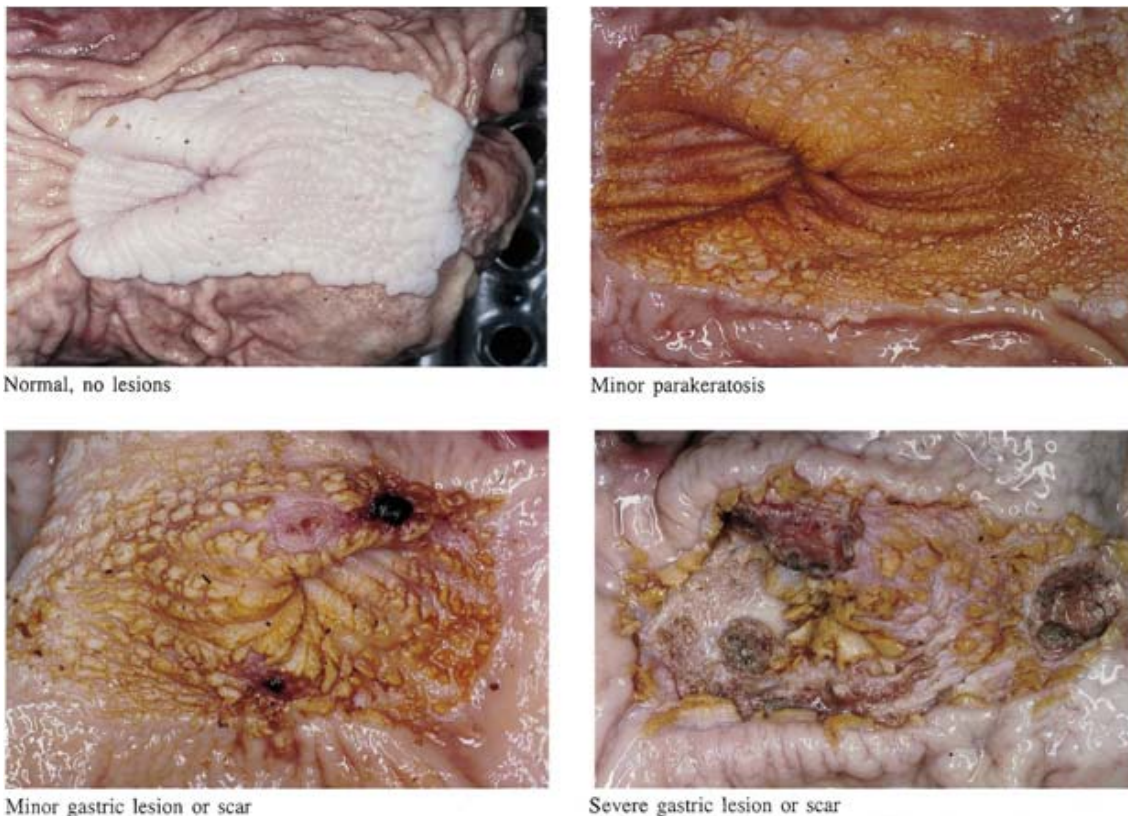
### **pH**

The pH of the different intestinal sections was measured before sample taking, by making a small incision at each of the different sites. A glass Crison pH25 Meter which was calibrated at standard temperature was used by inserting the probe into the intestine through the small incision made. The pH meter probe was placed directly into the piece of small intestine and the instrument was given time to stabilize before the pH reading was taken where after the probe was rinsed with distilled water. The probe was rested in a KCl 3M electrolytic solution between each measurement. The pH of the stomach, duodenum, jejunum, ileum and colon was measured and recorded. An incision was made in the intestinal tract at the same site where the samples for histology were taken from (Chapter 5). The probe was rinsed with distilled water between measurements.

### **Ulcers**

Upon slaughter all the stomachs of the pigs were collected and inspected for lesions. Each stomach was cut open using surgical scissors along the midriff of the outer curvature of the stomach from the oesophagus to the pylorus. The stomach contents were expelled and the remaining contents washed out gently using cold running water. The conditions of the stomach were scored on two scales for each of the *oesophageal*, fundic and pyloric areas.

Firstly the lesion was scored on a scale from 1 to 3 with 1 being normal, 2 indicating discoloration and minor parakeratosis, physical damage or a small ulcer and 3 indicating severe damage associated with haemorrhage. This scoring method was based on criteria outlined by Mackin *et al.* (1997). The same individual performed all the scoring. The criteria for physical damage can be seen in Figure 4.1. Secondly the area affected by lesions was scored on a scale of 1 to 4 with the area quartered; with a quarter of an area affected the score was 1, 2 if half of an area is affected, 3 if three quarters of an area is affected and 4 if the whole area is affected. This again represents categorical data and the incidence of the presence of lesions as well as the variation in the scale will largely determine the statistical value of the data.



**Figure 4.1** Scoring of ulcers on a scale of 1 to 3, with 1 being normal (top left), 2 being minor parakeratosis (top right) and minor scarring (bottom left) and 3 a severe lesion (bottom right). Adapted from Nielsen and Ingvarsten, (2000).

### Statistical analysis

Logistic regression using Proclogistic of SAS for Windows version 9.1.3 was used to describe the carcass data. Type 3 analysis of effects was done by Wald Chisq tests to

determine significance. The odds ratio was also determined for the carcass data. The odds ratio is the ratio of the odds of an event occurring in one group to the odds of it occurring in another group, or to a sample based estimate of that ratio.

## Results and discussion

Results are shown in Table 4.11 Significant differences ( $P < 0.05$ ) were observed for pH in the stomach, duodenum and colon. The pH in the stomach was highest for the meal diet and the lowest, and closest to optimal ( $\text{pH} < 4.0$ ), on the Acid Buf<sup>TM</sup> diets with the pelleted diet being intermediary and equal to all other treatments. The stomach pH range for an adult pig is 2.5 to 4.0, which is maintained by the secretion of hydrochloric acid. A low stomach pH is required to initiate protein digestion by the enzyme pepsin and to prohibit bacterial growth. Pepsins, derived from pepsinogens by the actions of hydrochloric acid, have a pH optimum of 1.6 to 3.0, which is highly acidic (Phillis, 1976). It is essential to maintain the pH of the stomach below 4.0 to achieve optimum pre-digestion of proteins.

The results show that pigs on both the pelleted and meal treatment containing Acid Buf<sup>TM</sup> had the lowest, and closest to optimal pH for protein digestion. The higher pH in the stomachs of the pigs that received the meal diet without Acid Buf<sup>TM</sup> was not ideal for the optimum enzymatic digestion of proteins since optimal pre-digestion of proteins occurs below a pH of 4.0. Although the stomach pH of the pelleted diet without Acid Buf<sup>TM</sup> was 3.71 it was still not as effective for optimal protein digestion as the two treatments containing Acid Buf<sup>TM</sup> (Table 4.1).

The differences in stomach pH with regards to the different treatments may be linked with the growth parameters described in Chapter 3. Feed conversion ratio (FCR) showed significant differences with the meal diet doing significantly ( $P < 0.05$ ) worse than the pelleted diet with Acid Buf<sup>TM</sup>. The pelleted diet with AB caused the lowest and closest to optimum pH in the stomach (3.15) leading to the lowest FCR of the four different treatments.

The average daily gain (ADG) on pelleted feed containing Acid Buf<sup>TM</sup> was significantly better ( $P < 0.05$ ) than that on meal diets. The ADG of the pigs on the pelleted feed without Acid Buf<sup>TM</sup> was found to be intermediary and equal to all other treatments (Table 3.3). The higher ADG and better FCR on the pelleted diet containing Acid Buf<sup>TM</sup> can partly be as a result of better pre-digestion of proteins in the stomach due to an optimal pH being maintained.

**Table 4.1** pH of the stomach, duodenum, jejunum, ileum and colon ( $\pm$  standard deviation) of pigs slaughtered after receiving either pelleted or meal diets with or without Acid Buf<sup>TM</sup>

	<b>Stomach</b>	<b>Duodenum</b>	<b>Jejunum</b>	<b>Ileum</b>	<b>Colon</b>
<b>Pelleted</b>	3.71 <sup>ab</sup> $\pm$ 0.54	5.23 <sup>b</sup> $\pm$ 0.73	6.26 $\pm$ 0.11	6.39 $\pm$ 0.06	6.03 <sup>a</sup> $\pm$ 0.19
<b>Meal</b>	4.18 <sup>a</sup> $\pm$ 0.79	5.78 <sup>ab</sup> $\pm$ 0.45	6.36 $\pm$ 0.05	6.42 $\pm$ 0.25	6.68 <sup>b</sup> $\pm$ 0.14
<b>Pelleted AB</b>	3.15 <sup>b</sup> $\pm$ 0.52	4.12 <sup>c</sup> $\pm$ 0.68	6.09 $\pm$ 0.37	6.15 $\pm$ 0.38	5.85 <sup>a</sup> $\pm$ 0.29
<b>Meal AB</b>	3.16 <sup>b</sup> $\pm$ 0.96	6.18 <sup>a</sup> $\pm$ 0.23	6.20 $\pm$ 0.30	6.33 $\pm$ 0.14	5.88 <sup>a</sup> $\pm$ 0.27

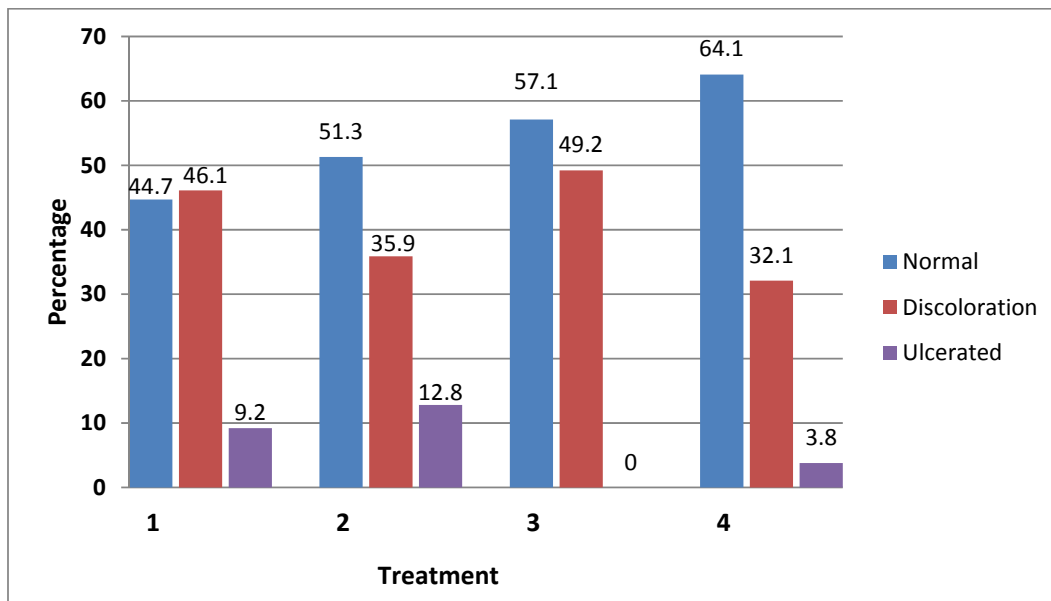
<sup>a,b,c</sup>means in the same column with different superscripts differ significantly ( $P < 0.05$ )

AB=Acid Buf<sup>TM</sup>

The pH of the small intestine ranges from 4.5 to 6.5, with the higher pH reached in the proximal region after the addition of bile salts and pancreatic enzymes. At a higher pH of about 6, the bile salts are most effective, unionized and poorly absorbable. If gastric secretion is excessive and the pH falls, the bile salts become ionized, are absorbed and there is little or no fat solubilisation and fat may appear in the stool. Bile salts ensure digestion of the feed substrates and allow for absorption of nutrients by the epithelial cells on the surface of the villi and prior to the terminal ileum (Merchant *et al.*, 2011).

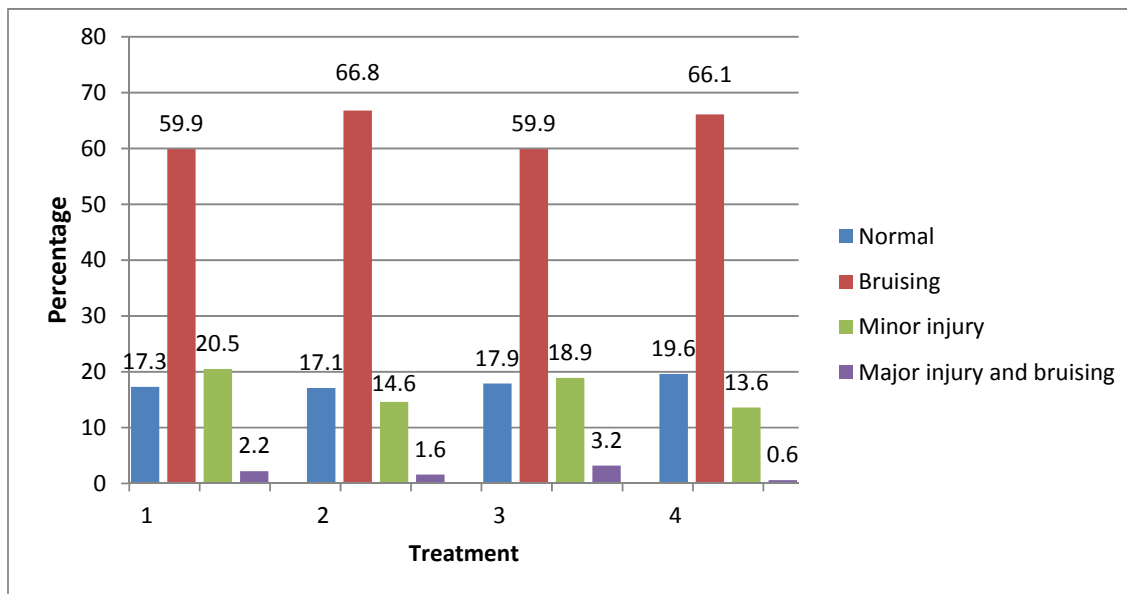
The pH in the duodenum was highest and closest to optimum with the meal Acid Buf<sup>TM</sup> diet and lowest in the pelleted Acid Buf<sup>TM</sup> diet with the control diets being intermediary and equal to the Acid Buf<sup>TM</sup> diets (Table 4.1). No pH differences ( $P > 0.05$ ) were observed for diets in the jejunum and ileum. The highest ( $P < 0.05$ ) pH value (6.68) in the colon was observed for the meal diet while all other diets were equal.

As seen in Figure 3.2, the highest percentage of normal stomachs was found in Tr4; meal with Acid Buf<sup>TM</sup> with 64.1% of the stomachs being normal. The second highest percentage (57.1%) of normal stomachs were found in treatment 3, pelleted with Acid Buf<sup>TM</sup>, although Tr3 had the highest percentage of discoloration with minor parakeratosis at 49.2%. The percentage of normal stomachs in the pelleted Tr1 and the meal Tr2 diet was 51.3% and 44.7%, respectively. There were no severe ulcers in pelleted diet with AB, with only 3.8% of the stomachs examined in the meal diet with AB showing severe ulceration. This is significantly ( $P < 0.05$ ) less than in the pelleted and the meal diet. The meal diet had the highest number of severe ulcers with 12.8% of the stomachs examined showing ulceration.



**Figure 3.2** Ulcer scores of the fundic area for the four different treatments: Tr1 - pelleted, Tr2 – meal, Tr3 pelleted with Acid Buf<sup>TM</sup>(AB), Tr4 meal with AB, indicated as percentage after logistic regression using Proc logistic of SAS

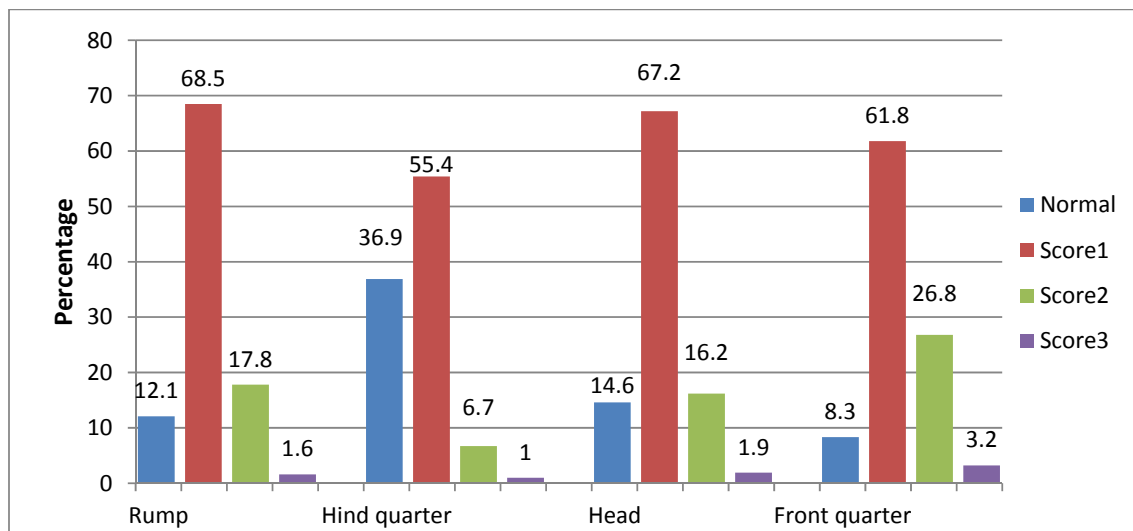
Logistic regression using Proc logistic of SAS for Windows version 9.1.3 was used to describe the carcass scoring data (Figure 4.3).



**Figure 4.3** Carcass scoring indicated as percentage for the four different treatments (Tr); Tr1 - pelleted, Tr2 – meal, Tr3 pelleted with Acid Buf<sup>TM</sup> (AB), Tr4 meal with AB, after logistic regression using Proc logistic of SAS

The model included score as response variable and treatment as the only main effects. Using type 3 analysis it was found that there was no significant differences ( $P>0.05$ ) between the effects of the treatments on carcass scoring. As can be seen from Figure 4.3, treatment 2 and 4, meal and meal with Acid Buf™ respectively, tend to show more bruising than the pelleted diets. Treatment 1 and treatment 3, the pelleted diets tend to show more minor and major injuries on the carcass than the meal diets

Logistic regression using Proc logistic of SAS for Windows version 9.1.3 was used to describe the area scoring data. The model included score as response variable and treatment and area as main effects (Figure 4.4).



**Figure 4.4** Areas scoring indicated as percentage for the four different areas after logistic regression using Proc logistic of SAS

A statistical analyses of the effect of the dietary treatments on the areas that showed bruising/lacerations indicated that treatments were not significantly different, however the score for the areas of the carcass differed significantly ( $P < 0.0001$ ; Figure 4.4). As indicated in Figure , most of the carcasses in all areas were scored 1 which implies that there were only minor marks on the carcass. The hind quarter had the highest normal score at 36.9%. The forequarter scored significantly less normal grading ( $P < 0.0001$ ) than the hindquarter and the odds ratio was calculated at 3.959. This means that the odds of an injury on the carcass are much more likely to occur on the front quarter of the carcass than the back quarter. It was expected that the front quarters would show higher laceration scores as it is this area that is normally lacerated during conflict/aggression interactions between two pigs.



## Conclusion

The results reported in this study revealed that when Acid Buf<sup>TM</sup> was included at a level of 4g.kg<sup>-1</sup> to the diet the changes in the intestinal pH were beneficial for optimal digestion and intestinal tract health. When Acid Buf<sup>TM</sup> was included in the pelleted diet, the cumulative feed intake did not change significantly but the feed conversion ratio as well as ADG was significantly better, when compared to the pelleted diet without Acid Buf<sup>TM</sup> as described in Chapter 3. This can be associated with the results of Figure 4.2 which indicates that no severe stomach ulcers were found in the pelleted with AB treatment. Dietary treatments did not significantly affect carcass injuries/lesions at slaughter, indicating that the different treatments did not influence their behaviour as pertaining to aggressive encounters. It is thus concluded that the inclusion of Acid Buf<sup>TM</sup> to both pelleted and meal maize soya diets for growing finishing pigs optimize intestinal pH, decreased stomach ulcers and thus increased production without any visible negative effects.

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## CHAPTER 5

### Effect of the inclusion of Acid Buf<sup>TM</sup> on histological parameters of the gastrointestinal tract of growing pigs

#### Abstract

This experiment evaluated the effect of feeding a maize-soya based diet in a pelleted and meal form with or without adding Acid Buf<sup>TM</sup> (AB) at 4g.kg<sup>-1</sup> on the histological parameters of the gastrointestinal tract of pigs. Specifically the effect of the different treatments on the villi height, crypt depth and villi height crypt depth ratio of the duodenum and jejunum of growing-finishing pigs will be investigated. The four treatments (Tr) were: Tr1 – pelleted, Tr2 – meal, Tr3- Pelleted with Acid Buf<sup>TM</sup> at 4g.kg<sup>-1</sup>, Tr4 - meal with Acid Buf<sup>TM</sup> at 4g.kg<sup>-1</sup>. The average villi height measured in the jejunum was significantly higher in pigs fed the pelleted AB diet than those fed the meal, meal with AB and pelleted diets. The mean crypt depth of the duodenum when fed the pelleted AB diet were significantly shallower ( $P<0.05$ ) than when the pelleted, meal and AB meal diets were fed. The mean crypt depth of the jejunum of pigs fed the pelleted diet was the deepest and differed ( $P<0.05$ ) from all the other treatments. The AB pelleted diet resulted in significantly higher ( $P<0.05$ ) villi height crypt depth ratio in both the duodenum and the jejunum compared to the other treatments.

#### Introduction

The small intestine is divided into three sections namely the duodenum, jejunum and ileum. The duodenum is the shortest segment and the villi in this region are broad, tall and numerous. Fewer goblet cells occur in the epithelium. Duodenal (Brunner's glands) with mucus secreting cells in the submucosa characterizes this region. The jejunum exhibits fewer villi than the duodenum and the villi in this region are both shorter and narrower. More goblet cells are found in this segment. The ileum contains even fewer villi and these villi are narrower and shorter than those in the jejunum. Prominent Peyer's patches characterize this segment (Di Fiore, 2012).

Domeneghini *et al.* (2004) suggested that changes in the intestinal mucosa may be caused by nutritional factors. In addition various bacterial populations in the gastrointestinal tract are capable of modifying intestinal microstructures and the immune system (Babińska *et al.*, 2005). In one particular study, histological research was done to investigate the effect of various diets (e.g. milk diet, diet with a varied addition of faba beans) and dietary systems on

the morphometric and functional characteristics of the intestines (Mroz, 2001). Results indicated that feed additives (probiotics and prebiotics) do not have an adverse effect on the morphometric characteristics of the intestines. Although dietary factors increase the height of intestinal villi as well as the number and depth of crypts (Mroz, 2001), crypts are responsible for the proliferation of epithelial cells, the production of defences - antibacterial immunity agents, and endocrine substances. Defence reactions are activated in crypts, supporting antibody production and phagocytosis (Manning & Gibson, 2004). Diet components, fibre content and the applied dietary method and feeding system affect intestinal micro flora, as well as the proliferation and secretory activity of intestinal crypt enterocytes.

Animals need a supply of nutrients and oxygen that are obtained via the digestive system and the respiratory system, respectively (Akers & Denbow, 2008). For normal metabolism cells of the animal's body need the three major classes of nutrients (carbohydrates, proteins and lipids) delivered to the cells in their simplest forms (monosaccharides, amino acids and fatty acids). It is the function of the gastro intestinal tract to reduce the consumed feedstuffs to simpler molecules and to transfer them to the blood so they can be delivered to the cells for metabolism (Frandsen *et al.*, 2009).

The gastrointestinal tract is essentially a long smooth muscle extending from the mouth to the anus. The tube has two distinct layers of smooth muscle in its wall namely circular and longitudinal layers and is lined with epithelia that function as selective barriers between the lumen and body fluids (Frandsen *et al.*, 2009). The digestive tract includes four major layers. From the lumen outward they are: The mucosa, the submucosa, the muscularis externa and the serosa (Akers & Denbow, 2008).

Dietary changes after weaning can also have an effect on gut structure and function. A study by Deprez *et al.* (1987) compared a pelleted diet and the same diet fed in slurry form and recorded higher villi in the intestines of the pigs fed the slurry. Villi height may have been affected by the pelleted diet because of its abrasive nature, alternatively the higher villi recorded when the pigs were fed the slurry may be a reflection of the higher energy intake. Several studies including those of Kelly *et al.* (1991) and Spreeuwenberg *et al.* (2001) have demonstrated that villi are higher in pigs that consume more food. The study by Spreeuwenberg *et al.* (2001) also suggested that reduced energy intake; independent of diet type, is a major cause of villous atrophy.

Voluntary food intake is another factor that affects the structure and function of the intestines, as the presence of food or more precisely nutrient flow along the small intestine is one of the most potent stimuli of intestinal proliferation (Diamond & Karasov., 1983). Kelly *et*

*al.* (1992) gathered an extensive amount of evidence that the oral intake of food and its presence in the gastrointestinal tract are necessary for structural and functional maintenance of the intestinal mucosa. Several studies show that the exclusion of nutrients from the lumen either by starvation, restriction or intravenous feeding results in villous atrophy and a decrease in crypt cell production rate (McNeill, 1971; Goodlad *et al.*, 1992).

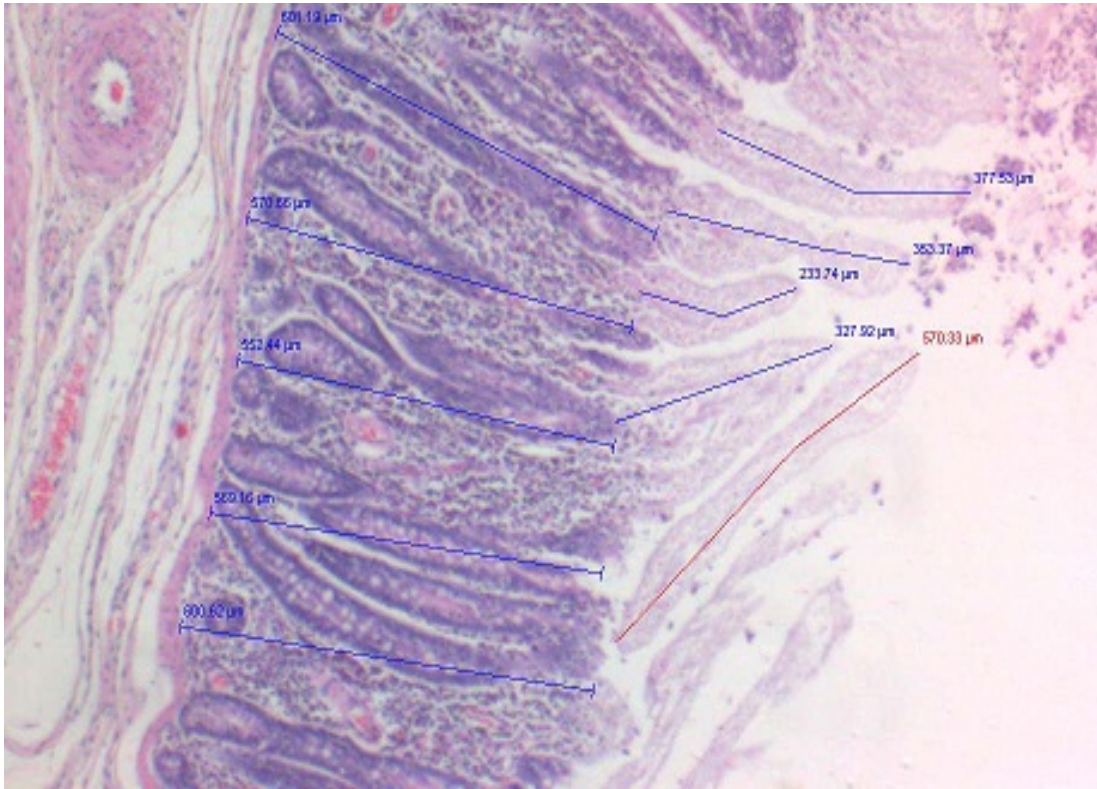
Although there are several factors influencing intestinal morphology that can be described separately, it should be understood that many of these factors interact with one another so that the effect can be seen in both mucosal architecture and biochemistry (Pluske *et al.*, 1997). In this experiment, the intestinal morphology of pigs that had been fed a balanced diet either in a meal or pelleted form, with or without a commercial buffer was studied histologically.

## **Materials and methods**

### **Histological analysis**

To determine the influence of Acid Buf<sup>TM</sup> on the histological parameters, 40 samples of the duodenum and 40 samples of the jejunum were collected, 10 from each treatment. 5 measurements pertaining to villi height and crypt depth could be made per slide. Upon slaughter at the same time that the stomachs of the pigs were collected and inspected for lesions, samples of the duodenum and jejunum were collected at the same location where the pH was measured (Chapter 4). Both the duodenum and jejunum were transversely cut, and then cut in length using surgical scissors to give a 3cm<sup>2</sup> sample. The samples were rinsed with a 0.9% saline solution and fixed in a 10% buffered formalin solution. Samples were subsequently submitted to the Stellenbosch University School of Medicine histology lab (Tygerberg campus) for processing. Sample processing (Presnell & Schreiber, 1997) consisted of washing, trimming, alcohol dehydration, xylene clearing and impregnation with paraffin wax. Tissue sections measuring 3-4µm were cut using a microtome, fixed on slides and stained using haematoxylin and eosin (H&E). Slides were examined by using an Olympus IX70 inverted light microscope. Photos of all the slides were taken using the OlympusColorView II Soft Imaging System and analysed using the following software: analysis version 5.1; Olympus Soft Imaging Solutions. Image calibration: Magnification = 4; X calibration = 2.10526 µm / P; Y calibration 2.10526 µm / P; X/Y Ratio = 1; Calibration length = 1. Images were saved as .tif files with µm calibration. From these images villi height of 10 consecutive intact villi were measured from the tip of the villus to the villous-crypt

junction while crypt depth was measured from this junction to the lower limit of the crypt (Figure 5.1).



**Figure 5.1** Villi height and crypt depth measurements of an H&E stained cross section of the jejunum

The histological data absolute mean villi height, absolute mean crypt depth and mean villi height crypt depth for each of the four treatments for both jejunum and duodenum collected from these measurements were subjected to statistical analysis.

### Statistical analysis

One-way ANOVA was used SAS for Windows version 9.1.3 to describe the histological data. One-way ANOVA compares three or more unmatched groups, based on the assumption that the populations are Gaussian. In order to determine if the test is significant, The F regression statistic was used. For the model to be significant, a P-value equal to, or smaller than 0.05 (for 95%) is needed.

Also, the spread of scores (or measured data) in each condition should be roughly similar. (The spread of scores is reflected in the variance, which is simply the standard deviation squared). In the case of the histological data, it was less obvious that the spread of scores was similar, and a more formal test was required. There are various ways to test for homogeneity of variance. Two tests for homogeneity were conducted:

Bartlett's Test for Homogeneity: Equal variances across samples are called homogeneity of variances. Some statistical tests, for example the analysis of variance, assume that variances are equal across groups or samples. The Bartlett test was used to verify that assumption. Bartlett's test is sensitive to departures from normality. The collective measurements were suspected to come from non-normal distributions, and the Bartlett's test was simply used to test for non-normality. The chi-square test value, used in the Bartlett's test estimated the probability of the observed results given the underlying hypothesis (Glantz, 2002).

Levene's Test for Homogeneity: Levene's test was used in conjunction with the Bartlett test. Levene's test is less sensitive than the Bartlett test to departures from normality (Glantz, 2002).

### Results and discussion

The main focus of this study was on the influence of the different dietary treatments (see Chapter 3 for more detail) on the mean villi height and crypt depth, as well as the villi height depth ratio from both the duodenum and jejunum. According to Songer, (2005), necrosis of the small intestine is uncommon in natural cases, although, as previously stated a number of factors play a role in the structure and function of the small intestine (Pluske *et al.*, 1997). As indicated in Table , one way ANOVA showed there were no significant differences ( $P=0.4$ ) between the different treatments for mean villi height in the duodenum. There were however significant differences in mean villi height in the jejunum, ( $P<0.0001$ ). As indicated in (Table 5.2), pigs on the pelleted diet with AB had a higher ( $P<0.05$ ) mean villi height ( $466.16\mu\text{m}$ ) than pigs on the other treatments and there was no significant difference between the pelleted diet ( $397.58\mu\text{m}$ ) meal diet ( $364.71\mu\text{m}$ ) and AB meal diet  $385.72\mu\text{m}$ ).

**Table 5.1** ANOVA procedure results showing degrees of freedom (DF), F-value, and P-value for jejunum and duodenum villi height, crypt depth and villi height crypt depth ratio

	ANOVA		
	DF	F	P-value
<b>Jejunum villi height</b>	3	7.75	< 0.0001
<b>Duodenum villi height</b>	3	0.98	0.4
<b>Jejunum crypt depth</b>	3	33.74	< 0.0001
<b>Duodenum crypt depth</b>	3	8.79	< 0.0001
<b>Jejunum VH:CD</b>	3	17.01	< 0.0001
<b>Duodenum VH:CD</b>	3	4.45	0.0051

**Table 5.2** Absolute means and standard deviation (SD) of villi heights of the duodenum and jejunum associated with the feeding of Acid Buf™ to diets of grower finisher pigs in either meal or pelleted form

Treatment	Duodenum		Jejunum	
	Mean	SD	Mean	SD
<b>Pelleted</b>	489.05 <sup>a</sup>	± 139.36	397.58 <sup>b</sup>	± 95.75
<b>Meal</b>	437.42 <sup>a</sup>	± 132.68	364.71 <sup>b</sup>	± 93.73
<b>Pelleted with AB</b>	443.46 <sup>a</sup>	± 133.91	466.16 <sup>a</sup>	± 132.68
<b>Meal with AB</b>	446.64 <sup>a</sup>	± 126.19	385.72 <sup>b</sup>	± 83.58

<sup>a,b</sup> means values in the same column with different superscripts differ significantly (P<0.05)

AB=Acid Buf™

The results obtained in Table do not agree with Heddemannet *al.* (2006), who investigated the effect of particle size and processing method on the morphological characteristics in the small intestine. Four diets were fed in their investigation: fine non pelleted, fine pelleted, coarse pelleted and coarse non pelleted. Pigs fed the coarse non pelleted diet had longer villi (527µm) than pigs fed the coarse pelleted diet (442µm). Although the villi height of the pigs fed the fine pelleted and fine non pelleted diet did not differ significantly from each other. The findings that there were no differences between the fine pelleted and non-pelleted diets, agrees with the results from the duodenum in Table .

One way ANOVA of the mean crypt depth of the duodenum and jejunum showed significant difference P<0.0001 (P<0.05) between the four different treatments (Table ). This indicates that the data do not show homogeneity of variance between the different treatments.

Heddemannet *al.*'s, (2006) pigs fed the coarse diet tended to have increased crypt depths, although no significant differences (P>0.05) between the different treatments could be found. This is in contrast with the results obtained from this study (Table . The mean crypt depth of the duodenum of the pigs when fed the pelleted AB diet (428.12µm) were significantly shallower (P<0.05) than the pelleted (539.51µm) meal (525.68µm) and AB meal (554.64µm) diets, where there were no significant difference between treatments. Crypts are responsible for the proliferation of epithelial cells, the production of defences - antibacterial immunity agents, and endocrine substances. Defence reactions are activated in crypts, supporting antibody production and phagocytosis (Manning and Gibson, 2004) In this study the shallower crypt depth of TR3 did not seem to have any visible or measurable effect on the pigs. None of the pigs receiving TR3 showed any signs of disease of metabolic challenges because of the shallower crypt depth.



**Table 5.3** Absolute means and standard deviation (SD) of crypt depths of the duodenum and jejunum associated with the feeding of Acid Buf<sup>TM</sup> to diets of grower finisher pigs in either meal or pelleted form

Treatment	Duodenum		Jejunum	
	Mean	SD	Mean	SD
<b>Pelleted</b>	539.51 <sup>a</sup>	± 108.18	477.76 <sup>a</sup>	± 87.23
<b>Meal</b>	525.68 <sup>a</sup>	± 124.87	333.99 <sup>c</sup>	± 74.9
<b>Pelleted with AB</b>	428.12 <sup>b</sup>	± 103.81	345.82 <sup>c</sup>	± 74.14
<b>Meal with AB</b>	554.64 <sup>a</sup>	± 102.29	428.22 <sup>b</sup>	± 70.52

<sup>a,b</sup> means values in the same column with different superscripts differ significantly (P<0.05)

AB=Acid Buf<sup>TM</sup>

As seen in Table the mean crypt depth of the jejunum of the pigs when fed the pelleted diet (477.76µm) was the deepest and differed significantly (P<0.05) from all the other treatments. There were no significant difference between the meal diet (333.99µm) and the pelleted AB diet (345.82µm). These two treatments had the shallowest mean crypt depth. The meal AB diet (428.22µm) was intermediary and differed significantly from the other treatments.

The results displayed in Table 5.2 and Table 5.3 in this study correlates with Jones *et al.* (2010) who investigated the interrelationship between hypersensitivity to soya bean proteins and growth performance in early weaned pigs. The pigs were fed either dried skim milk, soya bean meal, soya protein concentrate or extruded soya protein concentrate. Villi height and crypt depth from the duodenum was measured and analysed. Their study revealed that pigs fed soya bean meal had a shallower villi height and deeper crypt depth compared to pigs fed dried skim milk. The pigs fed soya bean meal also had a lower average daily gain compared to pigs fed dried skim milk. In the study by Jones *et al.* (2010) it was concluded that villi height provided a positive correlation to growth performance. Soya bean sensitivity may play a role in how the villi height and crypt depth respond to the different diets.

As seen in Table 5.1 one way ANOVA analysis of the mean villi height crypt depth ratio of the duodenum showed significant difference (P<0.0001) between the four different treatments. One way ANOVA analysis of the mean villi height crypt depth ratio of the jejunum also showed significant difference (P=0.0051) between the four different treatments. This indicates that the data does not show homogeneity of variance between the different treatments.

**Table 5.4** Means and standard deviation (SD) of villi height crypt depth ratio of the duodenum and jejunum associated with the feeding of Acid Buf™ to diets of grower finisher pigs in either meal or pelleted form

Treatment	Duodenum		Jejunum	
	Mean	SD	Mean	SD
Pelleted	0.95 <sup>ab</sup>	± 0.34	0.86 <sup>c</sup>	± 0.27
Meal	0.85 <sup>b</sup>	± 0.23	1.18 <sup>b</sup>	± 0.51
Pelleted with AB	1.14 <sup>a</sup>	± 0.61	1.41 <sup>a</sup>	± 0.51
Meal with AB	0.83 <sup>b</sup>	± 0.29	0.92 <sup>c</sup>	± 0.23

<sup>a,b</sup> means values in the same column with different superscripts differ significantly (P<0.05)

AB=Acid Buf™

Table 5.4 shows the villi height crypt depth ratio between the different treatments. The pigs on the pelleted AB diet had the largest villi height to crypt depth ratio in both the duodenum (1.14) and the jejunum (1.41). In the duodenum the pelleted AB diet differed significantly from the meal diet (0.85) and the AB meal diet (0.83). In the duodenum the pelleted diet (0.95) was intermediary and equal to all the treatments. In the jejunum, the diets differed significantly from each other, except for the pelleted diet and the meal diet with AB. The lowest villi height to crypt depth ratio was in the pelleted (0.86) diet. The ratio with the meal AB diet (0.92) was larger than the pelleted diet but smaller than the meal diet (1.18). The villi height to crypt depth ratio of the pelleted diet with AB is the only diet that gave a villi height to crypt depth ratio of more than 1. This generally indicates that the gut is healthy. The absorption surface is also optimized for absorption and digestion. This can be linked to production parameters discussed in chapter 3

## Conclusion

The average villi height of the meal diet, AB meal diet and pelleted diet were exceeded by the AB pelleted diet in the jejunum. The crypt depth was the deepest in the AB pelleted diet. The villi height: crypt depth ratio in both the jejunum and duodenum was the largest. The villi height crypt depth ratio is a useful criterion for estimating the digestive capacity in the small intestine (Montagne *et al.*, 2003). In a study by Hedemann *et al.* (2006) the maintenance of the villi height crypt depth ratio suggests that a reduction in villi height is less deleterious when it is not accompanied by increased crypt depth.

When comparing the average daily gain results obtained in Chapter 3, Table 3.3, a positive relationship is seen between average villi height, villi height to crypt depth ratio and average

daily gain. The pelleted AB diet had a higher mean villi height in the duodenum, a larger villi height to crypt depth ratio and a better average daily gain than the meal and AB meal diets.

The results reported in this study revealed that when Acid Buf<sup>TM</sup> was included at a level of 4g.kg<sup>-1</sup> to the diet, in both pelleted and meal form, the changes in the villi height crypt depth ratio in the duodenum as well as the jejunum improved significantly.

As previously stated morphological and functional changes in the intestinal mucosa are mainly caused by nutritional factors (Schweiger *et al.*, 2003). Dietary factors can increase and decrease the height of the intestinal villi as well as the number, and depths of crypts (Mroz, 2001). Villus height was increased by 14% when comparing a wet pelleted feed to a dry mash in weaned pigs (Yang *et al.*, 2001). Crypts are responsible for the proliferation of the epithelial cells and the production of immunity agents and endocrine substances, giving an optimal environment for absorption of nutrients (Manning and Gibson, 2004).

The pigs on the pelleted diet containing Acid Buf<sup>TM</sup> had the best villi height to crypt depth ratio. The results obtained from this study can be linked to better performance regarding average daily gain and feed conversion ratio, as seen in Chapter 3.

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## CHAPTER 6

### General conclusion

Results of the experiments in this study have demonstrated that pig producers may benefit from using Acid Buf<sup>TM</sup>(AB) at 4g.kg<sup>-1</sup>; as discussed throughout the study, various factors including performance parameters, presence of ulcers and their severity, histological characteristics and pH of the small intestine, were all in some way positively influenced.

The feed conversion ratio as well as average daily gain was significantly better when comparing a pelleted diet with AB to a meal diet without AB. The feed conversion ratio and average daily gain improved when the pelleted diet with AB was compared with a pelleted diet without AB. The cumulative feed intake did not change significantly between the four different dietary treatments and from these findings it can be concluded that the inclusion of AB had a positive effect on the production

Acid Buf<sup>TM</sup> included in both the pelleted and meal diets optimized the intestinal pH, decreased stomach ulcers and increased production without any visible negative effects. The stomach pH was closest to optimal when a pelleted diet containing AB was fed. The optimization of stomach pH may aid in better digestion of feedstuffs that may in turn lead to better nutrient utilization. Remarkably the pelleted diet containing AB was the only treatment that showed no severe ulceration of the epithelial lining of the stomach. The addition of AB to the meal diet also decreased ulceration when compared to the diets not containing AB.

There is a positive relationship between villi height to crypt depth ratio and absorption potential in the small intestine. Although there was no significant difference in the mean villi height in the duodenum, the mean villi height in the jejunum showed a positive response when AB was added to the pelleted diet. The crypt depth in the duodenum between the different treatments was significantly improved when AB was added to the pelleted diet. In both the duodenum and jejunum an increased villi height crypt depth ratio that was significantly better than in all other treatments was seen with the pelleted AB diet.

As discussed throughout the study performance parameters, ulcer formation and histological parameters are all influenced by a number of factors. There was an overall positive response to Acid Buf<sup>TM</sup> inclusion in the diet which can be attributed to a combination of factors. The improvement of the histological characteristics of the small intestine is of importance as this directly correlates with increased daily gain and improved FCR. Reduced ulceration of the stomach and optimal pH leads to better nutrient utilization and performance. Overall the

pelleted diet with Acid Buff™ included gave the best results in most of the different experiments conducted.

The results obtained from this study are very positive. Some of the commercial growers in South Africa mixing own feeds do not use pelleted diets in the growth and finisher phase because of cost of pelleting and not knowing the effects of non-visible factors such as stomach ulceration and intestinal pH, on production performance. The inclusion of a dietary buffer like Acid Buff™ to pelleted diets should yield positive results, however the profitability of the use of Acid Buff™ compared to the cost of pelleting requires further study.