# Fibre inclusion and water quality interaction on performance and water consumption in growing pigs

**By**

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**Declaration**

The acknowledgement and citation of other individuals throughout this document does not nullify the originality of the authors work presented in this document, this thesis was completed by the author under the supervision of Professor Michael Chimonyo at the University of KwaZulu-Natal (Pietermaritzburg campus) where the thesis will be exclusively submitted.


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**Abstract**

The study was conducted to assess the interaction between fibre inclusion and water source on water consumption, growth performance and nitrogen (N) balance of growing pigs during early post weaning phase. In Experiment 1, sunflower husks were used to dilute a basal diet at to obtain two fibre inclusion levels, low (0 g/kg) and high (160 g/kg), the two water sources used were reservoir water (R) and dairy effluent (D). The four treatment combinations (LR, LD, HR and HD) were arranged in a 2 × 2 factorial arrangement. Twelve pigs (11.83 ± 1.33 kg body weight (BW) were allocated to each of the four treatments for four weeks. Water source did not affect scaled feed intake (SFI), average daily gain (ADG) and increased gain to feed ratio (GF). Fibre inclusion, however, significantly reduced ADG and increased GF ratio. There was an interaction between fibre inclusion and water source on scaled feed intake (SFI). Pigs on the high fibre diet consumed 3.4 g/day more feed when given reservoir water compared to the pigs that were supplied with the dairy effluent. There were no differences in SFI of the pigs on the low fibre diet regardless of the water type.

For the nitrogen balance trial, 12 pigs for each treatment, with an average body weight of 27 ± 3.2 kg, were used. There was an interaction between fibre inclusion and water source on N digestibility and retention. Nitrogen digestibility reduced ($P < 0.05$) by 4.6 % for pigs on the low fibre diets. The N digestibility HD treatment was significantly increased by 4.3 % compared to those on the HR treatment. Similarly, while there was no difference between LD and LR on N retention, pigs on the LD treatment had a 2.2 % increase in N retention compared to LR pigs. It can be concluded that using dairy effluent as a source of drinking water for growing pigs on high

fibre diets significantly reduces growth and feed efficiency. Dairy effluent improves N retention when pigs are fed on high fibre diets.

**Acknowledgements**

**Dedication**

This thesis is dedicated to my late father, Mr Rabbie Leviton (A.K.A "Ocean") Mabuza, your little girl grew up just fine daddy. I also dedicate this work to the whole Mabuza family, Mabuza, Mshengu, Shabalala, we made it.

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# LIST OF ABBREVIATIONS

| Term/Symbol | Description | Units |
|---|---|---|
| ADF | Acid detergent fibre | g/kg |
| ADFI | Average daily feed intake | kg/day |
| ADG | Average daily gain | kg/day |
| ADWI | Average daily water intake | litres/day |
| BW | Body weight | kg |
| CF | Crude fibre | g/kg |
| COD | Chemical oxygen demand | mg $O_2$/l |
| CP | Crude protein | g/kg |
| DE | Digestible energy | MJ/kg |
| DF | Dietary fibre | |
| DM | Dry matter | g/kg |
| DN | Digested nitrogen | g/day |
| FCR | Feed conversion ratio | |
| FNE | Faecal nitrogen excretion | g/day |
| GF | Gain to feed ratio | |
| GIT | Gastrointestinal tract | |
| LH | Lucerne hay | g/kg |
| MC | Maize cob | g/kg |
| N | Nitrogen | |

| | | |
|---|---|---|
| NDF | Neutral detergent fibre | g/kg |
| NI | Nitrogen intake | g/day |
| NSP | Non starch polysaccharides | |
| PU | Citrus pulp | |
| RN | Retained nitrogen | g/day |
| RB | Rice bran | |
| SAS | Statistical Analysis System | |
| SEM | Standard error of means | |
| SFI | Scaled feed intake | |
| SH | Sunflower husk | g/kg |
| SWI | Scaled water intake | |
| TDS | Total dissolved solids | mg/l |
| TNE | Total nitrogen excretion | g/day |
| UNE | Urinary nitrogen excretion | g/day |
| WHC | Water holding capacity | g/g |

**Appendices**

Appendix 1: Animal ethics Approval letter

# CHAPTER 1: General Introduction

## 1.1 Background

The quality and availability of both feed and water are important in determining the success of pig enterprises (Nyachoti and Kiarie, 2010). Maize and soy bean are the main nutrient providing ingredients in pig diets (Lesson, 2012). With the rising costs of grains, agro-industrial by-products, and forages are alternative feed ingredients due to their availability and affordability (Len *et al*., 2009). The common properties of these feed alternatives are their bulkiness and resistance to digestion by enzymes in the digestive system of non-ruminant animals, especially weaned pigs (Len *et al*., 2009). Until recently, minimal focus has hence been drawn towards exploring the prospect of fibre inclusion in weanling diets (Kallabis and Kaufmann, 2012). The recognized threat of feed scarcity makes the need to explore the effects of fibre inclusion in weanling diets.

Fibre inclusion also influences water intake in pigs (Bakare *et al.*, 2013), this hence presents the need to optimize water usage in pigs and ensure water availability for pigs. Water scarcity issues are currently on the increase (Wallace and Austin, 2004). Constituting approximately 82 % of the body weight of a weaned pig and about 55 % of a pig at market body weight, inadequate water intake is more likely to have the most adverse effects on animal performance compared to other nutrients (Nyachoti and Kiarie, 2010). Regardless of the known significance of water for profitable pig production, little research has been conducted for better understanding its optimal usage (Nyachoti and Kiarie, 2010), because of it has been previously considered as easily accessible and inexpensive.

A possible method of addressing the concern of water availability is the recycling of waste water through feeding pigs. The ability of pigs to tolerate a wide range of water quality parameters without any drastic effect on their health and performance (McLeese *et al*., 1992; Tofant *et al*., 2011) makes the prospect of recycling waste water acceptable. The dairy industry is a possible source of large volumes of waste water. The South African dairy industry consumes approximately 4.5 million $m^3$ of water per annum, 75 to 95 % of that water is discharged as effluent annually (Water Research Commission, 1989).

One of the biggest challenges faced by the dairy industry is effluent discharge, due to the high biological oxygen demand (BOD) of dairy effluent. Most dairy factories rely on municipal sewage treatment facilities to dispose their effluent without threatening the environment. Due to the high costs involved in effluent disposal to municipal sewers, some factories opt for irrigation of pastures as a method of effluent discharge (Strydom *et al*., 1993). Irrigation, however, runs a high risk of surface water pollution through runoff from the irrigated fields hence compromising the aquatic ecosystem.

The absence of toxic chemicals in dairy effluent and presence of dissolvable organic components gives the prospect of the reusability of this waste water in pig production (Sarkar *et al.*, 2006). As scarcity levels increase for fresh water and good quality feed, the use of high fibre alternative feed ingredients and low quality alternative water sources such as waste water may eventually be a practice to be adopted in the pig industry. There is, therefore, the need not only to determine how fibre inclusion in pig diets, but also assess the influence of waste water intake on pig

performance. The interaction between fibre inclusion and water quality also warrants investigation.

## 1.2 Justification

Whole grain crops such as maize and wheat are the main energy sources for pig diets, however these are also staple foods for the human population. There is hence a growing competition between humans and pigs for the grains; the increased demand consequently increases market prices for the grain. Meanwhile, food processing plants generate large volumes of crop residues such as sunflower hulls, soybean hulls, maize cob and maize stover, in most cases these by-products are thrown away as waste. Inclusion of these by-products into pig diets is, thus, sustainable and may reduce the cost of pig feeds. There is little knowledge of the effects of fibre in weaned and growing pigs. Recycling waste water from the dairy industry will help secure continuous water supply for pig farmers. Dairy effluent contains considerably high dissolvable organic substances (total dissolved solids; TDS) that can be metabolized by the pigs, which may increase pig performance.

## 1.3 Objectives

The broad objective of the study was to determine interactions between fibre inclusion and water quality on the performance and water consumption of growing pigs. The specific objectives were to:

1. Determine the effect of fibre inclusion and water source on water consumption, feed intake and performance; and

2. Assess the effect of fibre inclusion and water source on nitrogen balance in growing pigs.

## 1.4 Hypothesis

The hypotheses tested were that:

1. There exists an interaction between fibre inclusion and water source that influences water and feed consumption and performance in growing pigs; and

2. The interaction between fibre inclusion and water affects nitrogen balance in growing pigs.

## 1.5 References

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# CHAPTER 2: Review of Literature

## 2.1 Introduction

Water and feed are two of the most important resources in pig production. Whilst the limited availability of grains as feed ingredients for pigs is well recognised, limited focus has been drawn toward water scarcity as a subject of interest. In the past, water was considered an abundant resource. In recent years, however, the availability of fresh water resources is becoming limited due to climatic change and increased human populations across the world.

There is currently a lot of interest on the inclusion of agro industrial by products in cereal based diets as to ensure feed sustainability for the pig industry. These feed ingredients contain high fibre content. A number of studies have been done on how the inclusion of these fibrous ingredients affects the performance of growing and breeding pigs, however limited focus has been drawn towards the effect of fibre inclusion in pigs during the post-weaning period. Fibre inclusion has also been associated with increased water intake. There is, however, limited information on how the quality of the water affects the ability of pigs to utilise fibrous diets. As water scarcity continues to rise, the potential of using waste water is likely to increase. This highlights the need for better understanding of the effects of water quality on pig performance. The review discusses the effects of fibre inclusion, water quality and their interactive effects on pig performance.

## 2.2 Dietary fibre

There are numerous definitions of dietary fibre (DF) that are used in literature, the main reason for this being the constant debate among researchers about the components to be considered as part of dietary fibre in animal diets (DeVries, 2003). The most commonly accepted definition describes DF

as the oligosaccharides and carbohydrate polymers that are resistant to hydrolysis by endogenous enzymes in the small intestine of an animal (Turner and Lupton, 2011). Dietary fibre can also be viewed as the sum of all resistant starch, non-starch polysaccharides (NSP), non-digestible oligosaccharides and lignin complexes in a plant material (De Leeuw *et al*., 2008; Banino, 2012). The solubility of DF is highly dependent on their primary structure but also on the nature of the binding to other cell-wall components (Smits and Annison, 1996). Thus, fibrous ingredients can be classified according to whether they provide predominantly insoluble or soluble fibre components as shown in Table 2.1. It is important to understand the major properties of dietary fibre that influence its utilization in pigs.

## 2.2.1 Bulk properties of fibre

The physiological properties and fermentability of fibrous ingredients are difficult to predict from their monomeric composition and are related to bulk properties such as their water-holding properties, viscosity and solubility (Asp, 1996). The effective use of these ingredients in non-ruminant diets depends, to a large extent, on the adequate estimation of their physicochemical properties and nutritional value. To efficiently utilise high fibre agro-industrial by product ingredients in pig diets, it is imperative to better understand how their bulk properties may influence nutrient availability and overall performance.

## 2.2.2 Water holding properties of fibre

Both the terms water holding (WHC) and water binding capacity (WBC) reflect the ability of a fibre source to incorporate water within its matrix. The WBC describes the ability of a sample to bind water when exposed to an external stress, also measures the amount of fibre that will bind to the surrounding water in a specific medium under predetermined conditions (Guillon and Champ, 2000).

**Table 2.1** Classification of common ingredient sources for pig diets according to their main carbohydrate compositions

| Carbohydrate classification | Common ingredient sources in pig diets | Main carbohydrate composition | Constituent monomers | Solubility |
|---|---|---|---|---|
| Oligosaccharides (3<DP<10) | Soybean meal, peas, rapeseed meal, cereal grains | Fructo- and galacto-oligosaccharides | Fructose, galactose and glucose | ++ |
| Polysaccharides (10< DP) | Whole/ partly milled grains and seeds, legumes | Physically inaccessible starch | Glucose | - |
| | Raw potatoes, sweet potatoes, legumes, high amylose maize | Crystalline resistant granules | Glucose | - |
| | Cooled heat-treated starchy products | Retrograded amylose | Glucose | - |
| Non starch polysaccharides | Cereal and legume hulls | Hemicellulose | Glucose, rhamnose, xylose, galactose, fucose, arabinose | +/- |
| | Cereal and legume by products (e.g. maize stover), forages | Cellulose | Glucose | - |
| | Barley, oats, rye | β glucans | Glucose | + |
| | Sugar beet pulp, fruits | Pectins | Uronic acid | + |

++ → High solubility

+  → Medium solubility

+/- → Low solubility

-   → Minimal to no solubility

DP → degree of polymerisation.

Sources: Montagne *et al*. (2003); De Leeuw *et al*. (2008).

On the other hand, WHC describes the ability of a fibre to hold water within the feed matrix under atmospheric pressure. Although WBC gives a clearer more detailed understanding of a fibre source, outlining also its porosity and volume (Elleuch *et al*., 2011), the ease of determination is the main reason why WHC is more commonly considered when evaluating how water holding properties of a feed may affect pig performance when compared to WBC (Bakare *et al*., 2013).

There are several methods available for measuring WHC, such as centrifugation, dialysis bags and filtration (Elhardallou and Walker, 1993) and each gives different results. It is therefore difficult to make a direct comparison of the numerical values of WHC obtained in different studies. WHC is in most cases related to Swelling capacity which is a measure of the volume that a predetermined weight of fibre occupies as it absorbs water within its matrix under known conditions (Guillon and Champ, 2000). The primary chemical structure, particle size and the hydrophilic /hydrophobic balance of fibre determine its WHC. For example, the high WHC of soluble fibres increases their viscosity and also their interactions with other molecules in the gut. Fibres with a high WHC have a laxative effect as a direct consequence of their ability to form gels and hold large amounts of water.

**2.2.3 Solubility of dietary fibre**

The categorizing of dietary fibres as either soluble (e.g. pectins) or insoluble (lignin and cellulose) may not particularly help in determining their physiological effects (Blackwood, 2000). Such a distinction, however, may assist on better understanding the interactions between water and fibre in the digestive system of a pig. Solubility is mainly determined by factors such as functional groups such as sulphates and carboxyl (COOH) and glycosidic link between monosaccharides (Elleuch *et al*., 2011). These factors give a better understanding of the reason why fibre sources such as husks from different plants differ in solubility strengths, yet have the same constituent monosaccharide (Banino, 2012).

**2.2.4 Fibre viscosity**

Viscosity refers to the direct relationship between the flow of fibre matrix and the force applied to move it (Dikeman and Fahey, 2006). The molecular weight, hydrodynamic volume and conformation of a fibre determine its viscosity. Generally, fibres with high molecular weights, mostly water soluble fibres, have high viscosities. At high inclusion levels, soluble fibres significantly increase the viscosity of the intestinal contents, reducing the rate of nutrient absorption and gastric emptying in the small intestines. This consequently lowers the nutrient value of the feed (Guillon and Champ, 2000; De Leeuw *et al.*, 2008).

**2.3 Need for using high fibre ingredients in pig diets**

Maize and soybean are the main energy and nutrient providing ingredients in pig and poultry diets across the world (Lesson, 2012). However in most developing countries there is more need for the use of maize and soya bean for human consumption than for feeding livestock, the high demand for these feed resources has also elevated the cost per unit ton of these grains over the years (Steinfeld and Opio, 2010). With elevated grain crop costs, agro-industrial by-products and forages are considered as alternatives due to their availability and affordability (Len *et al.*, 2009). It is widely accepted that cereals and their by-products have a potential to be used as alternatives to maize and soya bean meals, however the argument is that the demand for feed in the pig and poultry industry is too large for these alternative ingredients to sufficiently meet the demand (Lesson, 2012). Considering that most of the countries that have more need for maize and soya bean for human consumption are more populated with small scale farmers compared to commercial farmers (Steinfeld and Opio, 2010), the prospect of using cereals such as wheat and their by-products for animal feed is a worthy enough opportunity to explore.

Most Asian countries have successfully used vegetable foods and agro-industry by-products, such as rice bran, sweet potato vines, tofu residue, water spinach, cassava leaves, cassava residue and brewer's grain as alternative feed resources for pigs (Len, 2008). To efficiently utilise high fibre agro-industrial by product ingredients in pig diets, it is imperative to better understand their physicochemical properties and how these properties may influence nutrient availability when formulating diets. Table 2.2 shows the physicochemical properties of the commonly used agro-industrial by products in pig diets.

Regardless of the limitations, inclusion of dietary fibre in growing pigs has numerous benefits that need to be exploited.

## 2.4 Functional benefits of fibre in weanling diets

The post-weaning period is one of the most critical stages in the pig production system, factors such as the environmental surroundings, social behaviour and diet composition often induce stress related problems such high mortality and poor growth (Molist *et al*., 2014). Immature immune and digestive system of pigs at the post weaning stage are the core contributors to the commonly observed cases of poor feed digestion, stunted growth, intestinal stasis and in most cases high risk of post-weaning diarrhoea (PWD) (Lallès *et al*., 2007). Dietary approaches including the use of highly digestible ingredients and antibiotic growth promoters (AGP) in post weaning diets were observed to minimize cases of anorexia, improve gut health and overall performance (Mateos *et al*., 2006). However in some cases, these approaches have had no contribution to improving growth performance during the post weaning period (Berrocoso *et al*., 2013). The inclusion of high fibre ingredients in diets of weaned pigs has shown improved gut functioning and reduced incidences of diarrhoea and poor performance (Molist *et al*., 2011; Gerritsen *et al*., 2012).

**Table 2.2** Chemical compositions and bulk properties of common fibrous ingredients

| Components | GN | LH | MC | MS | RB | SH | GH | PU |
|---|---|---|---|---|---|---|---|---|
| Dry matter (DM) (g/kg) | 882 | 811 | 948 | 947 | 810 | 941 | 940 | 896 |
| Gross energy (MJ/kg DM) | 22.9 | 17.7 | 17.8 | 16.8 | 19.9 | 19.7 | 17.4 | 17.3 |
| Crude protein (g/kg DM) | 117 | 189 | 52.2 | 53.4 | 190 | 59.5 | 60.2 | 70 |
| Ether extract (g/kg DM) | 21.3 | 12.2 | 7.5 | 5.1 | 19.9 | 63.9 | 15.9 | 24 |
| Ash (g/kg DM) | 27.9 | 86.6 | 40.8 | 61.5 | 72.5 | 33.1 | 70.8 | 69 |
| **Bulk characteristics** | | | | | | | | |
| Crude fibre (g/kg DM) | 236 | 287 | 168 | 320 | 156.1 | 408 | 213 | 131 |
| NDF (g/kg DM) | 775 | 398 | 873 | 724 | 378 | 558 | 749 | 211 |
| ADF (g/kg DM) | 654 | 386 | 501 | 482 | 184 | 279 | 348 | 154 |
| Bulk density (g DM/ml) | 0.9 | 1.4 | 1.2 | 1 | 1.3 | 0.7 | 1.3 | 0.32 |
| WHC (g water/g DM) | 6.8 | 12.1 | 7.8 | 18.3 | 5.9 | 6.8 | 14 | 9.95 |

GN = groundnut haulms; LC = Lucerne hay; MC = maize cob; MS = maize stover; RB = rice bran; SH = sunflower husks; GH = grass hay; PU = dried citrus pulp. NDF = neutral detergent fibre; ADF = acid detergent fibre; WHC = water holding capacity.

Source: Ndou (2012).

**2.4.1 Gut health and functioning**

Maintenance of gut health is essential, this is highly influenced by the interactions between the diet, the gut microflora and the mucosa (the mucus overlying the epithelium and digestive epithelium), and these interactions are highly complex and should exist in a subtle balance (Montagne *et al*., 2003). There is increased interest in the use of fibre to enhance gut health due to its recognised positive influence gut flora balance and gut functioning in pigs (Lindberg *et al*, 2014). Post-weaning diarrhoea (PWD) a is a very common health related problem among pigs during the first 4 weeks after weaning, at this stage the digestive and immune system of the pigs is still developing hence making the pigs more susceptible to bacterial infection (Montagne *et al*., 2003).

Dietary fibre can induce changes in the gut flora populations by providing substrate to cellulolytic bacteria that lower the pH of the gut as they ferment the fibre. The low pH suppresses the growth of pathogenic organisms such *Escherichia coli* and *Salmonella* spp. and promotes the growth of advantageous organisms such as *Lactobacillus* and *Bifidobacteria* spp., such changes may help reduce PWD incidences in pigs (Montagne *et al*., 2003). Fibre ingredients high in soluble NSP content increase digesta viscosity and promote the proliferation of *E. coli* in the small intestine, this is mainly because soluble NSP provide less substrate for hindgut fermentation hence promoting the proliferation of pathogenic bacteria making pigs more prone to bacterial infection (Kim *et al*., 2012). Fonseca *et al*. (2012) observed that both the type and level of fibre included in the diet influence its effect on the health of the pigs. They found that the inclusion of insoluble fibre at a low inclusion level (15 g cellulose/ kg feed) reduced the incidence of PWD by 2 % compared to when pigs were given the cereal based diet.

An 11 % increase in the incidence of PWD was also reported in that pigs were fed on a diet with a higher inclusion of soluble fibre (30 g soy bean hulls/ kg feed) compared to the control diet (Fonseca *et al*., 2012). A positive relationship between the inclusion of ingredients high in fermentable carbohydrates, particularly soluble fibre, and the incidence of PWD was also reported. Hopwood *et al*. (2004) also observed an increase in *E. coli* colony counts from 0.98 log10 viable cfu/g mucosal scraping when fed a rice-based diet, to 4.14 $\log_{10}$ viable cfu/g mucosal scraping on the pigs fed a diet with 50% inclusion of pearl barley which is a highly fermentable fibre source ingredient. It can be concluded that the beneficial effects of DF in growing pigs depend on the nature and inclusion level of the particular fibre source used. Fibre sources high in insoluble NSP is more effective in reducing the incidence of PWD and improving overall development of the gastrointestinal tract (GIT) in pigs during the PW period.

Insoluble dietary fibre also influences epithelial cells of the intestinal lining to secrete mucins (Montagne *et al*., 2003). Mucins are large, heavily glycosylated, extracellular proteins that establish a selective molecular barrier at the epithelial surface (Hollingsworth and Swanson, 2004). They enhance the functioning of the mucus lining, which protects against foreign organism invasion, chemical and physical injury to the epithelium and in some cases may reduce the incidence and severity of ulcers (Montagne *et al*., 2003). Fibrous diets reduce the occurrence of gastric ulcers in pigs, Mason *et al*. (2013) reported an overall decrease in the follicular gastritis and its severity when pigs were fed on diets containing 150 to 350 g/kg maize silage compared to those fed a cereal based diet. The reduction in the occurrence and severity of gastric ulceration is a desired benefit considering that gastric ulcers can contribute up to 50 % of mortality losses during the mid-growth phase in piggeries (Main *et al*., 2012).

Fibre sources, especially those high in soluble fibre components may be used to improve gut health and functioning in post weaning diets.

### 2.4.2 Protein digestibility

The majority of the ingredients used for pig diets in all the growth phases are generally high in dietary crude protein (CP), most of these ingredients however often contain anti nutritional factors that may compromise digestive functioning in young pigs (Bindelle *et al*., 2007). Due to their limited digestive capacity, excess dietary CP can be detrimental to pigs during the post weaning phase, the excess dietary CP may lead to the formation of toxic metabolites from the accumulation of non-digestible protein in the pigs GIT. Consequently this may promote the occurrence of PWD and inflammation of the intestinal wall (McGarr *et al*., 2005; Pieper *et al*., 2012). Inclusion of fibre in weanling diets prevents health implications associated with high CP diets during post weaning (Nyachoti *et al*., 2006).

Fibre is identified as a nutrient diluting agent in diets, hence to ensure that the included fibre is more beneficial than it is detrimental, it is essential to ensure that the fibre inclusion levels are not too high as this may result in excessive reduction in dietary CP levels. Excessively low dietary CP may result in inadequate supply of essential amino acids such as isoleucine, which may significantly reduce production performance in pigs (Nyachoti *et al*., 2006; Hermes *et al*., 2009). Prohászka and Baron (1980) reported that although low CP (130 g CP/kg) diets may reduce the proliferation of haemolytic *E. coli* counts in the small intestines in pigs, growth performance is significantly reduced when compared to pigs given a high CP (210 g CP/kg) diet. Similar observations were made by Bikker *et al*. (2006), they observed a negative effect on the growth performance when pigs were given diets with high DF (134 g fermentable carbohydrate/kg feed) and excessively low CP levels (150 g CP /kg).

The interaction between DF and CP levels in pig diets was quite evident. Hermes *et al.* (2009) reported that fibre inclusion increased the incidence of PWD when pigs were fed a diet containing 160 g CP/kg of feed. The opposite effect of fibre inclusion was observed when pigs were given a diet containing 200 g CP/kg of feed. This information suggests that fibre inclusion in weanling diets can improve the efficiency of post weaning pigs in utilising high CP diets and reduce the negative impacts of high CP diets in post weaning pigs. The effectiveness of this approach is however dependant on finding a balance between the CP and DF levels included in the diets.

### 2.4.3 Pig performance

Post weaning anorexia is one of the most commonly observed problems during the post weaning period, mainly due to drastic reductions in feed intake (FI) when pigs are fed cereal based diets during the early post weaning phase. The use of insoluble fibre sources such as wheat straw and oat hulls in a cereal based diet at inclusion levels of 50 and 100 g/kg, respectively, has been shown to increase FI during the first 14 days post weaning (Wenk, 2001; Gerritsen *et al.*, 2012). It is of high importance to consider the physicochemical properties of the fibre source and the basal diet used when including high fibre ingredients in pig diets.

Mateos *et al.* (2006) used a maize based diet with 64 g NDF/kg of feed and rice based diet with 34.3g NDF/kg of feed, using oat hulls as a fibre source, both diets were diluted with 20 and 40 g per kg of feed. At the same fibre inclusion levels, the pigs receiving the rice based diet showed increased FI and average daily body weight gain (ADG). The opposite was observed with the pigs receiving the maize based diet. They suggested that this was probably due to the neutral detergent fibre (NDF) levels of the diets since even at the highest fibre

inclusion level, the rice based diet had lower (60 g/kg) NDF compared to the maize based diet prior to the addition of the fibre (64 g/kg). Acid detergent fibre (ADF) is as important as NDF when using fibrous feed ingredients in pig diets. It is a good indicator of digestibility, hence energy intake, making it one of the most important measurement to consider when evaluating the effects of fibre inclusion on pig performance. Bakare *et al.* (2013) observed that although ADFI may increase with increment levels of dietary ADF, ADG was negatively related to dietary ADF concentration (Figure 2.1). Fibre inclusion is negatively related to nutrient density, hence at higher fibre inclusion levels, feed intake may increase as the pig attempts to consume enough feed to meet its daily nutrient requirement. However with high ingestion of bulky feed, the gut capacity of the pig is filled before it can consume enough feed to meet its daily requirement the observed decreased ADG as a result of increased ADF levels in the feed

### 2.4.4 Pig behaviour

Observing the feeding behaviour of pigs in relation to the inclusion of fibre in their diets is a good indicator to how the pigs adapt to the fibrous diets. For example, the increase in time spent eating and number of visitations to the feed source has been related to increase in feed intake with increment levels of DF in diets fed to pigs (Bakare *et al.*, 2013). The need to consume more feed is due to nutrient dilution by fibre inclusion; hence the animal will attempt to eat as much as it can to meet its maintenance requirements (Whittermore *et al.*, 2001).
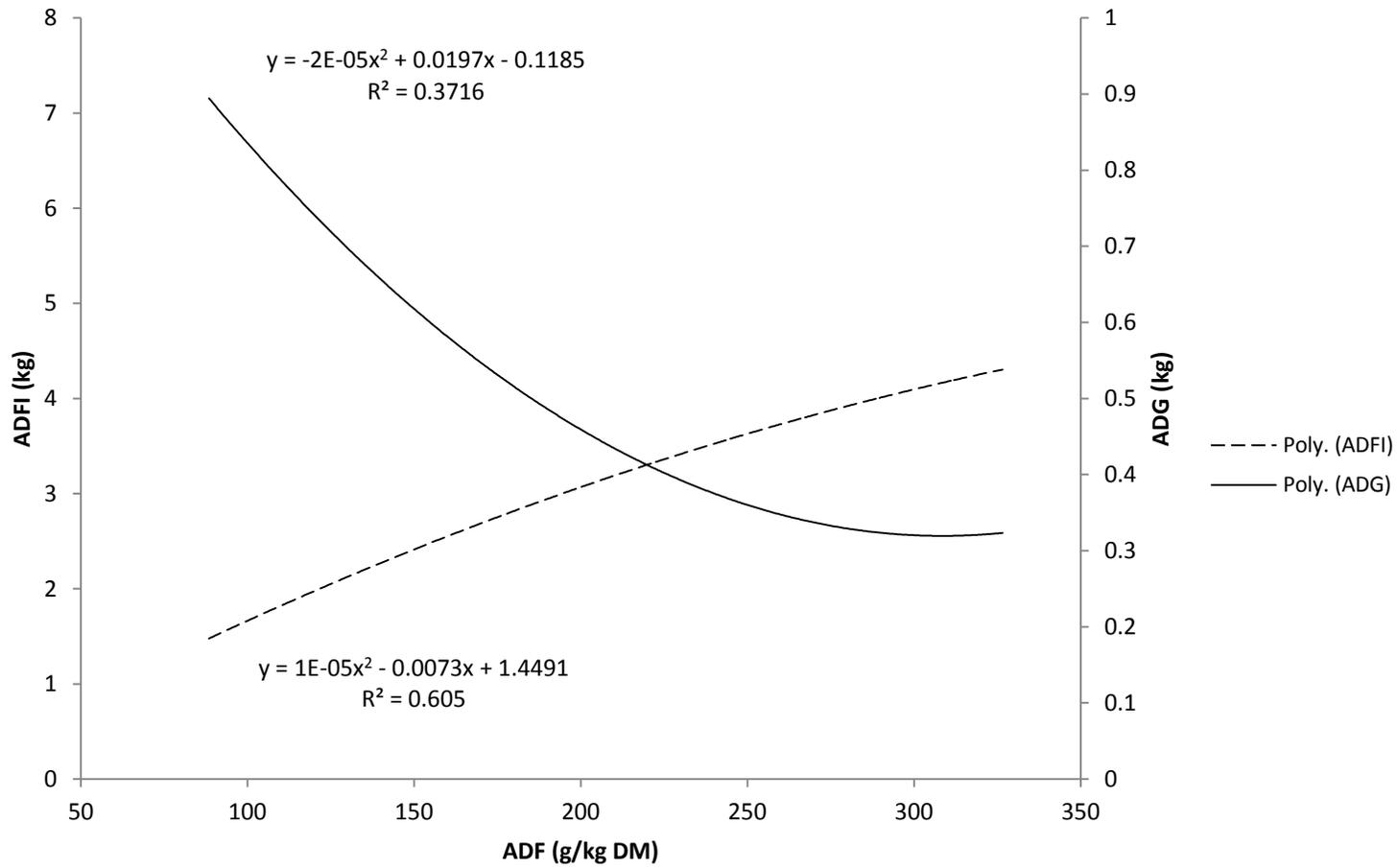
**Figure 2.1** Influence of increment acid detergent fibre (ADF) concentration on average daily feed intake (ADFI) and average daily gain (ADG)

Source: Bakare *et al*. (2013)

Gut capacity may influence how pigs can be able to utilise fibrous feeds (Ndou *et al*., 2013), since younger pigs have a lower gut capacity, fibre inclusion may result in growth requirements not being met as the piglets may reach their gut capacity before they have consumed enough nutrients for growth. Pigs also exhibit stereotypic behaviours such as lying down, sitting or standing often, these behaviours are normally brought about by some level of deficiency on the environmental or dietary factors an animal is exposed to (Mason, 1991). Fibre inclusion in pig diets also reduces stereotypic behaviours in pigs and the time spent exhibiting these behaviours (Danielsen and Vestergaard, 2001; Robert *et al*., 2002). When pigs spend more time eating, they have less time to exhibit stereotypic behaviours. On the other hand, some postural behaviours are crucial for pigs, more especially for young pigs as such behaviours including lying down, standing and sitting give the pigs a certain level of rest that may help store energy for growth purposes (Ekkel *et al*., 2003). Similar to stereotypic behaviour, postural behaviours in pigs are highly influenced by the environment surrounding them and the diet they are given.

Since fibre inclusion influences behaviours related to feed consumption, it is important to explore the interactions that may exist between fibre level and water consumption patterns.

## 2.5 Fibre and water interactions

Fibre is characterised by its bulk properties which are mainly water holding capacity, water binding capacity, viscosity and swelling capacity, all of which determine how a particular fibre source ingredient influences pig performance. The functional characteristics of these properties are highly influenced by their interaction with water. Water can influence the physiological functioning of dietary fibre in different ways highly determined by the water binding strength and availability of the polysaccharide composition in the dietary fibre

(Chaplin, 2003). Water bound to fibre can either be 'free' or 'trapped', trapped water having a lower entropy (freedom of movement) compared to free water (Chaplin, 2003). With the increase in particle size of dietary fibre, the volume of trapped water increases (Thebaudin *et al*., 1997), this is particularly important to consider in animal feeding as it may help explain water consumption of animals given high fibre diets. Apart from the known directly proportional relationship between feed and water intake (Jackson, 2007), the bulkiness of the fibrous material may have an effect on water intake due to its water binding properties. These observed relationships are an indication that fibre inclusion influences water consumption in pigs, hence indicates a need for further investigation on the actual effect of fibre inclusion on water use.

## 2.6 Alternative water resources

Water is a critical resource in animal production; however little research has been done on optimizing its use in pigs (Nyachoti and Kiarie, 2010). Rapid urbanization and industrialization has led to increased demand for fresh water (Eriksson *et al*., 2002). The high demand for water has resulted in approximately 40 % of the population in most countries experiencing water scarcity over the past decade in most countries (Wallace and Austin, 2004). The competition for fresh water resources for human use and agricultural purposes is increasingly limiting access to good quality water for pig production (Wallace and Austin, 2004). The limited availability of fresh water resources is likely to threaten growth and development in the pig industry (Nyachoti and Kiarie, 2010).

Re-use of waste/grey water from urban areas and various industries has become a subject of interest as a possible sustainable method for the mitigation of water scarcity. Environmental conservation and protection agencies have however successfully developed stricter regulatory

prohibitions for qualities of water discharged from various industries. These conditions have elevated the cost of water treatment and more over increased the difficulty of meeting such standards (Sarkar *et al*., 2005). It is therefore, important to assess the available non-potable water sources and their quality parameters before considering them for reuse in pigs.

There is a number of waste water types, otherwise referred to as non-potable water, waste water is water declared unfit for human use but can be used for other purposes. Rain water and grey water are the most practical non-potable water types that can be accessed by pig farmers as alternative fresh water sources. The ability of pigs to tolerate a wide range of water quality parameters without any drastic effects on their health and performance indices (Tofant *et al*., 2008; McLeese *et al*., 2010) makes the prospect of using non-potable water acceptable.

### 2.6.1 Rain water

Rain water is generally safe to drink. It can, however, be easily contaminated depending on how it is collected. If water runs along the soil surface prior to collection, it can easily be contaminated by pollutants such as plant and animal residue and microorganisms (e.g. bacteria). Rain water use carries some health risks depending on the degree of contamination. There are, however, some treatment measures that do not require sophisticated machinery (e.g. filtration) that can be used to reduce pollutants that may be present in the water (Ilemobade *et al*., 2009). The main challenge with rain water harvesting is the construction of proper collection and harvesting infrastructure that will eliminate or reduce the potential of rainwater contamination through pollutant contact during harvesting (Karim, 2010). If rain water is to be used for pigs, proper quality assessment should be made to ensure that the water meets the quality standards.

**2.6.2 Grey water**

Grey water is waste water from urban and household buildings excluding the proportion of water arising from toilets (Winward, 2008). The re-use of waste/grey water from various industries has become a subject of interest as a possible sustainable method for the mitigation of water scarcity. Unlike most waste water types grey water is void of highly toxic chemicals and low in microbial coliforms hence generally easier to treat. If used prior treatment it may cause health problems such as diarrhoea (Almeida *et al*., 1999). Grey water is encouraged for household purposes like washing cars and irrigating lawns, however with proper treatment; grey water can be harvested from safe grey water sources to be used in feeding livestock. The dairy industry is one of such grey water sources that may be explored. The dairy industry is one of the main water polluters within the food processing industry producing between 0.2 and 1.0 l of effluent per litre of milk processed (Sarkar *et al*., 2006).

The South African dairy industry consumes approximately 4.5 million m$^3$ of water per annum, 75 to 95 % of that water is discharged as effluent annually (Water Research Commission, 1989). Grey water from the dairy industry generally has high biochemical oxygen demand (BOD, the amount of oxygen utilised by bacteria to oxidise organic material) levels due to its high organic contamination load suitable for rapid microbial growth (Hooda *et al*., 2000). One of the biggest challenges faced by the dairy industry is effluent discharge, due to the high BOD value of dairy industry effluent; most dairy factories rely on municipal sewage treatment facilities to dispose their effluent without threatening the environment.

Due to the high costs involved in effluent disposal to municipal sewers, some opt for pasture irrigation as a method of effluent discharge (Strydom *et al*., 1993). Irrigating pastures runs a high risk of surface water pollution through runoff hence compromising the aquatic

ecosystem. The absence of toxic chemicals in grey water from the dairy industry and presence of dissolvable organic components gives the prospect of the reusability of this water in animal production (Sarkar *et al*., 2006). With proper treatment, dairy effluent can be used as drinking water for pigs.

## 2.7 Water quality considerations for waste water reuse for pig consumption

There is need to identify and understand the possible effects of water quality issues associated with the use of alternative water resources on pig performance and wellbeing. This will help develop more sustainable methods of water supply for the pig industry using the identified fresh water alternatives. The quality of drinking water for pigs can affect feed intake, growth rate, feed conversion efficiency, mortality and profitability (Stull *et al*., 1999). Typical measures considered in water quality evaluation include organoleptic properties (taste and odour), chemical and physical properties, microbial contamination, organic compounds composition and the concentration of mineral elements (Patience, 2004). Chemical (i.e. mineral contamination, pH and hardiness) and microbial properties are the two major measures of water quality to consider when evaluating water quality standards for pigs (Veenhuizen, 1993).

## 2.7.1 Mineral contamination

A method widely used to estimate mineral contamination of water is the determination of total dissolved solids (TDS, also referred to as salinity) which quantifies all dissolvable salts in water (Kober, 1993). The TDS value is measured as the amount of dry matter remaining after evaporating a water sample at 100ºC (Patience, 2004). Generally most of the water sources available for pigs are saline; hence there are recommendations toward the use of saline waters for pig production (Table 2.3).

**Table 2.3** Guidelines for the use of saline water for pigs

| Level | Effect | Recommendation |
|---|---|---|
| 0 - 1000 | No significant adverse effects | Immediate access allowed without any previous exposure to saline waters. |
| 1000 - 2000 | Possible temporal initial reluctance to drink. No adverse effects to be expected. Reluctance to drink may lead to a decline in water intake and production. However, adaptation may be observed within a week. | Immediate access allowed preferably with previous exposure to saline waters at approximately 50 % TDS levels |
| 2000 - 3000 | Careful monitoring of water provision especially for intensive systems. Expected decline in water intake and production. Adaptation within a week | Immediate access allowed only with previous exposure to saline waters approximately at 50% TDS |
| 3000 - 4000 | Significant decline in production. Recovery dependent on exposure to salinity level and provision of lower saline water. Tolerance species dependent | Immediate access allowed only with previous exposure to saline waters approximately at 50% TDS |
| > 4000 | Significant decline in production. May have adverse effect on production and possible health effects. | NO access allowed |

Source: South African water quality guidelines **(1996)**

For drinking water to be considered safe, it should contain TDS levels below 1000 ppm. Levels above 7000 ppm are, however, unsafe and more likely to result is mild cases of diarrhoea (Kober, 1993; NRC, 1998). Total dissolved salts, however, do not identify the specific amounts and types of dissolvable salts making up the TDS in the water sample. For example, a high TDS level containing high concentrations of calcium and magnesium may have less effect on the health and performance of a pig compared to a different sample of the same TDS level, but containing higher above.

McLeese *et al*. (1992) reported increased feed conversion efficiency for weanling pigs fed on water at 217 ppm compared those fed on water with 4390 ppm TDS. Other reports show similar effects (up to 6000 ppm) (Patience, 2004). To address the problem of mineral contamination, it is more appropriate to identify the specific types of minerals present in the water sample and their specific amounts. Due to higher costs associated with determining specific mineral concentrations, unless otherwise there is a pre-suspected mineral contaminant present in the water that may affect productivity, it is more practical to determine and correct for TDS levels and in most cases can be effective. It is also important to take note that the geological origin of the water source is a major contributor to the type and degree of mineral contamination in the water (Herczeg *et al*., 2001). Understanding the local geological characters of the water source can hence assist in identifying potential mineral contaminants, more especially for ground water obtained from a particular area. Most water resources available to livestock are generally high in mineral levels. The main mineral contaminants of interest to pig producers are sulphates, nitrates and nitrites (NRC, 1998). The biggest concern about high concentrations of sulphates is the occurrence of mild diarrhoea in pigs (Maenz *et al*., 1994).

Water resources available to pigs generally have sulphates levels lower than 3000 ppm which has minimal if any effect on pig performance (Veenhuizen *et al.*, 1992; Patience *et al.*, 2004). Other studies have however reported that sulphate levels as low as 750 ppm can affect the performance of younger pigs at the early post weaning stage (Veenhuizen *et al.*, 1992). Susceptibility of weanling pigs to sulphate salts should particularly be carefully considered as it can result in diarrhoea of an osmotic nature which limits future pig performance. Nitrate and nitrite contamination is also of concern in pig production. The main source of nitrate and nitrite water contamination is leaching (from soils) and surface water run-off pre exposed to high nitrogen levels from various sources such as organic waste, nitrogen fertilisers and silage juices (WHO, 1985). High nitrite levels are highly toxic to pigs and can, in some cases, indicate the possibility of microbial contamination (Emerick, 1974). Nitrate poisoning reduces feed intake; poor growth and feed conversion efficiency in growing pigs, and can increase abortions among sows (Meek, 1996).

**2.7.2 pH**

For optimal pig performance, it is recommended to maintain water pH levels between 6.5 and 8.5 (NRC, 1998). Low pH levels may result in reduced average daily gain and average daily feed intake (Walsh *et al.*, 2007). At pH levels above 8.5, the water is less palatable, the water becomes slippery and this may make it less acceptable to animals (Kobber, 1993). Feeding practices such as the use of acidifiers as additives and feeding of acid liquid whey supplements via the water may reduce water pH. In cases where such additives are being used, a routine analysis of the water should be conducted (Nyachoti and Kiarie, 2010).

Below 6.5, pH levels may affect the efficiency of medication via drinking water as it may result in the precipitation of the administered medication.

### 2.7.3 Hardiness

Water hardness measures the sum of divalent cations in the water, particularly calcium and magnesium salts. It is expressed as calcium carbonate ($CaCO_3$) (Nyachoti and Kiarie, 2010). Hard water ($CaCO_3$ levels >300 ppm) with excess calcium may limit phosphorus utilisation, whereas soft water ($CaCO_3$ levels 60 ppm) has no known negative effects on pig performance. Phosphorous supplementation is advised when pigs are subjected to hard water (Kober 1993).

### 2.7.4 Microbiological aspects of water

Pathogens (disease causing organisms) most commonly transmitted through drinking water are predominantly of faecal origin, hence often referred to as enteric pathogens (Hunter *et al*., 2002). The main types of bacteria that reduce water quality include Cryptosporidium, *E. coli*, *Salmonella* and *Leptospira* (NRC 1998; Thacker, 2001). The degree of bacterial water pollution is estimated by measuring the level of coliforms, which represents a group of generally pathogenic bacteria (Meek, 1996). A count of more than 5000 coliforms per 100 ml is used as a guideline for maximum levels in water for pigs (NRC 1998), the degree to which the water quality level can impact pig performance, is however highly dependent on the virulence of the specific pathogens present in the water (Meek 1996). Chlorination is the most widely accepted and practiced method of microbial contaminated water treatment, the quality of the water determines the level of chlorine required to effectively disinfect the water (Patience *et al*., 1995).

**2.8 Summary**

The use of high fibre ingredients in pig diets has been recognised to influence water intake in pigs. Given the current water scarcity threat in most parts of the world, the need to explore alternative fresh water sources and their effects on pig performance has become more apparent. A review has hence been done on the effects of identified common fibre sources and possible alternative fresh water sources on the feed intake, water consumption and growth performance in growing pigs. The objective of the current study was to determine interactions between fibre inclusion and water source on the performance and water consumption of growing pigs. The realization that the simultaneous use of high fibre alternative feed resources and low quality fresh water alternatives for pig production is inevitable presents the need to better understand the interactions affecting pig performance that may exist between these resources.

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# CHAPTER 3: Interaction between fibre inclusion and water source on growth performance and water consumption in growing pigs

**Abstract**

With the growing interest in the incorporation of high fibre ingredients in post weaning diets and the recent fresh water scarcity threat, the current study was conducted to investigate the interaction between fibre inclusion and water source on water consumption and growth performance of pigs at the early post weaning phase. A total of 48 male pigs, with an initial average body weight of $11.83 \pm 1.33$ kg were used in a $2 \times 2$ factorial arrangement. Sunflower husks were used to dilute a basal diet at 160 g/kg DM inclusion to obtain two fibre inclusion levels (0 and 160 g/kg fibre inclusion). The pigs drank either reservoir water (fresh water source) or dairy effluent. Fibre inclusion significantly reduced average daily gain (ADG) and increased gain to feed (GF) ratio. There was an interaction between fibre inclusion and water source on scaled feed intake (SFI). Dairy effluent reduced SFI of the pigs on the high fibre diet, however did not affect SFI when pigs were given the low fibre diet. Fibre inclusion helps pigs adapt better to acidic water with high total dissolved solids levels. It can be concluded that dairy effluent can be successfully used as an alternative water source for feeding pigs.

**Key words**: *scaled feed intake; total dissolved solids; sunflower husks; dairy effluent.*

**3.1 Introduction**

Current interests are focused on the incorporation of fibrous ingredients in maize-soybean-based diets to improve gut health and functioning in growing pigs. Although the effects of fibre inclusion on pig performance remain controversial, fibre induces beneficial gut microbiota modifications that stimulate gut development in pigs, which may contribute to improved performance and well-being (Gerritsen *et al*., 2012; Molist *et al*., 2014). The effect of dietary fibre on gut functioning in pigs has been mainly attributed to the bulk properties of the particular fibre source used (Canibe and Bach Knudsen, 2002; Ndou *et al*., 2013). The extent to which dietary fibre influences nutrient digestibility and absorption is determined by how its bulk properties (such as water holding capacity, solubility and viscosity) interact with the available water molecules in the digestive tract of the pig (Blackwood *et al*., 2000).

Most agro industrial by products, such as sunflower husks, are high in insoluble fibre. Insoluble fibre reduces digesta retention time (Brooks *et al*., 1990), limiting the amount of time for water reabsorption in the large intestines. High fibre inclusion, therefore, potentially leads to higher water requirements with increased dietary fibre in pig diets. Bakare *et al.* (2013) observed an increase in the number of visitations to the water source as pigs were given fibrous diets. Water is key in digestion, absorption and metabolic processes, growing pigs require between 5 to 7 l of water per day (Nyachoti and Kiarie, 2010). With the current increased competition for fresh water resources for household consumption and agricultural purposes, access to fresh water for production of pigs and other livestock is threatened (Wallace and Austin, 2004). Water recycling, therefore, needs to be explored. Most waste water bodies from industrial areas are toxic and

require extensive treatment procedures. The majority of effluent from dairy processing is, however, less polluted, depending on the point of collection (Sarkar *et al.*, 2006).

The dairy industry is one of the major contributors to waste water generation (Hooda *et al.*, 2000). In South Africa, about nine billion litres of water is used in milk processing annually, between 75 to 95 % of that water is discharged as effluent (Water Research Commission, 1989). Pigs have a high tolerance of a variety of water quality standards, allowing them to maintain productivity despite exposure to low quality water (McLeese *et al.*, 1992). There have been a number of reports on how water quality and fibre inclusion affect the productivity of pigs. There is, however, limited information on how pigs respond to high fibre diets relative to the quality of water. The objective of the study was to determine the interaction of fibre inclusion and water source on growth performance and water consumption in growing pigs. It was hypothesized that there exists an interaction between water source and fibre inclusion on growth performance and water consumption in growing pigs**.**

## 3.2 Materials and Methods

### 3.2.1 Ethical considerations

The trial was conducted according to the conduct by the Certification of Authorization to Experiment on Living Animals provided by the University of KwaZulu-Natal Animal Ethics Committee (Reference Number: 083/14/Animal).

**3.2.2 Study site**

The study was conducted at Ukulinga Research Farm, University of KwaZulu-Natal, Pietermaritzburg, situated in a subtropical hinterland, located at 30° 24`S, 29° 24` E and is approximately 700 m above sea level. The climate is characterized by an annual rainfall of 735 mm, mean annual maximum and minimum temperatures are 25.7°C and 8.9°C, respectively. Light to moderate frost occurs in winter.

**3.2.3 Pigs and housing**

Forty eight, 5-week old pigs with an average body weight $11.8 \pm 1.33$ kg were purchased from a local farm. A pig house with single heating, lighting and ventilation system, containing 48 mounted individual cages ($1.5 \times 1$ m) was used to house the pigs. The cages were arranged in two rows, with 36 cages on each side. To determine water consumption, 25 l buckets were fitted to each pen and connected to the pressure controlled nipple drinkers. A HOBO TEMPERATURE, RH©, 1996 ONSET logger was used to measure the ambient temperature and relative humidity. Temperature within the house was maintained between 22 and 25 $^{0}$C.

**3.2.4 Treatments and experimental design**

A high quality commercial grower feed sourced from Meadow Feeds Company (Pty) Ltd., Pietermaritzburg, was used as the basal feed. The ingredient composition of the basal diet is shown in Table 3.1. The use of sunflower husks (SH) as the source of fibre was based on availability and abundance and its reduced effect on feed intake. The sunflower husks were obtained from Willowton Oil & Cake Mills in Pietermaritzburg.

**Table 3.1** Ingredient composition of basal diet

| Raw material | Inclusion (%) |
|---|---|
| White maize | 65.32 |
| Wheat middlings | 4 |
| Soya Hi Pro (46%+) | 26.45 |
| Sunflower oil | 0.57 |
| Limestone powder | 1.08 |
| Monocalcium phosphate (KK) | 0.89 |
| Salt fine | 0.58 |
| Methionine DL powder | 0.13 |
| Tryptophan | 0.05 |
| Threonine | 0.13 |
| Biolysine 70 % | 0.37 |
| Sucram | 0.01 |
| Choline chloride liquid 75 % | 0.03 |
| Vit/Min weaner premix | 0.35 |
| Zinc Bacitracin 15 % | 0.03 |

The sunflower husks were included in a commercial diet at 160 g/kg DM, growing pigs have been observed to cope with fibre levels up to 160 g/kg with no effect on health and performance (Bakare *et al*., 2013; Ndou *et al*., 2013). The two water sources used were the reservoir water used for feeding pigs at Ukulinga Research farm and dairy effluent was obtained from a local dairy processing plant. The effluent used was the water disposed from the first wash of the tankers after emptying the milk (involving no use of chemicals).

The pigs were allocated to the treatments in a $2 \times 2$ factorial arrangement. The four treatment combinations were the low fibre diet (0 g sunflower husk/kg feed DM) with reservoir (LR), low fibre diet and dairy effluent (LD), high fibre diet (160 g sunflower husk/kg feed DM) and reservoir water (HR) and the high fibre diet with dairy effluent (HD). The chemical compositions for the dietary and water treatments are shown in Table 3.2 and Table 3.3, respectively.

### 3.2.5 Laboratory analyses

The chemical composition analysis of the experimental diets was performed at the Discipline of Animal and Poultry Science Laboratory at the University of KwaZulu-Natal, Pietermaritzburg. To determine dry matter (DM) content, samples were oven-dried at $65^{o}C$ for 48 hours. The dried samples were then subjected to bomb calorimetry to determine gross energy (GE). Nitrogen (N) content of the DM was determined using the Dumas Combustion method using a LecoTruspec Nitrogen Analyser, St Joseph MI, USA, according to 990.03 of AOAC (1990). Crude protein (CP) content was then calculated as N x 6.25. Ether extract (EE) was determined using Soxhlet apparatus according to method 920.39 of AOAC (1990).

**Table 3.2** Chemical composition of experimental diets

| Component (g/kg) | Basal diet | Sunflower husks | Experimental diet |
|---|---|---|---|
| Dry matter | 989 | 941 | 989 |
| Gross energy | 18.1 | 19.7 | 18.2 |
| Crude protein | 181 | 59.5 | 178 |
| Ether extracts | 53 | 63.9 | 55.4 |
| Ash | 61 | 33.1 | 53.8 |
| Crude fibre | 26 | 408 | 129 |
| Neutral detergent fibre | 192 | 558 | 318 |
| Acid detergent fibre | 88 | 279 | 178 |
| Bulk density  (g DM/ml) | 1.45 | 0.8 | 1.69 |
| WHC  (g water/g DM) | 3.76 | 6.8 | 4.62 |

WHC: water holding capacity

**Table 3.3** Water parameters of dairy effluent and reservoir water

| Determinant | Units | Reservoir water | Dairy effluent |
|---|---|---|---|
| Chemical oxygen demand | mg $O_2$/l | <20 | 5488 |
| Nitrate/nitrite concentration | mg N/l | 0.56 | 3.07 |
| pH at $25^0$C | pH units | 7.1 | 4.8 |
| Sulphate concentration | mg $SO_4$/l | 2.56 | 13.46 |
| Suspended solids at $150^0$C | mg/l | <10 | 2042 |
| Total coliforms | colonies/100 ml | 0 | 0 |
| Total dissolved solids at $180^0$C | mg/l | 119 | 1681 |
| Total solids at $150^0$C | mg/l | 42 | 4087 |

Neutral detergent fibre (NDF) and acid detergent fibre (ADF) contents were determined using ANKOM Fibre Analyser (Ankom, Macedon, NY, USA), according to Van Soest (1991). The ash content was determined after incineration of the sample at 550°C for 4 h according to method 990.05 (AOAC, 1990). The quality of the two water treatments was determined by Talbot & Talbot Laboratories Pty Ltd, Pietermaritzburg, South Africa. The chemical oxygen demand (COD) was analyzed using a Closed Reflux Titrimetric Method from Burns and Marshall (1965). A standard operating procedure by Degen and Nussberger (1956) was used to analyze suspended solids. Nitrate/nitrite concentration was however, analyzed using Lachat method from Lachat Instruments (1998). The calibration method was used to measure pH (Meade, 2005). The sulphate was analyzed using the turbidimetric method by Rossum and Villarruz, (1961). The Sokoloff (1933) standard operating procedure was used to analyze total dissolved solids (TDS).

### 3.2.6 Pig management

On arrival at Ukulinga from the farm where they were purchased, the pigs were weighed and ear tagged for identification purposes, then randomly assigned into the pens. The pigs were provided with stress pack medication through drinking water for three days to eliminate the effects of stress due to environmental change and transportation. The pigs were given a 10-day adaptation period, during which they were given *ad libitum* access to the control diet and reservoir water. After the adaptation period, the pigs were weighed, sorted on a weight basis and assigned to the treatments in individual pens. The pigs were subjected to the experimental treatments for four weeks. Cleaning was done every day. Feed and water spillages were collected. To ensure *ad libitum* access to water, the buckets were refilled with a measured amount of water daily.

To reduce fermentation and bacterial contamination, the dairy effluent was treated with chlorine at 1.5 mg per litre of water (Department of Water and Environmental Affairs, 2014). The pigs were allowed *ad libitum* access to feed and water for the entire duration of the trial. Faecal consistency for each pig was monitored daily during the trial to identify cases of diarrhoea.

### 3.2.7 Measurements

Water intake was estimated by measuring the water in the bucket at the beginning and at the end of each week. Spill trays were placed beneath the cages under the nipple drinkers to account for spillage losses. A measured amount of water was placed in an open container in the each of the four sectioned areas of the pig house, to estimate evaporation losses. Water remaining in the containers after a 24-hour period was subtracted from the initial measured amount to determine evaporation loss. The evaporation and spillage losses were subtracted from the water allocated to each pig every week to determine water intake.

The pigs were weighed weekly throughout the trial. Feed intake was determined by weighing the feed trough at the beginning and end of each week. A plastic tray was placed under each trough to collect feed spillages. The feed spilled was sun dried, weighed and discarded daily. Weights of feed refusals and spillages were subtracted from the total weight of the feed allocated to determine feed intake for each week. To determine average daily gain (ADG), the difference between body weight at the beginning and at the end of the week was divided by seven. The difference between the weight of feed at the beginning and at the end of the week was also divided by 7 to estimate the average daily feed intake (ADFI). The same method was used to estimate average daily water intake (ADWI). To determine gain: feed ratio (GF), the ADFI was

divided by the ADG. Both the ADFI and ADWI were divided by the body weight of the animal to determine the scaled feed intake (SFI) and scaled water intake (SWI), respectively.

**3.2.8 Statistical analyses**

The PROC CAPABILITY procedure of SAS (2008) was used to check for normality of the data. The significance of the main effects and interactions on response variables were tested using the General Linear Model procedure (SAS, 2008). The model used was:

$Y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha \times \beta)_{ij} + (\alpha \times \gamma)_{ik} + (\beta \times \gamma)_{jk} + (\alpha \times \beta \times \gamma)_{ijk} + e_{ijkl}$;

Where;

$Y_{ijk}$ = response variable (ADFI, ADWI, ADG, GF, SFI, SWI);

$\mu$ = overall mean response;

$\alpha_i$ = effect of fibre inclusion level (i = 0 and 160 g/kg);

$\beta_j$ = effect of water source (j = reservoir and dairy effluent);

$\gamma_k$ = effect of week (k = 1, 2, 3, 4);

$(\alpha \times \beta)_{ij}$ = interaction between fibre inclusion level and water source;

$(\alpha \times \gamma)_{ik}$ = interaction between fibre inclusion level and week;

$(\beta \times \gamma)_{jk}$ = interaction between water source and week;

$(\alpha \times \beta \times \gamma)_{ijk}$ = interaction between fibre inclusion level, water source and week;

$e_{ijkl}$ = residual error.

Separation of the least square means was performed using the with PDIFF option (SAS, 2008).

## 3.3 Results

### 3.3.1 Levels of significance

Table 3.4 shows the levels of significance of fibre inclusion, water source and week on performance and water consumption of growing pigs. Fibre inclusion affected (P < 0.01) ADFI, ADG and FCR. Water source did not affect (P > 0.05) any of response variables. There was a fibre inclusion × water source interaction on SFI. There was also a significant fibre inclusion × water source × week interaction on SWI, ADFI and ADWI.

### 3.3.2 Effects of fibre inclusion and water source on water intake

The overall ADWI and SWI did not differ among treatments (Table 3.5). There was, however, a significant fibre inclusion × water source × week interaction on both ADWI and SWI. Figure 3.1 shows the changes in ADWI over the 4 week period. There was an increase in ADWI across all the treatments over the four week period. Differences in ADWI were observed in Weeks 3 and 4, pigs on the LR treatment had the highest (P < 0.05) ADWI compared to those on treatments LD, HD and HR, respectively. Figure 3.2 shows the changes in SWI over the study period. Pigs on the HR treatment had the highest SWI throughout the trial, the opposite was observed from the pigs on the LD treatment. The SWI of the pigs on the control treatment (LR) was the same as that of the pigs on the HD treatment throughout the trial.

**Table 3.4** Level of significance of fibre inclusion, water source, week and their interactions on growth performance and water consumption in growing pigs

| Source of variation | Response variable | | | | | |
|---|---|---|---|---|---|---|
| | ADFI | ADG | GF | ADWI | SWI | SFI |
| Fibre inclusion | NS | ** | ** | NS | NS | * |
| Water source | NS | NS | NS | NS | NS | NS |
| Week | ** | ** | ** | ** | ** | NS |
| Fibre × water source | NS | NS | NS | NS | * | * |
| Fibre × week | ** | NS | NS | ** | NS | NS |
| Water source × week | NS | ** | ** | ** | NS | NS |
| Fibre inclusion × water × week | ** | NS | NS | ** | ** | NS |

*P < 0.05; ** P < 0.01; NS: not significant (P >0.05)*

ADFI - average daily feed intake; ADG - average daily gain GF- gain to feed ratio; ADWI -average daily water intake; SWI - Scaled water intake SFI - scaled feed intake; LR: Low fibre diet (0 g/kg SH) and reservoir water; LD: Low fibre diet and dairy effluent; HR: High fibre diet (160 g/kg SH) and reservoir water; HD: High fibre diet and dairy effluent

**Table 3.5** Effects of fibre inclusion and water source on growth performance and water consumption of growing pigs

| Parameters | Treatments | | | |
|---|---|---|---|---|
| | LR | LD | HR | HD |
| ADFI | 1.4 ± 0.05 | 1.3 ± 0.05 | 1.3 ± 0.05 | 1.3 ± 0.05 |
| SFI | 53.0 ± 1.53$^a$ | 54.3 ± 1.53$^a$ | 58.1 ± 1.53$^b$ | 54.7 ± 1.53$^a$ |
| ADWI | 2.7 ± 0.17 | 2.6 ± 0.17 | 2.7 ± 0.17 | 2.4 ± 0.17 |
| SWI | 0.10 ± 0.005 | 0.09 ± 0.005 | 0.11 ± 0.005 | 0.1 ± 0.005 |
| ADG | 0.76 ± 0.04$^a$ | 0.73 ± 0.04$^a$ | 0.62± 0.04$^b$ | 0.54 ± 0.04$^c$ |
| GF | 1.9 ± 0.21$^a$ | 2.1 ± 0.21$^a$ | 2.2 ± 0.21$^b$ | 2.6 ± 0.21$^c$ |

*$P < 0.05$; ** $P < 0.01$; NS not significant ($P > 0.05$)

ADFI - average daily feed intake; ADG - average daily gain GF- gain to feed ratio; ADWI -average daily water intake; SWI - Scaled water intake SFI - scaled feed intake; LR: Low fibre diet (0 g/kg SH) and reservoir water; LD: Low fibre diet and dairy effluent; HR: High fibre diet (160 g/kg SH) and reservoir water; HD: High fibre diet and dairy effluent.
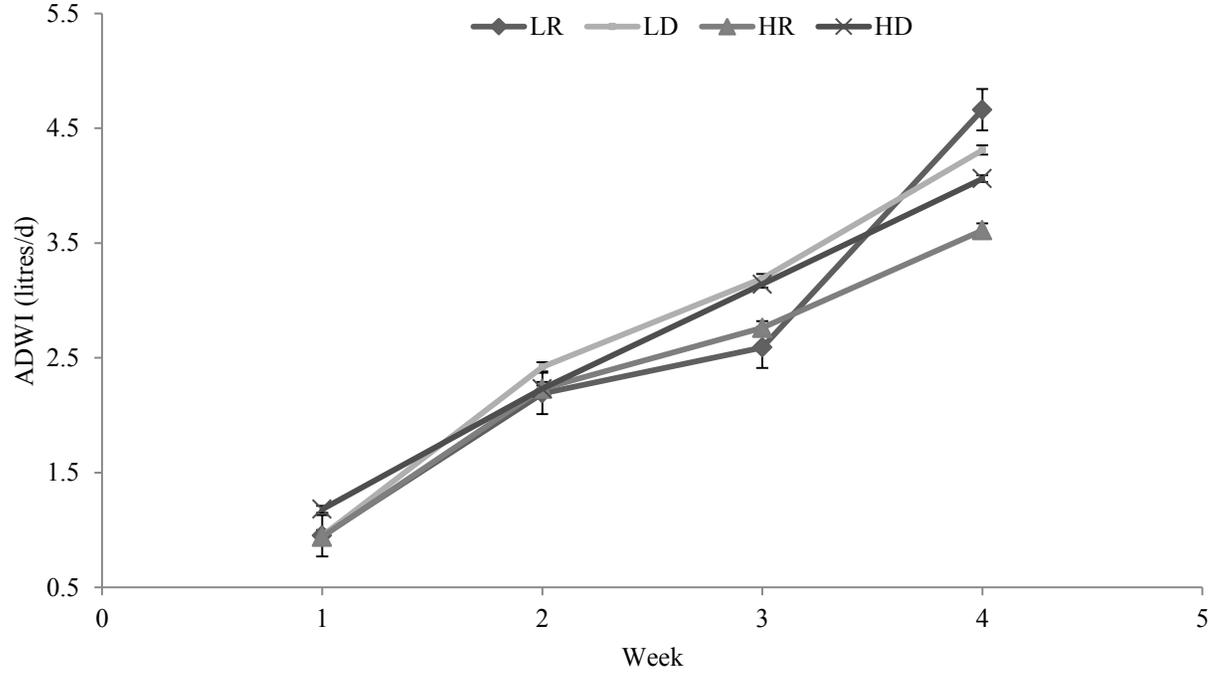
**Figure 3.1** Weekly changes in average daily water intake (ADWI) in growing pigs

LR: Low fibre diet (0 g/kg SH) and reservoir water; LD: Low fibre diet and dairy effluent; HR: High fibre diet (160 g/kg SH) and reservoir water; HD: High fibre diet and dairy effluent.
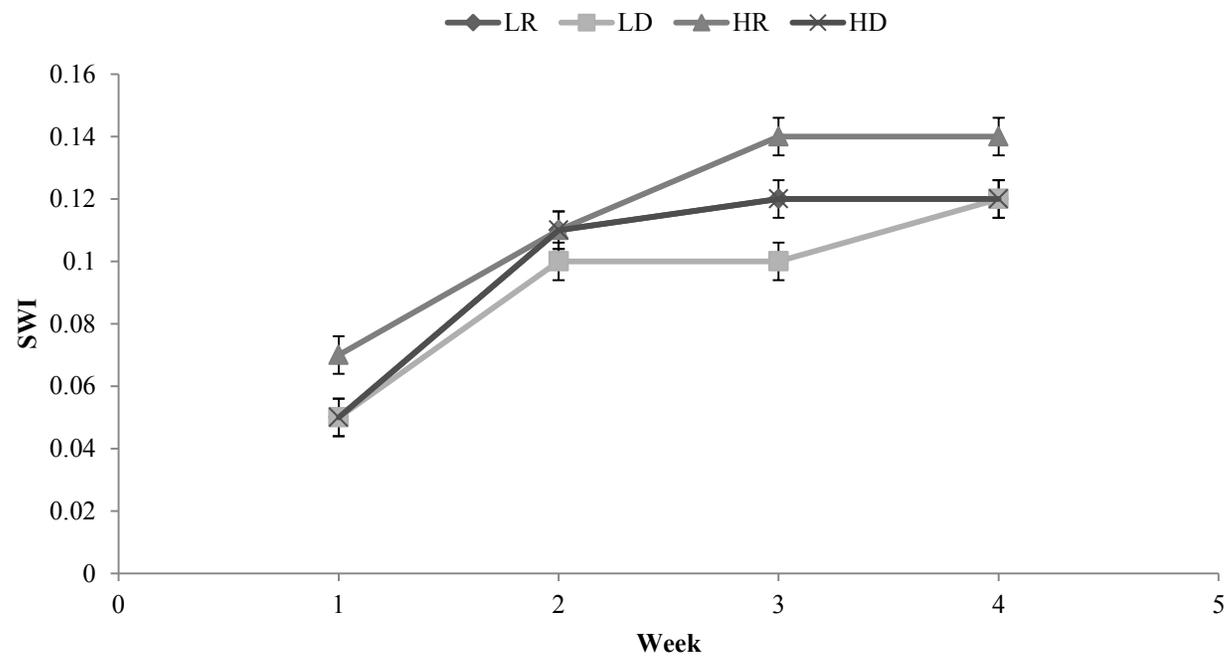
**Figure 3.2** Weekly changes in scaled water intake (SWI) in growing pigs

LR: Low fibre diet (0 g/kg SH) and reservoir water; LD: Low fibre diet and dairy effluent; HR: High fibre diet (160 g/kg SH) and reservoir water; HD: High fibre diet and dairy effluent.

### 3.3.3 Effects of fibre inclusion and water source on feed intake

The overall ADFI was not affected by any of the treatments, however there was a significant fibre inclusion × water source × week interaction effect observed shown in Figure 3.3. Pigs on the HD treatment had the lowest ADFI in Week 1. In Week 4, however, the lowest ADFI was observed in pigs on the LR treatment, while those on the HD treatment had the highest ADFI. There was no significant difference in the ADFI of the pigs on the LD and HR treatments throughout the trial. Although fibre inclusion and water source did not affect SFI (P > 0.05), there was a significant interaction on SFI.

### 3.3.3 Weekly effects of fibre inclusion and water source on ADG and GF

Figure 3.4 shows changes in ADG over the four week period. ADG increased across all treatments from Weeks 1 to 4. In Weeks 1 and 2, water source did not affect (P > 0.05) ADG, while fibre inclusion significantly reduced ADG. Pigs on the HD treatment had the lowest ADG in Weeks 1 and 4 hence the lowest overall ADG (0.54 kg/day), the highest overall ADG (0.76 kg/day) was observed from the pigs on the LR treatment. Figure 3.5 shows the changes in GF from Week 1 to 4. In Week 1, pigs on the LD and HD treatments had higher GF values compared to the pigs on the LR and HR treatments, the opposite was observed from Weeks 2 to 4. Feed intake was positively correlated to water intake as shown in Figure 3.6.

### 3.4 Discussion

Dairy effluent was used as the recycling water source and sunflower husks were used as a fibre source to assess how water quality influences the response of pigs to high fibre diets. The main interest of the study was to assess the interaction between fibre inclusion and water quality on
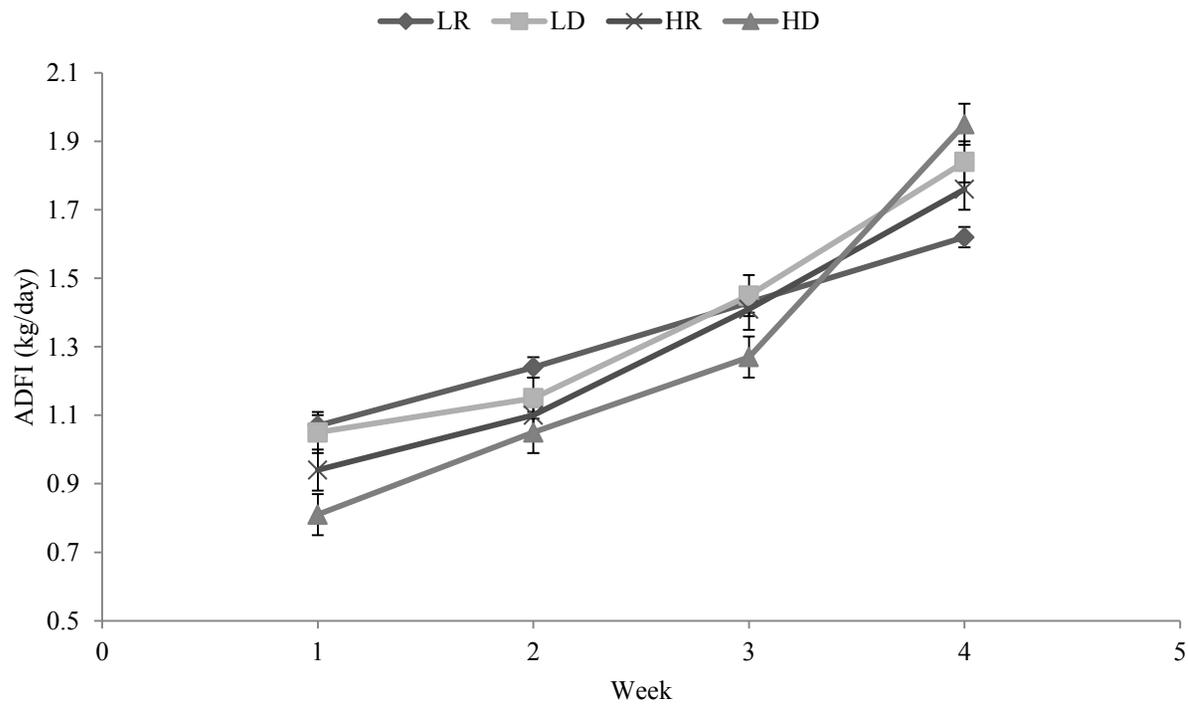
**Figure 3.3** Weekly changes in average daily feed intake (ADFI) of growing pigs

LR: Low fibre diet (0 g/kg SH) and reservoir water; LD: Low fibre diet and dairy effluent; HR: High fibre diet (160 g/kg SH) and reservoir water; HD: High fibre diet and dairy effluent.
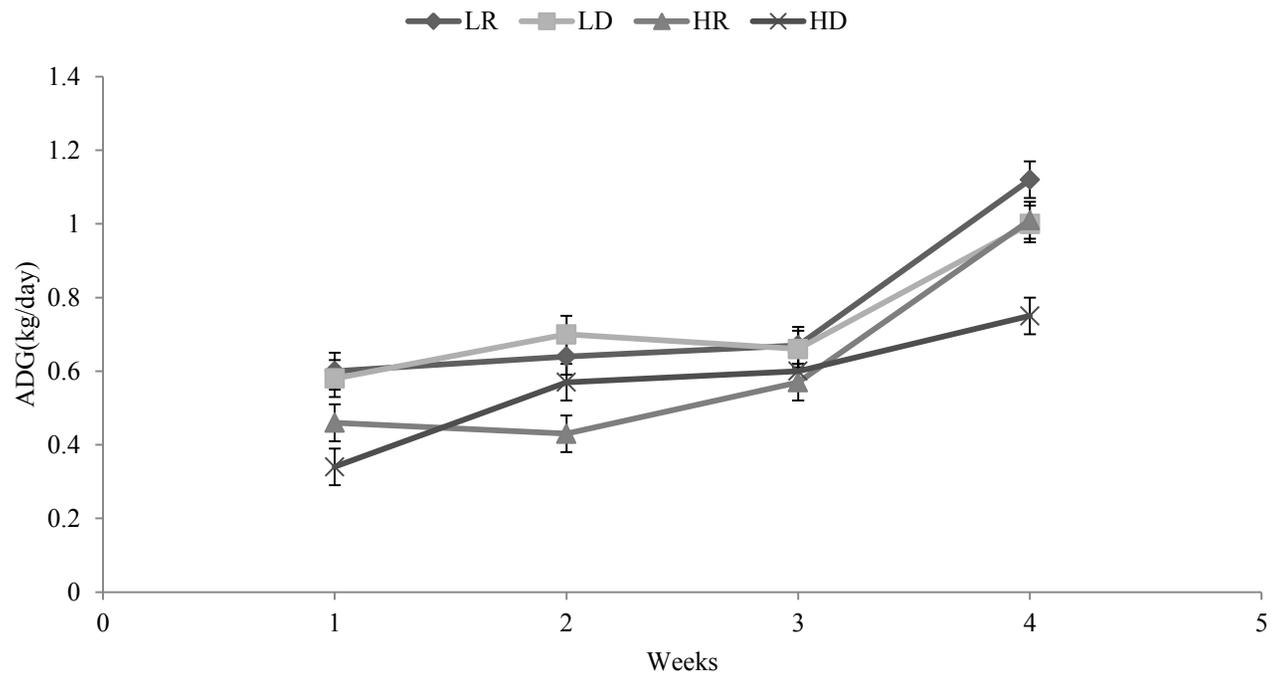
**Figure 3.4** Weekly changes in average daily gain (ADG) of growing pigs

LR: Low fibre diet (0 g/kg SH) and reservoir water; LD: Low fibre diet and dairy effluent; HR: High fibre diet (160 g/kg SH) and reservoir water; HD: High fibre diet and dairy effluent.
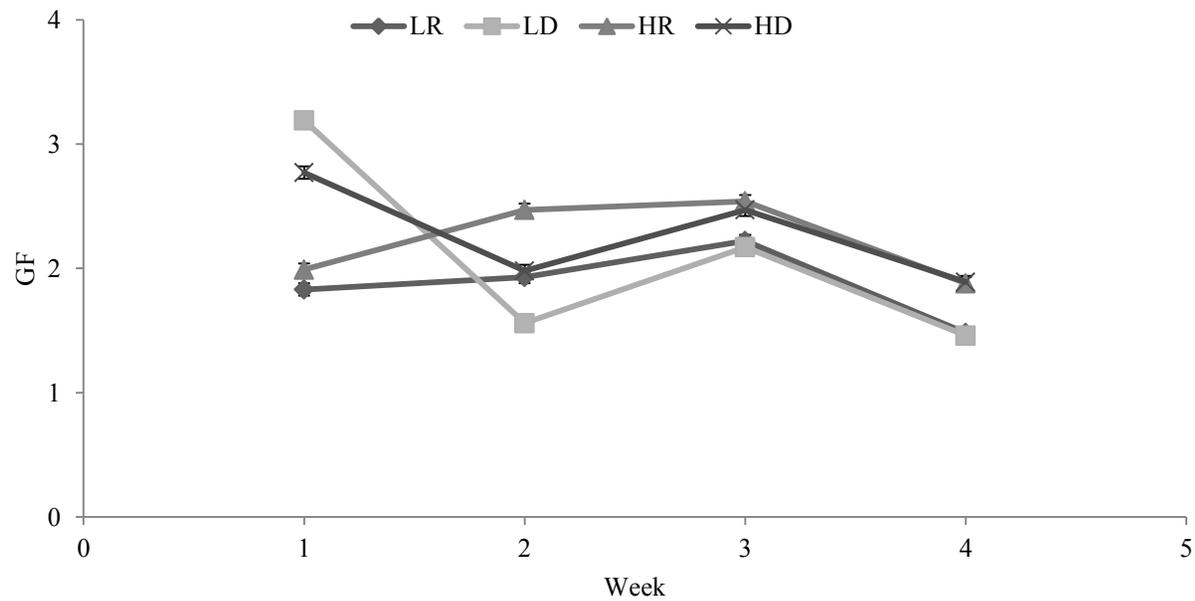
**Figure 3.5** Weekly changes in gain to feed ratio (GF) in growing pigs

LR: Low fibre diet (0 g/kg SH) and reservoir water; LD: Low fibre diet and dairy effluent; HR: High fibre diet (160 g/kg SH) and reservoir water; HD: High fibre diet and dairy effluent.
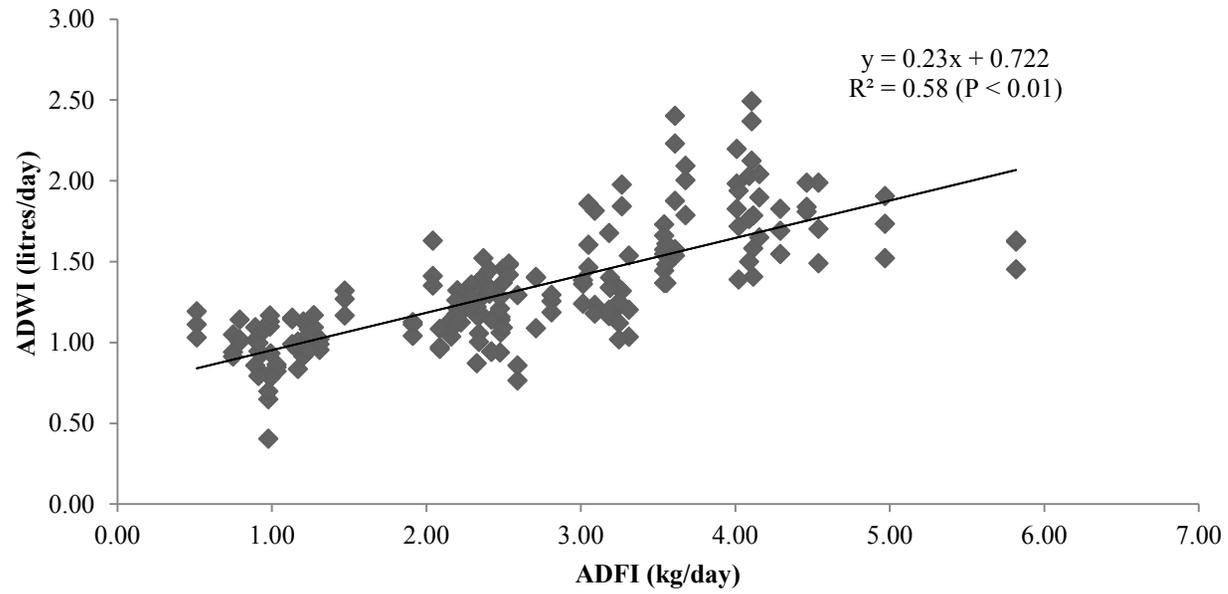
**Figure 3.6** Relationship between average daily water intake (ADWI) and average daily feed intake (ADFI) by growing pigs

growing pigs, this interest is mainly because pig producers are increasingly encouraged to use fibrous feeds for sustainability purposes. At the same time, the use of high volumes of water in pig production and increased water scarcity threats also encourages farmers to use recycled water for feeding pigs. Pigs were observed to be clinically healthy throughout the trial. Sunflower husks are high in insoluble fibre content (Heo *et al.*, 2013), the sunflower husks used in the current study also had high insoluble fibre content measured as ADF (279 g/kg) and NDF (558 g/kg). The nature of insoluble fibre to trap and retain water from the intestinal environment, reducing digesta retention time (Brooks *et al.*, 1990) and limiting the absorption of water from the gut (Shaw and Patience, 2000), may explain the observed increase in water intake by pigs with the inclusion of fibre in the diet for majority of the experimental period.

Similarly, in an attempt to meet their nutrient requirements for growth and maintenance, pigs on the high fibre diet also had a higher SFI to compensate for the reduced availability of nutrients and energy density in the high fibre diet (Rijnen *et al.*, 2003). When pigs were given dairy effluent instead of reservoir water, SFI was not affected by fibre inclusion, suggesting that the pigs were unable to achieve compensatory feed intake. A possible explanation could be the increased burden of simultaneously adapting to a low quality, high fibre diet and low quality, relatively saline and acidic water. Pigs at the early post weaning stage are highly susceptible to dietary limitations, and environmental changes, any stress due to these factors arising during this period affects subsequent performance (Lallès *et al.*, 2007), hence the observed inability of the pigs to achieve compensatory feed intake when consuming the high fibre diet and low quality water.

Given that the dairy effluent was collected after the first wash of the milk delivery trucks involving no use of chemicals, the low pH of 4.8 was not expected. A possible explanation for the observed low pH may be related to the high COD (5488 mg $O_2$/L) of the effluent, providing suitable conditions for the proliferation of lactic acid producing bacteria present in the milk residue of the effluent, hence the observed drop in the pH. Milk residue generally has a 100 bacterial count which doubles up every 20 minutes after collection (Singh *et al.*, 2014), it is also possible that the time from collection to the actual analysis of the effluent samples may have been longer than expected which may have influenced the further pH drop from the expected 6.5 to the observed 4.8. The low pH and high TDS (1681 mg/L) of the dairy effluent may have contributed to the observed decrease in SWI of the dairy effluent compared to the reservoir water when pigs were given the low fibre diet. In agreement with the current observations, Kober (1993) indicated that high levels of TDS (1000 – 5000 mg/L) may cause water refusal from pigs. The dairy effluent, however, had no effect on SWI when pigs were fed the high fibre diet. A possible explanation for this observation is that fibre reduces the salt concentration in feed, hence enabling the pigs to better tolerate the salinity in the dairy effluent.

Water intake highly influences feed intake in pigs, on average, growing pigs drink three litres of water per kg of feed (Shaw *et al.*, 2006), a decrease in water intake reduces feed intake. As expected, the increase in SWI with the inclusion of fibre in the diet coincides with the observed increase in SFI when pigs were provided with reservoir water. In week 4 of the trial however, pigs drinking the dairy effluent had higher ADFI compared to the pigs receiving the reservoir water regardless of the fibre level in the feed. It was expected that since the pigs on the high fibre diet had the highest water intake they would hence consume more feed, however, regardless of

the lower water intake, pigs were observed to consume more feed when given the dairy effluent water. The reason behind this observation is unclear; a possible explanation could be related to the fat content in the dairy effluent. Most dairy effluent water bodies have a significant amount of digestible fat residues (Sarkar *et al*., 2006), fats stimulate the release of appetite hormones hence the observed increase in feed intake. The fat content of the dairy effluent was not determined in this study; hence this explanation suggests a need for further investigation.

Despite the increase in both feed and water intake with the inclusion of fibre, pigs on the high fibre diet had a suppressed ADG. The observed reduction in ADG with the inclusion of fibre agrees with Nyachoti *et al*. (2006) who reported a significant reduction in weight gain of pigs fed on high fibre diets. The limited ability of young pigs to digest fibrous material (Molist *et al*., 2014) and their limited gut capacity (Ndou, 2012) may have induced satiety prior the ingestion of enough feed to compensate for the low nutrient dense fibrous feed. Consequently, the observed increase in GF with the inclusion of fibre coincides with the observed decrease in weight gain despite the increase in feed intake of the high fibre diet. In agreement with the current study, Nyachoti *et al*. (2006) reported that the inclusion of fibrous feed ingredients in pig diets limits the exposure of nutrients to enzymatic digestion and absorption for the animal to achieve potential growth.

Bakare *et al*. (2013) reported a negative relationship between the ADF content of feed and ADG of growing pigs. This may also explain why pigs had a lower ADG (0.62 g/day) when given the high fibre diet with a higher ADF content (178 g/a) compared to the ADG (0.76 g/day) of pigs on the control diet with a lower ADF content (88 g/kg). Replacing reservoir water with dairy

effluent further reduced the ADG of the pigs (0.54 g/day) which can be expected as the GF was also highest (2.6 ± 0.21) due to the water source change. Pigs were however able to adapt to the high fibre diet and achieve compensatory growth as observed in Weeks 3 and 4. The ADG of the pigs on the high fibre and dairy effluent was significantly low even in week 4 where the pigs on the high fibre diet receiving reservoir water were observed to achieve compensatory growth. The dairy effluent appeared to reduce the ability of the pigs to attain compensatory growth. The reason behind this effect is not very clear, particularly because during the compensatory growth period (Weeks 3 and 4), the dairy effluent appeared to promote feed intake and had no effect on GF compared to the pigs receiving reservoir water.

## 3.5 Conclusions

The inclusion of fibre in post weaning diets suppresses weight gain and reduces feed efficiency; these effects are intensified when high fibre diets are coupled with low quality, high TDS and acidic water from non-portable water sources such as dairy effluent. Fibre inclusion assists pigs adapt better to high TDS acidic waters. Low water quality reduces growth and feed efficiency in growing pigs. In conclusion, dairy effluent water can be used as an alternative water source for pigs without compromising the health and growth performance. The ability of pigs to adapt to the low quality dairy effluent water is reduced when pigs are consuming fibrous diets. It is important to determine whether dairy effluent and high fibre influence the nitrogen balance of the pigs.

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# Chapter 4: Interaction between fibre inclusion and water quality on nitrogen balance in growing pigs

**Abstract**

The objective of the study was to assess the interaction between fibre inclusion and water source on nitrogen (N) balance and the partitioning of N between faeces and urine in growing pigs. A 2 × 2 (water source x fibre inclusion level) arrangement was used. Sunflower husks were used to dilute a basal diet at 160 g/kg DM inclusion. The pigs drank either reservoir water (fresh water source) or dairy effluent. Forty eight male pigs (initial body weight of 27 ± 3.2 kg) were used. There was a significant interaction between fibre inclusion and water source on N utilization and excretion patterns ($P < 0.05$). A 4.6 % reduction in N digestibility was observed when the pigs on the low fibre diets were given dairy effluent compared to the pigs receiving reservoir water ($P < 0.05$). A significant 4.3% increase in N digestibility was observed when pigs on the high fibre diets were given dairy effluent compared to those that received reservoir waster. Dairy effluent had no effect on N utilisation when pigs were given the low fibre diets. Pigs on the high fibre diets had a 2.2 % increase in N retention when they were given dairy effluent compared to those supplied with reservoir water. The use of dairy effluent as a fresh drinking water alternative is appropriate and improves nitrogen utilization in growing pigs consuming high fibre diets.

**Keywords**: Nitrogen utilisation; nitrogen excretion; nitrogen digestibility; dairy effluent.

**4.1 Introduction**

Pig production plays a vital role in sustainable meat supply for the human population as it provides the second most affordable animal based protein. Increased demand for pork has promoted use of diets that are associated with an increase in excretion of nitrogen in pig manure, which is detrimental to the environment (Moeser and Kempen, 2002; Jarret *et al*., 2012). Dietary fibre has received increasing attention over the past decades due to its recognised benefits in pig nutrition such as promoting microbial fermentation in the large intestines, improving gut functioning and health (Heo *et al*., 2013). It also reduces protein fermentation in the gut, consequently reducing nitrogen losses through excretion (Nahm, 2003; Jarret *et al*., 2012). Dietary fibre reduces nutrient loss through pig manure by shifting a significant amount of nitrogen in the form of urea excreted in urine to faeces where it is bound to bacterial nitrogen which is less volatile (Kerr *et al*., 2006; Hansen *et al*., 2007). The repartitioning of nitrogen excretion from urine to faeces also reduces ammonia emissions from pig slurry, hence promoting more environmentally friendly pig production.

There is little data, if any, on the influence of water quality on nitrogen excretion patterns and utilisation on growing pigs, particularly when pigs are consuming fibrous diets. Given the current water scarcity concerns raised and the expected growth in pig production for sustainable pork supply to the continuously growing world population, the need to assess the interactions between fibre inclusion in pig diets and the use of alternative water resources is becoming more apparent. The food industry produces a significant amount of low pollutant load effluent, within which the dairy industry is amongst the top effluent producers per unit product (Singh *et al*., 2014). Most dairy effluent water bodies contain significant amounts of dissolvable proteins and

up to 84 mg/l of nitrogen (Strydom *et al*., 1993; Sarkar *et al*., 2006; Singh *et al*., 2014). Use of dairy effluent in feeding pigs could, therefore, influence nitrogen balance and utilisation.

The interest in the recyling of dairy effluent for feeding pigs is driven by identified potential of the dairy effluent in providing dissolvable proteins and nitrogen which may potentially improve nitrogen retention in growing pigs. The objective of the current study was, therefore, to assess the interaction between fibre inclusion and water source on nitrogen utilisation and the redistribution of N between faeces and urine in growing pigs.

## 4.2 Materials and Methods

### 4.2.1 Study site

The study was conducted at Ukulinga Research Farm, University of KwaZulu-Natal, Pietermaritzburg, South Africa. Details are given in Section 3.2.1

### 4.2.2 Pigs and housing

The trial was conducted according to the conduct by the Certification of Authorization to Experiment on Living Animals provided by the University of KwaZulu-Natal Animal Ethics Committee (Reference Number: 083/14/Animal). Forty eight male pigs with an average body weight $27 \pm 3.2$ kg were used for the N balance trial. A pig house with single heating, lighting and ventilation system, containing mounted individual cages ($1.5 \times 1$ m) was used to house the pigs. Temperature within the house was maintained between 22 and 25 $^0$C.

### 4.2.3 Treatments and experimental design

Details on the treatments and experimental design are as described in section 3.2.1.

### *4.2.3.2 Quality parameters for water sources*

The quality of the reservoir water and dairy effluent was determined by Talbot & Talbot Laboratories Pty Ltd, Pietermaritzburg, South Africa. Details are provided in section 3.2.4.

### *4.2.3.3 Nitrogen levels in faeces and urine*

The DM content of faeces for N analyses was determined by oven drying a 2 g sample from the collected faeces over 24 h at 103°C (Kerr *et al*., 2006). Each dried sample was reweighed. The difference in the two weights was expressed as a percentage of the initial weight and recorded as the DM content of the faeces. The macro-Kjeldahl technique (Leek *et al*., 2005), was used to determine the faecal and urinary N concentration for the total Kjeldahl nitrogen. To determine the CP content, 0.05 g faecal or urine sample was weighed and transferred on a tissue paper to the Kjeldahl digestion flask. A catalyst (titanium dioxide) and 2 mL of concentrated sulphuric acid were then added to a flask connected to a fume trap attached to a pump. The samples were digested for four hours to digest to obtain a clear solution, which was then cooled for an hour. Digestion of a blank was also carried out as a control.

### 4.2.4 Measurements

### *4.2.4.1 Excreta collection and storage*

Urine and faeces were collected at 0800 h, after a 24 hour period from 0800h the previous morning for each collection day.

Collection was done on Monday, Thursday and the following Monday, over a 7 day nitrogen balance period. For urine collection, a plastic tray was placed below pen. For improved accuracy, a 1 mm sieve was also fixed under each pen to minimise faecal contamination of the urine. To reduce the volatilization of nitrogenous compounds from the collected urine samples, 2 ml of 25% sulphuric acid was added to each tray within five minutes of collection. Total urine was then weighed and recorded, after which a 250 ml urine sample was collected for analyses. Fresh faecal samples were collected immediately at the point of defaecation from each pig. For faecal sample collection, the 1 mm sieve suspended under the mounted pens was used to capture faecal material fallen out of the pens. Total faeces were measured as the combination of faeces collected from the pens and the faeces captured using the sieve (Ouellet *et al*., 2004). After all the faeces were weighed, a 250 g sample was collected for further analyses. The collected faecal and urine samples were then stored at 4°C, pending analyses.

### 4.2.4.2 Calculations for nitrogen balance measurements

To estimate nitrogen balance, nitrogen intake (NI), urinary nitrogen excretion (UNE), faecal nitrogen excretion (FNE), total nitrogen excretion (TNE), digested nitrogen (DN), retained nitrogen (RN) and nitrogen utilization (NU) were estimated according to Hansen *et al*. (2007). The equations used are given in Table 4.1. The percentage of nitrogen in the feed was multiplied by the daily feed intake to estimate the daily NI. Similarly, the nitrogen concentration in the urine and faeces was multiplied by the daily urine and faecal output to determine UNE and FNE, respectively. The daily feed intake and total faecal output used to determine NI and FNE were determined on a dry matter basis.

**Table 4.1** Calculations for nitrogen balance measurements

| Parameter | Units | Formula |
|---|---|---|
| Nitrogen intake (NI) | g/day | N % feed/100% × daily feed intake |
| Faecal nitrogen excretion (FNE) | g/day | N % faeces/100% × daily faecal output |
| Urinary nitrogen excretion (UNE) | g/day | N % urine/100% × daily urine output |
| Total nitrogen excretion (TNE) | g/day | FNE + UNE |
| Digested nitrogen (DN) | g/day | NI– FN |
| Retained nitrogen (RN) | g/day | DN – UNE |
| Nitrogen utilization (NU) | % | (RN/NI) × 100% |

Sources: Hansen *et al*. (2007); Patras *et al*. (2009)

The UNE and FNE determined were summed up to estimate TNE. The difference in NI and FN was determined as DN. The difference in DN and UNE was then determined as RN. The NU was then estimated as the RN expressed as a proportion on NI.

### 4.2.5 Statistical analyses

The PROC CAPABILITY procedure of SAS (2008) was used to check for normality of the data. The significance of the main effects and interactions on response variables were tested using the General Linear Model procedure (SAS, 2008).

The model used was:

$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha \times \beta)_{ij} + e_{ijk}$;

Where;

$Y_{ijk}$ = response variable (Nitrogen retention, faecal nitrogen, urinary nitrogen);

$\mu$ = overall mean response;

$\alpha_i$ = effect of fibre inclusion level (i = 0 and 160 g/kg);

$\beta_j$= effect of water source (j = reservoir and dairy effluent);

$(\alpha \times \beta)_{ij}$= interaction between fibre inclusion level and water source

$e_{ijk}$ = residual error.

Separation of the least square means was performed using the with PDIFF option (SAS, 2008).

## 4.3 Results

The N balance of the pigs is given in Table 4.2. Feed intake was not affected by either fibre inclusion or water source. There was a significant interaction between fibre inclusion and water source on water intake and N intake (P < 0.05). Water intake from the pigs on the HD did not differ from those on the LR treatment. Water intake was lower from the pigs on the HD compared to pigs on HR and LD treatments. Daily N intake was lower (P < 0.05) from the pigs on HR treatment compared to that of the pigs on HD treatment, however did not differ amongst the pigs consuming the low fibre diets (LR and LD).

Faecal output was only affected by water source, pigs drinking dairy effluent (both LD and HD) had lower faecal output compared to the pigs drinking reservoir water (LR and HR). Both fibre inclusion and water source significantly affected urinary output. Urinary output was lowest from the pigs on HR, highest from the pigs on LD and did not differ between the pigs on LR and HD. The interaction between fibre inclusion and water source also affected UNE and TNE, while fibre inclusion significantly reduced FNE regardless of the water source. When given dairy effluent water, pigs on the LD diet had lower UNE compared to the pigs drinking reservoir water on the same diet (LR). On the other hand, UNE was significantly higher when the pigs on the high fibre diet were drinking reservoir water compared to those that were drinking reservoir water on the same diet. Pigs on the LR and HD treatments had higher (P < 0.05) UNE compared to the pigs on the LD and HR treatments.

**Table 4.2** Effects of fibre level (low and high) and water source (reservoir and dairy effluent) on feed intake, water intake and nitrogen balance in growing pigs

| | LR | HR | LD | HD | se | FL | WS | FL × WS |
|---|---|---|---|---|---|---|---|---|
| | | **Treatments** | | | | | **Significance** | |
| Feed intake (kg/day) | 2.3 | 2.4 | 2.3 | 2.2 | 0.04 | NS | NS | NS |
| Water intake (kg/day) | 1.7$^a$ | 2.3$^b$ | 2.2$^b$ | 1.7$^a$ | 0.11 | * | NS | * |
| Nitrogen intake (g/day) | 70.5$^a$ | 63.8$^b$ | 66.3$^a$ | 66.5$^a$ | 1.12 | * | NS | * |
| Faecal output (kg/day) | 0.47$^a$ | 0.45$^a$ | 0.42$^b$ | 0.40$^b$ | 0.001 | NS | * | NS |
| Urinary output (litres/day) | 0.40$^a$ | 0.26$^b$ | 0.46$^c$ | 0.40$^a$ | 0.004 | * | * | NS |
| Urinary nitrogen excretion (g/day) | 42.4$^a$ | 38.9$^b$ | 37.2$^b$ | 41.5$^a$ | 1.34 | NS | NS | * |
| Faecal nitrogen excretion (g/day) | 14.7$^a$ | 11.8$^b$ | 15.1$^a$ | 10.1$^b$ | 0.62 | ** | NS | NS |
| Total nitrogen excretion (g/day) | 57.1$^a$ | 50.7$^b$ | 52.3$^c$ | 51.6$^c$ | 1.48 | ** | NS | NS |
| N concentration in urine (%) | 11 | 10.3 | 10.13 | 10.37 | 0.48 | NS | NS | NS |
| N concentration in faeces (%) | 3.25$^a$ | 2.59$^c$ | 3.57$^b$ | 2.52$^c$ | 0.10 | ** | NS | * |
| Nitrogen retention (g/day) | 13.38$^a$ | 13.14$^a$ | 14.01$^{ab}$ | 14.9$^b$ | 1.68 | NS | NS | * |
| Nitrogen digestibility (g/day) | 55.8$^a$ | 52.1$^b$ | 51.2$^b$ | 56.4$^a$ | 1.37 | NS | NS | * |
| Nitrogen utilisation (%) | 19$^a$ | 20.6$^a$ | 21.1$^{ab}$ | 22.4$^b$ | 2.32 | NS | NS | * |

*$P < 0.05$; ** $P < 0.01$; NS: not significant ($P > 0.05$). $^{abcd}$ Values in the same row with different superscripts differ ($P < 0.05$). Treatments: LR: Low fibre diet (0 g/kg SH) and reservoir water; LD: Low fibre diet and dairy effluent; HR: High fibre diet (160 g/kg SH) and reservoir water; HD: High fibre diet and dairy effluent. FL: fibre level; WS: water source

The TNE of the pigs on the low fibre diet was lower when pigs were drinking the dairy effluent water (LD) compared to those drinking reservoir water (LR). On the other hand, TNE was lower from the pigs drinking reservoir water (HR) compared to those drinking dairy effluent (HD) for the pigs consuming the high fibre diet. There was also a significant interaction between fibre inclusion and water source on the concentration of N in faeces, while N concentration in urine was not affected by either fibre inclusion or water source. Nitrogen concentration in faeces was not affected by water source for the pigs on the high fibre diets (HR and HD), faecal N concentration was higher (P < 0.05) from the pigs drinking the dairy effluent (LD) compared to those drinking reservoir (LR) water for the pigs on the low fibre diets.

There was a fibre inclusion and water source interaction on N digestibility, retention and utilisation. Pigs on the low fibre diet had lower (P < 0.05) N digestibility when drinking dairy effluent (LD) compared to those that were drinking reservoir water (LR), while those on the high fibre diets had significantly higher N digestibility when given the dairy effluent (HD) compared to those drinking the reservoir water (HR). Nitrogen utilisation was not affected by water source for the pigs on the low fibre diets (LR and LD), however, pigs drinking the dairy effluent (HD) had higher (P < 0.05) N retained compared to those drinking reservoir water (HR) when they were consuming the high fibre diet. Similarly, pigs on the HD treatment had higher N utilisation compared to the pigs on LR and HR however did not differ from the pigs on LD.

Figure 4.1 shows the amount of faecal, urinary and retained nitrogen, expressed as a percentage of ingested nitrogen as utilised by growing pigs. There was a fibre inclusion by water source
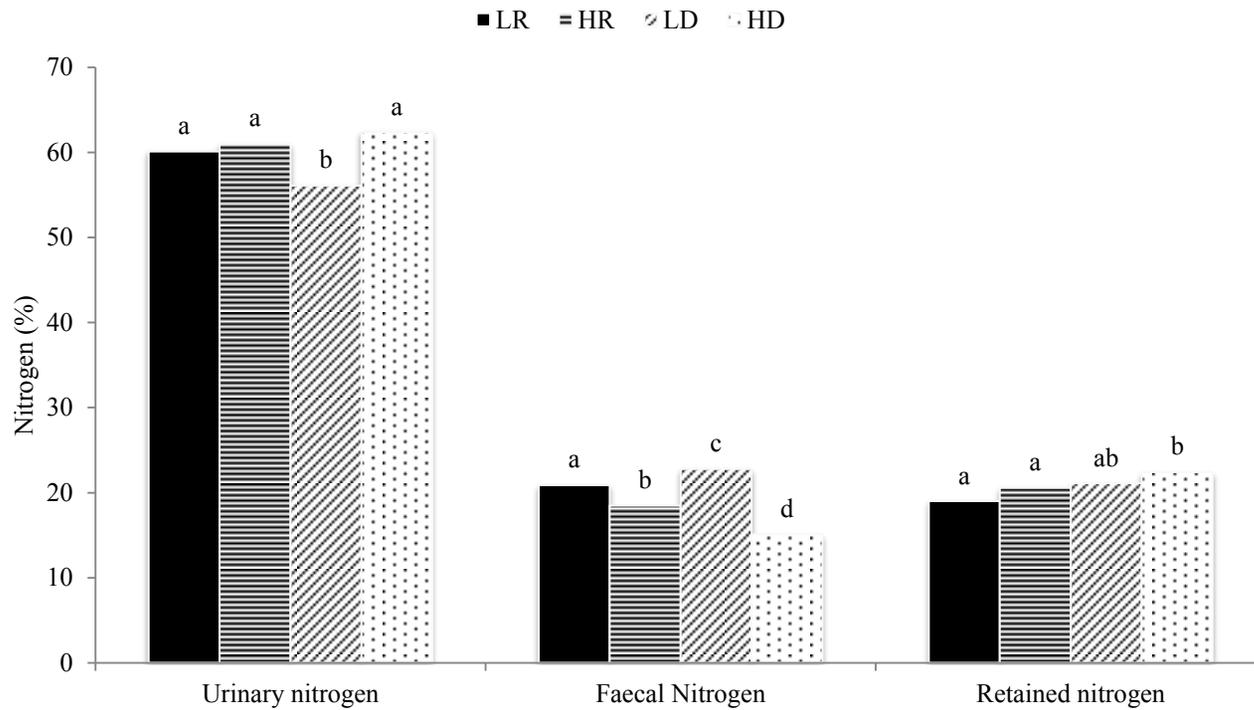
**Figure 4.1** Faecal, urinary and retained nitrogen expressed as a percentage of nitrogen intake

Different letters (a, b, c and d) in the category indicate that the treatment means significantly differ at P < 0.05. Treatment: LR: Low fibre diet (0 g/kg SH) and reservoir water; LD: Low fibre diet and dairy effluent; HR: High fibre diet (160 g/kg SH) and reservoir water; HD: High fibre diet and dairy effluent. Fibre L: fibre level; Water S: water source

interaction on urinary, faecal and retained N observed. Urinary N was significantly reduced for the pigs on the low fibre diet drinking dairy effluent when compared to the pigs drinking reservoir water, on the same diet. Urinary N was, however, not affected ($P > 0.05$) by water source when pigs were given the high fibre diet. Faecal N was observed to be higher ($P < 0.05$) when the pigs on the low fibre diets were given dairy effluent compared to those that were drinking reservoir water, however, when pigs were consuming the high fibre diet, pigs drinking the dairy effluent had a significantly lower faecal N compared to those drinking reservoir water. The retained nitrogen did not differ ($P > 0.05$) amongst the pigs consuming the low fibre diets (LR and LD), however when pigs were given the high fibre diets, retained nitrogen was significantly higher for the pigs drinking dairy effluent (HD) compared to those drinking reservoir water (HD).

## 4.4 Discussion

Inclusion of fibre in pig diets has minimal effect on nitrogen (N) metabolization by growing pigs (Zervas and Zijlstra, 2002; Hansen *et al*., 2006). Fibre inclusion has however been reported to have beneficial effects such promoting the repartitioning of N excretion from urine to faeces, reducing N losses through volatilization in pig manure during storage, hence improving its fertilizer value (Mpendulo *et al.*, 2014). The objective of the current study was hence to investigate whether the use of dairy effluent as a drinking water source influences N balance in growing pigs consuming fibrous diets. The observation that using dairy effluent as a drinking water source increased the daily N intake for pigs consuming the high fibre diets was surprising and difficult to explain.

A possible explanation could be that there was a significant amount of protein from the milk residue in the dairy effluent adding to the daily N intake, as reported to exist in most dairy effluent water bodies (Mukhopadhyay *et al*., 2003). The crude protein (CP) content of the dairy effluent was, however, not determined, as it was considered to be negligible. Even if it was a valid explanation, it is still not clear why the dairy effluent had the opposite effect on pigs fed on the low fibre diet, particularly considering that the pigs consuming the dairy effluent had a higher water intake compared to those drinking the reservoir water. If the dairy effluent had a substantial protein residue, it would increase daily N intake for the pigs on the low fibre diet compared to those on the high fibre diet. It should be noted that water intake was significantly lower when the pigs on the high fibre diets were drinking the dairy effluent compared to reservoir water.

The observed reduction in urinary N excretion (UNE) with the inclusion of fibre in the diet is in agreement with other observations reported in literature (Hansen *et al*., 2006; Patras *et al*., 2009). Dietary fibre provides substrate for bacterial fermentation in the intestines of the pig, consequently shifting N excretion from urine to faeces in the form of bacterial N (Hansen *et al*., 2007). Observations of the current study however show a reduction in faecal N excretion (FNE) as opposed to the expected increase observed in other studies (Nahm, 2003; Jarret *et al*., 2011). It would hence be expected that, if there was no repartitioning of N from faeces to urine, more N would have been digested and retained by the pig. In agreement with Hansen *et al*. (2006) fibre inclusion, however, did not affect the retention of N in pigs given reservoir water. The type and inclusion level of fibre and water quality, therefore, need to be determined when assessing N balance in growing pigs.

Although fibre inclusion had the same effect on FNE, the UNE was increased for the pigs drinking dairy effluent as opposed to the reduction observed for the pigs drinking reservoir water. The higher nitrate concentration of the dairy effluent compared to the reservoir water may explain the increase in UNE due to fibre inclusion as opposed to the observed decrease when the pigs were given reservoir water. Nitrogen in the form of nitrate is not readily taken up by the animal body but rather utilised by bacteria in the digestive system of the pig and converted into nitrite which is excreted as waste in urine by the pig.

Using the dairy effluent as a drinking water source for the pigs consuming the high fibre increased N digestibility and retention, dairy effluent use however had no effect on the pigs consuming the low fibre diet. Given the observed higher N intake due to the use of dairy effluent for the pigs on the high fibre diet compared to those drinking reservoir water, the understanding that N intake is positively related to N retention (Amaefule *et al.,* 2009) explains this observation. The simultaneous use of the high fibre diet and dairy effluent water was also observed to improve N retention and digestibility. A possible explanation could be that the combination of the high fibre diet with dairy effluent water provided two possible substrates for bacterial fermentation. The availability of the nitrate N from the dairy effluent and the NSP substrate from the dietary fibre in the feed may have possibly provided enough substrate for the bacteria in the gut such that there was minimal N from feed origin utilised by the for bacterial fermentation in the gut. Hence, the observed tendency to improve N digestibility and retention when pigs were given the high fibre diet with dairy effluent water.

## 4.5 Conclusions

In conclusion, although there was no improvement in N utilisation when pigs were given reservoir water, the reduced urinary N excretion due to the inclusion of fibre in the diet is a desirable result as it decreases N loss through volatilization, which is beneficial for the use of pig manure as fertilizer. Increased nitrite concentrations in alternative fresh water sources such as dairy effluent water improves N utilisation in pigs fed high fibre diets, however also has a negative environmental impact due to increased urinary N excretions in pig manure which reduces its fertilizer value.

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**CHAPTER 5: General discussion, conclusions and recommendations**

**5.1 General discussion**

The growing interest in the inclusion of fibrous ingredients in pig diets for sustainability purposes has encouraged research interest on dietary fibre as a beneficial nutrient in pigs. Dietary fibre has beneficial effects on pig nutrition. It improves gut development and reduces of odour emissions from pig slurry (Hansen *et al*., 2007). The effectiveness of dietary fibre is highly dependent on the fibre source used and the level of fibre inclusion in the diet (Ndou *et al*., 2013). Sunflower husks, for example, induce higher voluntary feed intake and reduced odour emission from slurry produced from growing pigs without any effect on pig performance when included up to 160 g/kg DM (Mpendulo *et al*., 2015).

Alongside the increasing feed scarcity threat is the less recognised, yet equally important threat of water scarcity. Due to its historical notation of being abundant, to date, although regarded as the most vital resource in pig enterprises, there is little research done on water utilisation in pigs. The behaviours of pigs fed on fibrous diets show increased frequency of visitations to the water source, suggesting an increased water requirement with the inclusion of fibre in pig diets (Bakare *et al*., 2013). The main hypothesis tested in the current study was that there exists an interaction between fibre inclusion and water source on performance, water consumption and nitrogen balance in growing pigs.

In Chapter 3, an experiment was carried out to test whether there is an interaction between fibre inclusion and water source affecting growth performance and water consumption of growing pigs. It was hypothesised that the interaction between fibre inclusion and water source affects performance and water consumption in growing pigs. There was an interaction

between fibre inclusion and water source on SFI. Pigs on the high fibre diet consumed more feed when they were given dairy effluent for drinking compared to those fed on reservoir water. This suggests that there could be a significant amount of appetite inducing components of the dairy effluent, possibly the fat residue, which promotes voluntary feed intake.

The reason why the dairy effluent increased feed intake when the pigs were given the high fibre diet could be related to the increased need for nutrient intake. High fibre diets have low nutrient density compared to the low fibre diet. Pigs fed on high fibre diet are, therefore, expected to consume higher amounts of feed in an attempt to meet their nutrient requirements (Rijnen *et al.*, 2003). Although the pigs fed on a low fibre diet were not affected by drinking dairy effluent, the observed reduction in ADG and increased GF ratio with the inclusion of fibre in the diet were intensified when pigs were given dairy effluent instead of reservoir water. The interaction between fibre inclusion and water source affected performance, however, had no effect on water consumption.

Chapter 4 was conducted to test whether the interaction between fibre inclusion and water source existed on nitrogen balance in growing pigs. It was hypothesised that the interaction between fibre inclusion and water source would affect nitrogen balance in growing pigs. The simultaneous use of the high fibre diet and the dairy effluent water improved N digestibility by 4.3 %, while a significant 4.6 % reduction in N digestibility was observed when the pigs on the low fibre diets were given dairy effluent compared to the pigs that received reservoir water. The improved N digestibility explains the observed 2.2 % increase in N retention when pigs were given the high fibre diet and dairy effluent water for drinking. While the use of dairy effluent water improved N utilisation when pigs were given a high fibre diet, there was no notable effect of the dairy effluent on N utilisation when pigs were given a low fibre diet.

Although pigs on the high fibre diet and dairy effluent had reduced growth performance and feed efficiency, they had improved N retention. The improved N retention suggests that the pigs were more efficiency utilising dietary protein. It was, however, surprising that the improved N retention did not yield increased growth performance and better feed conversion efficiency.

## 5.2 Conclusions

Dairy effluent can be successfully used as a source of drinking water for pigs without affecting performance when pigs are fed on a low fibre diet. With the inclusion of fibre in the diet, pigs struggle to maintain performance with the increased burden of simultaneously coping with low quality feed and water. On the other hand, although it negatively affects average daily gain and feed efficiency, the interaction between fibre and dairy effluent improved N retention for growing pigs.

## 5.3 Recommendations

Dairy effluent water can be used as a drinking water source for pigs without affecting growth performance given the pigs are given good quality low fibre diet. There is still a need to explore the possible use of other alternative fresh water resources such as rain water identified in the current study.

Further recommended research focus includes:

1. Determining the effect of the length of storage of dairy effluent on performance of different classes of pigs;

2. Understanding interactions of fibre source and water quality on performance of different classes of pigs;

3. Assessing the effects of water source and water quality on different age groups; and

4. Estimating the effects of feed form (pelleted/mashed) on water consumption for different age groups.

## 5.4 References

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**Appendix 1:** Animal ethics approval letter

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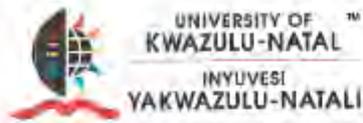
21 April 2014

Reference: 083/14/Animal

Miss SG Mabuza
Animal Science
School of Agricultural, Earth &
  Environmental Sciences
University of KwaZulu-Natal
PIETERMARITZBURG Campus

Dear Miss Mabuza

**Ethical Approval of Research Projects on Animals**

I have pleasure in informing you that the Animal Research Ethics Committee has granted ethical approval for **2014** on the following project:

"Effect of grey water from the dairy industry on pig performance."

Yours sincerely

Professor Theresa HT Coetzer
Chairperson: Animal Ethics Sub-committee

Cc     Registrar – Mr C Baloyi
       Research Office – Dr N Singh
       Supervisor – Prof. M Chimonyo
       Head of School – Prof. A Modi
       SAEES – Mrs M Manjoo

Animal Ethics Committee
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