EFFECT OF DIETARY FIBRE AFFECTING *AD LIBITUM* FEED INTAKE AND FEEDING BEHAVIOUR OF GROWING-FINISHING PIGS FED A USING SINGLE-SPACED ELECTRONIC FEEDERS

A thesis presented in partial fulfilment of the requirements for the degree of

Master of Science

in

Animal Science

at Massey University, Palmerston North

New Zealand

Shola Gabriel Olumodeji

2021

Abstract

The experiment was conducted to evaluate the effect of dietary fibre on the feeding behaviour of growing-finishing pigs. A total of 32 Duroc x (Large White x Landrace) pigs were used. The study consisted of 16 males and 16 females pigs. The initial liveweight was 22.4±2.2 kg for the male and 22.8±1.9kg for the female. Two pens of 8 females and two pens of 8 were used. The experiment was a 2 x 2 factorial design (2 finisher diets x two sexes), which lasted for ten weeks, and comprised of weeks 1-7 called the grower phase and weeks 8-10 called the finisher phase. The study consisted of two experimental groups (Group 1 and Group 2). The Group 1 pigs were fed the basal diet (13.5 MJ DE/kg + 0.65 g Lys / MJ DE) throughout the study, while the group 2 pigs were fed the basal diet during the growing phase then switched to the fibre-rich test diet (13.6 MJ DE/kg + 0.68 g Lys / MJ DE) during the finishing phase.

All diets were pelleted. The test (6% and 24.6%) and basal diet (4.2% and 14.4%) had different CF and NDF levels. The pigs were fed using the Osborne™ electronic feeder. Feeding behaviour data recorded by the electronic feeders were the number of visits, feeding duration (min), feeding rate(g/min) and feed intake per visit (kg). Data cleaning techniques were used to improve the accuracy of the data. Data were transformed to meet the condition of normality and homogeneity of variance. Also, the data was sorted on an hourly basis to reflect the diurnal feeding variation and analysed using the proc mixed function of SAS 9.4 (SAS Institute, Cary NC). Multiple comparisons were made using Fisher's LSD method ($P<0.05$).

The pigs fed the basal diet; the female pigs frequently visited the feeder more often but spent a shorter feeding time because they only ate smaller feed quantities ($P<0.05$). However, the male pigs visited the feeder less often but spent more time feeding because of the large quantity consumed ($P<0.05$). During their growing phase, all pigs fed the basal diet had an extended feeding time because of their frequent feeding visits than the finishing phase ($P<0.05$). However, finishing pigs (fed the basal diet) irrespective of their sex had a higher feeding rate and feed intake than growing pigs ($P<0.05$). The fibre-rich test diet changed the feeding behaviour pattern of the finishing pigs. Overall, finishing pigs fed the fibre-rich diet exhibited reduced hourly feed intake and feeding rate than pigs fed the standard (basal) compound diet ($P<0.05$). In contrast, the pigs fed the fibre-rich diet's hourly feeding duration and feeding visit was increased than the pigs fed the standard compound diet. Overall, this study concluded that sex, diet, and age influenced the hourly feeding behaviour of the pigs.

Keywords: Dietary fibre, feed intake, feeding rate, feeding duration, feeding visits, feeding behaviour

Acknowledgements

Like I acknowledged in my undergraduate thesis, “one of the hidden truths of life is that the path to the prize is always more valuable than the prize itself”. This thesis is a product of different emotions, including love, happiness, frustration, sadness, and anxiety. There were days when I looked like I got this. Also, there were days I was clueless and felt like giving up. It takes a whole lot than being clever towards finishing up a thesis. This is why I am grateful to everyone mentioned on this acknowledgement page for making this process as bearable as possible. Since this is the only part of my thesis that might not be checked for plagiarism, I might also copy some of the acknowledgement in my undergraduate thesis. There is no pressure to sound smart or reinvent the wheel here; I have already sounded smart in this thesis.

To my amiable thesis supervisor, Prof Patrick Morel, I say a big thank you for your guidance and for letting me tap from your inexhaustible wealth of knowledge. Thank you for the banters and for leading me through putting forth this beautiful piece of research. Being a Swiss is not that bad after all. I owe a huge chunk of my gratitude to my supervisor Dr Fifi Zaefarian. Thank you for the guidance, encouragement, and advice you’ve put into this work.

I want to thank the New Zealand Ministry of Foreign Affairs and Trade (MFAT) for sponsoring my education in New Zealand and granting me this life-changing opportunity. Special thanks to the scholarship team at Massey University, including Jamie Hooper and Saba Azeem, for a job well done. Massive gratitude to the New Zealand Pork (NZPork) and the Ministry of Primary Industry (MPI) for sponsoring this research. Thanks to Dr Kirsty Chidgey, Dr Catriona Jenkinson and Thanh Nguyen for playing a vital role in this research's success.

A heartfelt appreciation goes to Mr and Mrs Adeyinka for giving me a home away from home here in New Zealand. My appreciation goes to the friends (Ruth, Yomi, Debbie, Sandra, Kimberly, Ale, and others too numerous to mention) I have met in NZ and my partner in the “shugary” business, Anita. I want to acknowledge my Parent Mr and Mrs Martin Olumodeji, especially the special one, my lovely Mother and my siblings (Yinka, Biola, Tope, Yomi, Morayo and Faith). Saving the best for the last, I acknowledge the Almighty God for seeing me through my masters and for the strength he gave me to learn with zeal and diligence during the entire period of my stay in New Zealand.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

DE	Digestible energy
ME	Metabolizable energy
NSP	Non-starch polysaccharide
DON	Deoxynivalenol
VFI	Voluntary feed intake
VFA	Volatile fatty acid
GIT	Gastrointestinal tract
NDF	Neutral detergent fibre
ADL	Acid detergent lignin
ADF	Acid detergent fibre
TDF	Total dietary fibre
WBC	Water binding capacity
WHC	Water holding capacity
SCFA	Short chain fatty acids
GLP-1	Glucagon-like peptide
PYY	Peptide tyrosine tyrosine
SID	Standardized ileal digestibility
AID	Apparent ileal digestibility
CP	Crude protein
ATTD	Apparent total tract digestibility
CMC	Carboxymethylcellulose
DDGS	Distillers' dried grain with soluble
FIRE	Feed intake recording equipment

RFID	Radio frequency identification
DM	Dry matter
CF	Crude fibre

Chapter 1

Introduction

1.1 Background

The world as we know it is growing, and it is expected to reach over 9 billion people in 2050; the consequences of this are that by 2050, we need to produce 70% more food (FAO, 2009). More specifically, it is estimated that there will be a corresponding 60-70% increase in animal product consumption by 2050 with highly efficient and fast-growing species – such as pigs- likely to account for one of the major increases in the projected animal protein consumption (FAO, 2014; Makkar et al., 2014; Schiavone et al., 2017).

The increase in animal product consumption could be attributed to the growing human population and improved living standards, mainly from developing countries (FAO, 2009; FAO, 2011; USDA, 2016). Subsequently, in meeting up with the predicted future increase in consumption of animal protein, there will be a significant demand for finite animal production resources such as feed (FAO, 2009; Makkar et al., 2014). As a result, pig production systems have primarily used conventional diets based on cereals and high-quality protein supplements (Close, 1993).

Currently, livestock feed account for between 60-70% of production cost (Hasan, 2007; Swanepoel et al., 2010; Lucas & Southgate, 2012; Van Huis, 2013; Abu et al., 2015). In swine enterprises, feed represents between 55 and 75% of the total cost of production (Patience & Petry, 2019). This problem is worsened by the fact that there is a growing scarcity of resources to produce conventional animal feed because of their competitive use as food and fuel by humans and industries, respectively; as well as the environmental impact associated with their production (Van Huis, 2013; Makkara et al., 2014; Veldkamp & Bosch, 2015). Therefore, in light of the shortcomings of conventional feed ingredients, there is a need to evaluate an alternative feed ingredient to ensure more sustainable pork production.

Recent trends in the demand and supply of these conventional feedstuffs require swine producers to feed the pig a wide range of feedstuff which are unacceptable to human consumption because of their omnivorous nature (Close, 1993; Woyengo et al., 2014). These low-cost feedstuffs, such as cereal co-products from the biofuel and milling industries, are called “alternative feed ingredients” (Close, 1993; Woyengo et al., 2014). Since alternative feed ingredient is cheap, their use to supplement or substitute conventional feed ingredients in swine diets can be attractive economically (Owusu-Asiedu et al., 2006). In fact, most alternative feed ingredients have been reported to have high dietary fibre components because of their plant cell wall materials (Close, 1993). This high dietary fibre component is of interest in animal nutrition and welfare. Diet rich in fibre can be a cheap energy source. Furthermore, it can help improve the welfare of pigs because of its ability to reduce abnormal (or stereotypic) behaviour by ensuring satiety (de Leeuw et al., 2008).

1.2 Problem statement

However, most of these alternative feed ingredients are bulky and have high dietary fibre because of the non-starch polysaccharides found in their cell walls (Bedford & Schulze, 1998; Souffrant, 2001). This problem is worsened because most monogastric animals, including pigs, cannot degrade the non-starch polysaccharides found in the small intestine because their digestive enzymes are not suited (Bedford & Schulze, 1998). Similarly, the non-starch polysaccharides may also act as antinutrients (Stanogias & Pearce, 1985) and could negatively influence voluntary feed intake and nutrient digestibility, especially in grower and weaner pigs (Kyriazakis & Emmans, 1995; Zijlstra et al., 1999, 2001). Likewise, the mechanism through which the reduced feed intake reported for the pigs fed alternative feed ingredient is quite complex and poorly understood (de Lange et al., 2000a,b).

Much has been known of how dietary fibre in the alternative feed ingredient reduces feeding motivation by enhancing satiety through its physicochemical properties such as bulkiness, solubility and fermentability (Meunier-Salaun et al., 2001; Zaczek et al., 2003). Therefore, for swine producers to develop management and feeding regimes to manage the negative influence of non-starch polysaccharides and take advantage of most alternative feed ingredients, an understanding of the extent to which dietary fibre can influence the feeding behaviour of growing-finishing pigs is needed. However, very little is known about how dietary fibre influences feeding behaviour parameters such as feeder visits, feeding duration, feed intake, and feeding rate.

1.3 Objectives

Managing the influence of dietary fibre in voluntary feed intake requires understanding how it influences the behavioural feeding pattern in pigs. Therefore, the primary objective of this study is to investigate the effect of dietary fibre on the *ad libitum* feed intake and feeding behaviour of growing-finishing pigs. Also, other factors (such as age and sex) that could influence the feeding behaviour of the pigs in this study were being examined.

Chapter 2

Literature Review

2.1 Introduction

In monogastric nutrition, the emphasis is placed on feed intake regulation because of its crucial role in body maintenance and growth. It is also an essential part of the integral behaviour that affects optimum feed conversion and productivity in growing pigs (Henry, 1985; Nyachoti et al., 2004). The nutrient intake level depends on the total quantity of feed consumed by the pig (Nyachoti et al., 2004). In many pig production enterprises, pigs are fed *ad libitum* comprising of a complete diet mix. The voluntary feed intake is based on the pig's specific requirement for, most notably, energy. This is alongside other nutrients such as protein and essential amino acids (Henry, 1985). As a result, to modulate voluntary feed intake in growing pigs, there must be a balance in the ratio of the energy concentration to that of essential amino acid and protein in the diet (Henry, 1985; Perez & Roura, 2017).

There are physiological factors that affect feed intake in pigs. Some physiological factors include the transit time or rate of passage of the digesta through the digestive tract (Black et al., 2009). The satiety and hunger centre in the brain is stimulated by meal consumption, metabolite production from biochemical processes and absorption of digested nutrients (Nyachoti et al., 2004; Black et al., 2009). The satisfaction of appetite after feed consumption, which inhibits further eating, can be described as satiety. As a result, feed intake and feeding behaviour are greatly influenced by an integral process such as satiation (Burton-Freeman, 2000). More importantly, the inherent physico-chemical properties (such as bulkiness and viscosity) of the dietary fibre play an integral role in the manner in which satiety is achieved in the manner (Burton-Freeman, 2000).

More specifically, feed intake has been reported to have an inverse relationship with the rate of transit of the digesta through the digestive tract. However, the mechanism behind how feed intake is being influenced by the transit time of the digesta is still not well understood (Ratanpaul et al., 2019). Since pig eats to a constant energy intake and maintains normal metabolism and homeostasis, the addition of fibre decreases the digestible energy of the feed, thereby increasing feed intake (Ratanpaul et al., 2019). Other physiological effects of adding fibre to the diet include suppressing satiety through gut hormones (Tolhurst et al., 2012) and its direct effect on the hypothalamus region (Frost et al., 2014).

However, the increase in feed intake does not hold when fibre in the diet is very high (Ratanpaul et al., 2019). At a high fibre concentration, there is an increase in the hydration and swell capacity of the feed eaten by the pig, which results in gastric distension and a reduction in feed intake. This is due to reduced energy density, increased feed bulk, and digesta swelling in the stomach (Kyriazakis & Emmans, 1995; Brachet et al., 2015). Similarly, there is an increase in the gastrointestinal tract (GIT) capacity and a change in the transit time of the digesta because of the increase in feed intake (Ratanpaul et al., 2019). Eventually, a threshold point is reached in which there cannot be a further intake of feed that contains fibre to meet up with the declining energy density. At this point, the energy intake required for normal metabolism falls (Black, 2000).

On the other hand, in addition to energy, Henry (1979) observed that feed intake is also adjusted based on specific protein intake levels. This is, therefore, consistent with the fact that changes in feed or energy intake are closely related to the diet composition in terms of energy density, protein concentration and amino acid balance (Henry, 1985). Similarly, the diet's protein (or amino acid)-energy ratio necessary for optimum growth can also influence feed intake (Henry, 1985). Moreover, it is worthy to note that the ad libitum feed intake system for growing pigs in a commercial pig production enterprise serves as a cost-effective and labour-saving system (Owen & Ridgman, 1967).

2.2 Factors affecting feed intake in pigs

A vast range of factors affects feed intake in pigs. The level of feed intake is dependent on the interaction of multiple factors ranging from external, internal, social, and dietary factors. As a result of these interplay of numerous factors, feed intake is usually difficult to predict for pigs, especially groups of growing-finishing pigs at different growth stages (Nyachoti et al., 2004). Some of these external factors include environmental stimuli (Beattie et al., 2000) such as ambient temperature (Quiniou et al., 2000), humidity and ventilation (Ratanpaul et al., 2019). For instance, there is an associated increase in voluntary feed intake and body fat deposition at slaughter due to the decrease in temperature below the thermoneutral zone (Le Dividich et al., 1987). On the other hand, high temperature discourages feed intake and reduces body fat deposition (Rinaldo & Le Dividich, 1991). Even when the same breed of pigs are kept under the same environmental condition, differences in feed intake can still be exhibited due to intrinsic or animal-related factors (Nielsen, 1999; Bornett et al., 2000). Some of these animal-related factors include genotype, variation among pig within a breed, variation over time within individual pig and sex (De Haer & De Vries,1993; Fuller et al., 1995; Labroue et al., 1995; Knap, 2009).

Variation between the breeds of pigs can also influence feed intake. Quiniou et al. (1999) observed this in their study involving the effect of growth potential at three growth stages on the feeding behaviour of Pietrain, Large White and Meishan, representing lean, conventional, and fat types of pigs (or breed), respectively. They observe a linear increase in feed intake, the magnitude of which depended on pig type or breed. The Meishan breed had the highest feed intake, followed by Large White and Pietrain. In this same study, the pig breed significantly affected voluntary feed intake (VFI). Therefore, factors such as differences in VFI and feeding behaviour among different pig types can lead to differences in body composition among pig genotypes (Nyachoti et al., 2004).

The genetic line of the pig influences the composition of gain and the potential for rate. As a result, feed intake levels and patterns differ among pigs of divergent genetic lines (Cöp & Buiting, 1977; de Haer & de Vries, 1993). Pigs selected for faster gain have higher VFI levels than pigs with slow gain potential (Clutter et al., 1998). Similarly, over many years of intensive selection programs for pig genotypes with lean content and better feed conversion efficiency have inadvertently led to the current breeds of pigs declining or static feed intake levels (Webb, 1989). Pigs with a high potential for lean tissue growth tend to have a lower VFI compared to those with a low muscle accretion rate (Henry, 1985; Gu et al., 1991)

Other internal influences that can trigger differences in feed intake amongst animals raised under the same condition include factors such as the physiological stage of development (NRC, 2012), health status (Williams et al., 1997), age (Kanis & Koops, 1990), and body weight (Quiniou et al., 2000). Similarly, other aspects that influences feed intake includes social factors such as group housing (Bornett et al., 2000), stocking density (Nyachoti et al., 2004), space allocation, feeder space, group size in pens, familiarity with other pigs and regrouping (Ratanpaul et al., 2019).

Lastly, dietary factors can influence *ad libitum* feed intake and feeding behaviour in pigs. Some of these dietary factors include feed additives, dietary contaminants, feed processing, feed form, availability of drinking water, feed bulk, physical feed intake capacity and dietary nutrient content and balance (such as energy concentration, protein levels and amino acid balance (Li & Patience, 2017; Ratanpaul et al., 2019). Therefore, to ensure a sustainable pig enterprise, understanding various feed strategies and managerial decisions in predicting the feed intake in growing pigs is a much-needed skill (Nyachoti et al., 2004). However, due to the scope of this research, emphasis will only be placed on the role dietary factors play in *ad libitum* feed intake.

2.3 Influence of dietary factors on feed intake

The effect of the various dietary factors on the pig's feed intake will be discussed in the following sections.

2.3.1 Dietary energy concentration

The properties of a diet, such as its concentration and type of nutrient goes a long way in influencing feed intake in pigs. First of all, pigs consumed feed to meet the requirement of the first limiting nutrient, which mostly is energy-yielding nutrients (Cole et al., 1968; Henry, 1985; NRC, 1998; McNeilage, 1999). Dietary energy density is one of such dietary characteristics capable of inducing pigs to adjust their feed intake, especially their average daily feed intake (Henry, 1985). The study conducted by Oresanya et al. (2007) confirmed this. The study highlighted that young pigs fed a diet that contained low digestible energy (DE) content (14.22MJ/kg) consumed more feed (857 vs. 825 g/day) than pigs fed a diet containing higher DE (15.06MJ/kg). A similar result was reported by Beaulieu et al. (2009), in which five formulated diets containing different ME levels ranging from 12.41 to 14.34MJ/kg were fed to growing-finishing pigs (Figure 1).

With the decrease in the available dietary energy concentration, pigs will attempt to eat to a constant daily energy intake, in so doing, eating more until feed intake is depressed by other factors such as the pigs' environmental stimuli or physical intake capacity (Beaulieu et al., 2009). This is the same for cases when the energy concentration of a highly digestible diet is diluted by lower energy ingredients, resulting in an increase in feed intake at such a rate that digestible energy (DE) intake remains constant (Beaulieu et al., 2009). However, Hanson et al. (2015) observed in weaned pigs, a higher average daily feed intake (830 vs. 734 g/day) for a high metabolisable energy (ME) diet containing a 30% dried distiller grains with soluble (DDGS) than the control consisting of a maize-soybean diet with low metabolisable energy. This can be explained by the fibrous nature of the DDGS diet. Diets containing fibre have been reported to improve gut fill, increase weight and volume of the whole gut, and increase feed intake (Kyriazakis & Emmans, 1995). On the other hand, in young pig, Black et al. (1986) reported that, just like the energy concentration of the diet, the physical feed intake capacity of the growing pigs also serves as a significant limiting factor for growth

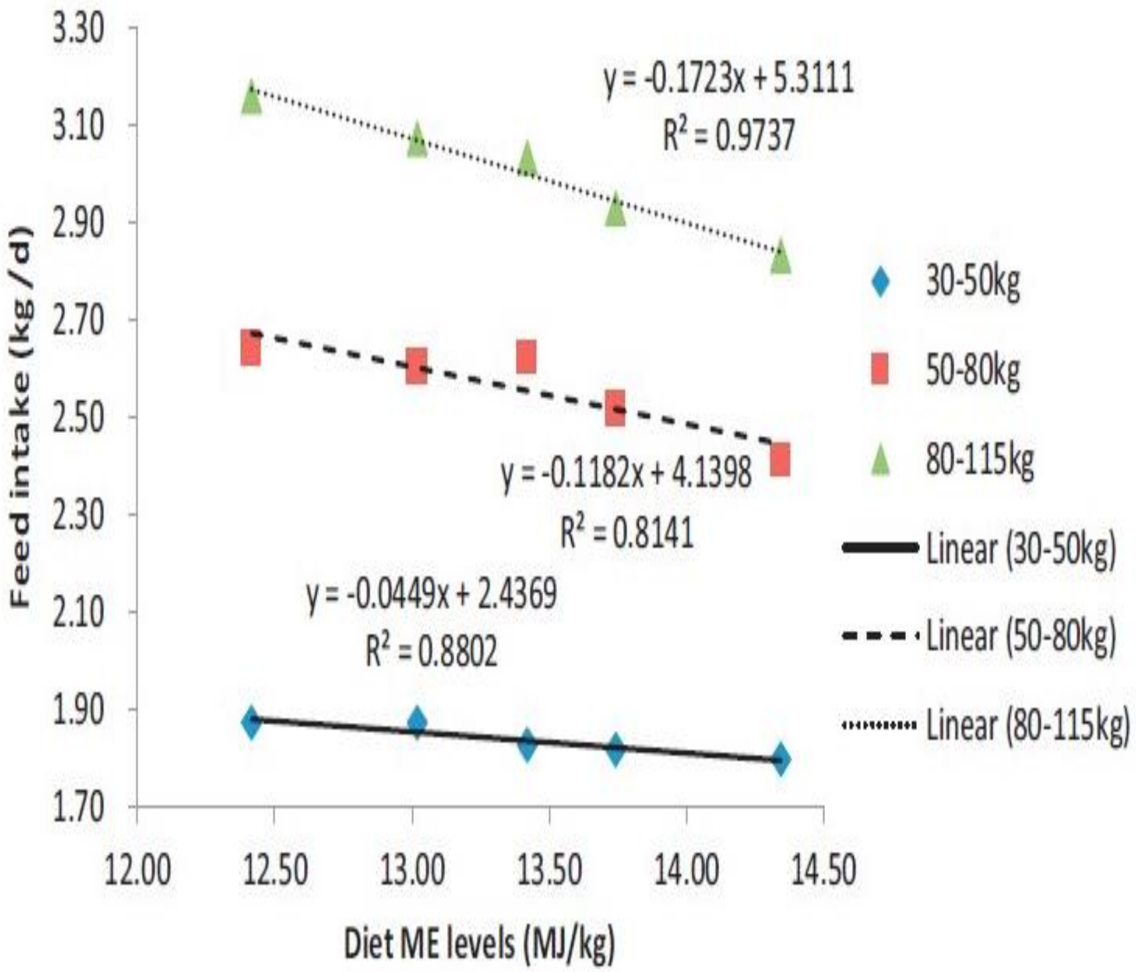

Figure 1: Average daily feed intakes of pigs consuming diets with ME ranging from 12.41 to 14.34 MJ/kg across three growth phases (Adapted from Beaulieu et al., 2009).

2.3.2 Amino acid balance and dietary protein level

The amino acid profile and the protein level of the diet play an important role in regulating feed intake in pigs. For instance, the optimum inclusion level of tryptophan in the diet is associated with enhanced feed intake in young piglets (Ettle & Roth, 2004; Naatjes et al., 2014; Nørgaard et al., 2015). On the other hand, factors such as an excess supply of total protein or essential amino acids and a severe deficiency in limiting amino acids have been reported to depress voluntary feed intake (Harper, 1959). In fact, a diet containing high protein levels have been reported to depress feed intake in growing pigs. A study reported by Le Bellego & Noblet (2002) in which piglet was fed 4 experimental diets with different crude protein levels further confirmed the influence of a diet on feed intake. In their study, piglets fed the diet with the highest crude protein level (224 g/kg) exhibited a significant decrease in the average daily feed intake compared to pigs fed low crude protein (204, 184 and 169g/kg) diets.

According to Li & Patience (2017), the negative impact of excess dietary protein can be explained due to an existing imbalance among the less-limiting amino acids, especially the large neutral amino acids (leucine, isoleucine, valine, phenylalanine, and tyrosine). Similarly, feed intake was depressed when a diet containing low-protein deficient in valine (limiting amino acid) was fed to pigs (Gloaguen et al., 2011). Alternatively, pigs were observed to consume more feed in an attempt to meet up with their limiting amino acid requirement when they were fed a diet that was deficient in one or more essential amino acids (Henry, 1985). However, the findings of this study were not consistent with those conducted by Robinson (1975) and Henry (1995). Overall, it is noteworthy to maintain feed intake; there has to be a balanced ratio of available energy to essential amino acids (Li & Patience, 2017).

2.3.3 Physical feed intake capacity and feed bulk

The level to which the animal's gut is filled depends on the bulkiness of the feed and the physical intake capacity to consume the feed (Nyachoti et al., 2004). The physical capacity of the digestive tract of pigs to consume feed and meet their nutrient requirement influences the level at which the quantity of a bulky feed can be consumed (Nyachoti et al., 2004). The physical feed intake capacity limits young pigs of about 20kg to consume and digest feed (Black et al., 1986). Black et al. (1986) also observed in their study that when the energy density of a diet is reduced below 3350 kcal/kg, growing pigs of about 50kg cannot compensate for such energy reduction. Gut fill and physical feed intake capacity (F_{phys}, kg/d) can be predicted by the equation proposed by Black et al. (1986), which can be expressed in units of feed intake

$F_{phys} = 0.111 \times BodyWeight^{0.803}$

or expressed in units of indigestible feed intake proposed by Whittemore (1998).

$F_{phys} = 0.013 \times BW / [1\text{-}Dig]$

Although these two approaches produce similar feed intake estimates, they fail to identify the influence of dietary fat (Revell & Williams, 1993) and dietary fibre (Eastwood et al., 1983; Kyriazakis & Emmans 1995) on voluntary feed intake.

2.3.4 Feed processing and form

Ad libitum feed intake in growing pigs is influenced by the form and processing of the feed ingredient. For example, reducing the particle size of cereal ingredients in growing-finishing pigs results in a depressed feed intake (Laurinen et al., 2000; Mavromichalis et al., 2000). More specifically, in the study carried out by Mavromichalis et al. (2000) using weaning pigs, they observed that when the particle size of a wheat-based diet was reduced from 1300 to 400 µm, there was an associated linear drop-in feed intake. A plausible explanation for the reduction in feed intake could be the pig’s attempt to control DE intake by altering feed intake (Nyachoti et al., 2004). Similarly, a reduction in feed intake for growing-finishing pigs fed pelleted feed was reported by Hancock & Behnke (2001). Still, there was an improvement in growth performance due to enhanced nutrient digestibility (Wondra et al., 1995b). However, it is agreed that after weaning, liquid feeding stimulates feed intake (Kim et al., 2001; Han et al., 2006; Missotten, 2010). Unlike dry and mash feeding, when feed is fed in the pellet or wet form, there is an overall improvement in the feed conversion efficiency (Patience et al., 1995; Botermans et al., 1997; Gonyou, 1999).

2.3.5 Feed additives

To induce a certain level of response in terms of improvement in performance through various ways, including enhancing feed intake, feed additives are included in pigs' diet (Nyachoti et al., 2004). Examples of feed additives include exogenous enzymes that aid in digestion. These enzymes improve feed intake by acting on the non-starch polysaccharides (NSP) components of the feed, thereby reducing the feed's bulkiness (Campbell & Bedford, 1992). A similar increase in voluntary feed intake has been reported for feed additives that enhance general health and gut health in pigs (Coffey & Cranwell, 1995).

Also, through a different mechanism such as masking the bitter taste of some feed ingredients and serving as an enhancement for good and acceptable taste, the flavouring agent may improve feed intake in pigs (Whittemore, 1998). For example, Baidoo et al. (1986) reported an increase in feed intake when 100g/kg of dextrose was added to a diet containing an equal quantity of soybean meal and canola meal fed to starter pigs. Similar results have been reported by Danielsen et al. (1994) when pigs were fed a diet containing dehulled rapeseed meal in which a flavouring agent was added. However, studies reported by Patience et al. (1995) and Whittemore (1998) have suggested that the effectiveness of flavouring agent have been inconsistent.

2.3.6 Dietary contaminants

One major contaminant currently facing the pig industry globally is mycotoxins found in the grain used for feed ingredients (Nyachoti et al., 2004). When mycotoxin-contaminated feed ingredient is fed to pigs, it is generally observed that there is a fall in overall production performance due to the reduction in feed intake (Nyachoti et al., 2004). For instance, feed intake was drastically reduced in a study conducted by Williams & Blaney (1994). Growing pigs were fed a diet comprising 500 or 750g/kg of maize naturally contaminated with *Fusarium graminearum*. In another study conducted by House et al. (2002), a similar result was reported. In this study, growing-finishing pigs with bodyweight varying from 23 to 110kg were fed a barley diet containing a naturally contaminated 2ppm of deoxynivalenol (DON) mycotoxin. There was a significant reduction in the feed intake (2.20 vs. 2.38kg/d). However, House (2003) did not observe a similar result in a subsequent trial when the same pig genotype was fed a diet containing 4ppm of DON or when a starter pig was fed 2ppm of DON compared to the control diet containing no inclusion of DON.

2.4 Availability of drinking water

Water is an essential requirement needed by all animals. Water plays a vast role in physiological functions involving digestion and nutrient utilisation (NRC 1998; Thacker 2001). Therefore, its availability will either improve or depress VFI (Nyachoti et al., 2004). Despite its primary role in body temperature regulation, it is also speculated to be involved in other bodily functions, such as its impact on VFI by mitigating temperature effects on VFI (Mount et al., 1971; Nienaber & Hahn, 1984). In weaned pigs, to maintain optimal feed intake, they should be drinking water soon after weaning (Brooks et al., 1984; Gill et al., 1986). However, in terms of water quality, studies have suggested that it may not affect the VFI of pigs (Patience et al., 1995; Nyachoti & Patience, 2003). Similarly, in a study conducted by McLeese et al. (1992), changes in feed intake (0.55 vs 0.57 kg/d) were insignificant for water containing 217 ppm and 4390 ppm of total dissolved solids.

Although much is known about the many dietary factors that affect *ad libitum* feed intake in growing pigs, it is still unclear the effect dietary fibre has on its underlying mechanisms responsible for the observed feeding behaviour and feed intake. Due to the nature of the scope of this study, it is also important to highlight that for this review; emphasis will be placed on just the influence the dietary fibre fraction has on feed intake. More importantly, satiety and feed intake will be interchangeably used. This is because there is an inverse relationship between feed intake and satiety. In fact, an increase in satiety is observed when a diet rich in fibre is consumed, which subsequently results in less hunger (Delzenne & Cani, 2005). As a result, when there is satiety, there is less feed intake and vice versa

2.5 Dietary Fibre

2.5.1 Definition

Dietary fibre plays an integral role in the digestive process of pigs. The definition of dietary fibre comprises either of the physiological and chemical definitions (Knudsen, 2001). According to the physiological definition, dietary fibre is a heterogeneous mixture of structural and non-structural polysaccharides and lignin found in a plant's cell wall that cannot be hydrolysed by enzymes found in the digestive system of pigs but efficiently by the microbial flora (Wenk, 2001; Souffrant, 2001; Agyekum & Nyachoti, 2017). On the other hand, in terms of the chemical definition, dietary fibre is described as the sum of the lignin and non-starch polysaccharide of the feed ingredients or plant material (Theander et al., 1994).

Similarly, any polysaccharides that reach the hindgut, such as oligosaccharides and resistant starch, of plant cell origin, including fructo-oligosaccharides, are classified as dietary fibre (Chesson, 1995; Agyekum & Nyachoti, 2017). Example of dietary fibre includes various NSP such as cellulose, pectins, mucilages, hemicellulose, β-glucans and gums including the non-polysaccharide lignin (Burton-Freeman, 2000). Therefore, to guarantee sustainable swine production, it is vital to ensure that fibre, non-starch polysaccharides, and cellulose, the most abundant carbohydrate found in nature, are efficiently utilised (Urriola et al., 2012).

The cell wall constituents of plants are complex and variable in their physical and chemical components and their metabolic effects (Agyekum & Nyachoti, 2017). Another point to consider is a wide variation in the amount and composition of fibre within and between feedstuff (Wenk, 2001). Dietary fibre co-products can change the carbohydrate component of pig diets from high-starch to containing less starch and more non-starch polysaccharides, which are the major constituent of fibre (Agyekum & Nyachoti, 2017). Many co-product or by-products of the biofuel industry are increasingly being used as dietary fibre in the pig's nutrition (Urriola et al., 2012).

Many advantages of incorporating fibre into the diet of pigs include reduction in cost of production (Agyekum & Nyachoti, 2017), relatively cheap raw material (Laitat et al., 2015), beneficial impact on animal health (Tabelling et al., 2003), reduced abnormal behaviour such as stereotypies (Owen & Ridgman, 1967) and improved animal welfare and performance (Correa-Matos et al., 2003; de Leeuw et al., 2004; Amerah et al., 2009). However, its importance has been downplayed due to disadvantages such as reducing nutrient digestibility and growth depression (Agyekum & Nyachoti, 2017). Although soluble fibres are easily digested, generally, pigs cannot utilise feed ingredients high in fibre, especially if it is of insoluble fibre origin (Urriola et al., 2012). Notwithstanding, pigs can absorb energy from releasing the volatile fatty acid (VFA) due to the microbial fermentation of the fibre in the GIT (Urriola et al., 2012). Furthermore, when fibre-rich ingredients are incorporated into the pig's feed, it lowers the overall digestibility of energy, and hence it reduces the energy value of the diet (Graham et al., 1986; Knudsen & Hansen, 1991; Wondra et al., 1995a; Noblet & Le Goff, 2001; Urriola et al., 2012). This is because the site of energy digestion is shifted from the foregut to the hindgut (Anguita et al., 2007).

2.5.2 Classification and determination of fibre in feed ingredients

Cellulose, hemicellulose, and lignin are the main components of the plant cell wall (Agyekum & Nyachoti., 2017; Figure 2). Cellulose is a linear polymer of glucose units with β-(1→4) linkages, unlike pectin, which comprises primarily of glucuronic acid units joined in chains by α-(1→4) glycosidic linkages (Agyekum & Nyachoti., 2017). Cellulose is an abundant organic substrate, and it forms the core structural constituent of plant cell walls. On the other hand, hemicelluloses are a complex polysaccharide matrix that includes xylose, arabinose, galactose, mannose, glucuronic acid, and β-glucan (Agyekum & Nyachoti., 2017). Also, the portion of the cell wall polysaccharides that are not digested or fermented by intestinal enzymes or bacteria but anchored by the phenolic polymer is the lignin component (Bedford & Schulze., 1998; Montagne et al., 2003; Metzler & Mosenthin, 2008; Knudsen et al., 2012).

In terms of their solubility in water or weak alkali, NSP can be classified into soluble or insoluble NSP (Knudsen, 2001). Example of soluble NSP includes pectin, gums, and β-glucans. Insoluble NSP includes cellulose and some other hemicellulose. In terms of their gastrointestinal tract (GIT) fermentability, soluble NSP is more rapidly fermented than insoluble NSP (Knudsen, 2001; Montagne et al., 2003). The fermentation in the insoluble NSP happens in the hindgut of the pig, with little or no fermentation occurring in the upper gut (Noblet & Le Goff, 2001). With the description of the component and the significant role of dietary fibre in pig nutrition, it is also essential to highlight the existing analytical procedures needed to determine the actual amount of dietary fibre in any feed ingredient.

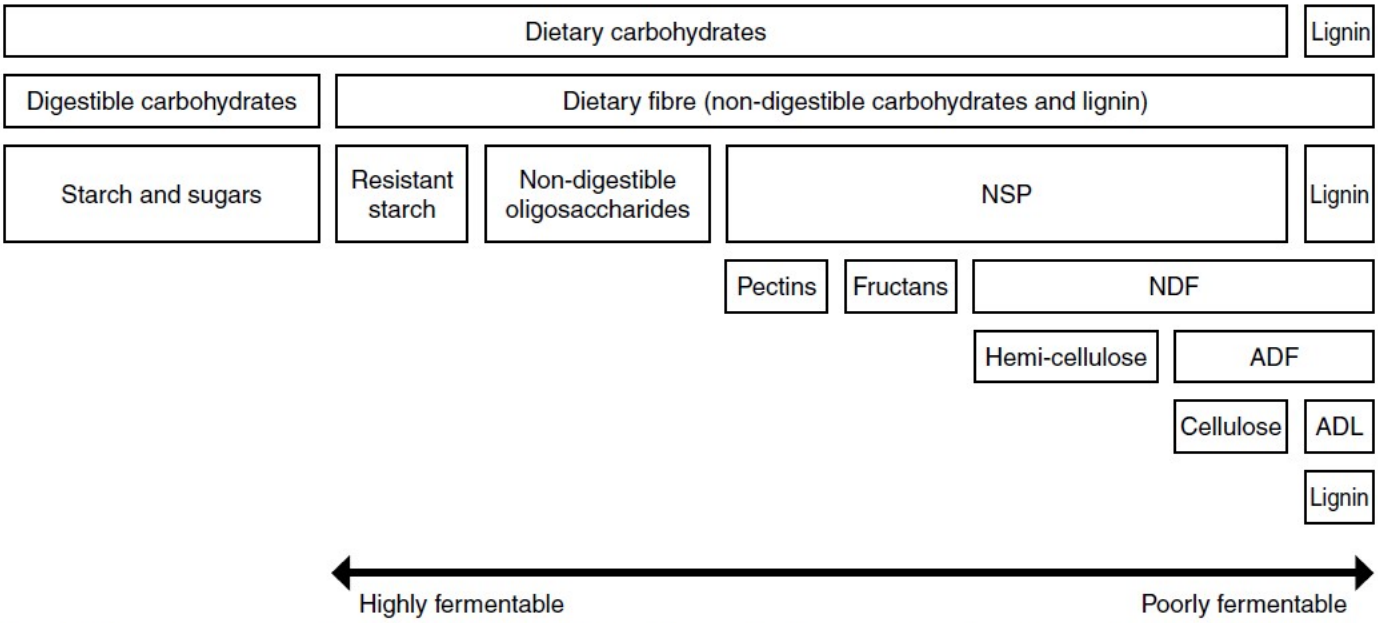

Figure 2: Composition of animal feed showing the different dietary fibre fractions. Adapted from Ratanpaul et al. (2019).

2.5.3 Analytical method for characterising fibre

Nutritionists use different methods in characterising the dietary fibre constituents of feeds and feedstuff. Two basic steps are commonly used in all of these methods. These steps involve the digestion of the carbohydrate and other non-fibre constituents (including protein and fat) in the feed ingredient and, after that quantifying the remaining undigested residue (Urriola et al., 2012). The digestion process uses different compounds ranging from chemicals (such as alkali, acid and detergent) to enzymes (such as amylase, protease and amyloglucosidase; Urriola et al., 2012). Subsequently, the undigested residue can be determined through a procedure ranging from weighting (gravimetric) to the use of chemical compounds (using gas chromatography or high-performance liquid chromatography; Urriola et al., 2012). However, the type of analytical method used is dependent on how fibrous the remnant is isolated and measured. Therefore, this technique can be classified into chemical-gravimetric, enzymatic-gravimetric, and enzymatic-chemical methods (Agyekum & Nyachoti, 2017).

2.5.4 The crude fibre analysis

The crude fibre analysis (which is part of the Weende proximate analysis) uses the chemical-gravimetric system of analysing feed ingredients (Mertens, 2003). In this method, the gastric and pancreatic secretions' digestive actions are mimic by boiling the feed with diluted acid and subsequently using dilute alkali (Mertens, 2003). The drying process follows this, and the residue is determined gravimetrically (Knudsen, 2001). More specifically, it was introduced to distinguish between available and unavailable carbohydrates for digestion (Mertens, 2003).

On one hand, the main advantage of crude fibre analysis is that it is very robust and reproducible within and among laboratories. However, cellulose, hemicellulose and lignin recovery is incomplete (Agyekum & Nyachoti, 2017; Figure 3) because only a small fraction of these polysaccharides is recovered due to their nature of solubility (Knudsen, 2001). As a result, this analytical method is not considered an acceptable definition for dietary fibre and, therefore, not suitable for portraying pig's dietary fibre constituents of pig's feed (Agyekum & Nyachoti, 2017).

2.5.5 The Van Soest detergent method

The Van Soest method developed by Van Soest and his co-workers built on the inadequacies of the crude fibre analysis (Van Soest, 1963; Van Soest & Wine, 1967; Van Soest et al., 1991). The Van Soest detergent analysis method, which classifies dietary fibre into insoluble and soluble components, seems to provide accurate interpretation (Agyekum & Nyachoti, 2017). This chemical-gravimetric procedure developed by Van Soest in the 1960s uses detergent to extract fractions such as neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (Van Soest & Wine, 1967; Van Soest et al., 1991; Souffrant, 2001; Mertens, 2003; Figure 3). When feedstuff or a diet is digested in a solution of neutral pH, it recovers the insoluble components of dietary fibre (i.e., cellulose, hemicellulose, and lignin); hence the NDF (Mertens, 2003; Figure 3).

With increasing NDF levels, there was an increase in the passage rate of digesta through the digestive tract when pigs were fed a diet containing neutral detergent fibre of different sources (Stanogias & Pearcet, 1985). On the other hand, the ADF recovers the cellulose and lignin when the feed ingredient is dissolved in an acid solution (Van Soest et al., 1991; Figure 3). Likewise, the acid detergent lignin (ADL) recovers the remaining lignin using sulphuric acid. Although the Van Soest analysis method of dietary fibre is an improvement over the crude fibre method, it cannot recover the soluble fraction of the dietary fibre in a feedstuff such as pectins, mucilages, gums, and β-glucans (Grieshop et al., 2001; Mertens, 2003). Besides, it is noteworthy that starch and protein are likely to contaminate the residue for the detergent fibre procedure, which could reduce its robustness and reproducibility (Mertens, 2003).

2.5.6 Total dietary fibre method

The total dietary fibre method aims to build on the gaps of the detergent method. This method is best suited for analysing feed ingredients meant for monogastric animals (especially pigs) with hindgut fermentation (Agyekum & Nyachoti, 2017). This process involves separating fibre into its soluble and insoluble components through enzymes (such as amylase, glucoamylase, and protease) which stimulate the digestive process in the small intestine (Prosky et al., 1984; Mertens, 2003; Agyekum & Nyachoti, 2017). The carbohydrates components of the total dietary fibre comprise celluloses of hemicelluloses, oligosaccharides, lignin, pectins, and gums. Therefore, the total dietary fibre is different from NSPs because of the presence of lignin (Agyekum & Nyachoti, 2017). Also, the fibrous component of the feed is recovered the most by the total dietary fibre (TDF) method rather than the NDF. However, the TDF procedure does not recover oligosaccharides soluble in aqueous ethanol (Agyekum & Nyachoti, 2017). Compared to the crude fibre and detergent methods, the total dietary fibre method is less repeatable and more time-consuming; however, the value obtained through this procedure better represents the perception of dietary fibre (Mertens, 2003).

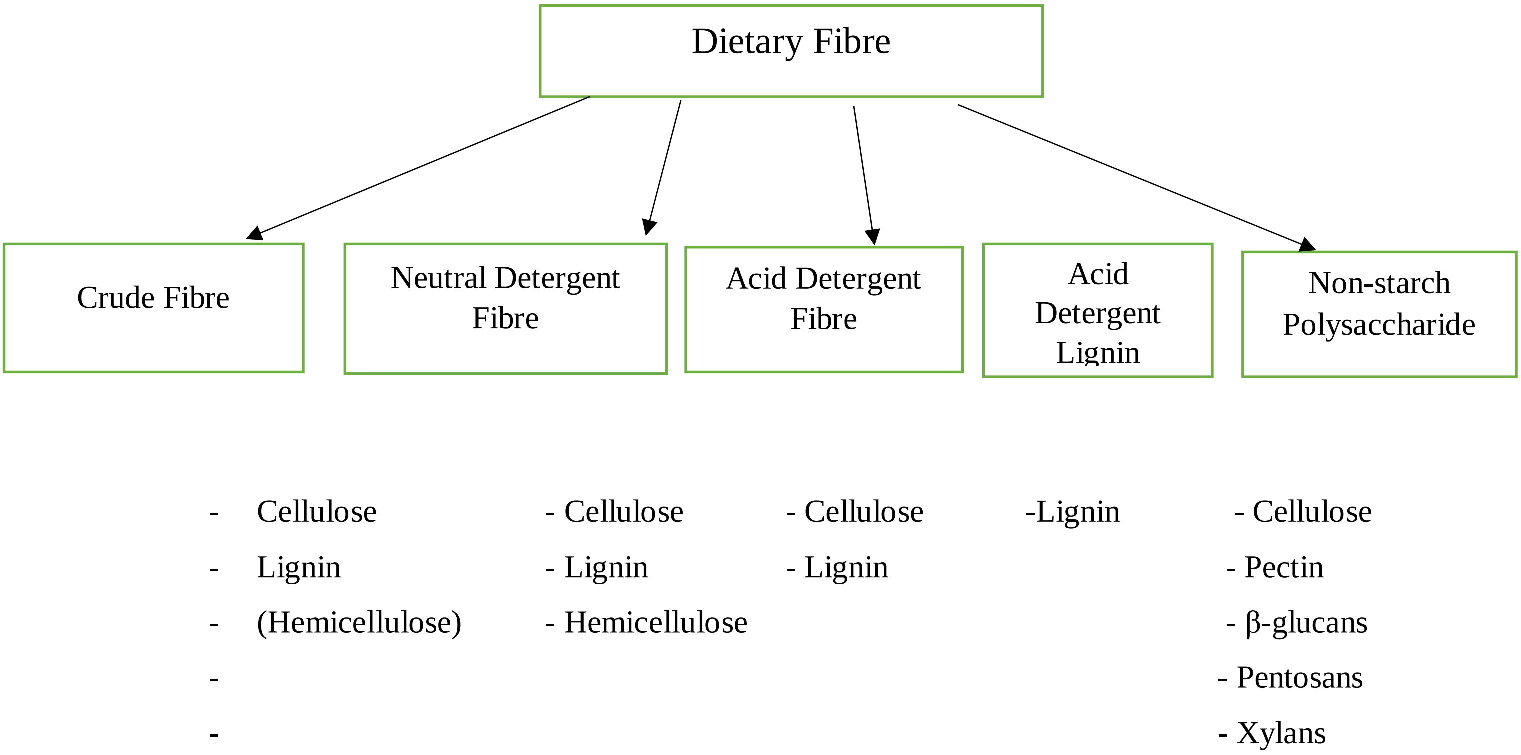

Figure 3: Fraction and compounds of dietary fibre. Adapted from Souffrant (2001) and Agyekum & Nyachoti (2017).

2.6 Physicochemical properties of the fibre

When certain properties of the physical nature of the fibre act in harmony with the intrinsic chemical properties, a wide array of physiological effects are exhibited as a result (Knudsen, 2001). The nature of the polymer found in the cell wall and the intermolecular association between the polymer dictate the physico-chemical properties of the fibre (McDougall et al., 1996). This unique feature distinguishes dietary fibre from other digestible polysaccharides such as sugar and starch (Urriola et al., 2012).

Many physico-chemical characteristics of fibre can influence the digestive processes, either separately or collectively, on the attribute of dietary fibre such as its bulkiness, gel-formation, viscosity, solubility, absorption, and water holding capacity. This can affect mastication time or stomach and gut fill, potentially stimulating satiety (Bergner 1980; Bolhuis et al., 2010). The main physicochemical characteristics of fibre can be classified as.

2.6.1 Hydration

The hydration properties of fibre include other characteristics such as swelling capacity, solubility, water-holding capacity (WHC), and water-binding capacity (WBC; Knudsen, 2011). The solubilisation process of polymer is first triggered through swelling, followed by a full extent of dispersion and extension as water spreads the macromolecules apart until they are solubilised (Thibault et al., 1992). There is a three-dimensional space expansion of the cell wall, as seen in Figure 4. Solubilisation involves the ability of fibre to dissolve in water (Oakenfull, 2001) and in other solvents such as diluted base, diluted acid, or an enzyme solution that mimic the solution in the GIT (Cho et al., 1997).

In water, dietary fibre swells to an extent, but it swells much less when dietary fibre such as pectin is submerged in a less hydrophilic substance than water (Knudsen, 2001). To this end, factor such as the linkage between and among monosaccharide units that make up the fibre affects its solubility (Oakenfull, 2001). For instance, in polysaccharides with an β-(1–4) linkage among glucose units (such as cellulose or linear arabinoxylans) resulting in an ordered or structure form, solubilisation is not possible because the strength of the noncovalent bond is increased as a result of its linear structure (Thibault et al., 1992; Oakenfull, 2001). Therefore, this stimulates the ordered conformation to be stabilised, resulting in it being insoluble. However, only swelling can occur under this condition (Thibault et al., 1992; Oakenfull, 2001).

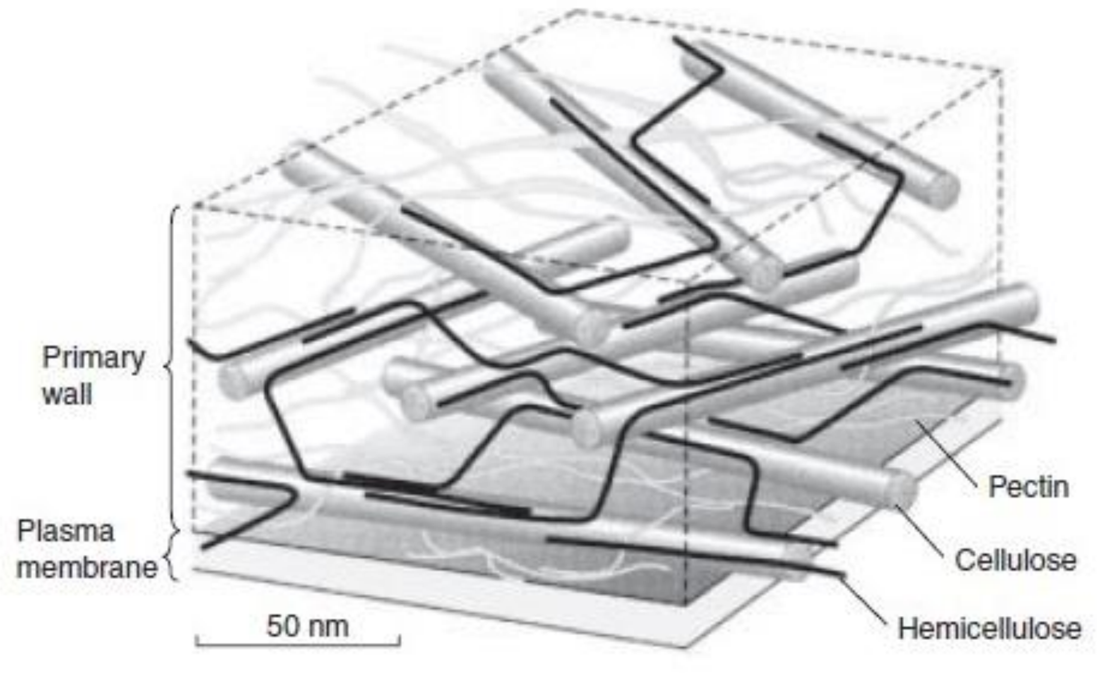

Figure 4: A three dimensional model of the plant cell walls. Adapted from McCann & Robert (1991).

2.6.2 Water-holding and water-binding capacity

The water holding capacity (WHC) and the water-binding capacity (WBC) are hydrating properties of fibre that are interchangeably used to describe the capacity of dietary fibre to integrate water into its matrix (Knudsen, 2001). The WHC is defined as the amount of water bound within the fibre matrix without applying an external force, the WBC. On the other hand, the amount of water retained within the hydrated fibre matrix after a force is applied (Robertson et al., 2000).

There are different mechanisms through which water is bonded in the fibre matrix; these include hydrogen bonding, water capillary action and ionic interaction (Chaplin, 2003). As a result of this mechanism, fibre, including the soluble and insoluble components, can bind to water (Oakenfull, 2001). There are different procedures through which the WBC can be measured in fibre. These include centrifugation, suction pressure and the use of a dialysis tubing immersed in simulated gut content (Stephen & Cummings, 1979; Cadden, 1987; Chaplin, 2003). On the other hand, the WHC can be measured using procedures such as the Baumann apparatus (Auffret et al., 1994) or the filtration method (Chaplin, 2003).

Certain factor influences the intensity of the WBC in the fibre. Examples of such factors include pH, the electrolyte concentration in the surrounding fluid, composition of fibre, and other physico-chemical structures within the fibre molecule (Knudsen, 2001; Urriola et al., 2012). On the other hand, for the WHC, the fermentability of the fibre is influenced by it (Agyekum & Nyachoti, 2017). Notably, the amount of water bound and the binding strength depend on the different fibre types (Cadden, 1987; Chaplin, 2003). For example, pectin-containing high fibre source has a higher WBC than fibre sources from cereal (Knudsen, 2001). Since there is a close association between the fibre's swelling properties and the WBC (Auffret et al., 1993), the WBC is often recommended to correctly measure the fibre's bulkiness (Kyriazakis & Emmans, 1995). As a result, insoluble fibre usually has a smaller WBC than soluble fibre (Auffret et al., 1994; Robertson et al., 2000). It is worthy to note that it is difficult to make a comparison of the WBC values obtained from different studies (Knudsen, 2001) due to the inconsistent results provided by the different methods of measuring the WBC, such as centrifugation, filtration and dialysis bags (Thibault et al., 1992).

2.6.3 Viscosity

Viscosity can be defined as gel formation in a high molecular weight aggregates solution due to the dissociation of dietary fibre (especially soluble fibre) in the gastrointestinal tract

(Dikeman & Fahey, 2006; Agyekum & Nyachoti, 2017). Soluble fibre is capable of increasing the viscosity of the digesta (Knudsen, 2001). The level at which viscosity is formed depends on the ability of the soluble fibre to form a covalent bond with surrounding water and fibre molecules (Knudsen, 2001). These viscous soluble fibres trigger mechanisms such as gastric distention and a slower emptying rate, leading to a reduction in feed intake due to increased satiety (Svihus & Hervik, 2019). For example, viscosity in pigs has been reported to increase when pigs are fed soluble fibre like gums, pectin or β-glucans (Takahashi et al., 2009). Usually, insoluble fibre does not cause viscosity but may indirectly influence viscosity through the way it absorbs water (Takahashi et al., 2009).

Likewise, viscosity is influenced by many other factors. For instance, factors such as the molecular weight, temperature, pH, fibre structure, chemical composition, particle size and concentration of the polymer affect the viscosity of the fibre (Knudsen, 2001; Takahashi & Sakata, 2002; Dikeman & Fahey, 2006; Kristensen & Jensen, 2011; Kumar et al., 2012; Ho et al., 2015). More specifically, the viscosity of the diluted solution is increased by larger molecules; this is made possible mainly due to the volume the large molecule occupies (Knudsen, 2001). For instance, a high-molecular-weight guar gums diet produced a more viscous solution than a low-molecular-weight guar gums diet even when both diets had an equal inclusion rate (Dikeman & Fahey, 2006). Similarly, greater apparent viscosity was observed in the caeca of the pig fed larger particle size fibre than in pigs fed small particle size fibre (Takahashi & Sakata, 2002).

Likewise, the viscosity and flow of the digesta are significantly influenced by the quantity of fibre in the diet. Jørgensen et al. (1996) confirmed this in their study where they reported that due to the high fibre content of the diet, a five to a six-fold increase in the flow of digesta was observed. Similarly, an increase in the volume of viscous digesta, low pH, reduction in satiety and transit time in the GIT have typically been associated with the digestive tract of pigs fed a high content of soluble fibre than a low fibre content or insoluble fibre. Consequently, a high fibre content diet causes more water binding in the stomach than a low fibre content (Drochner & Coenen 1986; Van der Meulen & Bakker, 1991; Johansen et al., 1996). For example, the effects of feeding growing pigs low and high levels of fibre on the pH in the postprandial state in the fundus region of the stomach were studied by Drochner & Coenen (1986). They observed that when pigs were fed a high fibre diet, the pH remained constant at about 2.5, increasing rapidly to 4 when fed a diet containing low dietary fibre. Subsequently, over the following 6 hours, the pH value decreased steadily to a level similar to the high fibre content diet (Figure 5).

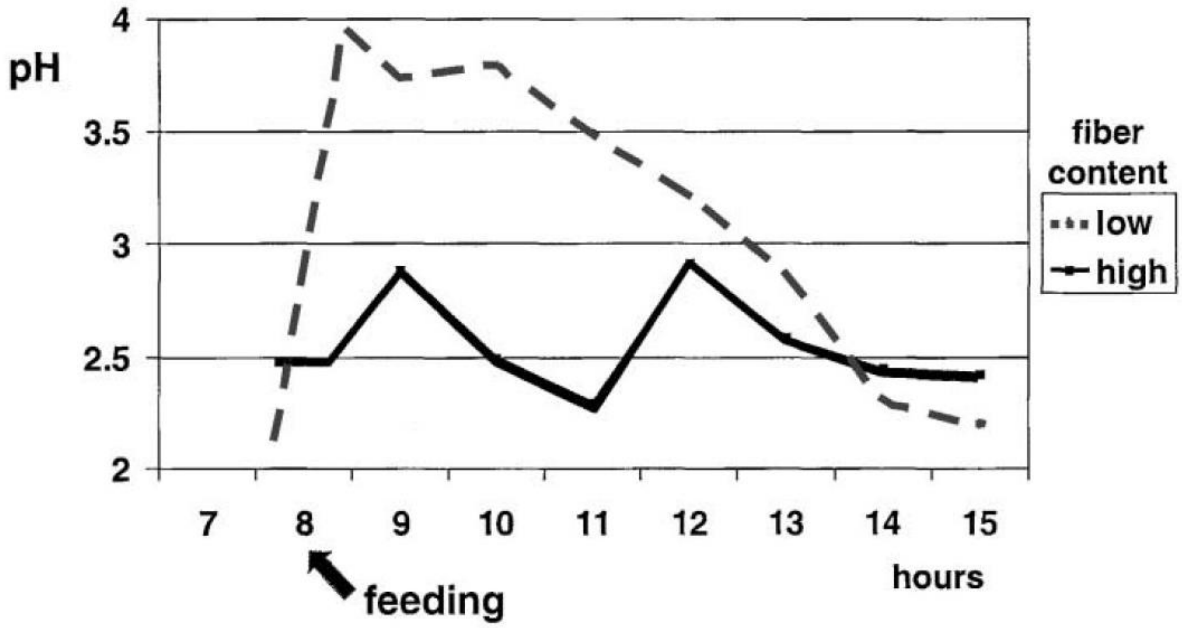

Figure 5: Postprandial pH values (in stomach fundus) after meals with a low or high fibre content in pigs (Drochner & Coenen, 1986).

2.6.4 Fermentation

Fermentability can be described as the capacity of microflora harboured in the intestine to ferment the NSP (Agyekum & Nyachoti, 2017). How dietary fibre is susceptible to the fermentation caused by the microbe in the guts depends mainly on how accessible the microbial population has to the fibre (Oakenfull, 2001). The fermentation is necessitated due to the increase in the surface area of the polysaccharide for microbial action, which is triggered by the swelling of the fibre due to water absorption (Canibe & Knudsen, 2001).

The rate of fermentability in dietary fibre often depends on the solubility and the WBC of the fibre (Urriola et al., 2012). Generally, soluble fibres are more fermentable than insoluble fibres (Agyekum & Nyachoti, 2017). This could be because soluble fibre has a higher WBC and swells to a more considerable extent than insoluble fibre (Auffret et al., 1993; Auffret et al., 1994; Oakenfull, 2001). The site of fermentation depends on the type of dietary fibre. For instance, for soluble fibre, fermentation occurs at the proximal colon, while for the insoluble fibre, fermentation is continued until the distal colon (Cho et al., 1997). The microbiome fermentation of fibre in the hindgut usually continue for many hours after feeding (Bolhuis et al., 2010). Consequently, there is a gradual release of energy from fermentation by-products, such as short-chain fatty acids (SCFA), which possibly extend the period of satiety between meals (Bolhuis et al., 2010).

The fermentability of the fibre does influence the faecal weight increase (Stephen & Cummings, 1979). The increase in the faecal output results from the fermentable fibre stimulating microbial growth, increasing the faecal biomass (Cho et al., 1997). A similar increase in the faecal output can also be attributed to undegraded residue from dietary fibre that was poorly fermented (Stephen & Cummings, 1979). Therefore, the faecal output increase in dietary fibre consisting of insoluble and soluble fibre is attributed to an increase in faecal microbial mass and residue of fibre that has been undegraded (Cho et al., 1997).

Short-chain fatty acids are a by-product of the fermentation of dietary fibre in the distal small intestine but principally in the colon, which influences satiety (Sleeth et al., 2010). These by-products include acetate, carbon dioxide, propionate, hydrogen and methane (Lunn & Buttriss, 2007). The level of fatty acid produced depends on the physicochemical structure of the dietary fibre (Lunn & Buttriss, 2007). Amongst the many volatile fatty acids produced from the fermentation of dietary fibre, acetate is the most abundant, comprising about 60% of the SCFA produced in the hindgut. In contrast, other VFAs such as propionate and butyrate are produced in lesser amounts (Lunn & Buttriss, 2007). Other functions of SCFA include ensuring stabilisation of glucose and insulin levels in the blood (Higgins, 2004) as well as stimulating the production of satiety-related hormones such as Glucagon-like peptide (GLP-1) and peptide tyrosine tyrosine (PYY; Darzi et al., 2011). Also, in the moment of decreased glucose absorption in the small intestine, SCFA could serve as an additional energy source (de Leeuw et al., 2005).

2.7 Dietary fibre and the digestive process

Dietary fibre has a significant impact on the GIT of pigs. Its impact ranges from long term alteration of the anatomy to the physiological processes of the digestive system in pigs (Wenk, 2001). Also, the fibre in the diet can affect feed intake and influence the digestive conditions in the stomach and small intestine even before it reaches the large intestine due to its physico-chemical properties (Souffrant, 2001). In the stomach, the presence of fibre in the diet triggers an increase in the retention time of the digesta, thereby leading to satiety or reduced feed intake

(Wenk, 2001). An opposite effect is exhibited in the small intestine; instead, a fibre decreases the mean retention time of the digesta, thereby creating less time for exposure of the digestive enzymes to act on it (Bindelle et al., 2008).

Studies had shown an alteration of the epithelial morphology when pigs were fed fibre containing diets (Agyekum & Nyachoti, 2017). For example, in growing pigs, Jin et al. (1994) reported enlargement of the villi and deepening of the crypts in the jejunum and ileum for pigs fed a diet comprising of 10% wheat straw in comparison with the control diet. These findings were consistent with those found in the studies that fed pigs diet rich in fibre (Jin et al., 1994; Brunsgaard, 1998; Serena et al., 2008). In addition, reduced transit time in the small and large intestine and increased peristaltic movement are associated with pigs fed high dietary fibre (Wenk, 2001). A similar result was reported by Jin et al. (1994) when they observed that fibre in the diet influences the rate of intestinal cell turnover alongside the intestinal morphology in pigs. This resultantly affected nutrient digestion, absorption and metabolism.

The ingestion of dietary fibre results in an increase in the size of the organs in the GIT due to the secretion of digestive juice and enzymes (Agyekum & Nyachoti et al., 2017). For example, a heavier stomach, large intestine, small intestine and liver weight were reported by two different studies conducted by Anugwa et al. (1989) and Pond et al. (1989). In their study, pigs were fed a diet comprising maize-soybean meal and 40% alfalfa meal compared to the control diet comprising just maize-soybean meal. Similar results were reported by Nyachoti et al. (2000) and Agyekum et al. (2012). Also, Zebrowska et al. (1983) confirmed this when they reported a doubling of saliva and gastric juice secretion of growing pigs when they were fed identical crude fibre content and increasing dietary fibre content (50 to 180g/Kg). Also, with the increase in dietary fibre, Zebrowska et al. (1983) reported an increased secretion of fluids of the upper digestive tract and bile and the doubling of the pancreatic juice (Table 2.1). As a result of the increased secretion of digestive enzymes, effective digestion of feed is anticipated, and higher activity of secretory organs resulting in enlargement of the organ (Zebrowska et al., 1983; Zebrowska, 1985; Langlois et al., 1987). Zebrowska et al. (1983) confirmed the findings of Mosenthin et al. (1994) in a similar experiment using pectin as the source of the soluble dietary fibre. Similar results have been reported by Langlois et al. (1987), Low (1989), Souffrant (2001), and Montagne et al. (2004).

Likewise, when growing-finishing pigs were fed diet containing high fibre content (268 g/Kg DM), as compared to those being fed low dietary fibre (59 g/Kg DM), a significantly heavier stomach, caecum, as well as a heavier and longer colon, was observed (Jørgensen et al., 1996). In fact, an increase in passage rate has been reported for low and highly soluble fibre (Ratanpaul et al., 2019). Another study conducted by Jørgensen et al. (1997) also confirmed this. In this study, a five to six times increase in the rate of passage measured at the end of the ileum were associated with pigs that consumed high dietary fibre diets (pea fibre and pectin; 268g/kg) than pigs fed low dietary fibre (59g/kg). This effect was attributed to the water holding capacity of the fibre used in the diet. Overall, Table 2.2 shows the general summary of the effect of dietary on the GIT processes in pigs.

Table 2.1: Dietary fibre and endogenous secretions in the digestive tract of pigs weighing approximately 50 kg. Adapted from Zebrowska et al. (1983).

Ingredients	Purified diet 1 Casein, starch, cellulose, vitamin mineral premix	Normal diet Barley, soybean meal, fish meal, vitamin-mineral premix
Crude fibre	Identical	Identical
Dietary fibre g/kg	50	180
Saliva and gastric juice, 3 per day	4	8
Pancreatic juice, 3 per day	1.2	1.2
Bile, 3 per day	1.2	1.7

Table 2.2: Summary of effects of soluble and total dietary fibre on rheological properties of the GIT content and digestion and absorption processes in pigs (Source: Knudsen, 2001)

	Dietary fibre		
	Soluble	Insoluble	Total
Stomach			
Viscosity	***	*	**
WBC	**	***	**
Emptying	*(*)	*	*
Small intestine			
Viscosity	**	-	*
WBC	**	***	***
Glucose-absorption	(*)	-	-
Large intestine			
Fermentation	****	***	***
Bulking	*	****	****
Mean-Transit Time	-	***	***
Energy			
Ileum	***	****	****
Faeces	-	****	****

Keys:

- : No relation

*-**** : Relative strengths of relation.

[a] Water binding capacity

2.7.1 Influence of age in the digestibility of fibre

The age of the animal plays a significant role in the digestibility of dietary fibre. This is why younger animals such as growing or finishing pigs can only digest a small quantity of fibre than older animals such as Sows (Le Goff & Noblet, 2001). This can be explained by a mechanism such as an increase in the number of bacteria microflorae with age, more developed GIT as well as a reduction of the relative feeding level (Dierick et al., 1989; Noblet & Shi, 1993; Varel & Yen, 1997; Lindberg, 2014). Also, mean retention time through the GIT, nutrient and fibre digestibility increases with the pig's age (Le Goff et al., 2002; Kim et al., 2007). For instance, Noblet & Knudsen (1991) observed that younger animals were unable to digest dietary fibre than adult animals; as a result, there was a more pronounced negative effect of the dietary fibre on the nutrient and energy digestibility in them.

Similarly, Whittemore et al. (2003) discussed in their study that pigs could get adapted to bulky food due to the increase in gut size and capacity that comes along with increasing body weight and age. Also, characteristics such as gut morphology (Jørgensen et al., 1996), mucosal maturity and integrity (Goodlad et al., 1995; Stark et al., 1995; Brunsgaard, 1998), nutrient absorption as well as the digestive processes in the GIT (Cummings & Englyst, 1995) of pigs is influenced by the physico-chemical properties of the fibre in the diet. The utilisation of dietary fibre from a different source varies in pigs (Wenk, 2001). In sows, the digestibility of fibre fractions in a diet was higher for soybean pulp (0.74) and maise (0.86) than in wheat bran (0.46) (Noblet & Knudsen, 1991). As a result, the level of dietary fibre influences digestibility and absorption and the type or source of fibre also play an essential role (Michel & Rerat, 1998; Wenk, 2001). For example, a reduction of faecal transit time and digestibility of nutrients when diet containing cellulose and insoluble lignified fibre is fed to pigs (Table 2.3).

Table 2.3: Effect of dietary fibre on the digestion processes and satiety in animals. Source: Wenk (2001).

Source of dietary fibre	Slower the emptying of the stomach	Achieving satiety	Shortening faecal transit time	Increasing microbial activity	Energy digestibility	
					Ileal	Faecal
Cellulose	Weak	Weak	Relevant	Not existing	Very important	Very important
Insoluble, lignified	Weak	Weak	Very important	Weak	Very important	Very important
Vegetables, fruit	Medium	Medium	Weak	Very important	Medium	Weak
Pectins/guar	Very important	Relevant	Weak	Very important	Medium	Weak

2.7.2 Influence of ileal and colonic brake on feed intake

The ileal and colonic brake can influence the quantity of feed consumed by pigs. Colonic and ileal brake is triggered by undigested nutrients (Black et al., 2009; Lee et al., 2013). Consequently, this results from the decline in the rate of passage of the digesta. Therefore, this increases the extent of digestion because of the corresponding increase in time available for enzymatic digestion to act on the digesta in the small intestine. Therefore, there is a reduction in feed intake through delayed gastric emptying (Ratanpaul et al., 2019). Including more quantity of indigestible dietary fibre encourages feed intake, which stimulates the rate of passage. As a result, the negative influence of ileal brake on feed intake may be compensated (Campbell, 1988; Black et al., 2009). These findings were consistent with the study conducted by Vicente et al. (2008), where they reported the effect of feeding cooked rice and maize to pigs from 25 until 53 days of age. The pigs fed cooked rice had a 23% higher feed intake than pigs fed cooked maize only.

A similar result has been reported by Mateos et al. (2006), in which piglets were fed cooked maize and cooked rice in the combination of expanded hulls at an inclusion rate of 20 and 40 g/kg. An increase in feed intake was reported for the piglets fed a combination of rice, and oat hull, unlike that of the piglets fed cooked maise and oat hull that observed a reduction in feed intake. This decrease in feed intake for piglets fed a combination of oat hull and cooked maize may be due to the higher indigestible fibre levels in the maize, increasing the digesta passage rate, resulting in more maize starch ending up in the distal intestine, thereby activating the ileal brake.

Furthermore, the conclusions drawn from the critical assessment of the studies mentioned above confirmed that indigestible dietary fibre exacts the following influence (Ratanpaul et al., 2019). Firstly, quick activation of the ileal brake of slowly digestible cereal grains, thereby exalting a negative impact on feed intake (such as reducing feed intake). Secondly, stimulating the rate of passage of digesta of highly digestible cereal gain, thereby encouraging feed intake and maximising digestion before the ilea brake has a chance to act. Therefore, these studies have shown that nutrient digestibility due to the inclusion of dietary fibre impacts feed intake. Therefore, the following sections will address the role of fibre in nutrient digestibility.

2.7.3 Effect of dietary fibre on nutrient digestibility

A high fibre diet has been observed to have an adverse influence on nutrient digestibility in pigs. The extent to which there is a reduction in nutrient digestibility may be due to the type (such as insoluble/soluble fibre) and level of fibre used, such as high/low fibre levels (Asp, 1996; Wenk 2001; Hopwood et al., 2004). The increased endogenous intestinal nutrient loss can explain reduced nutrient digestibility due to a high fibre diet (Schulze et al., 1994; Wenk, 2001; Souffrant, 2001; Montagne et al., 2003; Montagne et al., 2004). Besides, the negative influence of a high fibre diet can also be explained through the following mechanism. The solubility of the fibre is one such mechanism that influences nutrient digestibility, thereby affecting transit time and gut fill which impact feed intake. For example, Wenk (2001) reported a slowdown in the diffusion of substrate and enzymes in the pig's small intestine and an increase in the viscosity of the digesta, thereby hampering digestion and absorption. In this context, a similar effect of an increase in digesta's viscosity and reduction in nutrient digestion is also applicable for other soluble fibre such as guar gum, sugar beet pulp, oats, wheat (Knudsen & Hansen, 1991; Knudsen, 2001; Owusu-Asiedu et al., 2006).

In contrast, insoluble fibre fed to pigs exhibited a reduction in the passage rate of the digesta, thus allowing a decrease in the mixing time of other dietary components and digestive enzymes (Wenk, 2001). For example, similar results were reported from different studies conducted by Owusu-Asiedu et al. (2006), Wilfart et al. (2007a), Bindelle et al. (2008) and Le Gall et al. (2009). In these studies, insoluble fibre from corn bran, cellulose and wheat bran were utilised, also exhibited a decrease in nutrient digestibility due to a reduction in transit time of the digesta. However, in a study conducted by Urriola & Stein (2010) using DDGS as the insoluble fibre, there was no effect on the transit time of the digesta. Therefore, this suggests that the varying effects of the insoluble fibre on the transit time of the digesta differ amongst studies, which could be explained as a result of interfering factors intrinsic in the fibre found in natural feedstuffs (Agyekum & Nyachoti, 2017). Nonetheless, when diet containing insoluble NSP were fed to pigs, the transit time of the digesta in the hindgut was reduced compared to transit time in the small intestine that remain unaffected (Wenk, 2001; Wilfart et al., 2007a). Similarly, a diet high in NSP reduces nutrient digestibility because it encapsulates the nutrient, restricting access to the digestive enzymes for hydrolysis (Wenk, 2001).

2.7.4 Effect of dietary fibre on starch digestibility

Furthermore, in terms of the effect of dietary fibre on the digestibility of macronutrients such as starch, several reports have observed that the overall effect of starch digestibility in pigs is not influenced by the fibre content of the diet (Knudsen & Hansen, 1991; Knudsen et al., 1993; Högberg & Lindberg, 2004). For example, a study conducted by Wilfart et al. (2007b) confirmed no effect on starch digestibility when different inclusion rate of wheat bran was added to a barley-based diet or a cereal-based diet respectively. However, with an increase in fibre intake, there may be a reduction in starch digestion and absorption (Jenkins et al., 1987; Serena et al., 2009).

There is no effect of fibre on starch digestibility because the relatively long length of the small intestine has been efficiently digested by the time digesta reaches the end of the ileum (Knudsen & Hansen, 1991). In contrast, the activities of endogenous enzymes, especially carbohydrase, may be reduced due to the consumption of dietary fibre (Khokhar, 1994). More specifically, in a study conducted by Wenk (2001), he suggested that a reduction in the transit time of the digesta was as a result of intake of feed rich in fibre, which resulted in a greater percentage of the starch passing through the ileum undigested. Similar results of reducing ileal starch digestibility for growing-finishing pigs were reported by Gao et al. (2015) and Agyekum et al. (2016) when they included 30% DDGS and 5% inulin to a diet based on the maize-soybean meal. Thus, reducing the ileal starch digestibility could increase the ileal starch flow (Gao et al., 2015; Agyekum et al., 2016).

2.7.5 Effect of dietary fibre on protein and amino acid digestibility

Generally, ileal and total tract digestibility tend to reduce with a diet rich in fibre (Agyekum & Nyachoti, 2017). For example, Buraczewska et al. (2007) observed that when 4% or 8% apple pectin was added to wheat, maize and soybean meal-based diet, there was a reduction in the standardised ileal digestibility (SID) of crude protein and amino acid. Similarly, a reduction in ileal N digestibility was also reported by Schulze et al. (1994) when increasing levels of purified NDF gotten from wheat bran and diet based on soy isolate and corn-starch were fed to pigs. Likewise, linear or quadratic reduction in apparent ileal digestibility (AID) and SID of most amino acids were reported when an increase in the concentration of NDF (from 2.72% to 4.16%) was caused as a result of the inclusion of soy hulls (3-9%) to soybean meal-maize starch-based diet (Dilger et al., 2004).

A plausible explanation for the reduction in both ileal protein and amino acid protein digestibility in pigs when a diet rich in fibre was consumed is because of the accompanying increase in the exogenous and endogenous amino acid losses (Nyachoti et al., 1997; Wenk, 2001; Souffrant, 2001), digestion impairment and reduction in crude protein (CP) absorption (Mosenthin et al., 1994). Similarly, reducing the total tract protein digestibility in pigs may result from the increased faecal excretion of microflora such as bacterial protein (Nyachoti et al., 1997; Wenk, 2001; Souffrant, 2001). Likewise, there is an associated decrease in ileal nitrogen and amino acid digestibility when amino acid and peptides are withheld from digestion in the small intestine because the fibre absorbs them in the diet (Souffrant, 2001).

2.7.6 Effect of dietary fibre on lipid/fat digestibility

The influence dietary fibre exhibit on lipid digestibility has been widely studied in pigs. For example, Shi & Noblet (1993) observed a depression in lipid digestibility when a diet containing high fibre content was fed to pigs. Graham et al. (1986) also reported a reduction in the AID and the apparent total tract digestibility (ATTD) of fat when beetroot was added to a basal diet. A similar result was reported by Wilfart et al. (2007a) when growing pigs were fed a cereal-based diet with a 20% or 40% inclusion level of wheat bran. There are several mechanisms through which dietary fibre reduces lipid digestion in pigs. One of such methods is through the digesta passage rate (Agyekum & Nyachoti, 2017). For instance, the time required for the digestive enzymes to act on the dietary fat is reduced because dietary fibre triggers an increase in the rate of passage of the digesta (Schneeman & Gallaher, 1985; Story, 1985). However, another approach of dietary fibre depressing lipid digestibility is through binding with the bile salt in the duodenum, thereby rendering the bile salts unavailable for emulsification of lipids. Consequently, there is a reduction in blood cholesterol level due to the additional synthesis of bile salts from the blood cholesterol (Schneeman & Gallaher, 1985; Story, 1985).

Notably, the type of fibre plays a crucial role in the severity at which lipid digestibility is reduced (Dégen et al., 2007). In terms of the soluble fibre, substrate-enzyme interaction is prevented by increasing digesta viscosity elicited by the soluble fibre (Dégen et al., 2007). However, for insoluble fibre, the transit time of the digesta is reduced, which resultantly increases the excretion of lipid in the faeces (Dégen et al., 2007). On the other hand, not all studies have observed decreased lipid digestibility due to dietary fibre inclusion. For example, there was no effect on lipid digestibility in a study conducted by Le Gall et al. (2009) when pigs were fed fibre-rich diets containing wheat bran, maize bran, soybean hulls and sugar beet pulp. Similar results have been reported by Kil et al. (2010) when they fed a purified NDF rich diet.

Alternatively, an increase in lipid digestibility was reported by other studies. For instance, an increase in fat digestibility was observed in a study where growing pigs were fed a diet comprising brans from oats, rye and wheat (Högberg & Lindberg, 2004). This can be explained by the fact that fat digestibility is influenced by the solubility of the diet containing a mixture of different sources of fibre (Le Gall et al., 2009). Their findings were consistent with Gao et al. (2015), who fed growing pigs a diet containing 5% inulin and 5% sodium carboxymethylcellulose (CMC).

2.7.7 Effect of dietary fibre on energy metabolism

The influence of dietary fibre exhibit on energy metabolism has also been widely studied in pigs. The overall effect shows a negative influence of dietary fibre on the pig's energy metabolism (Agyekum & Nyachoti, 2017). For instance, energy digestibility was reduced due to lignin in the fibre of the diet (Wenk, 2001). The process through which dietary fibre influences energy metabolism negatively can be explained through different mechanisms (Agyekum & Nyachoti, 2017). One such mechanism is that the digestibility of energy-yielding nutrients such as protein, starch and lipid is generally decreased as a result of the substitution with cells of the fibre constituent in the diet of the pig, which resultantly leads to the low digestibility of energy (Urriola et al., 2012; Agyekum & Nyachoti, 2017).

Also, the ingestion of a diet high in fibre that increases the visceral organ mass may be another mechanism to explain the decrease in energy metabolism (Agyekum & Nyachoti, 2017). A significant portion of the nutrient and energy supplied to the body are directed to the maintenance of the visceral organs because they are metabolically active tissue (Yen & Oxygen, 1997; Agyekum & Nyachoti, 2017). More specifically, the visceral organs are jointly drained by the liver and the portal vein. As a result, it is collectively termed splanchnic tissues (Yen & Oxygen, 1997; Agyekum & Nyachoti, 2017). Therefore, when the whole body energy demand is measured in terms of the quantity of oxygen intake, it was reported that the portal vein alone accounts for nearly 25% (Yen et al., 1989). In addition, Yen & Oxygen (1997) reported that 45% of the whole-body energy demand in pigs is supplied to the splanchnic tissues.

Another mechanism that explains the negative effect of dietary fibre on energy metabolism is the increased production of amino acids and endogenous nitrogen due to the secretion of digestive juices and enzymes when dietary fibre is consumed (Agyekum & Nyachoti, 2017). Consequently, an increase in gut protein turnover is triggered by the increased production of endogenous nitrogen and amino acid production, improving blood flow and transport of digestive products through the digestive tissues (Lobley et al., 1980). As a result, substantial energy is needed for these processes, increasing the maintenance energy requirement (Wenk, 2001).

2.7.8 Effect of dietary fibre on mineral digestibility

So far, the effect of dietary fibre on mineral digestibility has been inconsistent. In a study conducted by Moore et al. (1988), they observed that the total tract digestibility of minerals such as P, Zn, Ca or Mn was not affected by fibre rich diet containing oat hulls alfalfa meal and soybean hulls inclusion. These findings are consistent with those found in a study carried out by Vanhoof & De Schrijver (1996) in which pigs fed a diet containing 6% inulin did not affect the AID and ATTD of P, Ca, Zn and Mg. However, in comparison with the maize-SBM diets, there was a depression in the per unit of minerals ingested of serum concentration of P, Cu, Ca and Zn when sows were fed high-fibre-diet containing a mixture of wheat bran, oats, maize-cobs and oat hulls (Girad et al., 1995).

2.8 Influence of dietary fibre on voluntary feed intake in growing pigs

Dietary fibre has a direct impact on feed intake. Evidence from recent studies has reported that dietary fibre may influence satiation or satiety (Gerstein et al., 2004). For example, when a diet containing up to 30% cereal grain co-products were fed to growing-finishing pigs, it did not elicit a decrease in feed intake (Stein & Shurson, 2009; Gutierrez et al., 2013; Agyekum et al., 2012; 2014; 2015). Similarly, for other classes of pigs like the low performing dry sow, Wenk (2001) reported that the inclusion of fibre in the diet increased feed intake. The increase in feed intake due to the addition of fibre can be explained due to the dilution effect of fibre, which is based on the mechanism that fibre is a low energy content fraction (Wenk, 2001). Since fibre reduces not only the DE content but also the nutrient and energy digestibility of the diet (Noblet & Le Golf, 2001), to meet up with energy requirement, the pig, therefore, increases its feed intake of the fibre rich diet (Cole et al., 1968; Torrallardona & Roura, 2009).

Furthermore, when there is a steady increase in the fibre concentration, a tipping point is reached when the pig cannot compensate for the diluting effect, resulting in reduced total dietary intake (Fowler, 1985). More importantly, pigs' nutrient and energy utilisation can be influenced negatively by consuming a diet high in fibre (Wenk, 2001; Owusu-Asiedu et al., 2006; Agyekum et al., 2014;2015). As a result, the amount of energy and available nutrient in the feed has been reported to depend on the quantity of fibre in the diet due to its diluting effect (Wenk, 2001). Hence, only a minimal inclusion level of fibre is recommended in a pig's diet, especially for growing pigs. For instance, a diet composing of high fibre has been observed to increase satiety (Langhans, 1999; Burton-Freeman, 2000; Slavin & Green, 2007), which greatly reduces feed and energy intake (Pereira & Ludwig, 2001; Wanders et al., 2011; Agyekum & Nyachoti, 2017). This is because not only does a diet high in fibre contains less metabolisable energy than a diet low in fibre (Rijnen et al., 1999), but it increases gut fill due to its bulky nature (Kyriazakis & Emmans, 1995; Owusu-Asiedu et al., 2006; Ndou et al., 2013). This is why the diets of growing-finishing pigs contain low fibre content to ensure maximum nutrient and energy intake (Wenk, 2001). Similarly, a diet rich in fibre has been reported to reduce feeding motivation (Brouns et al., 1995).

Another point to consider is the impact of the physico-chemical properties of fibre on feed intake. Dietary fibre is composed of non-starch polysaccharide that influences satiety in monogastric animals, including pigs (de Leeuw et al., 2008; Bolhuis et al., 2010). However, different types of dietary fibre have a varying effect on satiety levels (Slavin, 2010). The following section will emphasise the role of the physical and chemical properties of the fibre and how it exerts an effect on the feed intake or satiety.

2.8.1 The impact of physicochemical properties of the fibre on satiety

The satiating potential of diets with high fibre depends on its physico-chemical properties such as bulkiness (or water-binding capacity), viscosity, and fermentability (Benelam, 2009; Wanders et al., 2011; Souza da Silva et al., 2012). These physicochemical properties are expected to exert their influence on the digestive physiology in various ways throughout the gastrointestinal tract (Benelam, 2009). For example, through the mechanism in which mastication time is increased due to the stimulation of the mechanoreceptors in the GIT, the bulkiness of the fibre can reduce feeding motivation, thereby encouraging satiation (Paintal, 1954; Rolls & Rolls, 1997). Similarly, a reduction in the rate of gastric emptying and the postprandial glucose response (Hoebler et al., 2000) has resulted in early satiation when viscous, and gelling fibre is consumed (Georg Jensen et al., 2013).

Similarly, highly viscous fibre has been observed to cause satiety than low viscous fibre (Jensen et al., 2012). For example, a viscous soluble fibre with physicochemical properties such as high WHC tends to swell after absorbing more water. Therefore, it increases the bulking capacity of the feed and leads to gastric distension and reduced gastric emptying rate, thereby increasing satiety or reduction in feed intake in pigs (Aerni et al., 2000; Marciani et al., 2001; Jarrett & Ashworth, 2018). It is important to highlight that satiation is the sense of fullness during an eating period, leading to meal termination. On the other hand, satiety is the feeling of fullness between periods of eating that tend to impede the further continuation of eating (Gerstein et al., 2004). In a simpler term, while satiety is known as inter-meal satiety, satiation is known as intra-meal satiety (Blundell et al., 2010). Notwithstanding, this difference in the definition is mostly ignored in most fibre studies (Svihus & Hervik, 2019)

More specifically, factors such as decreased energy density, chewing and mastication period, and physico-chemical properties (such as its gelling properties) may facilitate satiation (Delzenne & Cani, 2005). Also, da Silva et al. (2012) reported that rather than the quantity of dietary fibre intake, the physicochemical proprieties of the fibre might play a more significant role in the feeling of satiety. For instance, it was hypothesised that by virtue of the nutrient trapped within a viscous matrix of viscous dietary fibre, it might lead to delayed gastric emptying and a delay in nutrient absorption in the small intestine. This could inadvertently reduce feed intake (Howarth et al., 2001; Ratanpaul et al., 2019).

The fermentability of dietary fibre also plays a significant role in satiety. For example, prolonged satiety is associated with fibres fermented at the caecum and colon (da Silva et al., 2012; 2013). To ascertain the impact of the respective dietary fibre physicochemical properties, a study showed that when adult pigs were fed fermentable fibre, they had less appetite to eat than fed viscous and bulky fibre (da Silva et al., 2012). Similarly, there was also a considerable variation between the efficacy of different fibre types regarding fermentability characteristics such as fermentation kinetics and SCFA-profile (da Silva et al., 2013). For example, butyrate is produced in large quantities by fermentation of resistant starch than other fibre (Champ et al., 2003). As a result, high levels of butyrate production could affect satiety and reduce feed intake due to the increased secretion of satiety-related peptides (Zhou et al., 2006).

Similarly, Bolhuis et al. (2010) reported that a much longer-term, highly fermentable fibre could potentially stimulate satiety for a longer time, thereby reducing feeding motivation. In this context, an increase in consumption of dietary fibre will certainly affect the bowel habit of the animal, not only due to its ability to trigger the production of SCFA and proliferation of microbes but also as a result of the fibre's water-holding characteristic and mechanical action (Knudsen, 2001; Figure 6). Also, in terms of the fermentation kinetics, the differential characteristics of various fibres may influence their ability to ensure satiation. However, it is still not known how fermentation kinetics and end-products of fermentation may affect feed intake or satiety (da Silva et al., 2013).

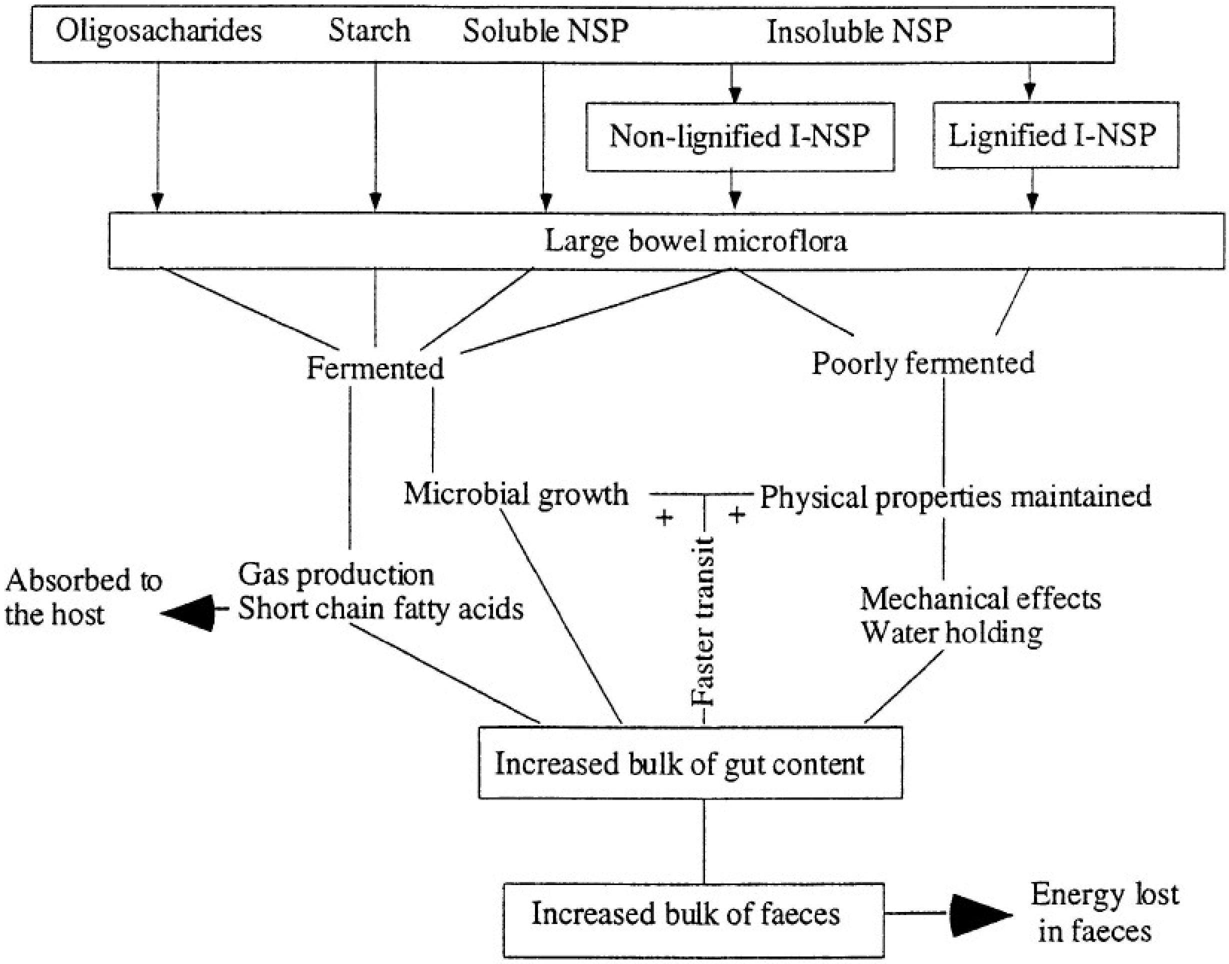

Figure 6: Mechanism of action of dietary fibre and undigested carbohydrates in increasing colonic and faecal weight and bulk. Adapted from Knudsen (2001).

Furthermore, the satiating feeling of dietary fibre is initiated by its underlying mechanisms such as the dilution effects it produces on the energy content of the feed ingredients (Delzenne & Cani, 2005), rise in saliva and gastric juice production as a result of increased chewing activity (D'Eath et al., 2009). Other mechanism includes gastric distension as a result of secretion of saliva, gastric juice and the high water-binding capacity of bulky fibre (Howarth & Saltzman, 2001; Büttner, 2006), delayed gastric emptying, and resultantly, a reduction in intestinal transit time (Brownlee, 2011) which triggers the afferent vagal signals of fullness (Howarth & Saltzman, 2001). In addition, the feeling of satiety is also significantly influenced by the SCFA (such as acetate, propionate, and butyrate), which are produced by the intestinal microbiome fermentation of certain types of fibre in the diet (Darzi et al., 2011). Furthermore, the SCFA can stimulate the cells of the entero-endocrine to produce satiety-related peptides such as PYY and

GLP-1 (Delzenne & Cani, 2005). These peptides can initiate satiety through various mechanisms that directly affect the central nervous system and gut motility (De Silva & Bloom, 2012). Also, the peptide reduces feed intake through a combination of ways, such as ensuring digestion and nutrient absorption by delaying gastric emptying, which resultantly slows transit time (ileal brake; Sleeth et al., 2010).

2.9 Feeding behaviour in pigs: Influence of dietary factors.

It is the natural behavioural inclination of pigs to express their foraging behaviour due to spending a long time feeding (Konstanze & Kaufmann, 2012). The standard compound feed used in commercial pig enterprises for growing pigs does not meet these requirements, resulting in low feeding motivation (Konstanze & Kaufmann, 2012). Many factors, including diet, can influence feeding behaviour. The quantity and composition and how the diet is presented could also affect the feeding behaviour of pigs (Brooks, 2005). For example, the time pig spends on eating and its water demand is influenced by the composition of the diet (Brooks, 2005). Figure 7 shows this relationship. Less satiety resulting from the pig being fed a diet below its voluntary feed intake capacity (for instance, in gestating sows) can lead to some expression of abnormal behaviour called stereotypies (Brooks, 2005). Similarly, incidences of vices such as tail biting and ear or flanks biting are caused by the diet's constituent (Brooks, 2005).

One major dietary factor that affects feeding behaviour is the inclusion of fibre in the diet. The inclusion of fibre in the diet has resulted in a behavioural response that stimulates a reduction in feeding motivation in pigs (Brouns et al., 1995; de Leeuw et al., 2008). A reduction in response is elicited in an operant conditioning test used to measure feed motivation due to a fibre-rich diet (Day et al., 1996a; Robert et al., 1997). A plausible explanation for this mechanism is that when pigs are fed a bulky diet due to fibre, a gastrointestinal distention triggers satiety, thereby spending a long time lying down (Robert et al., 1993; Brouns et al., 1994). This prolonged inactivity by the pig reduces their stereotypical behaviour (Day et al., 1996b). For example, when sows are fed fibre rich diet that is bulky, changes in feeding and stereotypic behaviour are exhibited. In a study conducted by Meunier-Salaun et al. (2001), these changes include a 20% decrease in feeding rate, a 7-50% reduction in stereotypical behaviour, and decreased physical activities such as restlessness and aggression, at least doubling in eating time. Also, studies conducted by Terlouw et al. (1991), Brouns et al. (1994), Bergeron et al. (2000) and Ramonet et al. (2000) reported a similar effect of reduced stereotypic behaviour when pigs were fed fibre rich diet.

Another separate experiment conducted by de Leeuw et al. (2008) reported a 30% reduction in operant response in feed motivation tests when fed a fibre-rich diet. Another study carried out by Whittemore et al. (2002) also exhibited a similar response. Their study reported a significant decrease in feeding rate and an increase in time spent eating when growing pigs were fed a diet containing a medium level of wheat bran and a high level of sugar beet pulp compared to the control diet that had a low dietary fibre level. The reduced feeding rate is a result of more time spent chewing (mastication) because the diet is high in fibre (and as a result, bulky) which therefore leads to a reduced ingestion speed (Ramonet et al., 1999; Whittemore et al., 2002). The level to which the feeding rate is reduced and the increased time spent feeding is dependent on the level of fibre in the diet. For the study reported by Whittemore et al. (2002), the diet with a high fibre level (sugar beet pulp) stimulated a more pronounced decrease in feeding rate and increase in time spent feeding than a diet with a moderate fibre level (wheat bran).

Similarly, various studies have reported a reduced feeding rate (Ramonet et al., 1999, Meunier-Salaun et al., 2001; Konstanze & Kaufmann, 2012) and an increase in feeding time (Robert et al., 1997; Ramonet et al., 1999; Danielsen & Vestergaard, 2001; Robert et al., 2002; Konstanze & Kaufmann, 2012). However, not all studies reported the same effect of a high-fibre diet on the feeding behaviour of pigs. For example, Renaudeau et al. (2003) conducted an experiment in the tropics where sows were fed a fibre-rich diet containing wheat bran that did not significantly affect feeding behaviour. Likewise, there is a reduction in the non-feeding visits to the electronic feeder in a commercial pig production enterprise when sows are fed a diet containing 20-30% dried sugar beet pulp (Brooks, 2005).

In terms of the activity rate, a study was conducted by Laitat et al. (2015) involving feeding fattening pigs with either a standard or a high fibre diet (comprising of sugar beet fodder). The result of the study reported a significant increase in the activity rate of pigs fed a high fibre rich diet (16.3 vs 10.4% ($P < 0.05$)). There was also a significant increase in the feeder occupation duration (103.4 *vs* 63.6 min per day per pig ($P < 0.01$)) for pigs fed the fibre rich diet. Other studies have also reported this increase in the time spent eating, which could be explained by the fattened pig spending more time eating to compensate for the dilution effect of the fibre in the diet (Schrama et al., 1998; Kallabis et al., 2012).

Furthermore, the physico-chemical properties of the fibre have the potential to influence behaviours in pigs. The physico-chemical properties of the fibre, such as the bulkiness and water holding capacity, can cause satiety because of its ability to stimulate an immediate post-meal effect through influencing mastication time and gut fill (Bolhuis et al., 2010). More specifically, when the fibre component of the diet fed to growing pigs are fermentable fibre, it initiates prolonged postprandial satiety, which causes not only a decrease in appetitive behaviour (or feed motivation) for many hours after feed intake but also a reduction in physical activities (de Leeuw et al., 2008). The reduction in the pig's physical activity is a coping mechanism that counterbalances the increased eating time and lowers energy utilisation of the diet, thereby promoting satiety (Schrama et al., 1998). Even though the physicochemical properties of fibre has been reported to exact influence feed intake (Kyriazakis & Emmans, 1995; Ndou et al., 2013), little has been known of its effect on the feeding behaviour in terms of the time spent eating for growing pigs (Bakare et al., 2013).

Therefore, it is important to highlight that there has been a gap in knowledge on the role dietary fibre plays in influencing feeding behaviour in growing pigs because most of the studies have focused on the effect of fibre on the behaviour and welfare of sows. Studies investigating *ad libitum* feeding of a diet rich in fibre on feeding behaviour of growing-finishing pigs are limited, hence this research. Therefore, the experiment aims to investigate the effect of dietary fibre on the *ad libitum* feed intake and feeding behaviour of growing-finishing pigs.

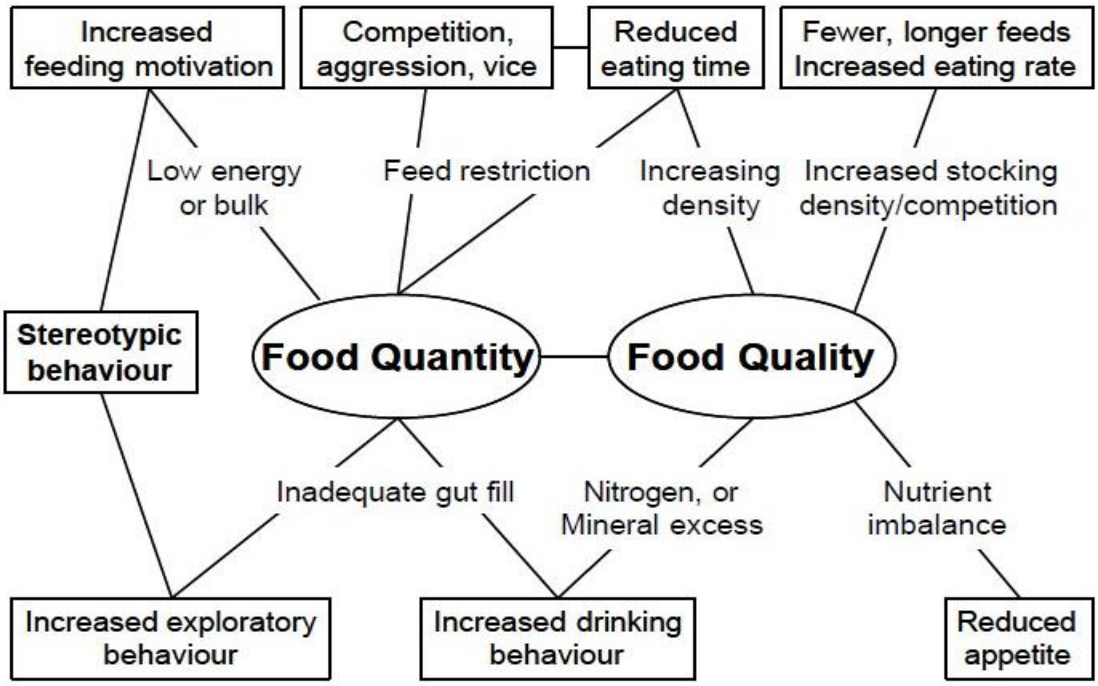

Figure 7: Effect of food quality and quantity on pig behaviour. Adapted from Brooks (2005).

Chapter 3

Methodology

3.1 Experimental procedure

The effects of diet affecting *ad libitum* feed intake and their interaction on the feeding behaviour of 32 growing-finishing pigs were assessed in this study. All pigs were of good health status and were vaccinated for the necessary disease at the farm before coming to the research facility. At the start of the study, the pigs were weighed and randomly assigned and exposed to the diets. The experiment was a 2 x 2 factorial design (2 finisher diets x two sexes), which lasted for ten weeks, comprising of weeks 1-7 called Period 1 (growing phase) and weeks 8-10 called Period 2 (finisher phase).

The study consisted of two experimental groups. Group 1 (basal) consisted of 16 pigs placed in two separate pens of 8 males and 8 females and fed an *ad libitum* equivalent of a commercial basal diet throughout the study (including the growing and finishing phase). On the other hand, Group 2 (test) consisted of 16 pigs placed in two separate pens of 8 males and 8 females. They were started with the same basal diet as the group 1 pigs during Period 1 (growing phase) but was changed to the test diet (fibre-rich alternative diet) in Period 2 (finisher phase) of the experiment.

The trial was done at the pig research facility of the monogastric research centre of Massey University. The experimental protocol was designed according to the guidelines of the current laws on the care and use of experimental animals. It was approved by the Massey Animal Ethics Committee (MUAEC 19/125).

3.2. Animals

A total of 32 Duroc x (Large White x Landrace) pigs were used. This consisted of 16 males and 16 females pigs. The initial liveweight was 22.4±2.2 kg for the male and 22.8±1.9kg for the female. In terms of the group type, initial weights were 23.5±1.1kg and 21.5±2.4kg for the pigs in Group 1 and Group 2.

The start of each group of pigs used in the experiment was delayed by one week. That is, Group 1 was introduced into the experiment one week before Group 2. This ensured a constant supply of pigs of similar weight from the commercial farm's stock to reduce the variation of liveweight. Similarly, to ensure that the variation in initial liveweight was kept as low as possible, all pigs in this study were selected randomly from different groups in the commercial farm. The individual pig was the experimental unit.

The experiment started with Group 1 (8 males and 8 females), and a week later, another group of 16 pigs (Group 2) were brought in (8 males and 8 females). It is important to note that the two groups of pigs spent an equal number of time (10 weeks) in the trial. This was made possible because the Group 1 pigs were first slaughtered, followed by the Group 2 pigs one week later. The health status and mortality of the pigs were monitored daily.

3.3 Housing/Pen

The trial was conducted in a closed room with a device installed to control ventilation and humidity. Ventilation consisted of a fan placed in the ceiling of the research facility controlled by a thermostat. To simulate commercial conditions, the pigs were housed in groups. The pigs were randomly assigned in groups of 8 of the same sex. The pigs were allocated into 4 pens. This comprised 16 males housed in 2 pens (8 males per pen) and 16 females housed in 2 pens (8 females per pen). The pigs within a pen received the same diet within each period.

The size of the whole pen is measured around 3.44m x 4.2m, with a group density of 1.81m^2/pig. The shape of all pens was designed to be as similar as possible. The walls and floor of the pen were made of concrete. The floor of the pen consists of a drainage outlet to ensure easy cleaning. Each pen also contained a designated feeding and sleeping area. The feeding and sleeping area dimensions are 3.44m x 2.62m and 3.44m x 1.58m. The sleeping area is equipped with a heating lamp, light, thermometer, and a little air vent to regulate the temperature and ventilation. The pen also had nipple drinkers connected to a water pipe on the wall in the feeding area (Figure 8). The pigs were individually fed using one single-spaced computerised electronic feeder (Osborne™ FIRE Feeder) placed in each pen (Figure 8).

The room temperature of the general feeding area for all pens had an average minimum and maximum temperature of 17.9±2.3°C and 20.9±2.6°C, respectively. Also, the insulated kennel (sleeping) area of all the pens had an average minimum and maximum temperature of 26±5°C and 34±3.6°C, respectively. The temperature of the general feeding area and the insulated kennel (sleeping) area was maintained by putting on or off the heating lamp situated in the insulated kennel based on how cold or hot the temperature of the pig research facility was. The pens were cleaned daily. Artificial lights were switched on from 1700 until 0900h because the period of the experiment coincides with the winter season with shortened daylight reduced.

Figure 8: Designated areas of the pen used in the study.

3.4 Diet and feeding

Pigs were assigned to two dietary treatments comprising a fibre-rich test diet and a commercially mixed basal diet. All diets were pelleted. The basal diet equivalent to a commercial diet (13.5 MJ DE/kg + 0.65 g Lys / MJ DE) was fed at the growing phase (Period 1) for all pigs. However, the finishing phase (Period 2) consisted of two diets (namely the basal diet and test diet) whose isoproteic and isoenergetic properties were the same. The test diet's DE and Lys/DE ratio was 13.6 MJ DE/kg and 0.68 g Lys / MJ DE, respectively. The two diets mainly differed in the level and type of dietary fibre ingredient used in the feed formulation. All diets were formulated according to standard recommendations for AA profiles (NRC, 2012) and digestible P (Jondreville & Dourmad, 2005).

Table 3.1 shows the composition of the commercially pelleted basal diet (2mm x 4mm) and the pelleted test diet (2mm x 4mm) fed to the pigs. The fibre-rich test diet (composed of by-product feed ingredients) was selected because it is an inexpensive and readily available potential alternative that could replace other expensive feedstuff components in a commercially mixed diet. Therefore, this implies that the satiating effects and feeding behaviour as a result of the physico-chemical properties of the fibre-rich test diet will be measured by its ability to overcome the effects of a reduced available energy supply of its fibre-rich nature compared to the basal diet (da Silva et al., 2013). The test diet was supplemented with synthetic amino acids, vitamins, and minerals to give similar calculated ratios of protein, amino acids, vitamins, and minerals to DE as those of the basal diet.

The basal diet was fed to all pigs in the trial for the first 7 weeks (including the Group 1 and Group 2 pigs). This allows habituation to their pen, group, and electronic feeding station, followed by a period when the experimental or test diet was introduced. The commercial basal grower diet was fed from 25 to 55-60 kg. After that, for the remaining 3 weeks of the experiment, the Group 1 (basal group) pigs were left to continue on the basal diet while the Group 2 (treatment group) pigs were discontinued from the basal diet and fed the fibre-rich test diet. Diets were manufactured as a pellet at the Massey University Research Feed Mill. Throughout the study, the pigs had unlimited access to feed through the electronic feeder and water through a nipple drinker.

Table 3.1: The composition and chemical analyses (g/kg as fed) of the two experimental diets.

Composition of the feed ingredients (g/kg as fed)		
	Test diet	Basal diet
Ingredients (g/kg)		
Barley	320.5	788.3
Canola meal	200	0.0
Broll (mixture of wheat middling and wheat bran)	150	0.0
Tallow	35	0.0
Soybean oil	0.0	10
DDGS	250	0.0
Soybean Meal	0.0	160
Lysine	5	2.5
Methionine	1	2
Threonine	2	2
Tryptophan	0.5	0.2
Premix Pig Grower	2	2
Dicalcium phosphate	10	30
Sodium Hydrophosphate	3	2
Salt	1	1
Limestone	20	0.0
Total	1000	1000

3.5 Chemical analysis

A handful of samples from the two diets were collected every day from the hopper of the feeders in all the pens, pooled together and kept in an airtight plastic container, subsampled, and sent to the Massey University Nutrition lab for analysis. The dry matter (DM) was determined in an oven according to the method 925.10 or 930.16 of AOAC. Total Nitrogen was determined based on Dumas Combustion method 968.06 of AOAC. Ash was determined by combusting the sample in a furnace for 4h at 550°C according to method 942.05 of AOAC. The CP content was calculated as nitrogen percentage multiplied by 6.25.

Also, the samples were analysed for other nutrients such as Calcium (prepared using AOAC 968.08D followed by colourimetric analysis), Phosphorus (prepared using AOAC 968.08D), Amino Acid Profile (Acid Stable; AOAC 994.12), Cysteine/Methionine (using performic acid oxidation of AOAC 994.12), Tryptophan (AOAC 2017.03), Fat (AOAC 922.06), Starch (AOAC 996.11, 996.16), Crude fibre (AOAC 962.09/978.10) and NDF/ADF/Lignin (AOAC 2002.04, 973.18). Similarly, gross energy (GE) was measured using an adiabatic bomb calorimeter. The composition of the diet is shown in Table 3.1. All nutrients analysed in this study used a similar AOAC (2005) procedure.

3.6 Measurement

For the duration of the experiment, the pigs were weighed regularly every week, and measurement on feed intake was carried out by the Osborne™ FIRE (Feed Intake Recording Equipment) electronic feeder. Parameters associated with feeding behaviour such as Feeder Occupancy Time (Time Spent Feeding or Feeding Duration), Feeding Rate, and Feeding Visits were value generated by the Osborne™ FIRE feeder when a pig enters the trough of the feeder to eat. A sample of fresh faeces was taken and stored in a frozen state on each weighing day for each pen.

A plastic bag was labelled using masking tape with a sample description written on it. The weight of the pigs was taken at the start of the trial and subsequently taken every week and before slaughter. The weighing was done using a conventional weighing machine for the duration of the experiment. The weighing was done around the same time every week to ensure consistency and reduce errors.

3.7 Osborne™ FIRE electronic feeder

In this study, the pigs were fed using an electronic feeder. An example of an electronic feeder system is the one used in this experiment called the Osborne™ FIRE feeder (Osborne Industries, Inc., Osborne, Kansas). This electronic feeder system allows for collecting feed intake of individual pigs while still ensuring the social interaction associated with groups (Young & Lawrence, 1994). Unlike a commercial electronic feeder with multiple spaces, the Osborne FIRE™ feeder used in this study is a single-spaced feeder that allows only one pig to feed at a time, thereby preventing competition between pigs (Figure 9). This is made possible by a race component that could be adjusted to ensure that only one pig at a time could enter the feeder. The mechanism for weighing consists of the feed trough, which is made up of fibreglass and mounted in a frame with its weight-bearing on a load cell (Figure 9).

Each feeder is linked to a control box that contained the FIRE system. The uppermost component of the feeder consists of the hopper, which serves as an inlet where feed can be topped. Every day, feed is weighed and put in the hoppers for each of the pens to ensure that feed is always available for the pigs. Typically, the leftover feed remaining in the hopper and trough is removed, weighed, and recorded for each pen weekly. The weighted leftover is removed from the total feed top-up for the week, giving the calculated feed intake for all the pigs in a pen. This calculated feed intake value is compared to the feed intake value generated by the electronic feeder for the week to check its accuracy.

Each pig was given a uniquely coded RFID (Radio Frequency Identification) tag clipped to their right ears. Also, the left ears were clipped with a regular ear tag that contains unique numbers for each pig to ease identification. When the pig enters the feeding trough, the identification circuit detects the RFID tag of the pig and immediately records the trough weight just before the animal starts feeding. When the pig has left after feeding, the electronic system detects no pig and records the weight of the trough after eating for that pig. When the feeder's weight in the trough is below a pre-set minimum, the feeder automatically top-up.

Also, top-up can happen when the animal is feeding, as the electronic system can adjust for the accurate weight during the process. Typically, the exit weight of a pig is usually the entry weight of another pig. The difference between entry and exit weight of the trough is recorded as the feed intake for the pig, and it is stored in an excel data file accessible via a proprietary software (WinFIRE) installed on a computer. These data can then be downloaded using the WinFIRE software on the computer. Data were checked daily to ensure that all the

RFID tags functioned and knew the pigs' health status through their feed intake. Pigs without any recorded feeding events were checked for health issues and missing or malfunctioning RFID tags.

The downloaded data consists of a daily summary data and a more detailed event log file showing all visit as it happens in real-time. Other parameters recorded by the feeder include the pig's RFID tag, entry time, exit time, top-up amount, date, location, and feed intake for a visit. Feeding behaviour parameters such as feeding rate, feeder occupation time and the number of feeding visits are typically calculated from the computer-generated Microsoft Excel data. Feeder occupation (or time spent feeding) is calculated as the exit and entry time difference. Feeding rate (g/min) is the feed intake at a visit divided by feeding duration. All feeders were calibrated at the start of the study and once per week during the experiment.

Figure 9: A photo of the Osborne™ feeder showing its component as a pig continue feeding.

3.8 Data cleaning

Since every visit to the feeder by the pig is recorded, several feeding events data have been observed to contain a considerable number of errors. This needs to be addressed to improve the accuracy of the data from the electronic feeder. These errors were due to animal-feeder interaction interactions and sometimes malfunctioning feeders (Casey, 2003). Therefore, for accurate feed intake to be determined by the feeder, appropriate editing methods to identify, edit and correct event data is needed before further analysis of the data (Casey, 2003).

For this study, after data were transferred and filtered from the database, errors in feeding events data such as visits at the feeders with negative feed intake were deleted. This is simply because feed intake cannot be a negative value. Any event data from the electronic feeder that was negative were removed from the final data. For most feeders used in this experiment, this editing method improved the accuracy of feed estimation. Similarly, pig visits with no feed consumed were also removed from the data because they did not meet the study's objective. Feeding event data containing negative entry and exit weight were removed because these could be errors associated with the sensitivity of the weighing trough in the electronic feeder. Event data files containing no values (zero) in their exit and entry weight were also removed to improve the accuracy of the feeder. Feeder occupation time (min) and feeding rate with high abnormal values were also removed.

3.9 Statistical analysis

After the data obtained from the Osborne™ FIRE feeder was cleaned, the data were sorted based on the hourly time of the day the animal went for feeding. Before further analysis was carried out, the condition for non-normality of the data distribution and homogeneity of variances was assessed using the Shapiro-Wilk and Levene test, respectively. Raw data from this study were not normally distributed, and the condition of homogeneity of variance wasn't met. So, feeding behaviour data such as feeder occupancy time and feeding visit data were log-transformed to ensure these conditions were met. Similarly, data from feed intake was also transformed using square roots. However, data from the feeding rate were not transformed as they met the assumptions for analysis of variance.

The data was sorted on an hourly basis to reflect the diurnal feeding variation during the study. Diurnal patterns for feed intake traits for the two pig groups in this study were estimated by summing up the number of feeding visits, mean feeder occupation time per visit, and feeding rate for each hour of the 24hrs period. Comparison of the hourly means based on the diet treatments was carried out using the PROC MIXED function of SAS 9.4 (SAS Institute, Cary, NC)

Similarly, the model for Feed intake, Feeding Visit, Feeding Rate and Feeder Occupancy were accounted for by the fixed effects of diet type (test vs basal), Sex (Male vs Females), Period, Hours, and their interactions. The random effect of the individual pig is nested within diet type and sex. Each pig was considered an experimental unit during this study, as each animal was an independent observation, and all animals were raised in the same conditions. For brevity, only significant effects were reported in the study. Multiple comparisons were made using the PDIFF (Fisher's least squared difference method) function of SAS when significant interactions were found. The Least square means were used to determine the differences in treatments and the interaction terms. Data presented in tables were re-transformed back to their original least square means. Differences were considered to be significant at $P \leq 0.05$.

Chapter 4

Results

4.1 Nutrient composition and digestible content of the diet

It is essential to highlight that 32 pigs (comprising 16 males and 16 females) were initially used at the start of the experiment. However, during the study, one female in the Group 2 was removed after failing to recover from a sickness. Therefore, this reduced the number of female pigs to 15 and the total number of pigs to 31. Table 4.1 showed the percentage of nutrients (as-fed basis) and the amino acid composition of test and basal diets.

Similarly, the gross energy and other nutrients such as crude protein, fat, starch, lignin, dry matter, ash, and calcium were higher in the test diet than in the basal diet. However, the phosphorous percentage in the basal diet was higher than it was in the test diet.

Table 4.1: Nutrient and amino acid composition of the test and basal diets.

	Test diet	Basal diet
Nutrient composition (as-fed basis)		
DM %	88.6	87.2
Ash %	6.2	4.9
CP	18.7	15.6
Fat %	7.7	3.6
Starch %	22.1	35.7
Crude fibre %	6.0	4.2
NDF %	24.6	14.4
ADF%	9.0	4.5
Lignin %	2.9	0.8
Ca (mg/g)	9.2	6.6
P (mg/kg)	8.1	8.5
GE (kj/g)	16.8	15.6
AIA %	0.2	0.4
Amino acids	mg/100mg	mg/100mg
Aspartic acid	1.18	1.21
Threonine	0.84	0.66
Serine	0.71	0.64

Glutamic acid	3.17	3.21
Proline	1.24	1.26
Glycine	0.80	0.58
Alanine	0.75	0.59
Valine	0.91	0.75
Isoleucine	0.62	0.58
Leucine	1.14	1.05
Tyrosine	0.57	0.54
Phenylalanine	0.79	0.82
Histidine	0.56	0.47
Lysine	1.05	0.85
Arginine	1.02	0.89
Cysteine	0.38	0.29
Methionine	0.40	0.40
Tryptophan	0.23	0.19

4.2 Hourly frequency of feeding visit.

Table 4.2.1 showed the significant predictors in the mixed model used in predicting the frequency of feeding visits of the pigs at a particular hour in this study. These significant predictors will be discussed at length in the following sections. It is important to highlight that feeding visits can only be positive integer numbers. For example, a pig can only go to the feeder to feed twice or thrice at a particular time of the day, not 0.8 times. Therefore, all feeding visit means in this study will be reported to their nearest whole number.

Table 4.2.1: Significant predictors in the hourly feeding frequency visits

	Type 3 Tests of Fixed Effects			
Effect	Num DF	Den DF	F Value	Pr > F
Hours	23	7269	219.74	<0.0001
Group	1	27	8.04	0.0086
Sex	1	27	0.01	0.9434
Growth-Stage	1	7269	88.99	<0.0001
Hours*Sex	23	7269	7.62	<0.0001
Hours*Group	23	7269	6.91	<0.0001
Hours* Growth-Stage	23	7269	2.55	<0.0001
Hours*Group* Growth-Stage	24	7269	3.21	<0.0001
Hours*Group*Sex	24	7269	7.95	<0.0001

4.2.1 Effect of hourly progression on the frequency of feeding visit in pigs

Figure 10 showed the frequency of feeding visits during each hour of the day from midnight (0 hrs) to 11 pm (23 hrs). The time of the day affected the number of times the pig visited the electronic feeder for food. Generally, Figure 10 showed that the number of feeding visits increased as the day progressed, with two peaks at 9 am, and 3 pm before it decreased.

Figure 10 showed that as the hours progressed from 1 am to 3 am; there was no significant effect on the frequency of feeding visits of the pigs. Around this time of the day, the pig averagely visits the feeder just once. When the hours progressed from 4 am to 9 am, there was a significant ($P<0.05$) increase in the number of times the pig visited the feeder for food. The number of feeder visits between 4 am, and 9 am significantly increased from once to 7 times. Therefore, this showed that feeding visits in growing-finishing pigs fed ad-libitum would peak around the hours of 9 am (Figure 10). However, there was no significant difference between the number of times the pig visited the feeder between 9 am and 10 am, with both times having seven visits.

After that, the number of feeder visits significantly ($P<0.05$) from 7 times to 3 times from 10 am to 12 pm. The number of feeding visits increased in the afternoon from 4 times to 6 times from 1 pm to 3 pm. During this period (from 1 pm to 3 pm), the increase in the frequency of feeding visits was significant ($P<0.05$). Even though statistically, feeding visits between 3 pm and 4 pm are the same, with a peak at 3 pm, the decline in feeding visits began to set in from 4 pm. This decline in feeding visit trend continued until 6 am the following day. However, feeder visits decreased significantly ($P<0.05$) from 4 pm to 8 pm and 11 pm to 1 am.

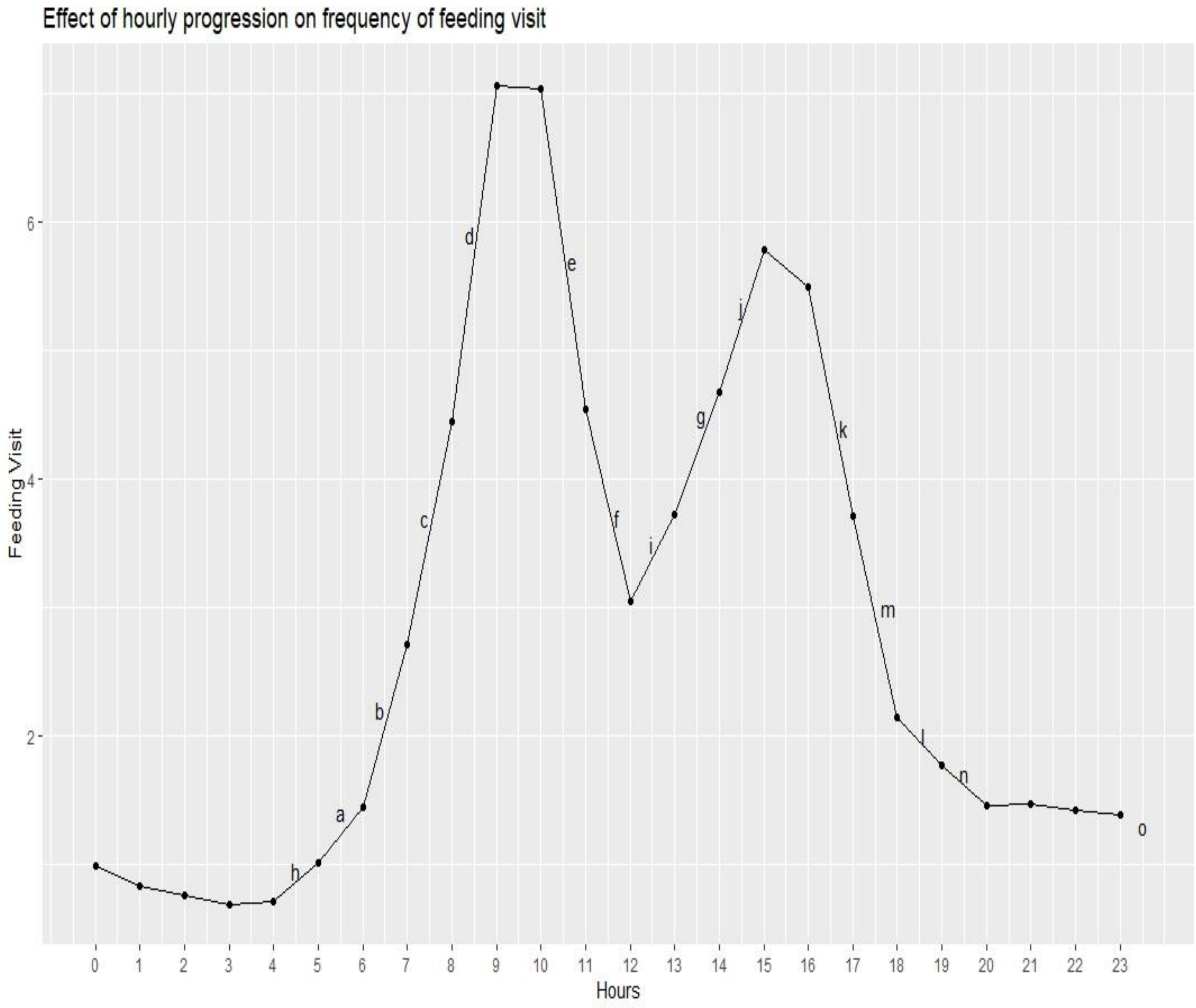

Figure 10: The difference in feeding visit as the day advanced.

Alphabets between two datapoints indicate a significant difference in feeding visits between the day's corresponding preceding and succeeding hours.

The points in the graph with no alphabet showed no significant difference in feeding visits between the corresponding preceding and succeeding hours.

4.2.2 Effect of the group type of the pig on the hourly frequency of feeding visit

The group type of the pigs on the hourly frequency of feeding visit is shown in Table 4.2.2. The result indicates that the group type influenced the number of times the pigs ate at the feeder in a particular hour of the day. Group 1 pigs visited the feeder less frequently compared to pigs in group 2 (P=0.0086).

Table 4.2.2: Least square means and standard error for feeding rate of group 1 and group 2 pigs

Group	Number of Feeding Visit	S.E[2]	S.E[3]	P-value[1]
Group 1	2.00[a]	0.02377	0.0563	0.0086
Group 2	2.76[b]	0.0246	0.0583	

[a,b] Values with different superscripts are significantly different from each other (LSD, P<0.05)

[2] Standard error was not back-transformed to its original form.

[3] Standard error was back-transformed to its original form.

[1] P-value from Table 4.2.1

4.2.3 Effect of the stage of growth of the pig on the hourly frequency of feeding visit

This study showed that the stage of growth of the pigs had a significant effect on how frequently the pig visited the feeder for food at a particular time of the day. The growing phase comprises the first seven weeks of the study. Also, the finishing phase includes the remaining three weeks of the trials. The research results report that during the growing phase of the pigs, they visited the feeder more often for food than their finishing phase of growth at a particular time of the day (P<0.0001; Table 4.2.3).

Table 4.2.3: Least square means and standard error for feeding visit in the grower and finisher phase

Growth-stage	Feeding Visit	S.E[2]	S.E[3]	P-value[1]
Growing Phase	2.60[a]	0.01716	0.0403	<0.0001
Finishing Phase	2.14[b]	0.01761	0.0414	

[a,b] Values with different superscripts are significantly different from each other (LSD, P<0.05)

[2] Standard error was not back-transformed to its original form.

[3] Standard error was back-transformed to its original form.

[1] P-value from Table 4.2.1

4.2.4 Effect of the sex of the pig on the frequency of feeding visit at a particular time of the day

As the time of the day progressed, the sex of the pig had a significant (P<0.05) effect on the hourly frequency of feeding visits. Figure 11 showed a visual presentation of the effect of sex of the pigs on the hourly feeding visits at a particular hour of the day for this study

The trend from Figure 11 showed that female pigs had a high frequency of feeder visits than male pigs. Similarly, this study showed that male and female growing-finishing pigs eat or visit the feeder at a different time of the day. Also, a total of the feeding visit frequency for the significant (P<0.05) hours throughout the day showed that the female pig visited the feeder more often when compared to the male pigs (36 visits vs 28 visits).

At midnight (0 hrs), male pigs showed higher (P=0.0416) feeder visits than female pigs. Also, from 1 am to 7 am, there was no significant difference (P>0.05) in feeding visits between the two sexes. However, at 3 am, male pigs significantly (P=0.046) visited the feeder for feed more frequently than the female pigs. The frequency of feeding visits for female pigs significantly increased (P>0.05) from 5 times before it peaked at 8 times between 8 am and 10 am. Female pigs visited the feeder for feed during these hours compared to the male pigs ($P<0.05$). At 11 am, the frequency of feeding visits drastically declines from 8 to 5 times for the female pigs and 6 to 4 times for the male pigs. However, at this time (11 am), the female pigs still had a significantly high ($P=0.0053$) feeding visit frequency than the male pigs.

Peak feeding visit in the morning usually is at 9 am for the females, and 10 am for the males. A drop follows this in the feeding visit up to noon. After that, the frequency of feeding visits continued to increase until 3 pm, but this feeding visit increase was not significant ($P>0.05$) between the two sexes. The peak feeding visit was at 3 pm for the female pigs and 4 pm for the male pigs in the afternoon. At 3 pm, a significant difference ($P=0.0282$) in feeding visit frequency between the two sexes was reported, with the 5 visits for the male pigs and 7 visits for the female pigs. Subsequently, from 3 pm for the female pigs and 4 pm for the male pigs until 8 am of the following day, a non-significant ($P>0.05$) downward trend in the frequency of feeding visits between the sex was observed in this study. However, at 11 pm, the male pigs significantly ($P=0.0233$) visited the feeder twice as much as the female pigs.

Overall, during the period of no daylight (especially late and very early in the morning), male pigs visited the feeder more often than female pigs. On the other hand, the female pigs had higher feeder visits during the day than the male pigs.

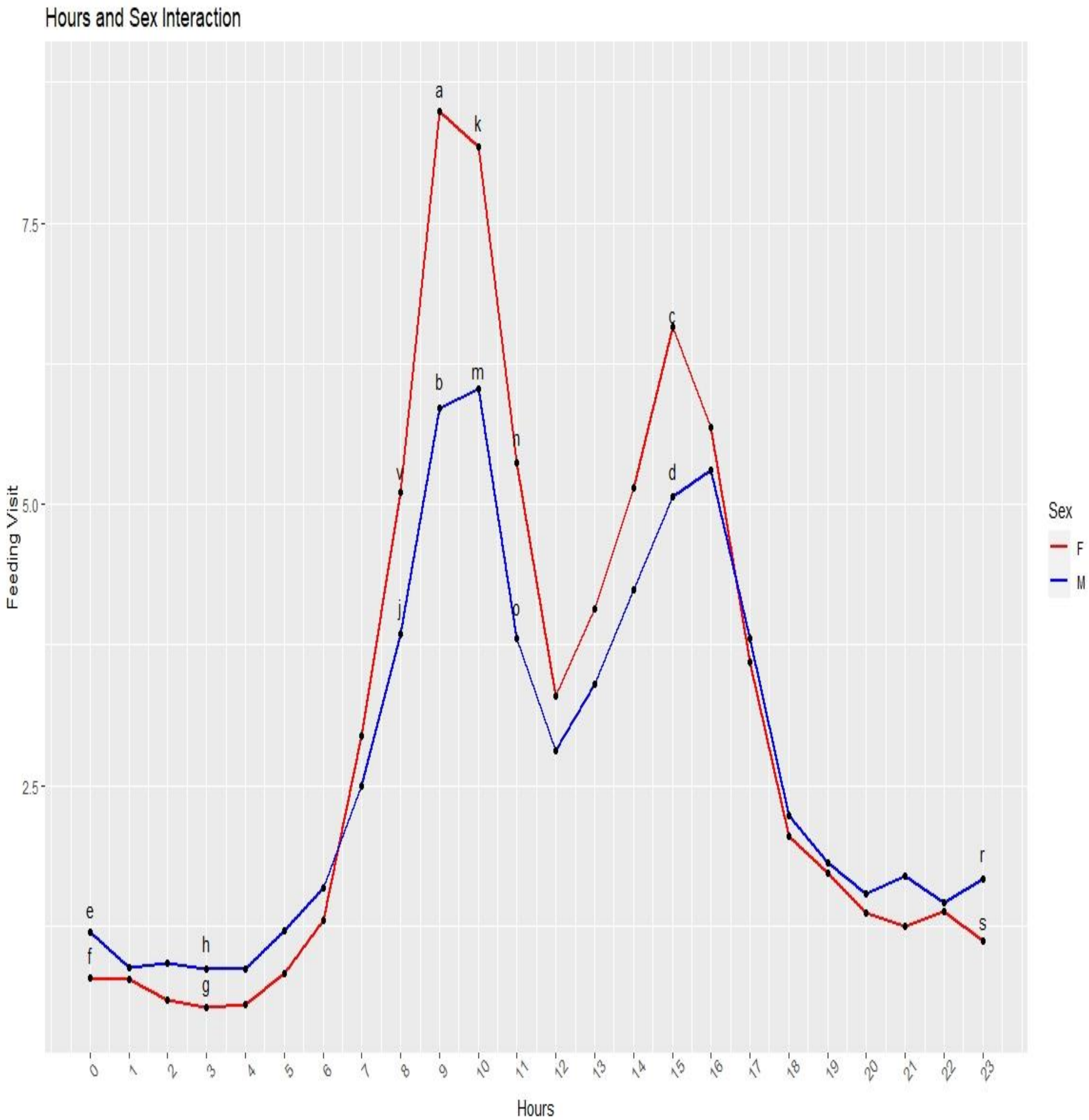

Figure 11: Difference in the frequency of feeding visits between the two sexes.

Different alphabets indicate a significant difference in the frequency of feeding visits between the two sexes at a particular hour of the day.

The points in the graph with no alphabet showed no significant difference in feeding visits between sexes at that hour.

4.2.5 The effect of the group type of the pigs on the frequency of feeding visits at a particular time of the day

As the day progressed, the pig type significantly ($P<0.05$) affected the hourly feeding visits. Similarly, the result of this study showed that growing-finishing pigs belonging to either group 1 or group 2 had a significantly different ($P<0.05$) feeding visits frequency at a particular hour of the day (Figure 12). The trend from Figure 12 showed that that group 2 pigs visited the electronic feeder more often than group 1. Also, the total of the feeding visits frequency for the significant ($P>0.05$) hours throughout the day showed that the group 2 pigs frequently visited the feeder for food compared to the group 1 pigs (36 visits vs 28 visits).

Also, from 5 pm to 4 am of the following day, group 2 pigs had a significantly ($P<0.05$) higher feeding frequency than the group 1 pigs. During these hours, the feeding frequency between both groups of pigs decreased significantly ($P<0.05$). That is, from 3 to 1 time for the group 1 pigs, and from 4 to 1 time for the group 2 pigs. However, as the morning advanced, the frequency of feeding visits increased from 1 time at 5 am to 4 times at 8 am across both groups. Within this period, the increase in the feeding frequency was not significant between the two groups of pigs.

The frequency of feeding visits continued to increase. It peaked at 8 visits at 9 am for the group 2 pigs, and 7 visits at 10 am for the group 1 pigs. At 9 am, group 2 pigs visited the feeder more frequently (8 times) than group 1 pigs (6 times, $P=0.0298$). A downward feeding visit trend followed this until noon. The frequency of feeding visits between the two groups was not significant ($P>0.05$) throughout these hours, mostly the same.

After that, the number of feeding visits continued to increase until it peaked at 3 pm with 5 visits for the group 1 pigs and 6 visits for the group 2 pigs. However, only the increase in the frequency of feeding visits from 12 pm to 1 pm was significantly different ($P<0.05$) between the two groups of pigs. Subsequently, from 3 pm to 4 am the following day, a decrease in feeding frequency began to set in. However, the decline in the feeding visit from 3 pm to 4 pm was not statistically significant ($P>0.05$) between the two groups.

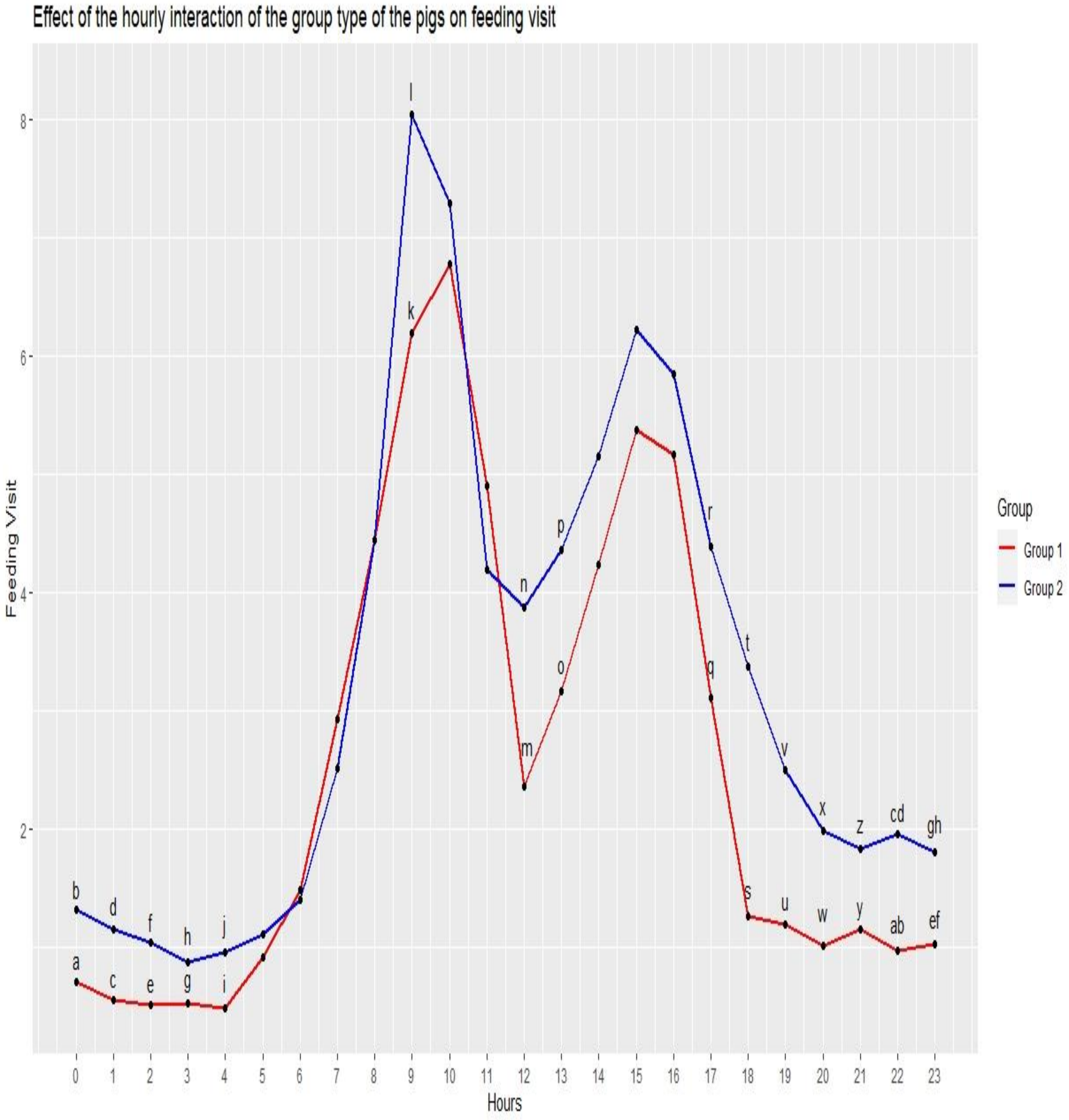

Figure 12: Difference in the frequency of feeding visits between the groups of pigs.

Different alphabets indicate a significant difference in the frequency of feeding visits between the two groups of pigs at a particular hour of the day. The points in the graph with no alphabet showed no significant difference in feeding visits between the two groups at that hour.

4.2.6 The effect of the stage of growth of the pig on the frequency of feeding visits at a particular time of the day

As the time of the day progressed, the growth stage of the pig had a significant (P<0.05) effect on the hourly feeding visits. Similarly, this study showed that at a particular hour of the day, the frequency of feeding visits of the pigs was significantly (P<0.05) affected when the pigs were at either the growing or finishing phase (Figure 13). The trend from Figure 13 showed that pigs during the growing phase visited the feeder more frequently compared to when they were at their finishing phase. Also, a total of the feeding visits frequency for the significant (P<0.05) hours throughout the day showed that during the growing phase, the pigs frequently visited the feeder for food compared to when they were at their finishing phase of growth (24 visits vs 17 visits).

From 7 pm to 7 am of the following day, pigs had a significantly (P<0.05) higher feeding visit frequency than the finishing phase during their growing phase. From 7 pm to 3 am of the following day, the feeding frequency for the growing and finishing phases decreased significantly (P<0.05) from 2 times to 1. However, as the morning progressed from 4 am to 7 am, the frequency of feeding visits between both phases increased significantly (P<0.05) from 1 to 3 times and 1 to 2 times for the growing and finishing phases.

Likewise, as the time moves from 7 am onwards, the frequency of feeding visits increased. It peaked at 7 visits at 9 am during the growing phase, and 7 visits at 10 am during the finishing phase. However, during this period, the increase in the feeding visits frequency was not significant between both phases (Figure 13). After the peak of both phases, it is followed by a declining feeding visit trend until noon. During these hours, the frequency of feeding visits between the two phases was not significant (P>0.05), mostly the same.

After that, the number of feeding visits continued to increase until it peaked at 3 pm with 6 visits for both phases. However, only the increase in the frequency of feeding visits at 1 pm was significantly (P<0.05) different between the two periods. Subsequently, After the peak of both phases in the afternoon, a significant (P<0.05) decline in the frequency of feeding visit trend was generally observed from 3 pm to 3 am the following day. However, the decline in the feeding visit from 3 pm to 6 pm was not statistically significant (P>0.05) between the two phases.

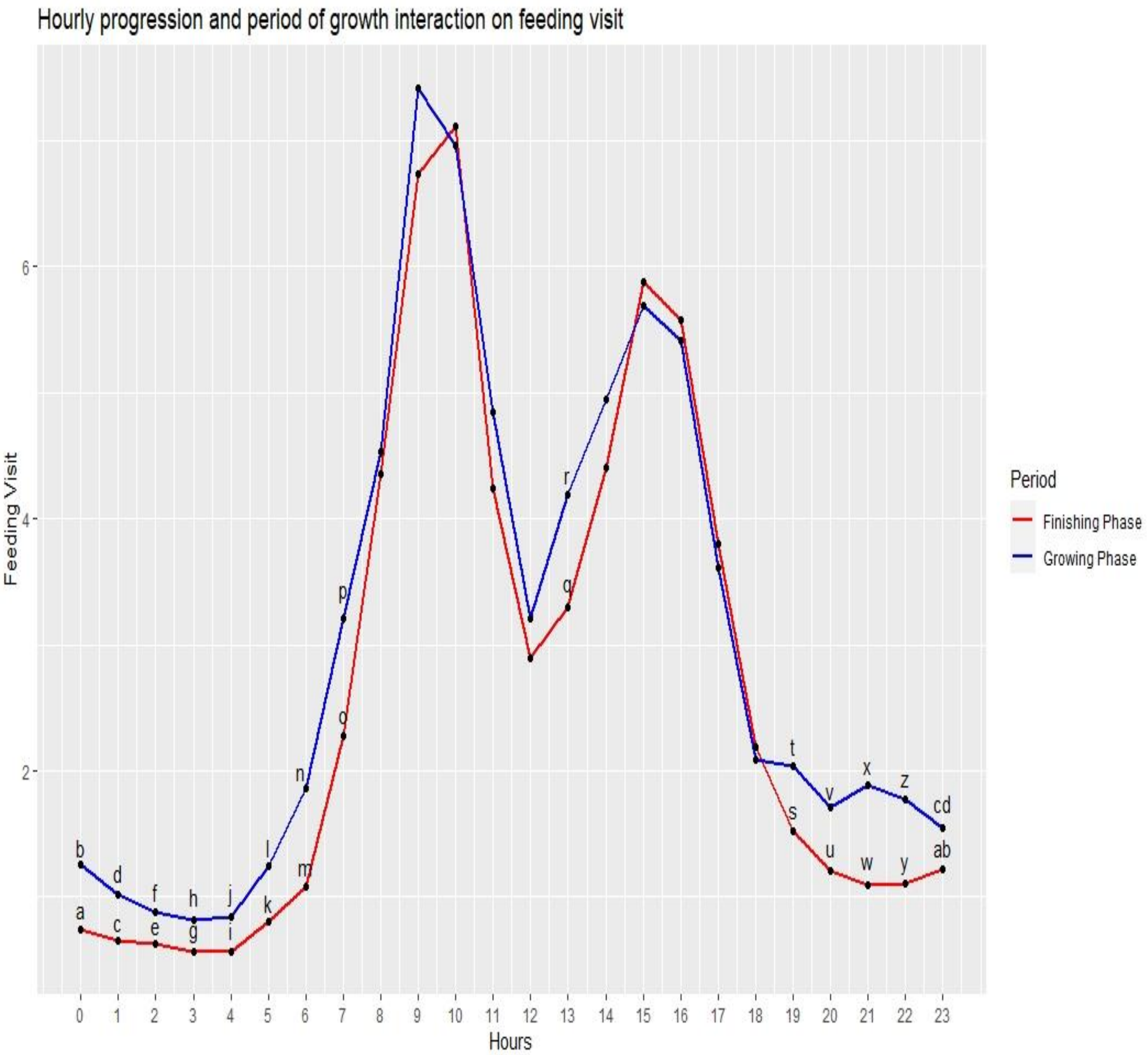

Figure 13: Difference in the frequency of feeding visits between the growing and finishing phases.

Different alphabets indicate a significant difference in the frequency of feeding visits between the two growth stages at a particular hour of the day.

The points in the graph with no alphabet showed no significant difference in feeding visits between the growth stages at that hour.

4.2.7 The effect of the group type of the growing pigs on the frequency of feeding visits at a particular time of the day

Figure 14 showed that, at certain times of the day, the group type of the growing pigs had a significant ($P<0.05$) effect on their hourly feed visit frequency. At a particular time of the day (such as at 5 pm to 2 am, 4 am to 5 am, 7 am, and 9 am), group 2 growing pigs visited the feeder more often than the group 1 growing pigs ($P<0.05$; Figure14). The feeding visit peaked at 9 am for the group 2 pigs and 10 am for the group 1 growing pigs. In the afternoon, peak feeding visits was at 3 pm for group 1 and group 2 growing pigs. Overall, the group 2 pigs visited the feeder during the growing phase than the group 1 pigs.

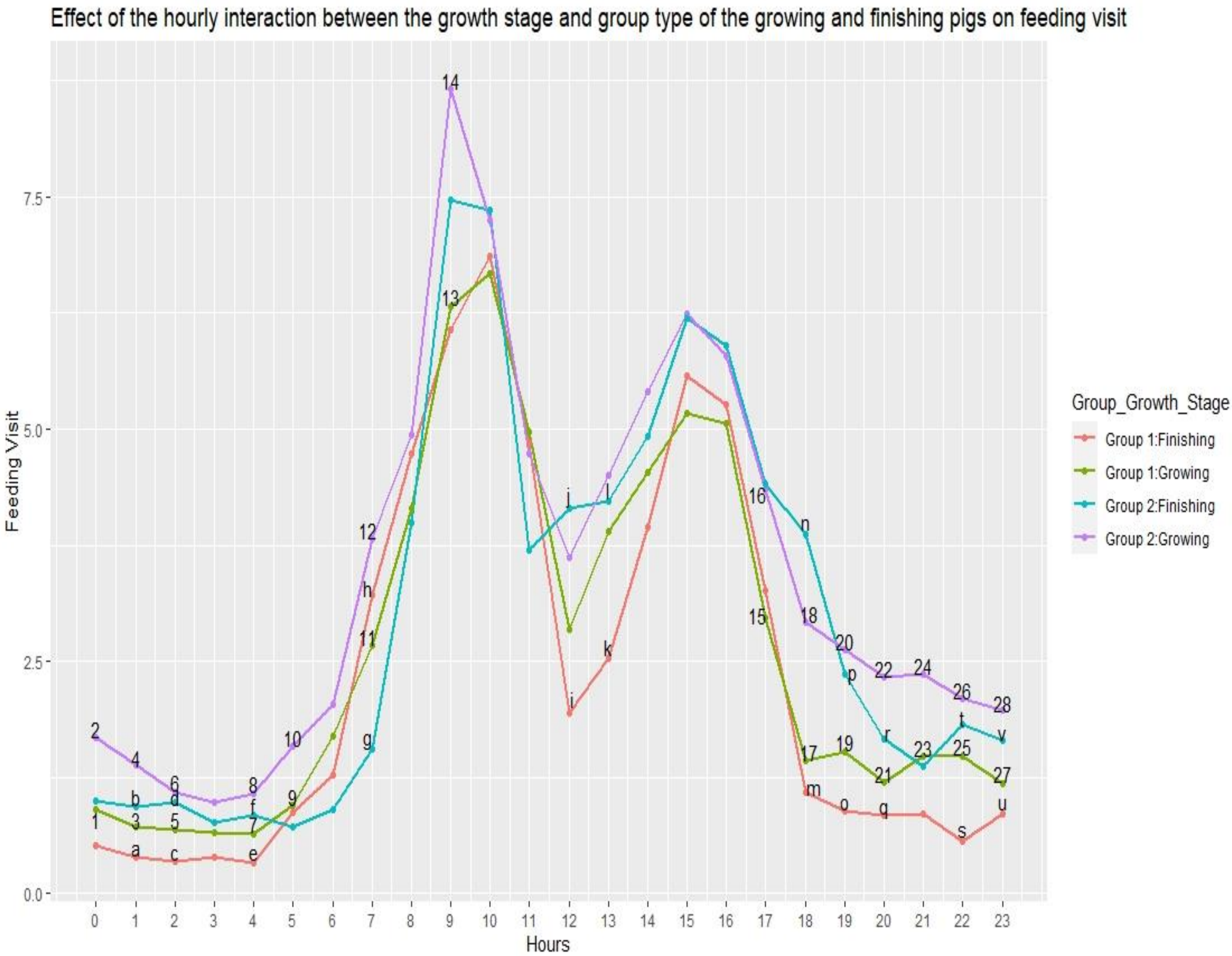

Figure 14: Difference in feeding visit between the different groups of finishing and growing pigs.

Different alphabets indicate a significant difference in feeding visits between the two groups of finishing pigs at a particular hour of the day.

The points in the graph with no alphabet showed no significant difference in feeding visits between the groups of pigs at that hour.

Different numbers indicate a significant difference in feeding visits between the two groups of growing pigs at a particular hour of the day.

The points in the graph with no number showed no significant difference in feeding visits between the groups of pigs at that hour.

4.2.8 The effect of the group type of the finishing pigs on the frequency of feeding visits at a particular time of the day

As the day progressed, the pigs' group type affected the hourly feeding visits of finishing pigs. Similarly, this study showed that at a particular hour of the day, the frequency of feeding visits of the finishing pigs was significantly ($P<0.05$) affected by the group the pig belongs to (Figure 14). The trend from Figure 14 showed that the group 2 pigs visited the feeder more frequently than group 1 pigs during their finishing phase at a particular time of the day. Also, a total of the feeding visits frequency for the significant ($P<0.05$) hours throughout the day showed that the group 2 finishing pigs frequently visited the feeder for food compared to the group 1 pigs (24 visits vs 13 visits; $P<0.05$).

During the finishing phase, from 6 pm to 4 am of the following day, the group 2 pigs visited the feeder significantly ($P<0.05$) more often than the group 1 pigs. However, at 9 pm, the number of times the pig visited the feeder was the same irrespective of the pig's groups. Similarly, this means that during this period (from 6 pm to 4 am of the following day), the feeding visits frequency decreased significantly ($P<0.05$) from 1 time to 0 for the group 1 pigs and 4 times to 1 for the group 2 pigs (Figure 14).

On the other hand, a feeding visit trend is observed as time advanced from 5 am onwards. This trend continued until it peaked at 9 am for the group 2 pigs and 10 am for the group 1 pigs. An increase in feeding visits from 5 am to the peak feeding visit time for the respective groups was observed. That is, an increase from 1 to 6 times for the group 1 pigs and 1 to 7 times for the group 2 pigs. However, during this period, apart from the feeding visit at 7 am, the increase in the frequency of feeding visit observed have been largely non-significant (P>0.05) between the two groups (Figure 14).

After the peak of both groups, it is followed by a declining feeding visit trend until 11 am for the group 2 pigs and noon for the group 1 pigs. During these hours, apart from noon, the frequency of feeding visits between the two groups was not significant (P>0.05), mostly the same. Typically, from this time (11 am and 12 pm), it takes 2 hours of inactivity (because of resting or sleeping) for group 1 or group 2 pigs to begin another round of feed visits in the afternoon.

After that, the feeding visit continued to increase until it peaked at 3 pm with 6 visits for both groups. However, only the increase in the frequency of feeding visits from 12 pm to 1 pm was significantly (P<0.05) different between the two groups of pigs. Subsequently, after both groups' peak in the afternoon, a significant (P<0.05) decline in the frequency of the feeding visit trend was generally observed from 3 pm to 6 am. However, the decline in the feeding visit from 3 pm to 5 pm and at 9 pm was not statistically significant (P>0.05) between the two groups of finishing pigs.

4.2.9 The effect of the interaction between group type and sex of the pig on the frequency of feeding visits at a particular time of the day

The frequency of feeding visits is affected by the group type and the sex of the pig during its feeding visit at a particular time of the day. There is a significant (P<0.0001) interaction between the time of the day (in hours) and the group type of the male and female pigs.

4.2.9.1 The effect of the group type on feeding visit in female pigs at a particular time of the day

The trend from Figure 15 showed that group 2 female pigs visited the feeder more frequently than group 1 female pigs at a particular time of the day. Also, a total of the feeding visits for the significant (P<0.05) hours throughout the day confirmed that group 2 female pigs had higher feeder visits than group 1 female pigs (21 visits vs 17 visits).

Female pigs exhibited a significant decline in feeding visit frequency from 6 pm to 11 pm. During this period, feeding visits dropped from 3 to 2 times for the group 2 pigs and remained at 1 time for the group 1 female pigs. Figure 15 further demonstrated that in the latter part of the evening, the group 2 female pigs significantly visited the feeder for food than the group 1 female pigs.

Likewise, this feeding frequency decline trend continued from midnight to 4 am for the group 1 female pigs and 5 am for the group 2 female pigs. However, only at 2 am, and 4 am a significant ($P<0.05$) difference between the two groups. During this period, group 2 female pigs visited the feeder more than group 1 female pigs.

Subsequently, an increase in the frequency of feeding visit trend was observed. This increase began at 5 am for the group 1 pigs and 6 am for the group 2 pigs. This trend continued until it peaked at 9 am for the group 2 pigs and 10 am for the group 1 pigs. An increase in feeding visits was observed until the peak feeding visit times for the respective groups. The feeding visit increased from 1 to 9 times for the group 1 female pigs and 1 to 8 times for the group 2 female pigs. However, throughout this period, apart from the feeding visit at 7 am, the increase in the frequency of feeding visit observed have been largely non-significant ($P>0.05$) between the two groups (Figure 15). At 7 am, the group 1 female pigs significantly ($P<0.01$) visited the feeder for food than the group 2 female pigs (4 visits vs 2 visits).

After the peak of both groups, it is followed by a declining feeding visit trend until noon for both groups of pigs. During these hours, apart from 11 am, the frequency of feeding visit between the two groups were not significant ($P>0.05$), mostly the same. At 11 am, the group 1 female pigs significantly ($P>0.01$) visited the feeder (7 times) for feed than the group 2 female pigs (7 visits vs 4 visits).

After that, the number of feeding visits continued to increase until it peaked at 3 pm with 8 visits for the group 1 female pigs and 6 visits for the group 2 female pigs. However, this increase in feeding visits was not significantly ($P>0.05$) different between the two groups. Subsequently, after the peak of both pigs' groups in the afternoon, a non-significant ($P>0.05$) decline in the frequency of feeding visit trend between the two groups was generally observed from 3 pm to 5 pm. Overall, for the female pigs, the only time the group 1 pigs significantly ($P<0.05$) visited the feeder to feed more than the group 2 pigs was at 7 am and 11 am. In contrast, in the evening and early morning, group 2 female pigs had higher feeder visits than group 1 females' pigs.

4.2.9.2 The effect of the group type on feeding visit in male pigs at a particular time of the day

The trend from figure 15 showed that group 2 male pigs visited the feeder more frequently than the group 1 male pigs throughout the study at a particular time of the day. Also, a total of the feeding visit for the significant hours throughout the day confirmed that group 2 male pigs visited the feeder more often for food than group 1 male pigs (66 visits vs 37 visits; $P<0.05$).

Male pigs exhibited a decline in feeding visit frequency from 4 pm to 4 am the following day for the group 2 pigs and 5 pm to 4 am the following day for the group 1 pigs. Feeding visits dropped from 7 to 1 time for the group 2 pigs and 3 to 1 time for the group 1 pigs. Also, there was a significant ($P<0.05$) decline in the frequency of feeding visits between the two groups during this period. The group 2 male pigs had a higher feeder visit than the group 1 male pigs (Figure 15). However, only the feeding visit frequency from 8 pm to 9 pm and 2 am to 4 am was insignificant ($P>0.05$), the same for the two groups.

Subsequently, an increase in the frequency of feeding visit trend is observed up to a particular time in the latter part of the morning. This increase began at 5 am for both groups. This trend continued until it peaked at 9 am for the group 2 pigs and 10 am for the group 1 pigs. From the point of increase to the peak feeding visit time for the respective groups, an increase in feeding visits from 1 to 5 times for the group 1 male pigs and 2 to 8 times for the group 2 male pigs was observed. However, during this period, apart from the feeding visit at 9 am, and 10 am, the increase in the frequency of feeding visit observed have been largely non-significant ($P>0.05$) between the two groups (Figure 15). At the 9 am, and 10 am hours, the group 2 pigs had a significantly ($P<0.05$) higher feeding visits frequency than the group 1 pigs.

After the peak of both groups, it is followed by a declining feeding visit trend until noon for both groups of pigs. This declining trend in the frequency of feeding visits between the two groups is significant ($P<0.05$). The group 2 male pigs dropped from 8 to 4 times, and the group 1 male pigs dropped from 5 to 2 times. Thereafter, the feeding visit continued to increase until it peaked at 3 pm with 7 visits for the group 2 pigs and 4 pm with 4 visits for the group 1 pigs. The increase in feeding visits was significantly ($P<0.05$) different between the two groups. The group 2 male pigs had a higher frequency of feeding visits than the group 1 male pigs.

Subsequently, after both groups peaked in the afternoon, a significant (P<0.05) decline in the frequency of feeding visit trend between the two groups of pigs was generally observed. Overall, the group 2 male pigs had a higher feed visits frequency when compared to the group 1 male pigs in this study.

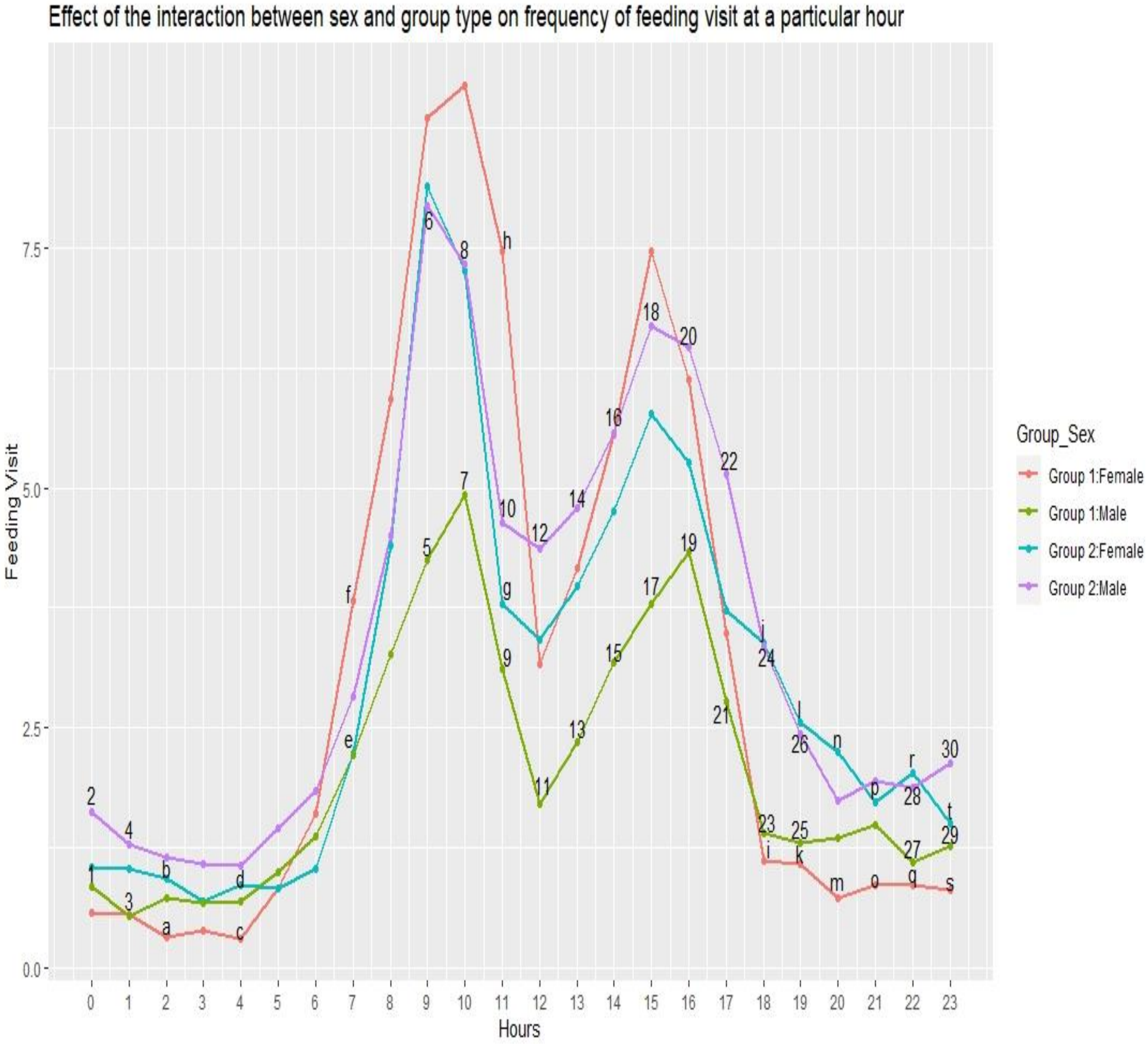

Figure 15: Difference in feeding visits between the group type of the female and male pigs.

Different alphabets indicate a significant difference in feeding visits between the two group types of female pigs at a particular hour of the day.

The points in the graph with no alphabet showed no significant difference in feeding visits between groups at that hour.

Different numbers indicate a significant difference in feeding visits between the two group types of male pigs at a particular hour of the day.

The points in the graph with no number showed no significant difference in feeding visits between groups at that hour.

4.2.9.3 The effect of the sex of the group 1 pigs on the frequency of feeding visits at a particular time of the day

The trend from Figure 16 showed that at a particular time of the day (hours), Group 1 female pigs visited the feeder more frequently than group 1 male pigs. Also, a total of the feeding visits for the significant hours throughout the day confirmed that the group 1 female pigs visited the feeder more often than the group 1 male pigs (64 visits vs 37 visits; $P<0.05$).

All group 1 pigs generally exhibited a decline in feeding visit frequency from 4 pm to 4 am for the female pigs, and 5 pm to 4 am for the male pigs. Within this period, feeding visits dropped from 6 to 0 times for the female pigs and 3 to 1 times for the male pigs. However, the only significant ($P<0.05$) decline in the feeding visit frequency was observed at the 4 pm, 8 pm, 9 pm, and 12 am hours of the day (Figure 16). This significant difference was because of the different sex of the pigs. Apart from the feeding visit frequency at midnight, the group 1 female generally had a significantly ($P<0.05$) higher feeding visit than the group 1 male pigs.

Subsequently, an increase in the frequency of feeding visit trend is observed. This increase began at 5 am for both sexes of the pigs. This trend continued until it peaked at 10 am for both sexes of the pigs. From the increase to the peak feeding visit time for both sexes, the feeding visit increased from 1 to 9 times for the group 1 female pigs and 1 to 5 times for the group 1 male pigs. Furthermore, during this period, apart from the feeding visit at 5 am, and 6 am, the increase in the frequency of feeding visit observed have been primarily significant (P<0.05) between the two sexes (Figure 16). The group 1 female pigs visited the feeder to feed more often than the group 1 male pigs.

After the peak hours of both sexes, it is followed by a declining feeding visit trend until noon for both sexes. During these hours, the frequency of feeding visits between the two sexes was significantly (P<0.05) different, with the female declining from 9 to 3 visits and the male pigs from 5 to 2 visits. Notwithstanding, the group 1 female pigs exhibited a higher feeding visit than the group 1 male pigs during this decline.

Thereafter, at 1 pm, the number of feeding visits continued to increase until it peaked at 3 pm with 8 visits for the group 1 female pigs and 4 pm with 4 visits for the group 1 male pigs. Similarly, this increase in feeding visits was significantly (P<0.05) different between the two sexes, with the group 1 female pigs visiting the feeder more frequently than the group 1 male pigs. Subsequently, after both sexes' peaked in the afternoon, a decline in the frequency of feeding visit trend between the two sexes was generally observed until 4 am the following day. This study observed that the group 1 female pigs were significantly (P<0.05) observed to visit the feeder than the group 1 male pigs. However, at night and early in the morning, the group 1 male pigs visited the feeder more frequently than the group 1 female pigs.

4.2.9.4 The effect of the sex of the group 2 pigs on the frequency of feeding visits at a particular time of the day

The number of feeder visits by the group 2 pigs is affected by the time of the day and their sex. The trend from Figure 16 showed that at a particular time of the day (hours), group 2 male pigs visited the feeder more frequently than group 2 female pigs. Also, a total of the feeding visits for the significant hours throughout the day confirm that the group 2 male pigs visited the feeder more often than the group 2 female pigs (3 visits vs 2 visits; P<0.05).

The group 2 pigs exhibited a decline in feeding visit frequency from 3 pm to 4 am and 5 am for the male and female pigs. Within this period, feeding visits dropped from 6 to 1 visit for the group 2 female pigs and 7 to 1 visit for group 2, the male pigs. However, the only significant decline (P<0.05) in the feeding visit frequency was observed at the 5 am hours of the morning (Figure 16). This significant difference was due to the different sex of the pigs. Therefore, the group 2 male pigs visited the feeder far more than the group 2 female pigs (2 visits vs 1 visit).

Subsequently, an increase in the frequency of feeding visit trend was observed. This increase began at 5 am for the male pigs and 6 am for the female pigs. This trend continued until it peaked at 9 am for both sexes of the pigs. From the point of increase to the peak feeding visit time for both sexes, feeding visits increased from 1 to 8 times for the group 2 female pigs and 2 to 8 times for the group 2 male pigs. Furthermore, during this period, apart from the feeding visit at 6 am, the increase in the frequency of feeding visit observed have been largely non-significant (P>0.05) between the two sexes (Figure 16). At 6 am, the group 2 male pigs significantly (P<0.05) visited the feeder more often than the group 2 female pigs (2 visits vs 1 visit).

After the peak hours of both sexes, it is followed by a declining feeding visit trend until noon for both sexes. The group 2 female pigs declined from 8 to 3 visits, and the group 2 male pigs from 8 to 4 visits. During these hours, the frequency of feeding visits between the two sexes was non-significantly different. Therefore, feeding visit frequency between sexes during this period was the same.

After that, at 1 pm, the number of feeding visits increased until it peaked at 3 pm with 6 and 7 visits for group 2 female and male pigs. However, this increase in feeding visits was not significantly different (P>0.05) between the two sexes of the pig. Subsequently, after the peak of both sexes in the afternoon, a decline in the frequency of feeding visit trend between the two sexes was generally observed until 4 am and 5 am the following day. This study observed that the group 2 male pigs significantly visited the feeder than the group 1 female pigs.

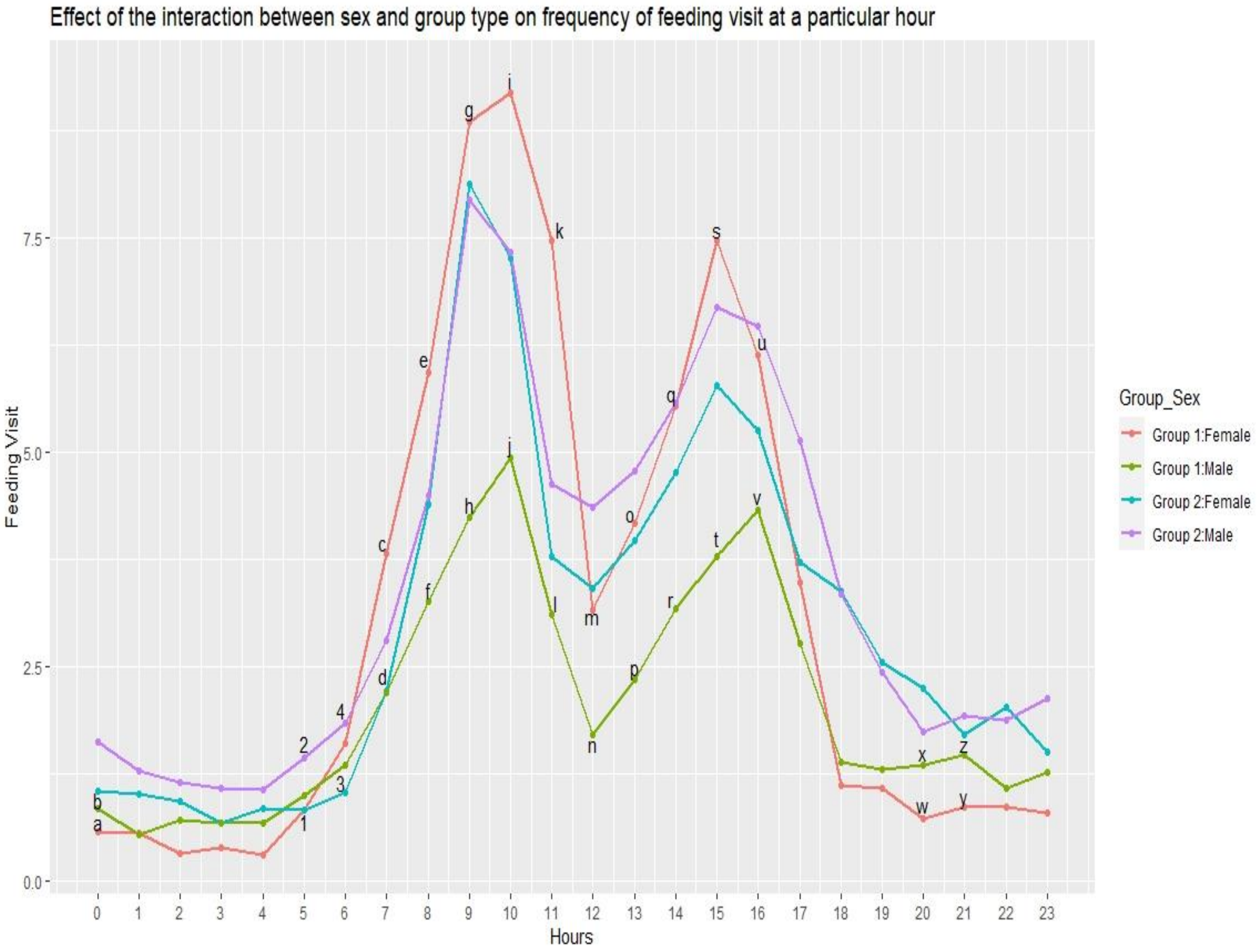

Figure 16: Difference in feeding visits between the different sexes of group 1 and group 2 pigs.

Different alphabets indicate a significant difference in feeding visits between the two sexes of group 1 pigs at a particular hour of the day.

The points in the graph with no alphabet showed no significant difference in feeding visits between sexes at that hour.

Different numbers indicate a significant difference in feeding visits between the two sexes of group 2 pigs at a particular hour of the day.

The points in the graph with no numbers showed no significant difference in feeding visits between sexes at that hour.

4.3. The effect of the growth stage on the feeding visit of the group 1 pigs at a particular time of the day

Figure 17 showed that, at certain times of the day, the growth stage of the group 1 pigs had a significant effect on their hourly feeding visit frequency. At all the times of the day that feeding visits frequency was significant (such as at 12 am to 2 am, 4 am, 12 pm to 1 pm, 7 pm, and 9 am to 10 pm; $P<0.05$), the group 1 pigs during the growing phase visited the feeder more often compared to during its finishing phase (Figure 17). The feeding visit peaked at 10 am for the group 1 pigs during the growing and finishing growth stage. In the afternoon, peak feeding visits was at 3 pm for the group 1 pigs during the growing and finishing growth stage. Overall, the group 1 pig visited the feed more frequently than its finishing phase during the growing phase.

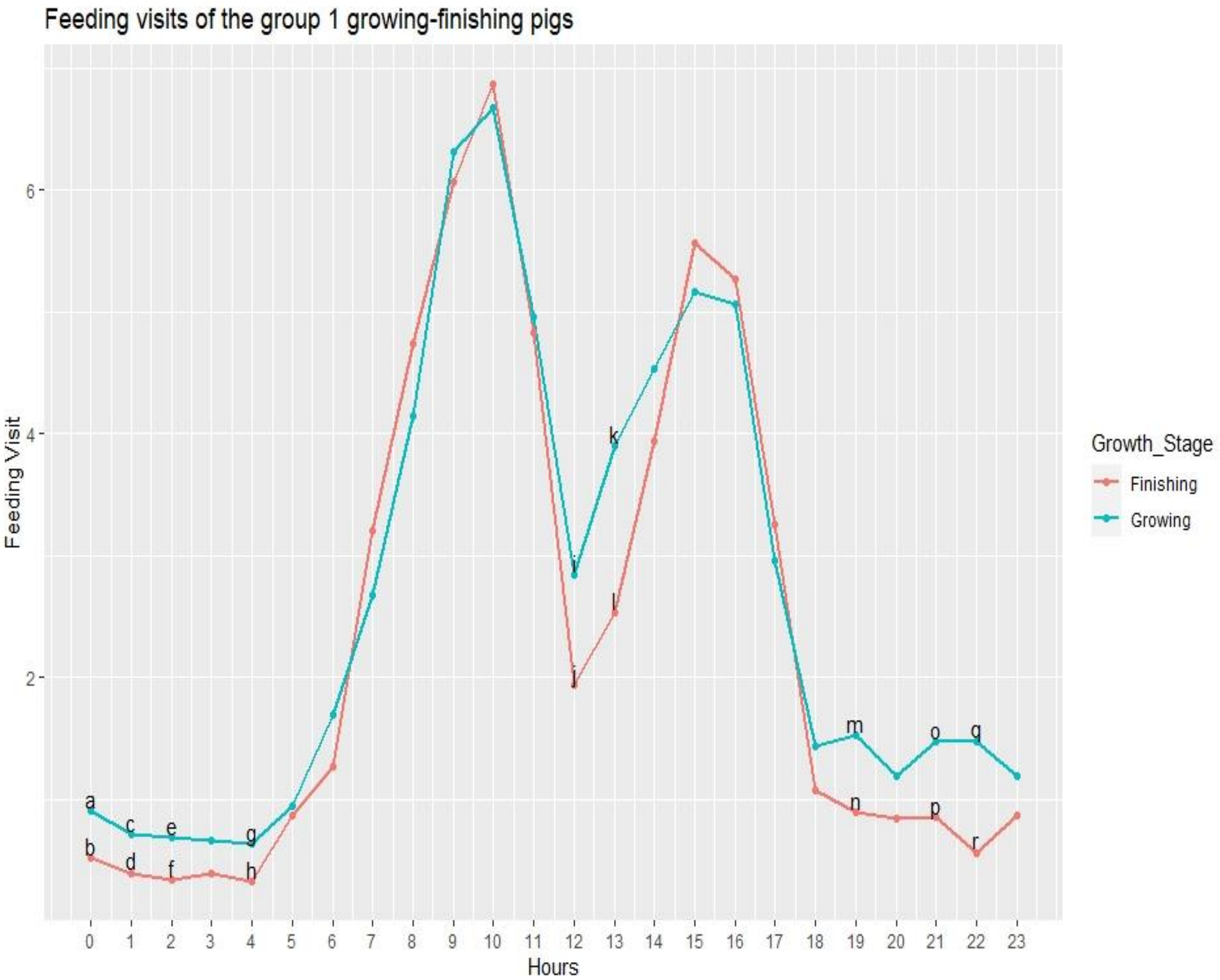

Figure 17: Difference in the frequency of feeding visits between the growing and finishing growth stage of the group 1 pigs.

Alphabet between two datapoints indicates a significant difference in feeding visit between the growing and finishing group 1 pigs.

The points in the graph with no alphabet showed no significant difference in feeding visits between the growing and finishing group 1 pigs.

4.4 Time spent feeding

Table 4.4.1 showed the significant predictors in the mixed model used in predicting the time spent in feeding by the pig in this study. These significant predictors will be discussed at length in the following sections. It is important to highlight that time spent feeding and feeding duration would be interchangeably used in this section.

Table 4.4.1: Significant predictors in the time spent feeding by the pigs

	Type 3 Tests of Fixed Effects			
Effect	Num DF	Den DF	F Value	Pr > F
Hours	23	7269	31.34	<0.0001
Group	1	27	3.69	0.0653
Sex	1	27	5.60	0.0253
Growth-Stage	1	7269	26.50	<0.0001
Hours*Sex	23	7269	2.45	0.0001
Hours*Group	23	7269	6.07	<0.0001
Hours* Growth-Stage	23	7269	3.55	<0.0001
Hours*Group* Growth-Stage	24	7269	2.67	<0.0001
Hours*Group*Sex	24	7269	3.15	<0.0001

4.4.1. Effect of hourly progression on time spent feeding in pigs

Figure 18 showed how long the pig spent eating during each hour of the day from midnight (0 hrs) to 11 pm (23 hrs). The time of the day has a significant ($P<0.05$) effect on how long the pig spends feeding during its visit to the electronic feeder. Generally, figure 18 showed that the pig spends a more prolonged time feeding as the day progressed, with two peaks at 8 am, and 3 pm before it decreased, respectively.

Figure 18 also showed a declining trend of the time spent feeding (or feeding duration) as the hours progressed from 4 pm to 3 am. During this period, the time the pigs spent feeding dropped from 6 to 2 mins. However, for this same period, the only time a significant ($P<0.05$) decline in the time spent feeding was observed was from 4 pm to 6 pm and 11 pm to 12 am the following day.

Subsequently, an increase in the time the pig spends feeding is observed in the morning. This increasing trend begins at 4 am until it peaked at 8 am. During this period, the length of time the pigs spent eating increased from 1.99 to 5.86 minutes. Furthermore, the increase in feeding time was significant ($P<0.05$) between the preceding and succeeding hours of the day. However, during this period, the pig's time feeding as the hour progressed from 3 am to 4 am and 7 am to 8 am were not significant ($P>0.05$). More specifically, in the morning, the pig spends a much longer time feeding at 8 am; however, there is no significant ($P>0.05$) difference between the time it spends feeding at 8 am and 7 am.

After the peak, it is followed by a significant ($P<0.0001$) drop in the time spent feeding by the pig from 5.87 mins at 8 am to 4.18 mins at 9 am. After that, as the hours of the day progressed from 9 am to 10 am, the time spent feeding began to increase. This increasing trend in the time spent feeding continued through the morning from 4.46 minutes at 10 am until it peaked at 3 pm with 6.06 minutes. However, during this period, the increase in the time spent feeding was not significant. Overall, as the hours progressed in a day, the pigs are most likely to spend a long time feeding in the afternoon between 3 pm and 4 pm. Throughout the day, the pigs averagely spend 95.88 mins eating in the feeder.

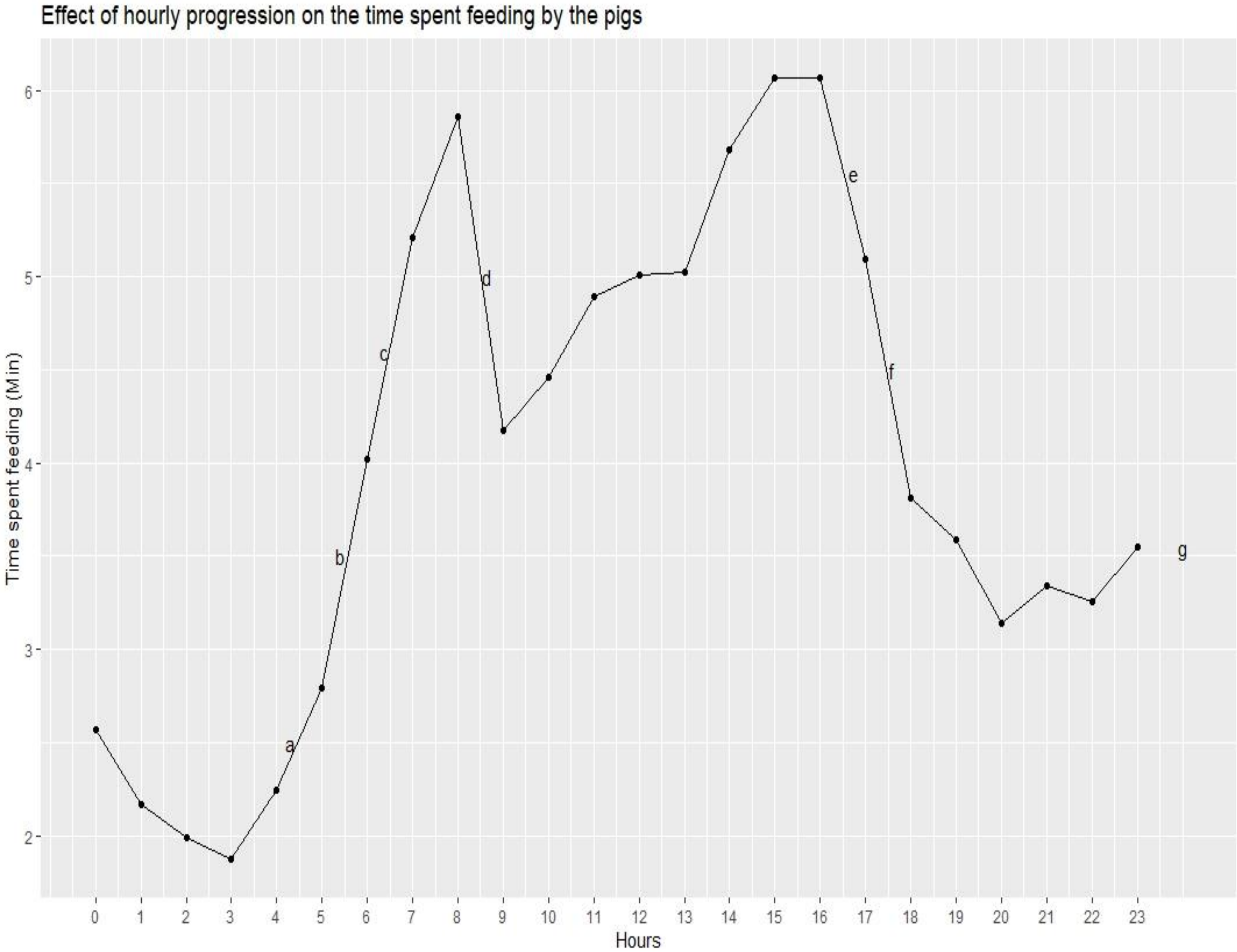

Figure 18: Difference in feeding time as the hours progressed in a day.

Alphabets between two datapoints indicate a significant difference in the time spent eating between the corresponding preceding and succeeding hours of the day.

The points in the graph with no alphabet showed no significant difference in the time spent feeding between the corresponding preceding and succeeding hours.

4.4.2 Effect of the sex of the pig on feeding duration

The effect of the sex of the pigs on how long it spends feeding is shown in Table 4.4.2. The result demonstrates that the feeding duration is influenced by the sex of the pig (P=0.0253). The male pigs spend a longer time feeding (4.26 mins) than the female pigs (3.41 mins).

Table 4.4.2: Least square means and standard error for feeding duration of female and male pigs.

Sex	Feeding duration (Minutes)	S.E[2]	S.E[3]	P-value[1]
Female	3.4066[a]	0.02345	0.0555	0.0253
Male	4.2614[b]	0.02266	0.0536	

[a,b] Values with different superscripts are significantly different from each other (LSD, P<0.05)

[2] Standard error was not back-transformed to its original form.

[3] Standard error was back-transformed to its original form.

[1] P-value from Table 4.4.1

4.4.3 Effect of the stage of growth of the pig on feeding duration

This study showed that the stage of growth of the pigs had a significant effect on the time spent feeding by the pigs. During the growing phase, the pigs spend a longer time in the electronic feeder eating (4.08 mins) when compared to the finishing phase (3.57 mins) of the study (P<0.0001; Table 4.4.3).

Table 4.4.3: Least square means and standard error for feeding duration of growers and finisher pigs.

Growth-Stage	Feeding-duration (Minutes)	S.E[2]	S.E[3]	P-value
Growing	4.0769^a	0.01647	0.0387	<0.0001[1]
Finishing	3.5667^b	0.01742	0.0409	

[a,b] Values with different superscripts are significantly different from each other (LSD, P<0.05)

[2] Standard error was not back-transformed to its original form.

[3] Standard error was back-transformed to its original form.

[1] P-value from Table 4.4.1

4.4.4 Effect of the sex of the pig on time spent feeding at a particular time of the day

As the day progressed, the sex of the pig had a significant (P<0.05) effect on the duration of feeding. Figure 19 showed a visual presentation of the effect of sex on the feeding duration at a particular hour of the day for this study

Generally, the hourly progression graph for both sexes of a pig showed that the feeding duration increased as the day progressed. The first peak was at 8 am for both sexes of pigs, and it declined (Figure 19). For both sexes of pigs, an increase in the feeding duration trend was observed at 4 am until it peaked at 8 am. During this period, there was a significant difference in feeding duration between the two sexes of the pig at 4 am (P<0.0001) and 6 am (P=0.0093). At both times, the male pig spent a long time eating (3.10 mins at 4 am and 4.85 mins at 6 am) compared to the female pigs (1.57 mins at 4 am, and 3.31 mins at 6 am).

After the peak feeding duration in the morning is later followed by a decline in feeding duration when the day progressed from 8 am to 9 am. The feeding duration of the female pigs dropped from 5.77 mins to 3.74 mins, while that of the male pigs dropped from 5.95 mins to 4.65 mins. However, at these hours (8 am and 9 am), there was no significant difference (P>0.05) in feeding duration between both sexes of the pig.

Another round of increased feeding duration in the afternoon started and peaked at 4 pm for the female pigs (Figure 19). In contrast to the female pig, the male pigs exhibited a different feeding duration pattern. It peaked at 11 am, followed by another decline. After that, another increase in feeding duration before finally peaked again at 3 pm (Figure 19). Nevertheless, only at 11 am was there a significant difference in feeding duration between both sexes, with the male pigs spending longer time feeding (5.77 mins) compared to the female pigs (4.14 mins; P=0.019)

After that, another round of decrease in feeding duration up to 3 am the following day for both sexes from the afternoon peak. Feeding duration reduced from 5.99 mins at 4 pm and 6.14 mins at 3 pm to 1.34 mins and 2.53 mins at 3 am the following day for the female and male pigs, respectively. At 9 pm, 11 pm, 12 am, 2 am, and 3 am, the male pigs spent a significantly (P<0.05) longer time eating in the feeder than the female pigs. Also, a total of the feeding duration for the significant hours throughout the day showed that the male pig spends significantly more time eating when compared to the female pigs (30.46 mins vs 19.47 mins; P<0.05).

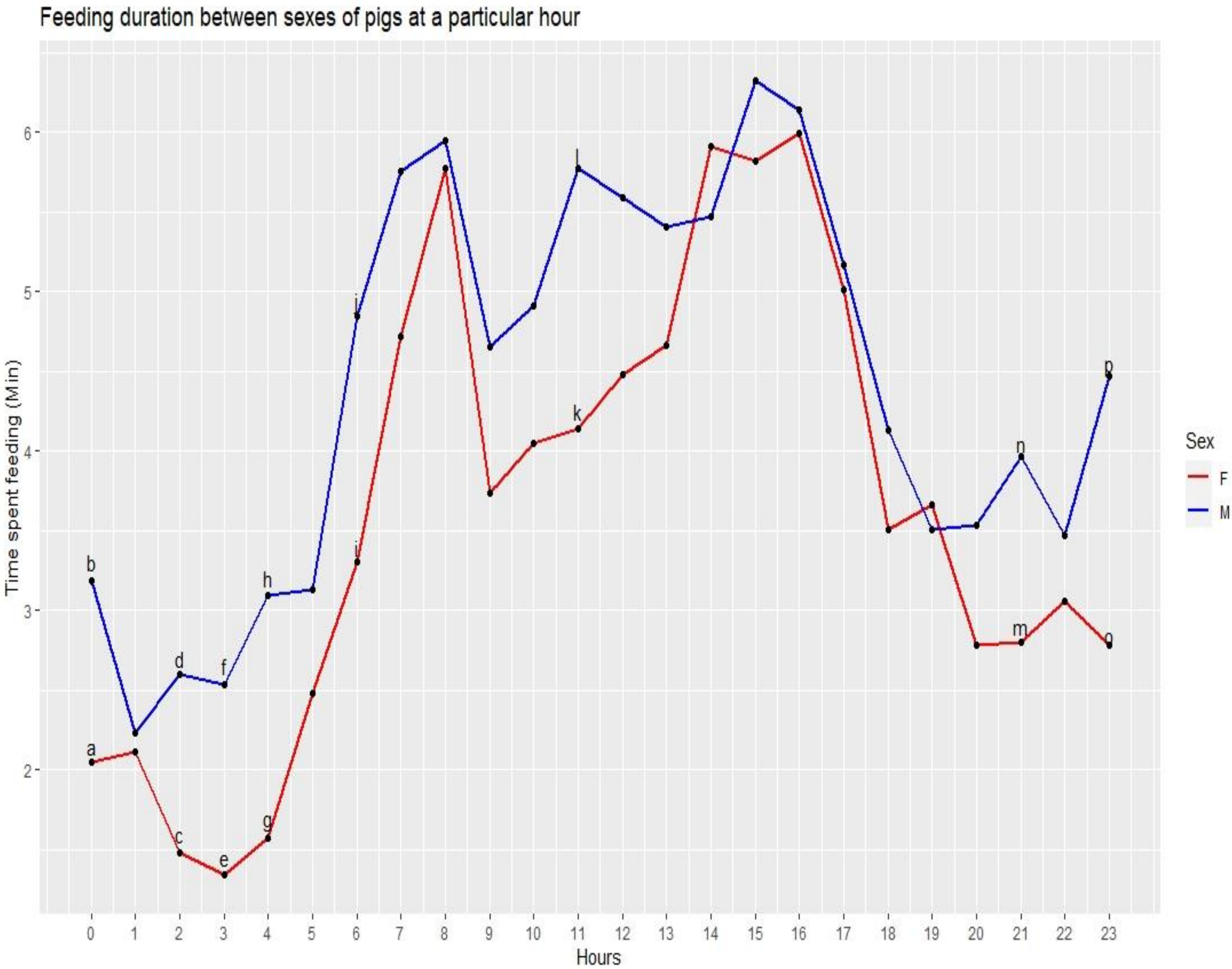

Figure 19: The significant difference in feeding duration between the two sexes.

Different alphabets indicate a significant difference in feeding duration between the two sexes at a particular hour of the day.

The points in the graph with no alphabet showed no significant difference in feeding duration between sexes at that hour.

4.4.5 Effect of the group type of the pigs on time spent feeding at a particular time of the day

As the day progressed, the group type of the pig has a significant ($P<0.05$) effect on the duration of feeding. Similarly, the result of this study showed that group 1 and group 2 growing-finishing pigs had a significantly ($P<0.05$) different feeding duration at a particular hour of the day (Figure 20).

Also, feeding duration patterns showed a decreasing trend from 5 pm to 2 am for the group 1 pigs and 4 pm to 5 am for the group 2 pigs. During this period, except for the 8 pm and 11 pm time of the day, feeding duration differed between the two groups of pigs. Feeding duration reduced from 2.88 to 1.29 mins for the group 1 pigs and 4.97 to 2.45 mins for the group 2 pigs. The group 2 pigs spent a significantly longer time feeding when compared to the group 1 pigs ($P<0.05$).

However, as the morning progressed, for the group 1 pigs, an increasing trend in time spent feeding began from 3 am with 1.40 mins until it peaked at 8 am with 6.46 mins. On the other hand, the increasing feeding duration for the group 2 pigs began from 6 am with 3.16 mins to 8 am with 5.30 mins. At 3 am, and 4 am, the group 2 pigs significantly ($P<0.05$) spent a more extended time feeding than the group 1 pigs ($P<0.05$). However, this trend changes from 6 to 7 am, with the group 1 pigs overtaking the group 2 pigs, spending significantly ($P<0.05$) longer time feeding.

After the feeding duration peaked in the morning, it is followed by a non-significant ($P>0.05$) decline when the day progressed from 8 to 9 am between the groups. The group 1 pigs spent lesser time feeding as the hours progressed from 9 am to 12 pm. It is later followed by another round of increasing feeding duration in the afternoon and peaked at 3 pm and 4 pm with 6.06 mins and 6.25 mins for the group 2 and group 1 pigs, respectively (Figure 20). The feeding duration between the two groups of pigs at any particular time during this increase was not significant.

Overall, the group 2 pigs spent a significantly ($P<0.05$) longer time feeding from later in the evening to early in the morning than the group 1 pigs. Also, a total of the feeding duration for the significant hours throughout the day showed that the group 2 pigs spent significantly ($P<0.05$) more time eating when compared to the group 1 pigs (39.63 mins vs 30.22 mins).

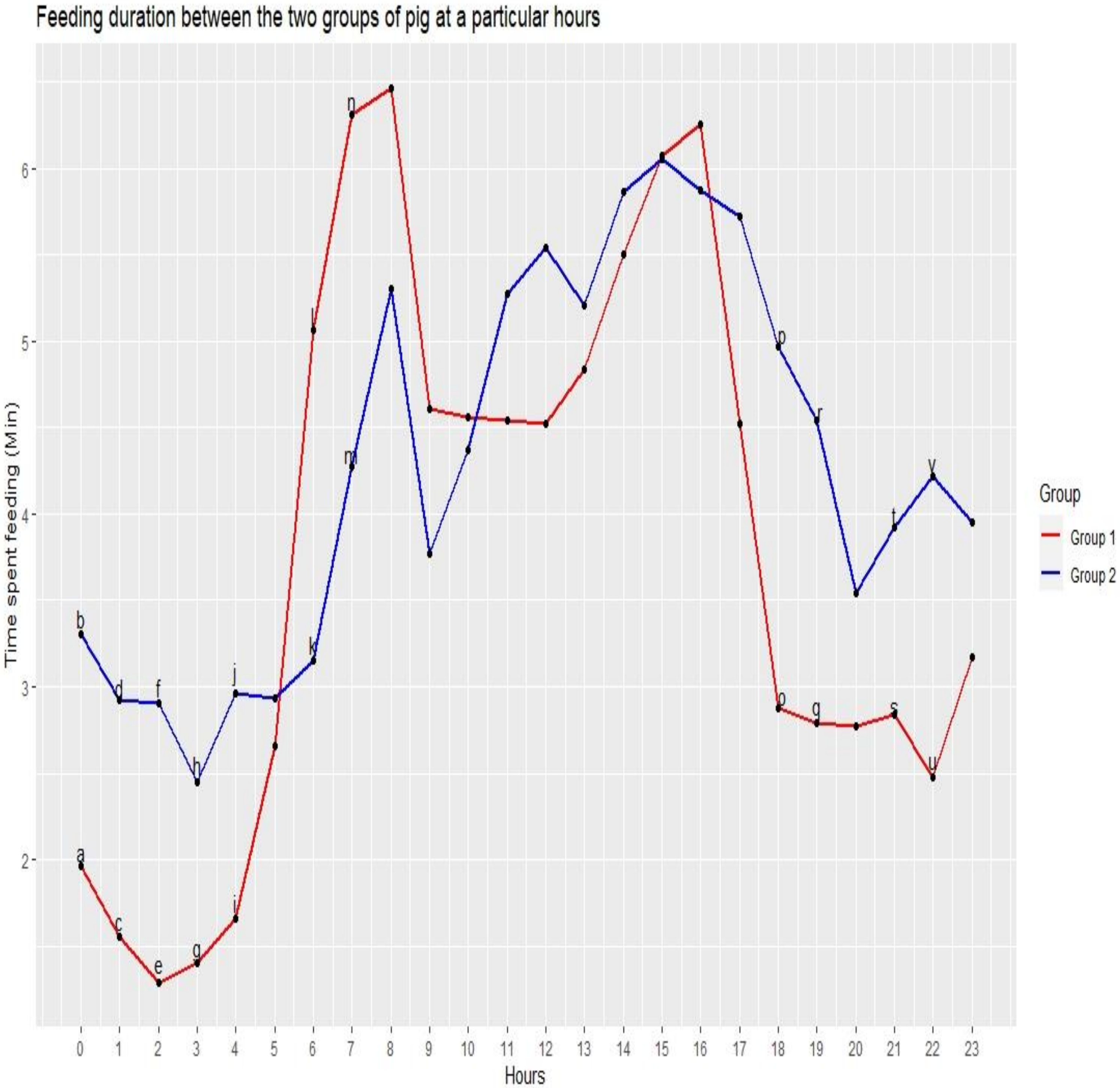

Figure 20: The significant difference in feeding duration between the two groups of pigs.

Different alphabets indicate a significant difference in feeding duration between the two groups of pigs at a particular hour of the day. The points in the graph with no alphabet showed no significant difference in feeding duration between the groups at that hour.

4.4.6 The effect of the stage of growth of the pig on the feeding duration at a particular time of the day

As the day progressed, the growth stage of the pig affected the duration of feeding. Similarly, this study showed that at a particular hour of the day, the time spent feeding by the pigs was significantly ($P<0.05$) different when the pigs were at either the growing or finishing phase (Figure 21).

As the morning progressed, an increasing trend in feeding duration was observed, with the increase beginning at 3 am for the growing pigs and 4 am for the finishing pigs. The increase in feeding duration continued until it peaked at 7 am for the growing pigs and 8 am for the finishing pigs. During this period, feeding duration increased from 2.21 to 6.54 mins for the growing pigs and from 1.99 to 6.35 mins for the finishing pigs. At a particular hour of the morning (such as at 3 am and from 5 am to 7 am), the growing pigs spent a significantly ($P<0.05$) longer time feeding compared to the finishing pigs.

After the peak of both phases, it is followed by a declining feeding duration trend until 9 am. During these hours, the time spent feeding between the two growth phases was insignificant, mostly the same. Subsequently, feeding duration began to increase at 10 am with 4.19 mins for the growing pigs before it peaked at 1 pm with 6.12 mins. For the pigs at the finishing stage of growth, feeding duration increased at 10 am with 4.75 mins, then peaked at 11 am with 5.13 mins before dropping to 4.10 mins at 1 pm. After that, another round of increase in feeding duration began at 2 pm with 5.44 mins; then it peaked at 4 pm with 6.65 mins. However, during this period, only from 12 pm to 1 pm, there was a significant ($P<0.05$) difference in feeding duration, with the growing pigs spending a longer time than the finishing pigs (Figure 21).

Subsequently, after the afternoon peak, a decline in the feeding duration was observed from 2 pm to 2 am for the growing pigs and 5 pm to 3 am for the finishing pigs. However, only at certain hours of the day (such as 5 pm, 9 pm, 10 pm, and 12 am to 1 am), there was a significant ($P<0.05$) difference in feeding duration between the two growth phases. Also, the feeding duration for the significant ($P<0.05$) hours throughout the day showed that the growing pigs spent a long time eating compared to the finishing pigs (47.36 mins vs 36.09 mins).

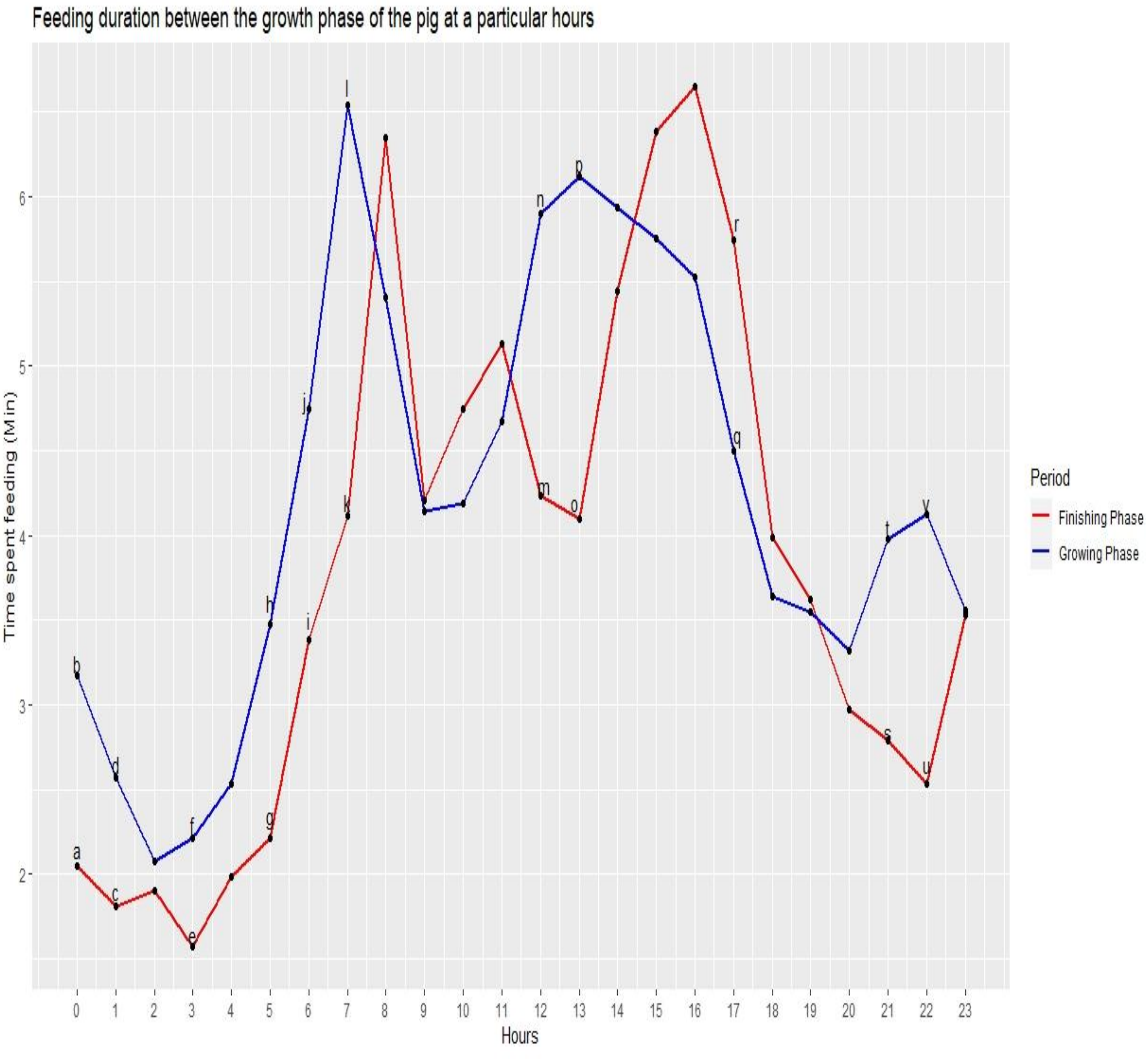

Figure 21: Difference in feeding duration between the different growth stages of the pigs.

Different alphabets indicate a significant difference in feeding duration between the two growth stages at a particular hour of the day.

The points in the graph with no alphabet showed no significant difference in feeding duration between growth stages at that hour.

4.4.7 The effect of the interaction between group type and growth stage of the pig on the hourly feeding duration

The hourly feeding duration is affected by the interaction between the group type and the growth stage of the pig. There is a significant (P<0.0001) interaction between the time of the day (in hours) and the group type of the growing and finishing pigs.

4.4.7.1 The effect of the group type of the growing pigs on the frequency of feeding duration at a particular time of the day.

Figure 22 showed that, at certain times of the day, the group type of the growing pigs had a significant (P<0.05) effect on their hourly feeding duration. At a particular time of the day (such as at 12 am to 2 am, 6 pm, and 8 pm to 9 pm), group 2 growing pigs spent a more extended time feeding than the group 1 growing pigs (P<0.05; Figure 22). The feeding duration peaked at 7 am for the group 1 pigs and group 2 growing pigs. In the afternoon, peak feeding duration was at 2 pm for group 1 and 1 pm for the group 2 growing pigs. Overall, the group 2 pigs spent more prolonged time feeding during the growing phase than the group 1 pigs.

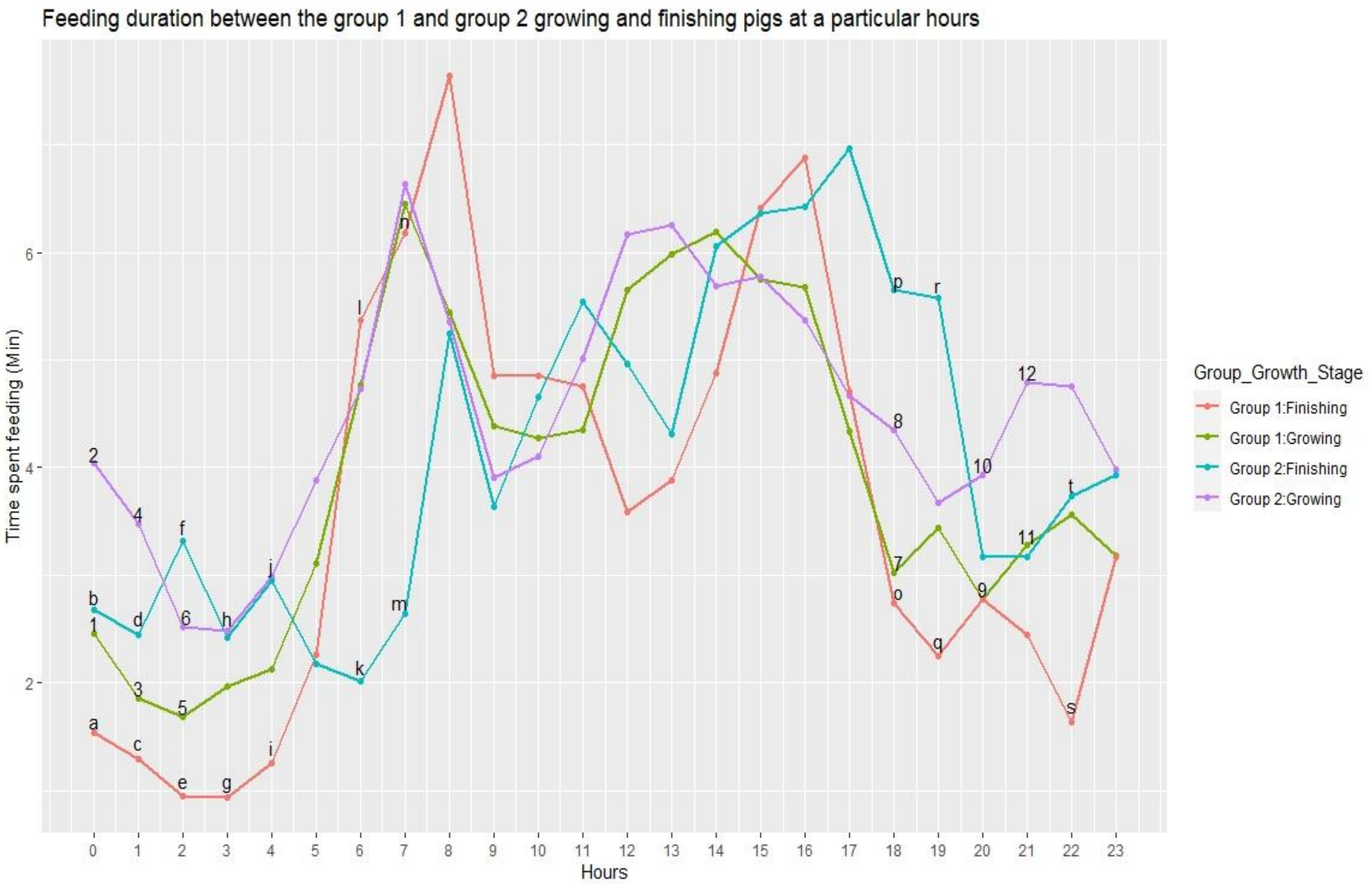

Figure 22: Significant difference in feeding duration between group 1 and group 2 growing and finishing.

Different alphabets indicate a significant difference in feeding duration between the two groups of finishing pigs at a particular hour of the day.

The points in the graph with no alphabet showed no significant difference in feeding duration between the two groups at that hour.

Different numbers indicate a significant difference in feeding duration between the two groups of growing pigs at a particular hour of the day.

The points in the graph with no number showed no significant difference in feeding duration between the two groups at that hour.

4.4.7.2 The effect of the group type of the finishing pigs on time spent feeding at a particular time of the day

At certain hours of the day, the group type of the finishing pigs had a significant ($P<0.05$) effect on feeding duration. A total of the feeding duration for the significant hours throughout the day showed that the group 2 finishing pigs generally spent a longer time (33.43 mins vs 24.15 mins) feeding than the other group 1 finishing pigs.

As the morning progressed, an increasing trend in feeding duration was observed, with the increase beginning at 4 am for the group 1 finisher pigs, and 7 am for the group 2 finisher pigs. The increasing feeding duration continued until it peaked at 8 am for group 1 and group 2 finisher pigs. During this period, feeding duration increased from 1.26 to 7.64 mins for the group 1 pigs and 2.64 to 5.25 mins for the group 2 finishing pigs. At a particular hour of the morning (such as from 6 am to 7 am), group 1 finishing pigs spent a significantly ($P<0.05$) more prolonged time feeding than group 2 finishing pigs. On the other hand, at 4 am, the group 2 pigs spent a more extended time feeding than the group 1 pigs ($P=0.0024$; Figure 22).

After the morning peak of both groups, it is followed by a declining feeding duration trend until 9 am with 3.64 mins for the group 2 pigs and noon with 3.59 mins for the group 1 pigs. For the group 2 pigs, the feeding duration began to increase. It increased from 10 am with 4.65 mins and peaked again at 11 am with 5.53 mins, before dropping to 4.32 mins at 1 pm. After that, another round of increased feeding duration for the group 2 pigs began at 2 pm with 6.05 mins, then peaked at 5 pm with 6.97 mins. For the group 1 finishing pigs, the increasing feeding duration began at 1 pm with 3.88 mins before it peaked at 4 pm with 6.88 mins. Generally, there was no significant difference between the two groups on the feeding duration within the above reported period of the day (Figure 22).

Subsequently, after the peak of both groups in the afternoon, a declining trend in feeding duration was generally observed. The feeding duration for the group 1 pigs declined from 5 pm with 4.71 mins to 3 am with 0.94 mins. Feeding duration for the group 2 pigs also declined from 6 pm with 5.65 mins to 6 am with 2.01 mins. Throughout this period, there was a significant difference between the two groups at certain hours of the day (such as at 6 pm to 7 pm, 10 pm, 12 am to 4 am, and 6 am). Within this period, group 2 finishing pigs spent more time eating than group 1 finishing pigs ($P<0.05$).

4.4.7.3 The effect of the growth stage on the feeding duration of the group 1 pigs at a particular time of the day

Figure 23 showed that, at certain times of the day, the growth stage of the group 1 pigs had a significant (P<0.05) effect on their hourly feeding duration. The group 1 pigs during the growing phase had extended feeding time compared to during its finishing phase at a specific time of the day (such as 12 am, 2 am to 4 am, 12 pm to 1 pm, 7 pm and 10 pm).

However, at 8 am, the group 1 pigs spent more time feeding during their finishing phase than during their growing phase. The feeding duration peaked at 7 am for the group 1 pigs during the growing phase and 8 am during the finishing growth stage. In the afternoon, peak feeding visits was at 2 pm for the group 1 pigs during the growing phase and 4 pm during the finishing growth stage. Overall, the group 1 pig spent a long time feeding during the growing phase compared to its finishing growth phase.

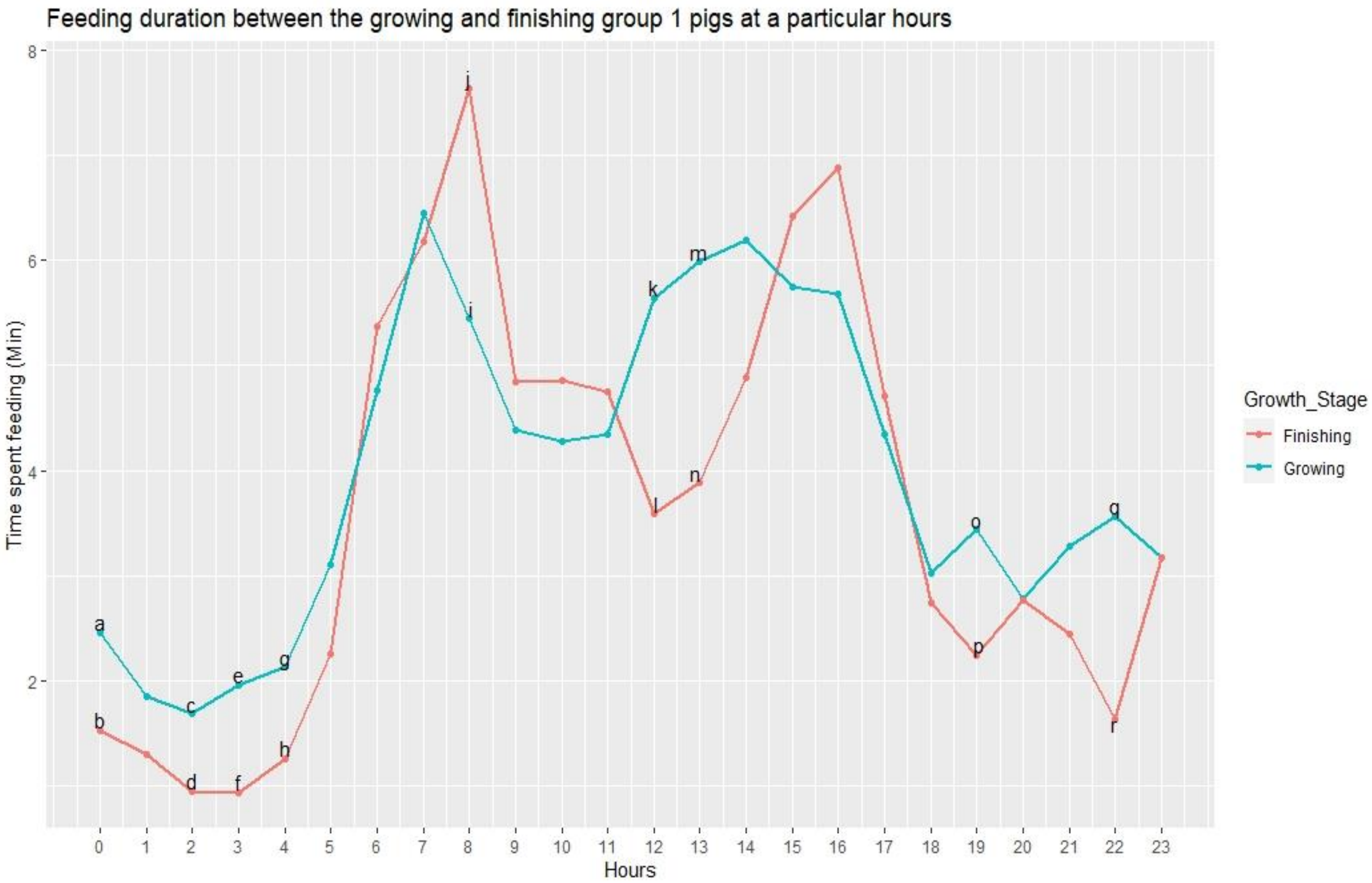

Figure 23: The difference in feeding duration between the growing and finishing growth stage of the group 1 pigs.

Alphabets between two datapoints indicate a significant difference in feeding duration between the growing and finishing group 1 pigs.

The points in the graph with no alphabet showed no significant difference in feeding duration between the growing and finishing group 1 pigs.

4.4.8 The effect of the interaction between group type and sex on feeding duration of pigs at a particular time of the day

The time spent feeding is affected by the group type and sex of the pig at a particular time of the day ($P<0.0001$).

4.4.8.1 The effect of group type of female pigs on feeding duration at a particular time of the day

At certain hours of the day, the group type of the female pigs had a significant ($P<0.05$) effect on feeding duration. Also, a total of the feeding duration for the significant hours throughout the day showed that the group 2 female pigs generally spent a significantly ($P<0.05$) longer time (40.04 mins vs 22.36 mins) feeding compared to the other group 1 female pigs.

As the morning progressed, an increasing trend in feeding duration was observed. The increase began at 5 am for group 1 female pigs and 6 am for group 2 female pigs. The increase in feeding duration continued until it peaked at 8 am for both groups of female pigs. During this period, feeding duration increased from 2.64 to 5.71 mins for the group 1 pigs and from 2.41 to 5.84 mins for the group 2 pigs (Figure 24). At 6 am, the group 1 female pigs spent a significantly longer time feeding than the group 2 female pigs (4.44 mins vs 2.41 mins; $P=0.0068$).

After the morning peak of both groups, it is followed by a declining feeding duration trend until 9 am with 3.93 mins for the group 2 pigs and 11 am with 3.04 mins for the group 1 pigs. At 11 am, the group 2 female pigs spent a significantly ($P=0.0055$) longer time feeding when compared to the group 1 female pigs (5.54 mins vs 3.04 mins). For the group 2 pigs, the feeding duration increased again from 10 am with 4.52 mins and peaked at 2 pm with 6.68 mins. On the other hand, for the group 1 female pigs, an increase in feeding duration began at noon with 3.71 mins, then peaked at 4 pm with 5.83 mins. Generally, there was no significant difference between the two groups of female pigs on the feeding duration during that time of the day.

Subsequently, after the peak of both groups in the afternoon, a declining trend in feeding duration was generally observed. Feeding duration for group 1 pigs declined from 5 pm with 4.37 mins to 4 am with 0.93 mins. The group 2 pigs also declined from 3 pm with 6.14 mins to 5 am with 2.33 mins. During this period, there was a significant difference between the two groups of female pigs during certain hours of the day (such as from 6 pm to 10 pm, 12 am, and 2 am to 4 am). The group 2 pigs spent more time eating than the group 1 pigs ($P<0.05$; Figure 24). Overall, group 2 female pigs spent a significantly ($P<0.05$) longer time feeding later in the evening to very early in the morning than the group 1 female pigs (34.50 mins vs 19.33 mins).

4.4.8.2 The effect of group type of the male pigs on feeding duration at a particular time of the day

At certain hours of the day, the group type of the male pigs affected feeding duration. Also, a total of the feeding duration for the significant hours throughout the day showed that the group 1 male pigs generally spent a significantly ($P<0.05$) longer time feeding (35.16 mins vs 34.38 mins) compared to the group 2 male pigs.

As the morning progressed, an increasing trend in feeding duration was observed. The increase began at 3 am for group 1 male pigs, and 4 am for group 2 male pigs. The increasing feeding duration continued until it peaked at 8 am for group 1 and group 2 male pigs. During this period, feeding duration increased from 1.97 mins to 7.30 mins for the group 1 pigs and from 3.58 mins to 4.81 mins for the group 2 male pigs (Figure 24). At 3 am, the group 2 male pigs spent a significantly ($P=0.0402$) longer time feeding than the group 1 male pig (3.20 mins vs 1.97 mins). However, from 7 am to 9 am, the group 1 male pigs spent a long time feeding than the group 2 males' pigs ($P<0.05$).

After the morning peak of both groups, it is followed by a declining feeding duration trend until 10 am with 5.69 mins for the group 1 pigs and 9 am with 3.62 mins for the group 2 pigs. After that, another round of increased feeding duration for the group 1 male pigs began at 11 am with 6.62 mins before dropping to 5.48 mins at noon. At 1 pm, the feeding duration for group 1 male pigs began to rise before it peaked at 4 pm with 6.7 mins. For the group 2 male pigs, the feeding duration increased again from 10 am with 4.22 mins and peaked again at 3 pm with 5.98 mins. Generally, there was no significant difference between the two groups on the feeding duration of the male pigs during this period of the day.

Subsequently, after the peak of both groups in the afternoon, a declining trend in feeding duration was generally observed. For the group 1 pigs, the decline in feeding duration started from 5 pm with 4.68 mins to 2 am with 1.97 mins. For the group 2 pigs, the decline started from 4 pm with 5.61 mins to 3 am with 3.20 mins. During this period, the feeding duration differed between the two groups at certain hours of the day (such as at 10 pm and 12 am to 3 am). The group 2 male pigs spent more time eating than the group 1 male pigs ($P<0.05$; Figure 24). However, at 8 pm, group 1 male pigs spent a long time feeding than the group 2 male pigs (4.40 mins vs 2.81 mins; $P=0.0378$).

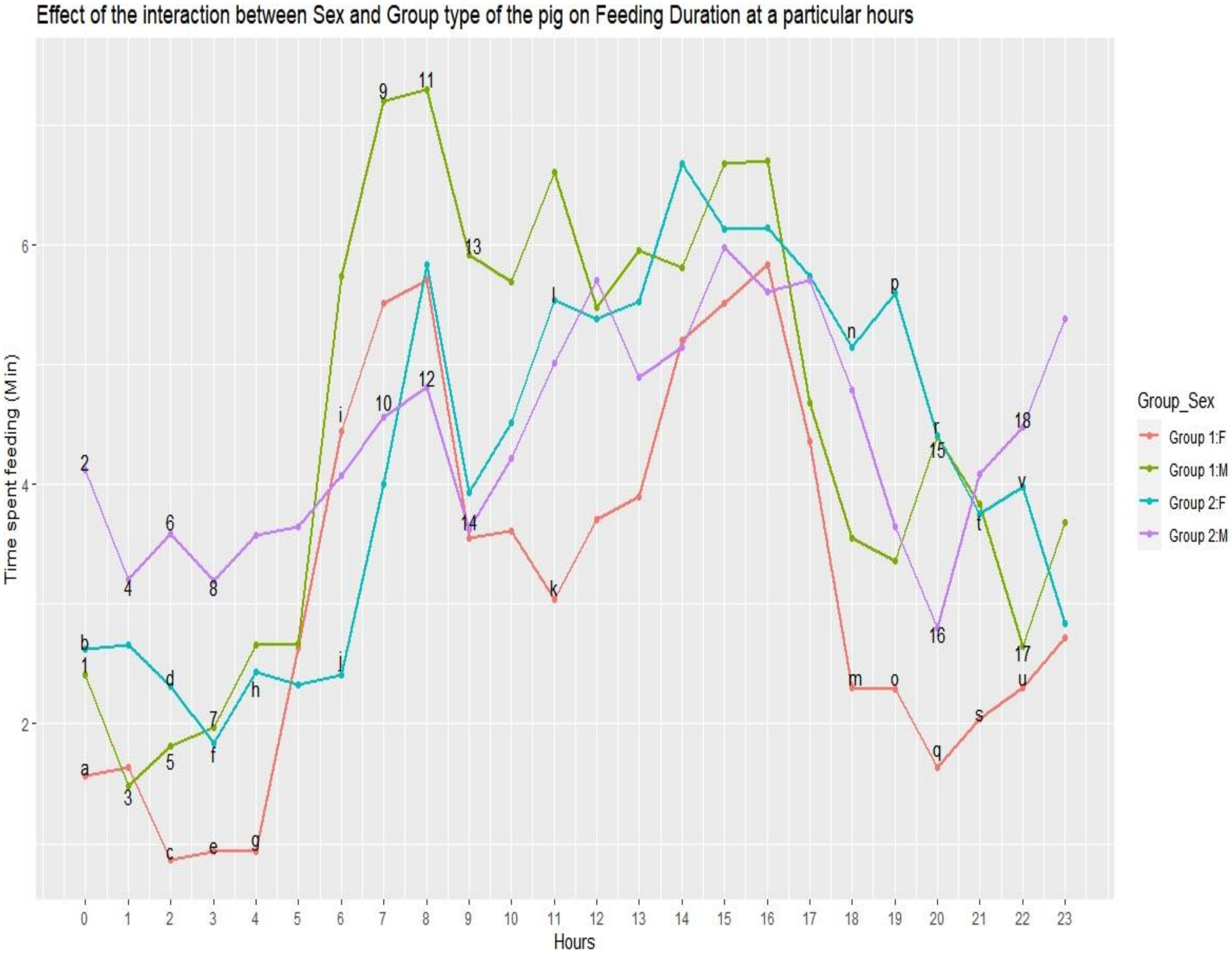

Figure 24: The significant difference in feeding duration between the different groups of the female and male pigs.

Different alphabets indicate a significant difference in feeding duration between the group 1 and group 2 female pigs at a particular hour of the day.

The points in the graph with no alphabet showed no significant difference in feeding duration between the two groups at that hour.

Different numbers indicate a significant difference in feeding duration between group 1 and group 2 male pigs at a particular hour of the day.

The points in the graph with no number showed no significant difference in feeding duration between the two groups at that hour.

4.4.8.3 The effect of sex of the group 1 pigs on feeding duration at a particular time of the day

At certain hours of the day, the sex of the group 1 pigs affected feeding duration. Also, a total of the feeding duration for the significant ($P<0.05$) hours throughout the day showed that group 1 male pigs had a prolonged feeding duration than group 1 female pigs (44.37 mins vs 24.21 mins).

As the morning progressed, an increasing trend in feeding duration was observed. The increase began at 5 am for group 1 female pigs and 2 am for group 1 male pigs. The increasing trend in feeding duration continued until it peaked at 8 am for both sexes of the group 1 pigs. During this period, feeding duration increased from 2.64 to 5.71 mins for the group 1 female pigs and from 1.82 to 7.30 mins for the group 1 male pigs (Figure 25). As the hours progressed from 2 am to 4 am, the group 1 male pigs spent a significantly ($P<0.05$) more extended time feeding than the group 1 female pigs.

After the morning peak of both sexes, it is followed by a declining feeding duration trend until 11 am with 3.04 mins for the group 1 female pigs and 10 am with 5.69 mins for the group 1 male pigs. After that, another round of increased feeding duration for the group 1 male pigs began at 11 am with 6.62 mins before it dropped again to 5.48 mins at noon. At 1 pm, the feeding duration for group 1 male pigs began to rise before it peaked at 4 pm with 6.7 mins. For the group 1 female pigs, the feeding duration increased at noon with 3.71 mins before it peaked at 4 pm with 5.83 mins. From 9 am to 1 pm, there was a significant ($P<0.05$) effect on feeding duration. As a result, the group 1 male pigs spent a more extended time feeding when compared to the group 1 female pigs.

Subsequently, after the peak of both sexes in the afternoon, a declining trend in feeding duration was generally observed. Feeding duration for the group 1 female pigs reduced from 5 pm with 4.37 mins to 4 am with 0.93 mins. Also, feeding duration for the group 1 male pigs reduced from 5 pm with 4.68 mins to 1 am with 1.47 mins. From 8 pm to 9 pm, there was a significant ($P<0.05$) difference between the sexes during this period. The group 1 male pigs spent a significantly ($P<0.05$) longer time eating than the group 1 female pigs (Figure 25). Overall, group 1 male pigs will significantly ($P<0.05$) spend a long time feeding compared to group 1 female pigs at certain hours of the day.

4.4.8.4 The effect of sex of the group 2 pigs on feeding duration at a particular time of the day

At certain hours of the day, the sex of the group 2 pigs affected feeding duration. Also, a total of the feeding duration for the significant ($P<0.05$) hours throughout the day showed that the group 2 male pigs had an extended feeding duration than the group 2 female pigs (26.89 mins vs 22.04 mins).

As the morning progressed, an increasing trend in feeding duration was observed. Feeding duration began to increase at 6 am for the group 2 female pigs, and 4 am for the group 2 male pigs. The increasing trend in feeding duration continued until it peaked at 8 am for both sexes of the group 2 pigs. During this period, the group 2 pigs' feeding duration increased from 2.41 to 5.84 mins for the female pigs and from 3.58 to 4.81 mins for the male pigs (Figure 25). As the day advanced from 5 am to 6 am, the group 2 male pigs spent a significantly longer time feeding than the group 2 female pigs ($P<0.005$).

After the morning peak of both sexes, it is followed by a declining feeding duration trend until 9 am for both sexes, with 3.93 mins for the group 2 female pigs and 3.62 mins for the group 2 male pigs. Thereafter, another round of increased feeding duration for the group 2 male pigs began at 10 am with 5.02 mins then peaked at noon with 5.70 mins. It dropped again to 4.90 mins at 1 pm, began another feeding duration increase trend, and peaked at 3 pm with 5.98 mins. For the group 2 female pigs, feeding duration began to increase at 10 am with 4.52 mins, then peaked at 2 pm with 6.68 mins. From 7 am to 3 pm, there was no significant difference between the two sexes on feeding duration during this period.

Subsequently, after the peak of both sexes in the afternoon, a declining trend of feeding duration was generally observed. For the group 2 female pigs, feeding duration dropped from 3 pm with 6.14 mins to 5 am with 2.33 mins. Feeding duration also dropped from 4 pm with 5.61 mins to 1 am with 3.21 mins for the group 2 male pigs. Within this period, at certain hours of the day (such as at 11 pm, 12 am, and 3 am), there was a significant (P<0.05) difference between the sexes. The group 2 male pigs spent a significantly longer time eating than the group 2 female pigs (Figure 25). However, from 7 pm to 8 pm, the group 2 female pigs spent a more extended time feeding than the group 2 male pigs (P<0.05). Overall, for all group 2 pigs, the male pigs significantly (P<0.05) spent a long time feeding compared to the female pigs at certain hours of the day.

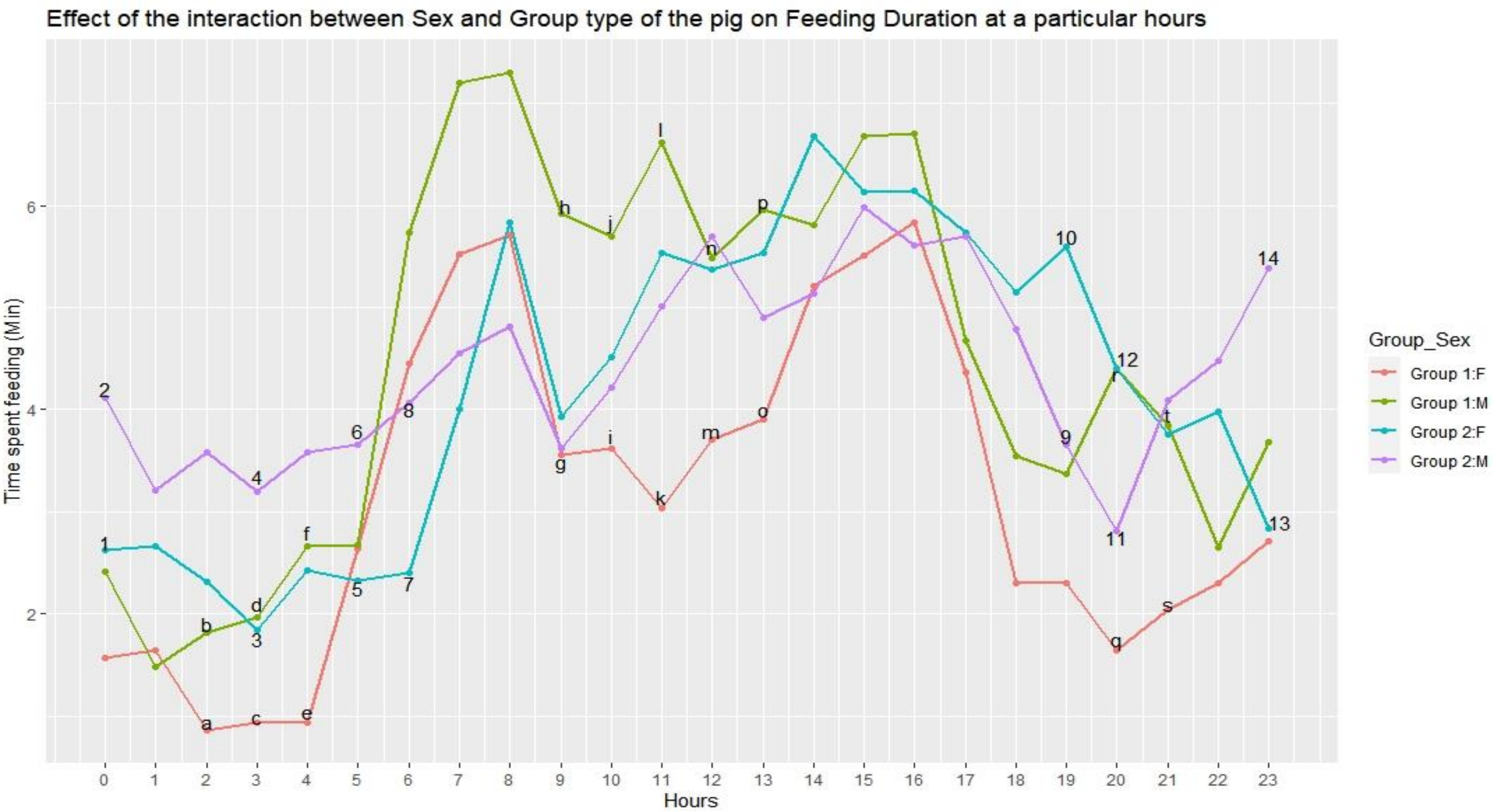

Figure 25: The significant difference in feeding duration between the different sexes of the group 1 and group 2 pigs.

Different alphabets indicate a significant difference in feeding duration between the two sexes of the group 1 pigs at a particular hour of the day. The points in the graph with no alphabet showed no significant difference in feeding duration between sexes at that hour.

Different numbers indicate a significant difference in feeding duration between the two sexes of the group 2 pigs at a particular hour of the day. The points in the graph with no number showed no significant difference in feeding duration between sexes at that hour.

4.5 Hourly feed intake

Table 4.5.1 showed the significant predictors in the mixed model used in predicting the pigs' hourly feed intake. These significant predictors will be discussed at length in the following sections.

Table 4.5.1: Predictors significant in predicting hourly feed intake of the pigs.

	Type 3 Tests of Fixed Effects			
Effect	Num DF	Den DF	F Value	Pr > F
Hours	23	7267	30.75	<0.0001
Group	1	27	0.00	0.9692
Sex	1	27	4.88	0.0359
Growth-Stage	1	7267	281.66	<0.0001
Group*Sex	1	27	4.46	0.0441
Hours*Sex	23	7267	1.92	0.0050
Sex*Growth-Stage	1	7267	4.52	0.0335
Hours*Group	23	7267	7.70	<0.0001
Hours*Growth-Stage	23	7267	5.30	<0.0001
Hours*Group*Growth-Stage	23	7267	3.60	<0.0001
Hours*Group*Sex	23	7267	2.48	0.0001
Group*Sex*Growth-Stage	1	7267	8.08	0.0045

4.5.1 Effect of hourly progression on feed intake in pigs

Figure 26 showed the amount of feed (in kg) consumed by the pigs during each hour of the day from midnight (0 hrs) to 11 pm (23 hrs). The time of the day had a significant ($P<0.05$) effect on the quantity of feed consumed by the pig during its visit to the electronic feeder. Generally, Figure 26 showed that the pig consumed more feed as the day progressed, with two peaks at 8 am and 4 pm before it decreased, respectively.

Also, Figure 26 showed a declining trend in feed intake as the hours progressed from 4 pm to 3 am the following day. During this period, the quantity of feed consumed by the pigs dropped from 0.195 to 0.049 kg. However, during this period, the only time a significant ($P<0.05$) decline in feed intake was observed was from 4 pm to 6 pm and 11 pm to 12 am the following day.

Subsequently, an increase in the feed intake of the pig was observed in the morning. This increasing trend began at 4 am until it peaked at 8 am. During this period, the feed intake of pigs increased from 0.049 to 0.179 kg. Furthermore, the increase in feed intake has mainly been significant ($P<0.05$) between the preceding and succeeding hours of the day. However, during this period, the feed intake of the pig as the hour progressed from 4 am to 5 am were not significant ($P>0.05$).

After the peak, it is followed by a significant ($P=0.0002$) drop in feed intake by the pigs from 0.179 kg at 8 am to 0.130kg at 9 am. After that, as the hours of the day progressed from 9 am to 10 am, the feed intake of the pigs began to increase until it peaked again at 11 am. It is then followed by another round of decreasing trends in feed intake until 1 pm. After that, at 2 pm, the feed intake trend continued to go up until it peaked at 4 pm. However, during this period, the increase in the feed intake of the pig was not significant. Overall, as the hours progressed in a day, the pigs are most likely to consume a large quantity of feed at 4 pm. Throughout the day, the pigs averagely consumed 2.952 kg of feed from the electronic feeder.

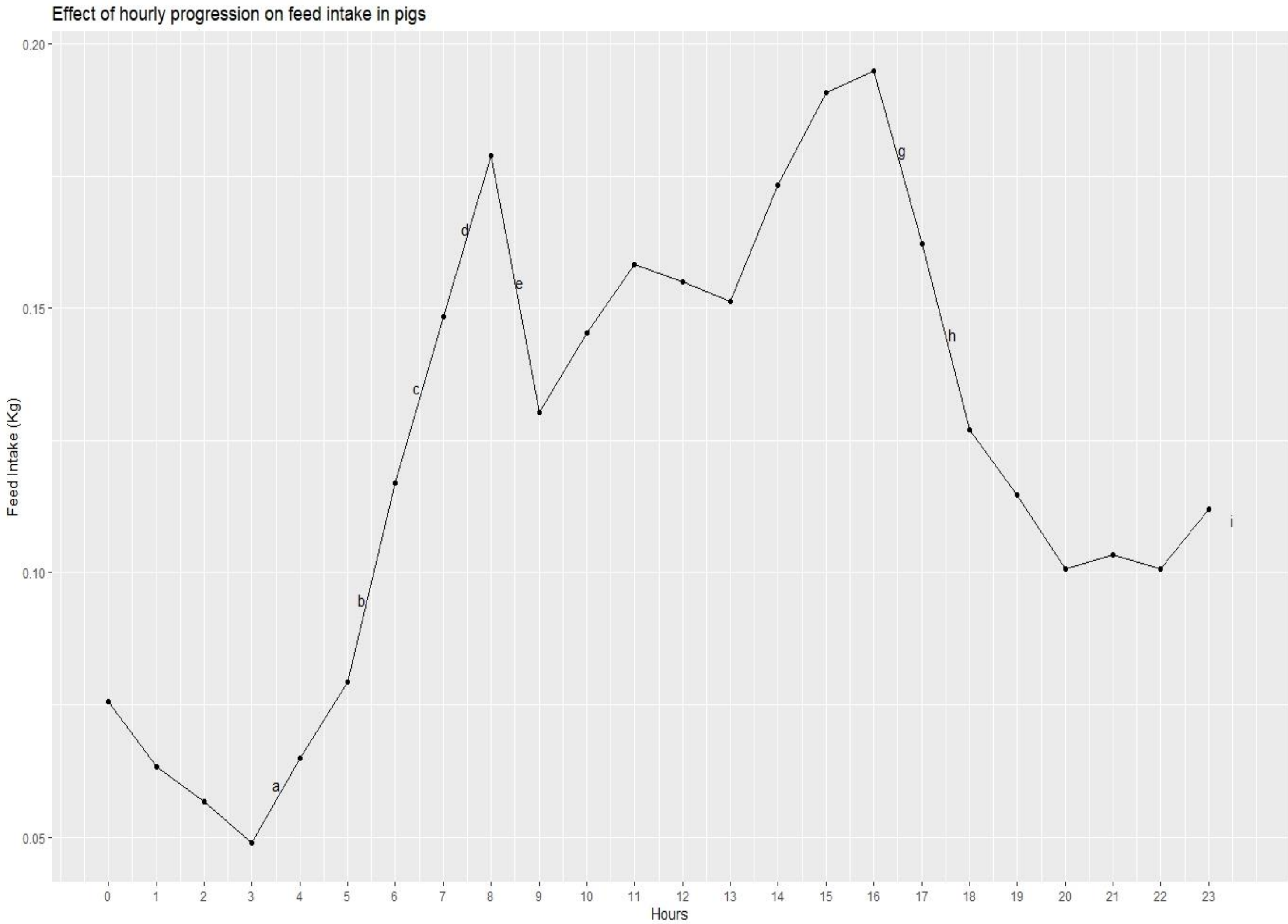

Figure 26: Difference in the feed intake of pigs as the hours progressed in a day.

Alphabet between two datapoints indicates a significant difference in the feed intake of pigs between the corresponding preceding and succeeding hours of the day.

The points in the graph with no alphabet showed no significant difference in feed intake between the corresponding preceding and succeeding hours.

4.5.2 Effect of the sex of the pig on the hourly feed intake

The effect of the sex of the pigs on the hourly feed intake is shown in Table 4.5.2. The result showed that the pigs' hourly feed intake is influenced by their sex (P=0.0359). The male pigs consumed more feed throughout the study than the female pigs (0.134 kg vs 0.105 kg; P=0.0359).

Table 4.5.2: Least square means and standard error for the hourly feed intake of female and male pigs.

Sex	Feed Intake (Kg)	S. E[2]	S. E[3]	P-value[1]
Female	0.105[a]	0.0137	0.0002	0.0359
Male	0.134[b]	0.0133	0.0002	

[a,b] Values with different superscripts are significantly different from each other (LSD, P<0.05)

[1] P-value from Table 4.5.1

[2] Standard error was not back-transformed to its original form.

[3] Standard error was back-transformed to its original form.

4.5.3 Effect of the stage of growth of the pig on the hourly feed intake

The effect of the pig's growth stage on the hourly feed intake is shown in Table 4.5.3. This study showed that the growth stage of the pigs had a significant (P<0.001) effect on the hourly feed intake of the pigs. The pigs consumed more feed throughout the study during the finishing phase of growth than the growing growth phase (0.148 kg vs 0.093 kg).

Table 4.5.3: Least square means and standard error for the hourly feed intake of grower and finisher pigs

Growth-Stage	Feed Intake (Kg)	S. E[2]	S. E[3]	P-value[1]
Growing Phase	0.093[a]	0.009597	0.0000921024	<0.0001
Finishing Phase	0.148[b]	0.01007	0.000101405	

[a,b] Values with different superscripts are significantly different from each other (LSD, $P<0.05$)

[1] P-value from Table 4.5.1

[2] Standard error was not back-transformed to its original form.

[3] Standard error was back-transformed to its original form.

4.5.4 Effect of the interaction between the group type and sex of the pig on hourly feed intake

Table 4.5.4 showed the interaction between the sex and the group type of the pig on the hourly feed intake. The result showed that the interaction between the group type and the sex of the pigs had a significant (P=0.0441) effect on the hourly feed intake of the pigs. Table 4.5.4 showed that the only significant interaction observed was between the two sexes of the group 1 pigs (P=0.0044).

As a result, group 1 male pigs consumed more feeds than group 1 female pigs (0.149 kg vs 0.092kg). In contrast, group 2 female and male pigs consumed the same quantity of feed (0.118 kg vs 0.119 kg; P= 0.9468). Male pigs in group 1 and group 2 also consumed the same amount of feed (0.149 kg vs 0.119 kg; P= 0.1334). Similarly, female pigs in group 1 and group 2 also consumed the same quantity of feed (0.092 kg vs 0.118 kg; P= 0.1611)

Table 4.5.4: Least square means and standard error for the hourly feed intake between the group type and sex of the pig.

Group and Sex Interaction		Feed Intake (Kg)	S. E[2]	S. E[3]	P-value[1]
Group 1	Female	0.092[a]	0.01874	0.0003512	0.0441
	Male	0.149[b]	0.01874	0.0003512	
Group 2	Female	0.118[ab]	0.02004	0.0004016	
	Male	0.119[ab]	0.01874	0.0003512	

[a, b, ab] Values with different superscripts are significantly different from each other (LSD, P<0.05)

[1] P-value from Table 4.5.1

[2] Standard error was not back-transformed to its original form.

[3] Standard error was back-transformed to its original form.

4.5.5 Effect of the interaction between the growth stages and sex of the pig on the hourly feed intake

Table 4.5.5 showed the interaction between the growth stages and sex of the pig on the hourly feed intake. This study showed that the interaction between the growth stages and the sex of the pigs had a significant (P=0.0335) effect on the hourly feed intake of the pigs. Table 4.5.5 also showed that female pigs consumed more feed on an hourly basis during the finishing phase compared to their growing phase (0.129kg vs 0.083 kg; P<0.0001). Similarly, the male pigs also consumed more feed on an hourly basis during their finishing stage than in the growing phase (0.169 kg vs 0.103 kg; P<0.0001). During the growing phase, hourly feed intake was the same for the two sexes of the pig (0.083 kg vs 0.103 kg; P=0.0963). However, during the finishing stage, the male pigs consumed significantly (P=0.0094) more feed on an hourly basis than the female pigs (0.169 kg vs 0.129 kg).

Table 4.5.5: Least square means and standard error for the hourly feed intake between the growth stage and sex of the pig.

Growth Stage and Sex Interaction		Feed Intake Means (Kg)	S. E[2]	S. E[3]	P-value[1]
Female	Growing	0.083[a]	0.0138	0.00019	0.0335
	Finishing	0.129[b]	0.01448	0.00021	
Male	Growing	0.103[ab]	0.01334	0.00018	
	Finishing	0.169[c]	0.01399	0.00020	

[a, b, ab, c] Values with different superscripts are significantly different from each other (LSD, P<0.05)

[1] P-value from Table 4.5.1

[2] Standard error was not back-transformed to its original form.

[3] Standard error was back-transformed to its original form.

4.5.6 Effect of the interaction between the growth stages, group-type, and sex of the pig on hourly feed intake

The interaction between the growth stages, group type, and sex of the pig on hourly feed intake is shown in Table 4.5.6. This study showed that the interaction between the growth stages, the group type, and the sex of the pigs had a significant (P=0.0045) effect on the hourly feed intake of the pigs.

In this study, there was a significant difference between the hourly feed intake of the two sexes of the group 1 pigs during the finishing phase of growth. The male pig consumed more feed than the female pigs (0.193 kg vs 0.111kg; P=0.0001). However, feed intake was the same irrespective of the sex of the group 2 finishing pigs (P=0.9562; Table 4.5.6). Similarly, feed consumption was also the same for the group 1 and group 2 female finisher pigs. On the other hand, during the finishing phase of growth, the group-type of the male pigs influenced feed intake on an hourly basis. This study observed that the group 1 male finisher pigs consumed more feed than the group 2 male finisher pigs (0.193 kg vs 0.147 kg; P=0.0443).

During the growing phase, hourly feed consumption was the same for the female group 1 and group 2 pigs (0.076 kg vs 0.091 kg; P=0.319). A similar effect was observed for the male growing pigs. The group 1 male growing pigs had the same feed consumption on an hourly basis compared to group 2 male growing pigs (0.111 kg vs 0.095 kg; P=0.3339). Hourly feed consumption was the same irrespective of the sexes of the group 2 growing pigs (P=0.8482; Table 4.5.6). However, group 1 male and female growing pigs exhibited a different feed intake behaviour. This study showed that group 1 male growing pigs consumed more feed than group 1 female growing pigs (0.111 kg vs 0.076 kg; P=0.0281).

Furthermore, group 1 female pigs were observed to consume more feed on an hourly basis during the finishing phase than when growing (0.111kg vs 0.076kg; P<0.0001). A similar result was also observed in which group 1 male pigs during their finishing phase consumed more feed on an hourly basis than what they consumed while growing (0.193kg vs 0.111kg; P<0.0001). The group 2 female pigs were observed during the finishing phase to have consumed more feed on an hourly basis than during their growing phase (0.148 kg vs 0.091 kg; P<0.0001). A similar result was also observed in which group 2 male pigs during their finishing phase consumed more feed on an hourly basis than what they consumed while growing (0.147kg vs 0.095kg; P<0.0001).

Table 4.5.6: Least square means and standard error for the hourly feed intake between the pig's growth stages, group type, and sex.

Growth Stage, Group Type and Sex Interaction		Feed Intake (Kg)	S. E[2]	S. E[3]	P-value[1]
Finishing phase	Group 1-Female	0.111[ae]	0.01978	0.0003913	0.0045
	Group 1-Male	0.193[c]	0.01978	0.0003913	
Finishing phase	Group 2-Female	0.148[ac]	0.02115	0.0004473	
	Group 2-Male	0.147[ad]	0.01978	0.0003913	
Growing phase	Female-Group 1	0.076[b]	0.01886	0.0003557	
	Female-Group 2	0.091[be]	0.02016	0.0004064	
Growing phase	Male-Group 1	0.111[ae]	0.01886	0.0003557	
	Male-Group 2	0.095[be]	0.01886	0.0003557	

[b, c, ab, ac, ad, ae, be] Values with different superscripts are significantly different from each other (LSD, P<0.05)

[1] P-value from Table 4.5.1

[2] Standard error was not back-transformed to its original form.

[3] Standard error was back-transformed to its original form.

4.5.7 The effect of the sex of the pig on feed intake at a particular time of the day

As the time of the day progressed, the sex of the pig had a significant (P=0.005) effect on the hourly feed intake. Figure 27 showed a visual presentation of the effect of sex of the pigs on the feed intake at a particular hour of the day for this study.

Generally, the hourly progression graph for both sexes of a pig showed that the quantity of feed consumed increased as the day progressed, with the first peak at 8 am for both sexes of pigs and after that a decline (Figure 27). For both sexes of pigs, an increase in the feed intake trend was observed at 4 am for female pigs and 6 am for male pigs until it peaked at 8 am. During this period, female and male pigs differed in their hourly feed intake at 4 am (P=0.0012) and 6 am (P=0.0148). The male pigs consumed more feed at 4 am, and 6 am (0.09kg at 4 am and 0.142kg at 6 am) than the female pigs (0.044 kg at 4 am and 0.094 kg at 6 am).

After the peak feed intake in the morning is later followed by a drop in feed intake when the day progressed from 8 am to 9 am. The feed intake of the female pigs dropped from 0.171kg to 0.117kg, while that of the male pigs dropped from 0.187 kg to 0.144 kg. However, at these hours (8 am and 9 am), there was no significant difference in feed intake between both sexes of the pig.

Another round of increase in feed intake was followed in the afternoon and peaked at 4 pm for the female pigs (Figure 27). In contrast to the female pig, the male pigs exhibited a different feed intake pattern. It peaked at 11 am, followed by another decline, and after that, another increase peaked again at 3 pm (Figure 27). Nevertheless, only at 11 am was there a significant (P=0.017) difference in feed intake between both sexes, with the male pigs having higher feed intake compared to the female pigs (0.186 kg vs 0.132 kg)

After that, from the afternoon's peak, there was another round of decrease in feed intake. The decrease in feed intake lasted up to 3 am of the following day for the female pigs, and 5 am for the male pigs. Feed intake reduced from 0.187 kg at 4 pm to 0.031 kg at 3 am for the female pigs and 0.204 kg at 3 pm to 0.089 kg at 5 pm for the male pigs. At 9 pm, 11 pm, 12 am, 2 am, and 3 am, the male pigs consumed more feed than the female pigs ($P<0.05$). Also, a total of the feed intake for the significant hours throughout the day showed that the male pig consumed more feed when compared to the female pigs (0.929 kg vs 0.568 kg; $P<0.05$).

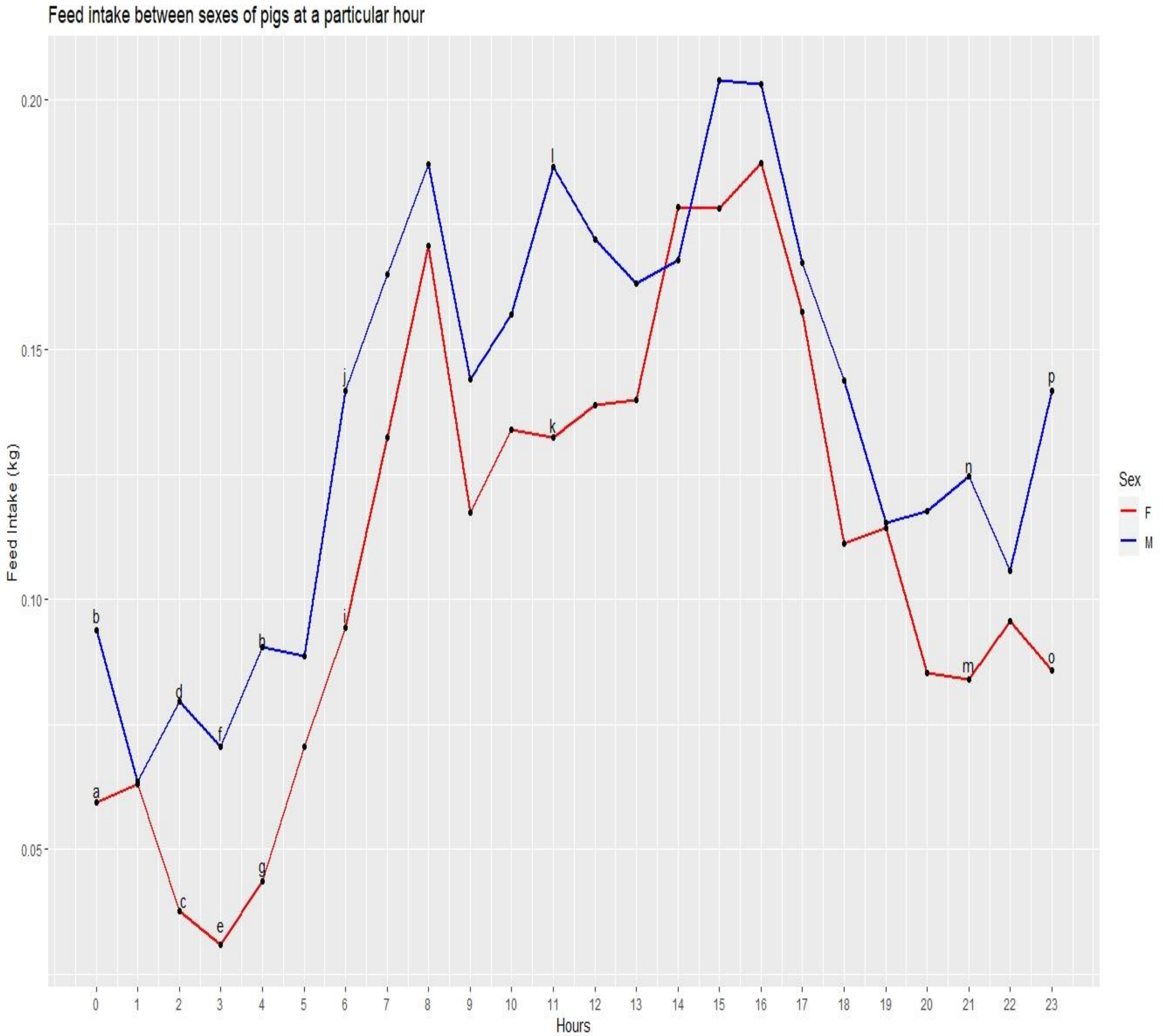

Figure 27: The significant difference in feed intake between the two sexes of pigs.

Different alphabets indicate a significant difference in feed intake between the two sexes at a particular hour of the day.

The points in the graph with no alphabet showed no significant difference in feed intake between sexes at that hour.

4.5.8 The effect of the group type of the pigs on feed intake at a particular time of the day

As the day progressed, the group type of the pig had a significant (P<0.0001) effect on the hourly feed intake. Similarly, this study showed that the group type of the growing-finishing pigs significantly affected feed intake at a particular hour of the day (Figure 28).

Feed intake pattern showed a decreasing trend from 5 pm to 2 am for the group 1 pigs and 4 pm to 5 am for group 2 pigs. During this period, especially at a particular time (such as at 7 pm and 10 pm), feed intake was significantly (P<0.05) different between the two groups. The group 2 pigs consumed more feed compared to the group 1 pig. However, this changes at 4 pm, when the group 1 pigs consumed more feed than the group 2 pigs (0.226 kg vs 0.166 kg; P=0.0223).

As the morning progressed, an increasing trend in feed intake began from 3 am with 0.036 kg until it peaked at 8 am with 0.221 kg for the group 1 pigs. On the other hand, the increasing trend in feed intake began from 6 am with 0.079 kg to 8 am with 0.141 kg for the group 2 pigs. From 12 am to 4 am, the group 2 pigs consumed a larger quantity of feed than the group 1 pig (P<0.05). However, this trend changed from 6 am to 8 am, with the group 1 pigs having a higher feed intake than the group 2 pigs (P<0.05).

After the peak, feed intake in the morning is later followed by a decline in feed intake when the day progressed from 8 to 9 am. This drop-in feed intake was significant between the two groups. The group 1 pigs had a higher feed intake than group 2 pigs (0.16 kg vs 0.104 kg; P=0.0088). For group 1 pigs, feed intake dropped as the hours progressed from 9 am to 12 pm.

This is later followed by another round of increasing trends in feed intake in the afternoon. This increase in feed intake peaked at 4 pm with 0.226 kg for the group 1 pigs and peaked at 3 pm with 0.170 kg for the group 2 pigs. Apart from the feed intake at 4 pm, the increase in feed intake between the two groups during this period was not significant.

Overall, the group 2 pigs significantly consumed more feed later in the evening and early in the morning than the group 1 pigs. However, as the morning progressed from 6 am to 9 am and 4 pm, the pattern changed, and the group 1 pigs significantly (P<0.05) consumed more feed than group 2.

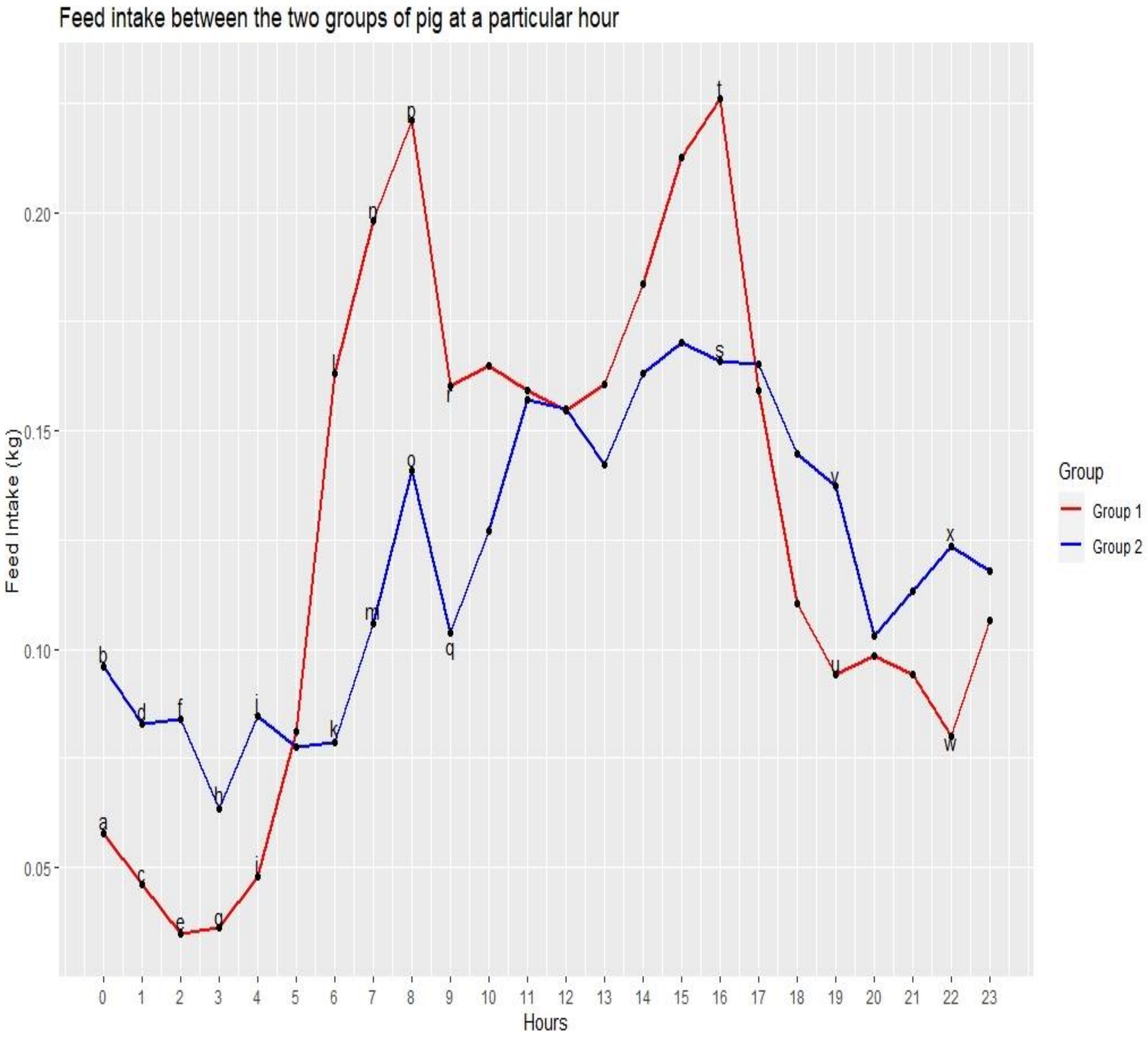

Figure 28: The significant difference in feed intake between the two groups of pigs.

Different alphabets indicate a significant difference in feed intake between group 1 and group 2 pigs at a particular hour of the day. The points in the graph with no alphabet showed no significant difference in feed intake between the pigs' group type at that hour.

4.5.9 The effect of the growth stage of the pig on feed intake at a particular time of the day

As the time of the day progressed, the growth stage of the pig affected the hourly feed intake (P<0.05). Similarly, this study showed that at a particular hour of the day, the feed intake of the pigs was significantly (P<0.05) different when the pigs were at either the growing or finishing phase (Figure 29).

As the morning progressed, an increasing trend in feed intake was observed. The increase began at 3 am for the growing pigs and 4 am for the finishing pigs. The rising trend in feed intake continued until it peaked at 7 am for the growing pigs and 8 am for the finishing pigs. During this period, feed intake increased from 0.045 kg to 0.138 kg for the growing pigs and 0.078 kg to 0.250 kg for the finishing pigs. At a particular hour of the morning (such as at 4 am, 6 am, and 8 am), the finishing pigs consumed more feed compared to the growing pigs (P<0.05).

After the peak of both phases, it is followed by a declining feed intake trend until 9 am. During these hours, the feed intake between the two growth phases was significant (P<0.0001), with the pigs during the finishing phase had a higher feed intake than the growing phase (0.173 kg vs 0.094 kg). Subsequently, feed intake increased at 10 am with 0.099 kg for the growing pigs before peaked at 1 pm with 0.142 kg. For the pigs at the finishing stage of growth, feed intake increased at 10 am with 0.2 kg, then peaked at 11 am with 0.213 kg before it dropped to 0.161 kg at 1 pm. After that, another round of increase in feed intake began at 2 pm with 0.217 kg, then peaked at 4 pm with 0.278 kg. During this period, at a particular hour of the day (such as from 10 am to 11 am and 2 pm to 4 pm), there was a significant (P<0.05) difference in feed intake. The finishing pigs consumed more feed compared to the growing pigs (Figure 29).

Subsequently, After the peak of both phases in the afternoon, a declining trend in feed intake was observed. The drop in feed intake started from 2 pm to 2 am for the growing pigs and 5 pm to 3 am for the finishing pigs. During this period, at certain hours of the day (such as from 5 pm to 8 pm, 11 pm, and 2 am), the finishing pigs had higher feed consumption compared to their growing phase (P<0.05). Overall, the feed intake for the significant (P<0.05) hours throughout the day showed that the pigs consumed more feed during the finishing phase than what they consumed during their growing phase (2.727 kg vs 1.434 kg).

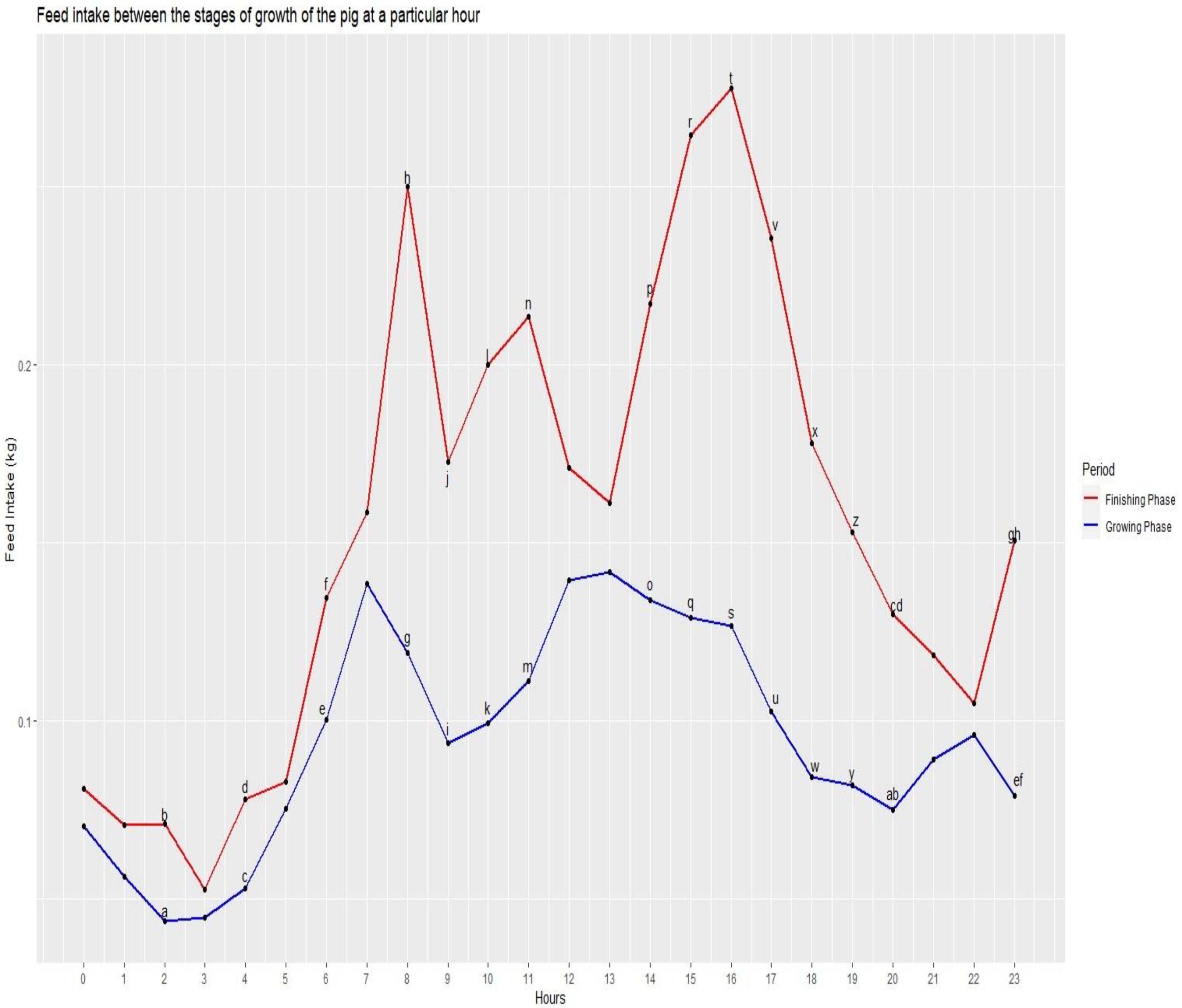

Figure 29: The significant difference in feed intake between the different growth stages of the pigs.

Different alphabets indicate a significant difference in feed intake between the two growth stages at a particular hour of the day.

The points in the graph with no alphabet showed no significant difference in feed intake between growth stages at that hour.

4.5.9.1 The effect of the interaction between group type and growth stage on feed intake of pigs at a particular time of the day

Feed intake is affected by the group type and the growth stage of the pig at a particular time of the day ($P<0.0001$; Figure 30).

4.5.9.1a The effect of the group type of the growing pigs on the feed intake at a particular time of the day

Figure 30 showed that only at 1 am was a significant difference in feed intake between the group type of the growing pigs. At 1 am, the group 2 growing pigs consumed more feed than the group 1 growing pigs ($P<0.05$; Figure 30). The feed intake peaked at 7 am for group 1 and group 2 growing pigs. In the afternoon, peak feed intake was at 1 pm for group 1 growing pigs and noon for group 2 growing pigs. Overall, the group 2 pigs consumed more feed during the growing phase than the group 1 pigs.

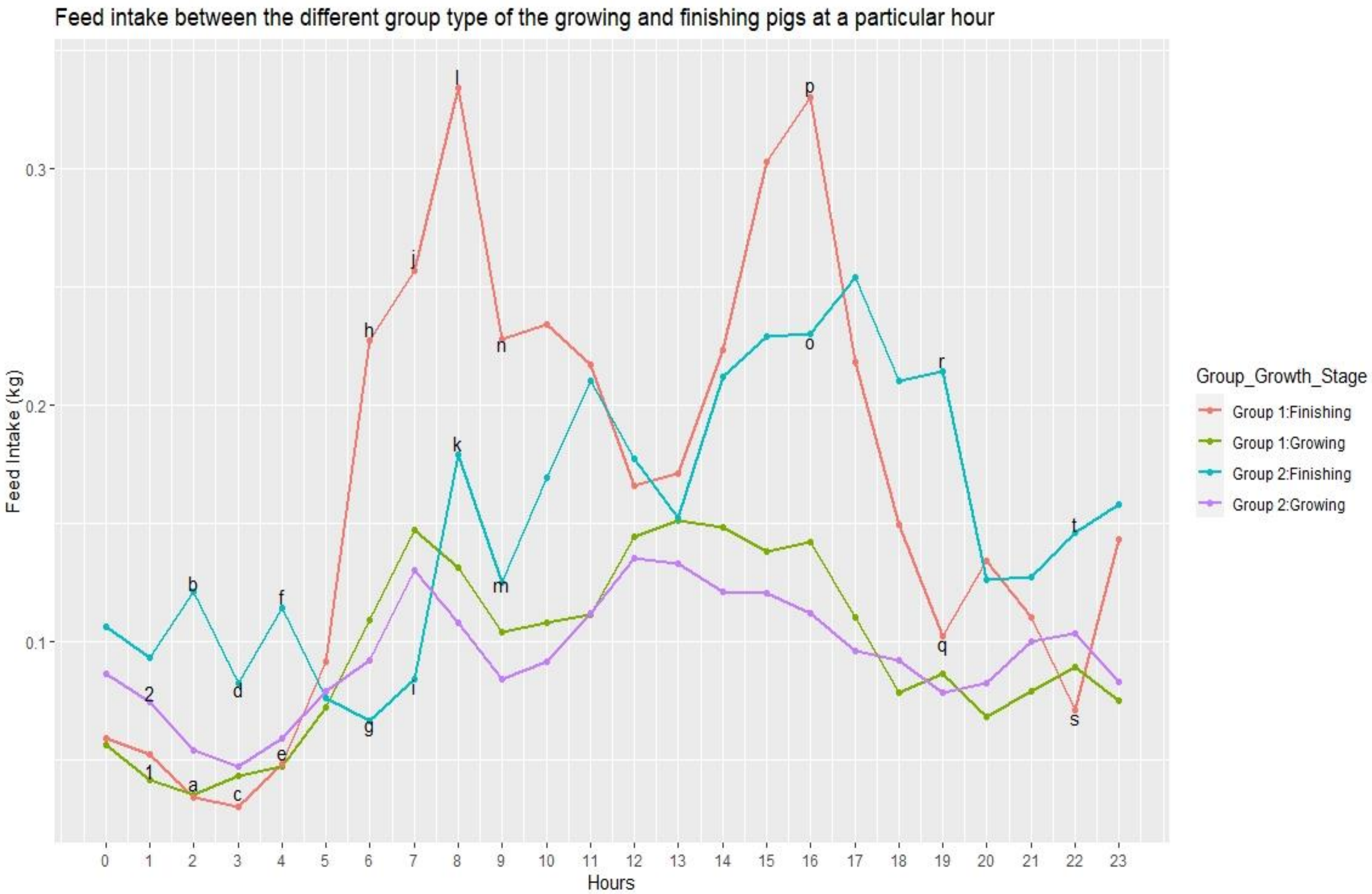

Figure 30: The significant difference in feed intake between group 1 and group 2 growing and finishing pigs.

Different alphabets indicate a significant difference in feed intake between group 1 and group 2 finishing pigs at a particular hour of the day. The points in the graph with no alphabet showed no significant difference in feed intake between the two groups at that hour.

Different numbers indicate a significant difference in feed intake between group 1 and group 2 growing pigs at a particular hour of the day. The points in the graph with no numbers showed no significant difference in feed intake between the two groups at that hour.

4.5.9.1b The effect of the group type of the finishing pigs on the feed intake at a particular time of the day

At certain hours of the day, the group type of the finishing pigs had a significant effect on their hourly feed intake. As the morning progressed, an increasing trend in feed intake was observed. The feed intake increase began at 4 am for the group 1 pigs, and 7 am for the group 2 pigs. The increasing trend in feed intake continued until it peaked at 8 am for both groups of finishing pigs. During this period, feed intake increased from 0.048 kg to 0.334 kg for the group 1 pigs and from 0.084 kg to 0.179 kg for the group 2 pigs. At certain hours of the morning (such as from 6 am to 8 am), group 1 finishing pigs consumed more feed than group 2 finishing pigs. On the other hand, at 4 am, the group 2 pigs consumed more feed than the group 1 pigs (P=0.0064; Figure 30).

After the morning peak of both groups, it is followed by a declining feed intake trend until 9 am with 0.125 kg for the group 2 pigs and noon with 0.166 kg for the group 1 pigs. Feed intake between the group 1 and group 2 finishing pigs was significantly different at 9 am. The group 1 pigs had a higher feed intake than the group 2 pigs (0.228 kg vs 0.125 kg; P=0.0041). For the group 2 pigs, the feed intake increased again at 10 am with 0.169 kg. Then it peaked at 11 am with 0.210 kg, before it dropped to 0.152 kg at 1 pm. After that, another round of increase in feed intake for the group 2 pigs began at 2 pm with 0.212 kg; then, it peaked at 5 pm with 0.254 kg. For the group 1 finishing pigs, the increasing trend in feed intake began at 1 pm with 0.171 kg and then peaked at 4 pm with 0.330 kg. At 4 am, the group 1 pigs consumed more feed than the group 2 pigs (0.330 kg vs 0.230 kg; P=0.0297).

Subsequently, after both groups peak in the afternoon, a declining trend in feed intake was generally observed. The decline in feed intake started at 5 pm with 0.218 kg to 3 am with 0.03kg for the group 1 finishing pigs. Feed intake for the group 2 pigs also dropped from 0.210kg at 6 pm to 0.066 kg at 6 am. Within this period, at certain hours of the day (such as at 7 pm, 10 pm, and 2 am to 3 am), group 2 finishing pigs ate more feed compared to group 1 finishing pigs ($P<0.05$). Overall, at late in the night and very early in the morning, group 2 finishing pigs generally consume more feed than the group 1 finishing pigs. On the other hand, group 1 finishing pigs consumed more feed during the rest of the day.

4.5.9.1c The effect of the growth stage on the feed intake of the group 1 pigs at a particular time of the day

Figure 31 showed that, at certain times of the day, the growth stage of the group 1 pigs had affected their hourly feed intake. At all the times of the day that feed intake was significant (such as at 6 am to 11 am, 2 pm to 6 pm, 8 pm and 11 pm; $P<0.05$), the group 1 pigs during the finishing phase consumed more feed compared to during its growing phase (Figure 31). The feed intake peaked at 7 am for the group 1 pigs during the growing phase and 8 am during the finishing growth stage. In the afternoon, peak feed intake was at 1 pm for the group 1 pigs during the growing phase and 4 pm during the finishing growth stage. Overall, during the finishing phase, the group 1 pigs consumed more feed than when they were growing.

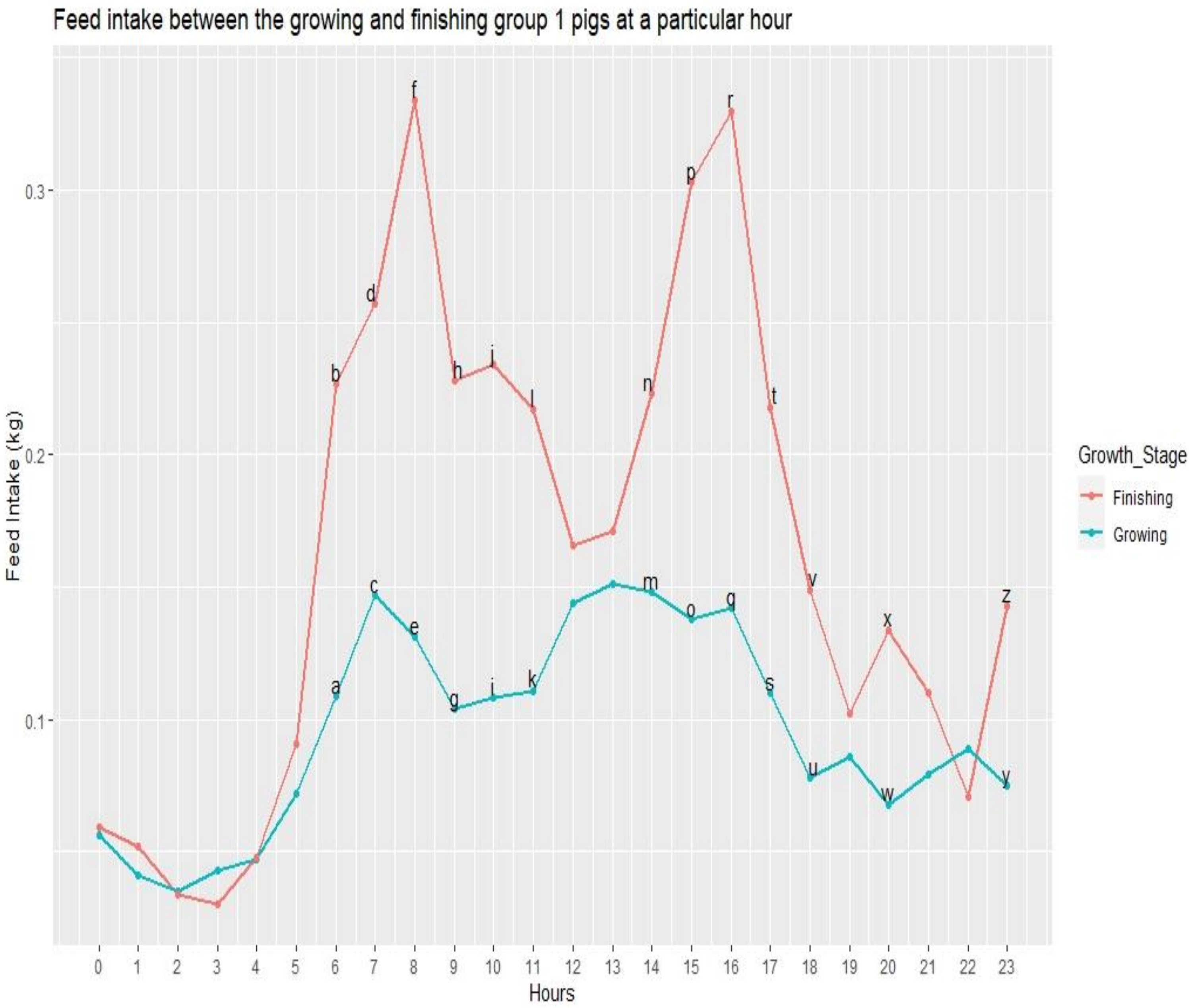

Figure 31: The difference in feed intake between the growing and finishing growth stage of the group 1 pigs.

Alphabet between two datapoints indicates a significant difference in feed intake between the growing and finishing group 1 pigs.

The points in the graph with no alphabet showed no significant difference in feed intake between the growing and finishing group 1 pigs.

4.5.9.2 The effect of the interaction between group type and sex of the pigs on feed intake at a particular time of the day

The hourly feed intake is affected by the group type and sex of the pig at a particular time of the day (P=0.0001; Figure 32 and 33).

4.5.9.2a The effect of group type on feed intake in female pigs at a particular time of the day

At certain hours of the day, the group type of the female pigs affected the feed intake. Also, a total of the feed intake for the significant (P<0.05) hours throughout the day showed that the group 2 female pigs generally consume more feed (0.863 kg vs 0.491 kg) compared to the group 1 female pigs.

As the morning progressed, an increasing trend in feed intake was observed. The increase in feed intake began at 3 am for the group 1 pigs and 7 am for the group 2 pigs. The increasing trend in feed intake continued until it peaked at 8 am for both group 1 and group 2 female pigs. During this period, feed intake increased from 0.018 kg to 0.180 kg for the group 1 female pigs and from 0.106 kg to 0.161 kg for the group 2 female pigs (Figure 32). At certain hours of the day (such as from 3 am to 4 am), the group 2 female pigs significantly (P<0.05) consumed more feed compared to the group 1female pigs. However, at 6 am, the pattern changed when the group 1 female pigs consumed more feed than the group 2 female pigs (0.130 kg vs 0.065 kg; P=0.0113).

After the morning peak of both groups, it is followed by a declining feed intake trend. Feed intake dropped until 9 am with 0.112 kg for the group 2 female pigs and 11 am with 0.101 kg for the group 1 female pigs. At 11 am, the group 2 female pigs consumed significantly (P=0.026) more feed when compared to the group 1 female pigs (0.169 kg vs 0.101 kg). For the group 2 pigs, their feed intake increased again from 10 am with 0.136 kg and peaked again at 2 pm with 0.188 kg. On the other hand, for the group 1 female pigs, an increasing trend in feed intake began at noon with 0.12 kg before it peaked at 4 pm with 0.202 kg. Generally, there was no significant (P>0.05) difference between group 1 and group 2 female pigs during this period of the day.

Subsequently, after the peak of both groups in the afternoon, a declining trend in feed intake was generally observed. Feed intake started to drop at 5 pm with 0.147 kg to 2 am with 0.017 kg for the group 1 female pigs. Similarly, for the group 2 female pigs, feed intake began to drop at 3 pm with 0.173 kg to 6 am with 0.065 kg. Throughout this period, at certain hours of the day (such as from 6 pm to 8 pm and 2 am), the group 2 female pigs consumed more feed compared to the group 1 female pigs ($P<0.05$; Figure 32). Overall, group 1 female pigs consume significantly ($P<0.05$) more feed, especially from the evening to very early in the morning compared to the group 1 female pigs.

4.5.9.2b The effect of group type on feed intake in male pigs at a particular time of the day.

At certain hours of the day, the group type of the male pigs affected the feed intake. Also, a total of the feed intake for the significant ($P<0.05$) hours throughout the day showed that the group 1 male pigs consumed more feed (2.239 kg vs 1.306 kg) compared to the group 2 male pigs.

As the morning progressed, an increasing trend in feed intake was observed. The feed intake increase began at 2 am for group 1 male pigs and 6 am for group 2 male pigs. The increasing trend in feed intake continued until it peaked at 8 am for both group 1 and group 2 male pigs. During this period, feed intake increased from 0.059 kg to 0.266 kg for the group 1 pigs and from 0.094 kg to 0.122 kg for the group 2 male pigs (Figure 32). Similarly, at this same period (from 6 am to 8 am), group 1 male pigs consumed more feed compared to the group 2 male pigs ($P<0.05$).

After the morning peak of both groups, it is followed by a declining feed intake trend until 10 am with 0.202 kg for the group 1 pigs and 9 am with 0.095 kg for the group 2 pigs. After that, another round of increase in feed intake for the group 1 male pigs began at 11 am with 0.231 kg before dropping again to 0.194 kg at noon. At 1 pm, feed intake for the group 1 pigs rose then peaked again at 4 pm with 0.252 kg. For the group 2 male pigs, the feed intake increased again from 10 am with 0.118 kg and peaked again at 3 pm with 0.168 kg. Within this period, at certain hours of the day (such as from 9 am to 11 am, 1 pm and 3 pm to 4 pm), the group 1 male pigs consumed more feed compared to the group 2 male pigs ($P<0.05$).

Subsequently, after the peak of both groups in the afternoon, a declining trend of feed intake was generally observed. Feed intake started to drop at 5 pm with 0.170 kg to 1 am with 0.044 kg for the group 1 male pigs. While for the group 2 male pigs, feed intake started to drop at 4 pm with 0.159 kg to 5 am with 0.089 kg. At 8 pm, there was a significant difference between the groups. The group 1 male pigs ate more than the group 2 male pigs (0.161 kg vs 0.081 kg; $P=0.004$). However, this pattern changed at 1 am when group 2 male pigs consumed more feed than the group 1 male pigs (0.086 kg vs 0.044 kg; P=0.0401).

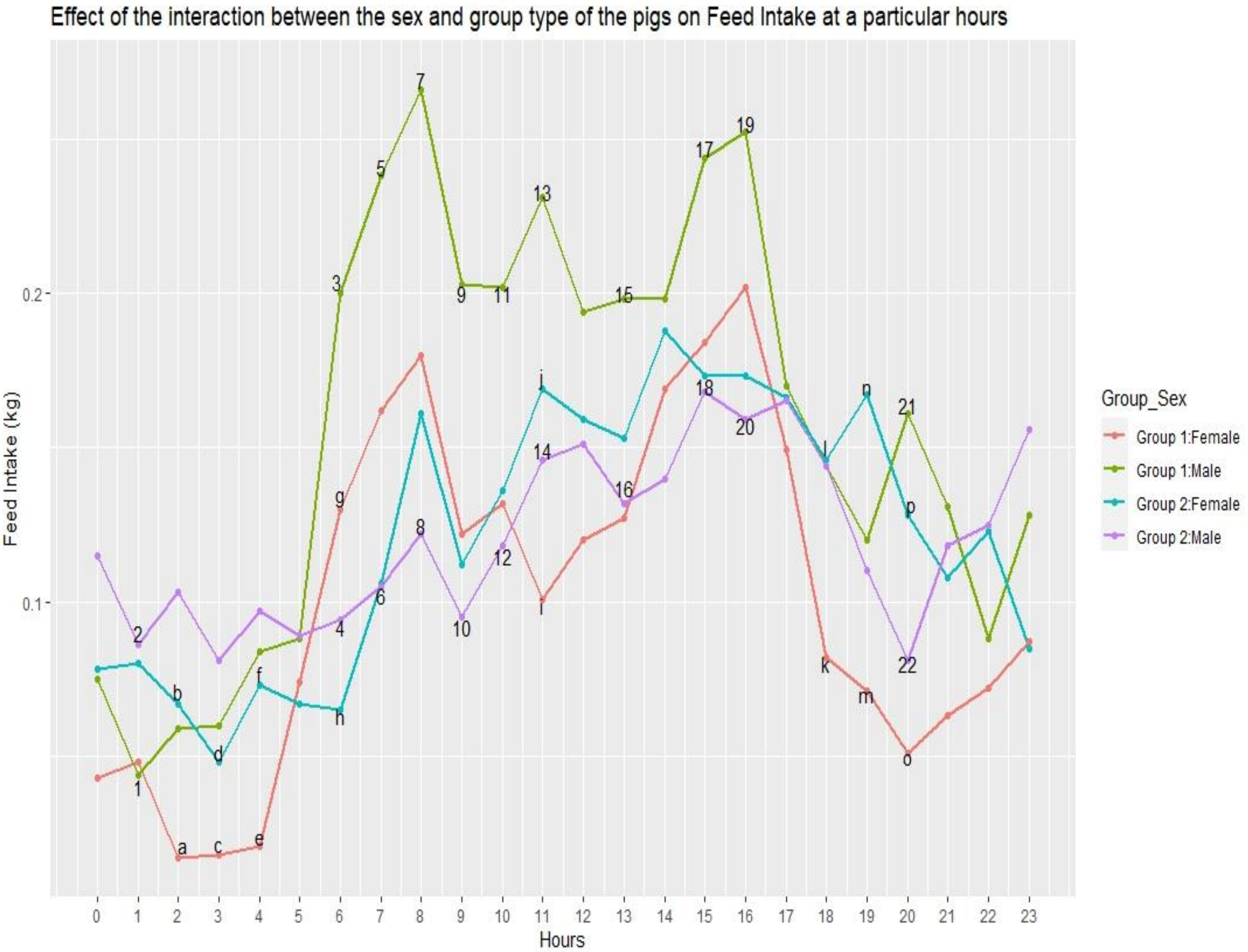

Figure 32: The significant difference in feed intake between group 1 and group 2 female and male pigs.

Different alphabet indicates a significant difference in feed intake between group 1 and group 2 female pigs at a particular hour of the day. The points in the graph with no alphabet showed no significant difference in feed intake between the two groups at that hour.

Different numbers indicate a significant difference in feed intake between group 1 and group 2 male pigs at a particular hour of the day. The points in the graph with no number showed no significant difference in feed intake between the two groups at that hour.

4.5.9.2c The effect of sex of the group 1 pigs on feed intake at a particular time of the day

At certain hours of the day, the sex of the group 1 pigs had a significant effect on the feed intake. Also, the feed intake for the significant ($P<0.05$) hours throughout the day showed that the group 1 male pigs generally consumed more feed than the group 1 female pigs (2.491 kg vs 1.397 kg).

As the morning progressed, an increasing trend in feed intake was observed. The feed intake increase began at 3 am for group 1 female pigs, and 2 am for group 1 male pigs. The increasing trend in feed intake continued until it peaked at 8 am for both sexes of the group 1 pigs. During this period, feed intake for the group 1 female pigs increased from 0.018 kg to 0.180 kg and from 0.059 kg to 0.266 kg for the group 1 male pigs (Figure 33). Throughout this period of increase in feed intake, during certain hours of the day (such as from 2 am to 4 am and 6 am to 8 am), the group 1 male pigs were observed to have consumed more feed compared to the group 1 female pigs ($P<0.05$).

After the morning peak of both sexes, it is followed by a declining feed intake trend until 11 am with 0.101 kg for the group 1 female pigs and 10 am with 0.202 kg for the group 1 male pigs. After that, another round of increase in feed intake for the group 1 male pigs began at 11 am with 0.231 kg before it dropped again to 0.194 kg at noon. At 1 pm, feed intake for group 1 male pigs rose before it peaked at 4 pm with 0.252 kg. For the group 1 female pigs, feed intake increased at noon with 0.120 kg before it peaked at 4 pm with 0.202 kg. During this period, from 9 am to 1 pm, there was a significant ($P<0.05$) difference in feed intake between the sexes. The male pigs consumed more feed when compared to the female pigs.

Subsequently, after the peak of both sexes in the afternoon, a declining trend in feed intake was generally observed. The drop in feed intake started at 5 pm with 0.149 kg to 2 am with 0.017 kg for the female pigs. The drop in feed intake for the male pigs started at 5 pm with 0.170 kg to 1 am with 0.017 kg. From 6 pm to 9 pm, there was a significant ($P<0.05$) difference between the sexes during this period. The group 1 male pigs consumed more feed than the group 1 female pigs (Figure 33). Overall, group 1 male pigs consumed more feed compared to the group 1 female pigs at certain hours of the day ($P<0.05$).

4.5.9.2d The effect of sex of the group 2 pigs on feed intake at a particular time of the day

At a particular hour of the day, the sex of the group 2 pigs affected the feed intake. As the morning progressed, an increasing trend in feed intake was observed. The increase in feed intake began at 7 am for group 2 female pigs, and 6 am for group 2 male pigs. The increasing trend in feed intake continued until it peaked at 8 am for both sexes of the group 2 pigs. During this period, the female pigs' feed intake increased from 0.106 kg to 0.161 kg and from 0.094 kg to 0.122 kg for the male pigs (Figure 33). An increase in feed intake trend between sexes of the group 2 pigs was not significant during this period.

After the morning peak of both sexes, it is followed by a declining feed intake trend until 9 am for both sexes, with 0.112 kg for the female pigs and 0.095 kg for the male pigs. After that, another round of increase in feed intake for the group 2 male pigs began at 10 am with 0.118 kg then peaked at noon with 0.151 kg. It dropped again to 0.132 kg at 1 pm and began another feed intake increase trend and peaked at 3 pm with 0.168 kg. For the group 2 female pigs, feed intake increased at 10 am with 0.136 kg, then peaked at 2 pm with 0.188 kg. From 8 am to 3 pm, there was no significant difference between the two sexes of the group 2 pigs on feed intake during this period.

Subsequently, after the peak of both sexes in the afternoon, a declining trend of feed intake was generally observed. Feed intake for the female pigs started to drop at 3 pm with 0.173 kg to 6 am with 0.065 kg. Similarly, feed intake started to drop at 4 pm with 0.159 kg to 5 am with 0.089 kg for the male pigs. During this period, it was only at 11 pm that there was a significant ($P=0.0108$) difference in feed intake between the two sexes. The group 2 male pigs ate more feed than the group 2 female pigs (0.156 kg vs 0.085kg).

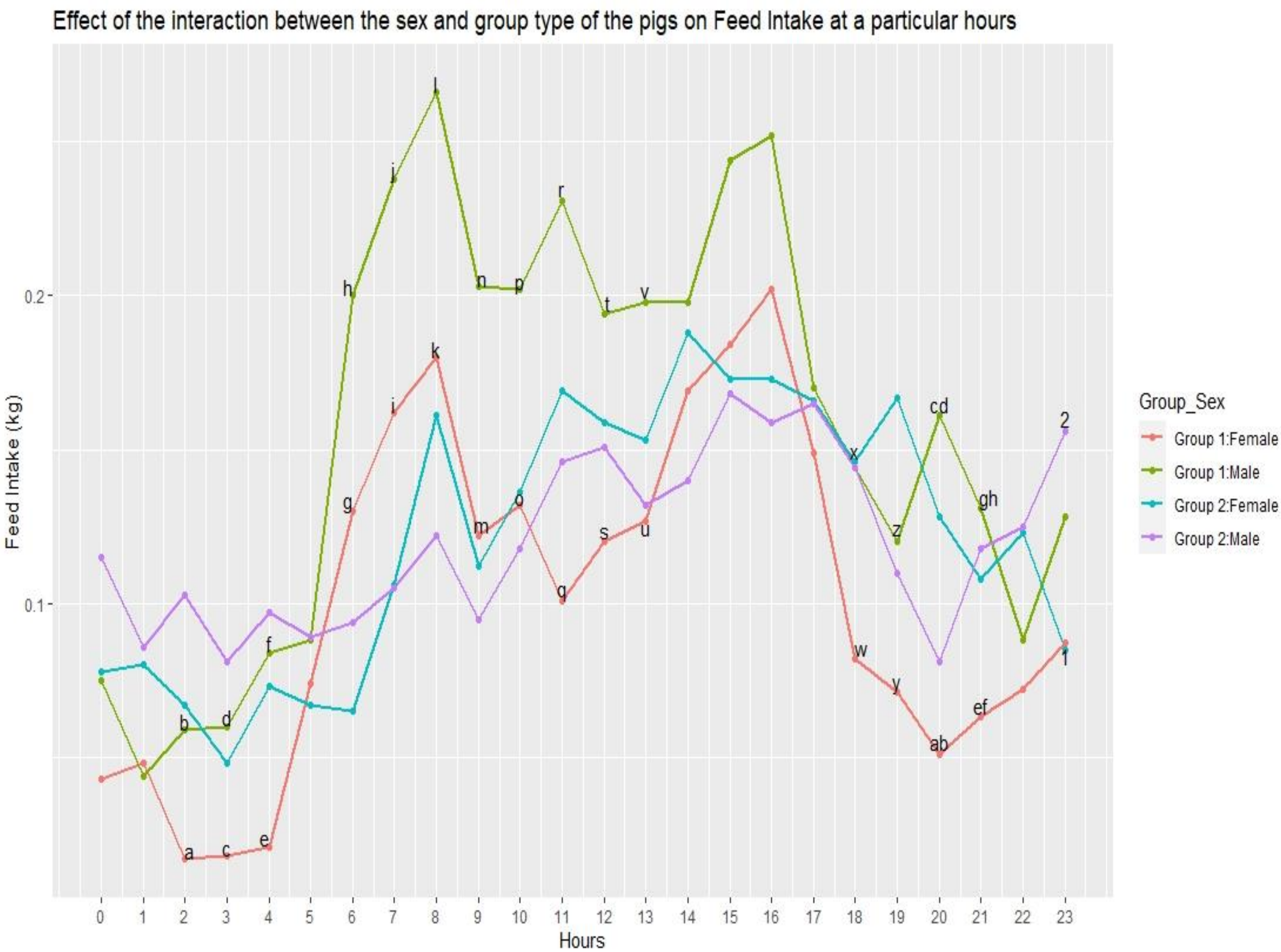

Figure 33: The significant difference in feed intake between the different sexes of group 1 and group 2 pigs.

Different alphabets indicate a significant difference in feed intake between the two sexes of the group 1 pigs at a particular hour of the day. The points in the graph with no alphabet showed no significant difference in feed intake between sexes at that hour.

Different numbers indicate a significant difference in feed intake between the two sexes of the group 2 pigs at a particular hour of the day. The points in the graph with no number showed no significant difference in feed intake between sexes at that hour.

4.6 Hourly feeding rate

Table 4.6.1. showed the significant predictors in the mixed model used in predicting the pigs' hourly feeding rate in this study. These significant predictors will be discussed at length in the following sections.

Table 4.6.1: Predictors significant in predicting hourly feeding rate of the pigs.

	Type 3 Tests of Fixed Effects			
Effect	Num DF	Den DF	F Value	Pr > F
Hours	23	7291	55.93	<0.0001
Group	1	28	0.18	0.6722
Sex	1	28	1.40	0.2460
Growth-Stage	1	7291	974.61	<0.0001
Hours*Sex	23	7291	3.01	<0.0001
Sex*Growth-Stage	1	7291	44.27	<0.0001
Group* Growth-Stage	1	7291	14.32	0.0002
Hours*Group	23	7291	10.06	<0.0001
Hours* Growth-Stage	23	7291	7.27	<0.0001
Hours*Group* Growth-Stage	23	7291	4.69	<0.0001

4.6.1 Effect of hourly progression on feeding rate in pigs

Figure 34 showed the amount of feed consumed over a given feeding duration (in g/min) by the pigs during each hour of the day from midnight (0 hrs) to 11 pm (23 hrs). The time of the day had a significant ($P<0.05$) effect on the quantity of feed consumed over a given feeding duration of the pig's visit to the electronic feeder. Generally, Figure 34 trend showed that as the day progressed, the feeding rate of the pig increased, with two peaks at 10 am, and 3 pm before it decreased, respectively.

Also, Figure 34 showed a declining trend in feeding rate as the hours progressed from 3 pm to 3 am the following day. During this period, the feeding rate of the pigs dropped from 33.105 to 14.547 g/min. However, during this period, the only time a significant ($P<0.05$) decline in feeding rate was observed was from 4 pm to 6 pm, and 12 am to 1 am the following day.

Subsequently, an increase in the feeding rate of the pig was observed in the morning. This increasing trend began at 4 am until it peaked at 10 am. Throughout this period, the feeding rate of pigs increased from 16.577 to 36.001 g/min. As the hours progressed from 4 am to 10 am, the increase in feeding rate was significant ($P<0.05$) between the preceding and succeeding hours of the day. However, the pig's feeding rate was not significant from 4 am to 5 am and 9 am to 10 am ($P>0.05$).

After the peak, it is followed by a significant drop in the feeding rate of the pigs from 36.001 g/min at 10 am to 26.999 g/min at 1 pm ($P<0.05$). After that, as the day advanced from 1 pm to 3 pm, the feeding rate increased until it peaked again at 3 pm. Within this period, the pig's feeding rate was significant ($P<0.05$). Overall, as the day advanced, the pigs are most likely to consume a large quantity of feed over a given feeding duration in the morning, especially at 10 am.

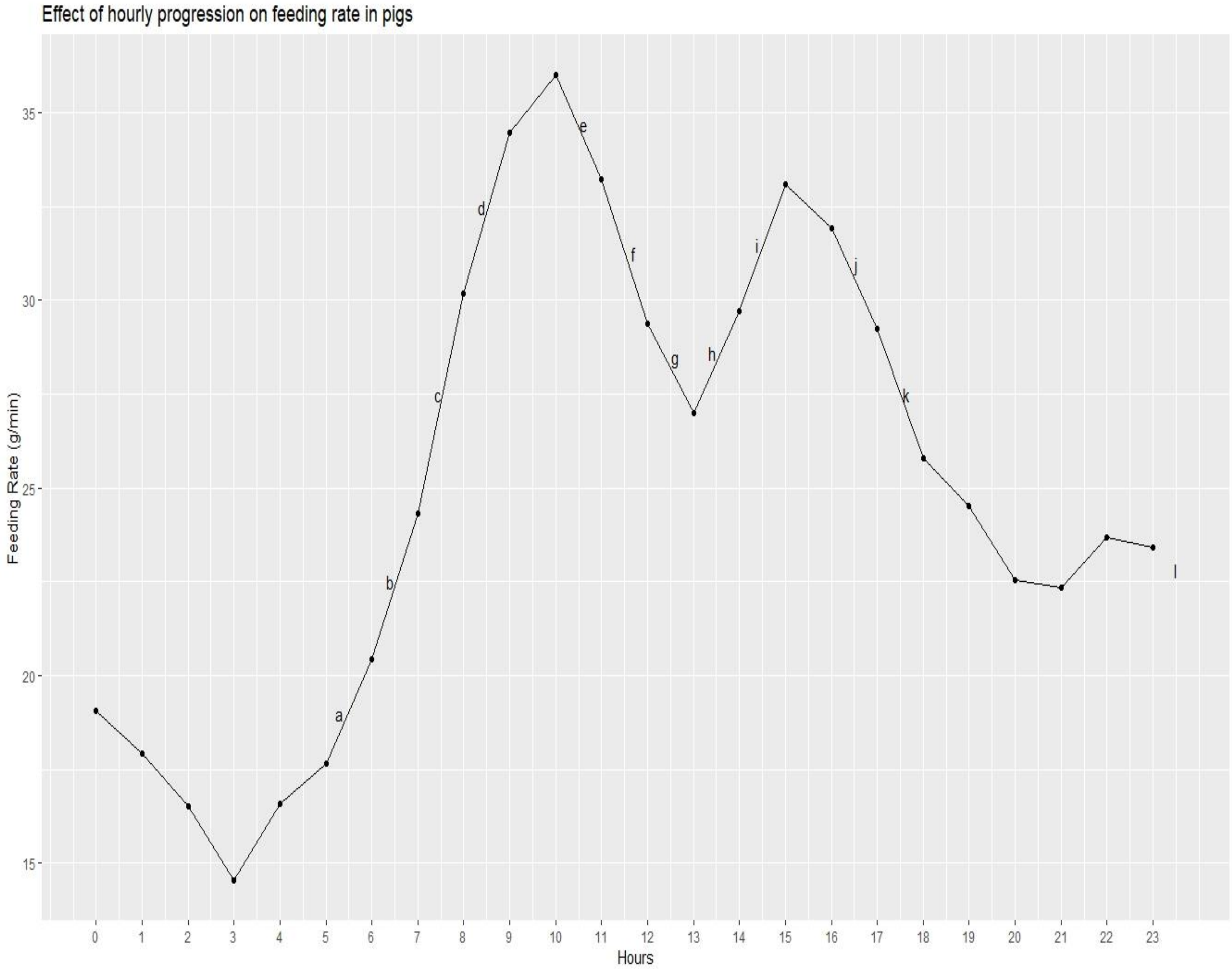

Figure 34: The significant difference in the feeding rate of pigs as the day advanced.

Alphabet between two datapoints indicates a significant difference in the feeding rate of pigs between the corresponding preceding and succeeding hours of the day.

The points in the graph with no alphabet showed no significant difference in feeding rate between the corresponding preceding and succeeding hours.

4.6.2 Effect of the stage of growth of the pig on the hourly feeding rate

The effect of the pig's growth stage on the hourly feeding rate is shown in Table 4.6.2. This study showed that the growth stage of the pigs had a significant effect (P<0.0001) on the hourly feeding rate. Throughout the study, during the finishing phase of growth, the pigs consumed more feed over a shorter feeding duration (high feeding rate) than the growing phase during their hourly feeding visit (30.52 g/min vs 19.781 g/min).

Table 4.6.2: Least square means and standard error for feeding rate in the grower and finisher phase

Growth-Stage	Feeding-Rate (g/min)	Standard Error	P-value[1]
Growing Phase	19.781[a]	1.0636	<0.0001
Finishing Phase	30.52[b]	1.0856	

[a,b] Values with different superscripts are significantly different from each other (LSD, P<0.05)

[1] P-value from Table 4.6.1

4.6.3 Effect of the interaction between the growth stages and sex of the pig on the hourly feeding rate.

Table 4.6.3 showed the effect of the interaction between the growth stages and sex of the pig on the hourly feeding rate. The result showed that the interaction between the growth stages and the sex of the pigs had a significant (P<0.0001) effect on the hourly feeding rate of the pigs. Female finisher pigs consumed more feed over a shorter feeding duration (or had a higher feeding rate) on an hourly basis compared to other grower pigs (28.118 g/min vs 19.668 g/min; P<0.0001).

Similarly, the male finisher pigs also had a higher feeding rate on an hourly basis compared to the period when they were growing (19.893 g/min vs 32.921 g/min; P<0.0001). During the growing phase, the two sexes' hourly feeding rate was the same (P=0.9156). However, this changed during the finishing phase. The male had a higher feeding rate on an hourly basis than the female (32.921 g/min vs 28.118 g/min; P=0.027).

Table 4.6.3: Least square means and standard error for feeding rate in the grower and finisher phase for male and female pigs.

Growth Stage and Sex Interaction		Feeding Rate (g/min)	Standard Error	P-value[1]
Female	Growing	19.668[a]	1.529	<.0001
	Finishing	28.118[b]	1.5606	
Male	Growing	19.893[a]	1.4788	
	Finishing	32.921[c]	1.5094	

[a,b,c] Values with different superscripts are significantly different from each other (LSD, P<0.05)

[1] P-value from Table 4.6.1

4.6.4 Effect of the interaction between the growth stages and the pigs' group on the hourly feeding rate.

The effect of the interaction between the growth stages and the pigs' group on the hourly feeding rate is shown in Table 4.6.4. This study showed that the interaction between the growth stages and the group a pig belonged to have a significant (P=0.0002) effect on the hourly feeding rate of the pigs. Table 4.6.4 also showed that for all group 1 pigs, throughout the study, a higher feeding rate was observed when they were at the finishing phase compared to when they were growing (31.625 g/min vs 19.583 g/min; P<0.0001). A similar result was observed in group 2 pigs. Group 2 finisher pigs consumed more feed over a shorter feeding duration compared to when they were growing (29.415 g/min vs 19.978 g/min; P<0.0001). On the other hand, the hourly feeding rate was the same during the growing phase irrespective of the pig's group (P=0.8529). Similarly, the hourly feeding rate for the finisher phase for group 1 and group 2 pigs was also the same (P=0.309).

Table 4.6.4: Least square means and standard error for feeding rate in the different growth stage for the group 1 and group 2 pigs.

Growth Stage and Group Interaction		Feeding Rate (g/min)	Standard Error	P-value[1]
Group 1	Growing	19.583[a]	1.4788	0.0002
	Finishing	31.625[b]	1.5094	
Group 2	Growing	19.978[a]	1.529	
	Finishing	29.415[b]	1.5606	

[a,b] Values with different superscripts are significantly different from each other (LSD, P<0.05)

[1] P-value from Table 4.6.1

4.6.5 The effect of the sex of the pig on feeding rate at a particular time of the day

As the time of the day progressed, the sex of the pig affected the hourly feeding rate (P<0.0001). Figure 35 showed a visual presentation of the effect of pigs' sex on the feeding rate at a particular hour of the day.

Generally, the hourly progression graph for both sexes of a pig showed that as the day advanced, the feeding rate increased. The first peak was at 10 am for both sexes of pigs and a decline (Figure 35). For both sexes of pigs, an increase in the feeding rate trend was observed at 4 am until they peaked at 10 am. During this period, the only significant (P=0.0262) time between the two sexes was at 4 am, with the male pigs had a higher feeding rate than the female (19.473 g/min vs 13.680 g/min).

After the peak feeding rate in the morning is later followed by a drop in feeding rate when the day advanced from 10 am to 1 pm. The feeding rate of the female pigs dropped from 35.651 g/min to 26.590 g/min, while that of the male pigs dropped from 36.350 g/min to 27.408 g/min. During this period, the drop-in feeding rate was not significant (P>0.05) between the sexes of pigs.

Another round of increase in feeding rate in the afternoon was observed. It peaked at 3 pm for both sexes of the pigs (Figure 35). An increase in feeding rate during this period was not significant (P>0.05) between the sexes of pigs. After that, from the peak in the afternoon, there was another round of decrease in feeding rate up to 3 am of the following day for both sexes of the pig. The feeding rate was reduced from 32.725 g/min at 3 pm to 11.674 g/min at 3 am for the female pigs and 33.485 g/min at 3 pm to 17.420 g/min at 3 pm male pigs. During this period, at certain hours of the day (such as from 8 pm to 9 pm, 11 pm to 12 am, and 2 am to 3 am), there was a significant (P<0.05) difference in feeding rate between the two sexes of pigs, with the male pigs having a higher feeding rate compared to the female pigs.

Also, a total of the feeding rate for the significant hours throughout the day showed that the male pig had a higher feeding rate when compared to the female pigs (155.973 g/min vs 114.082 g/min; P<0.05). Overall, from the interpretation of the graph, at late in the night and very early in the morning, male pigs generally had a significantly higher feeding rate than female pigs.

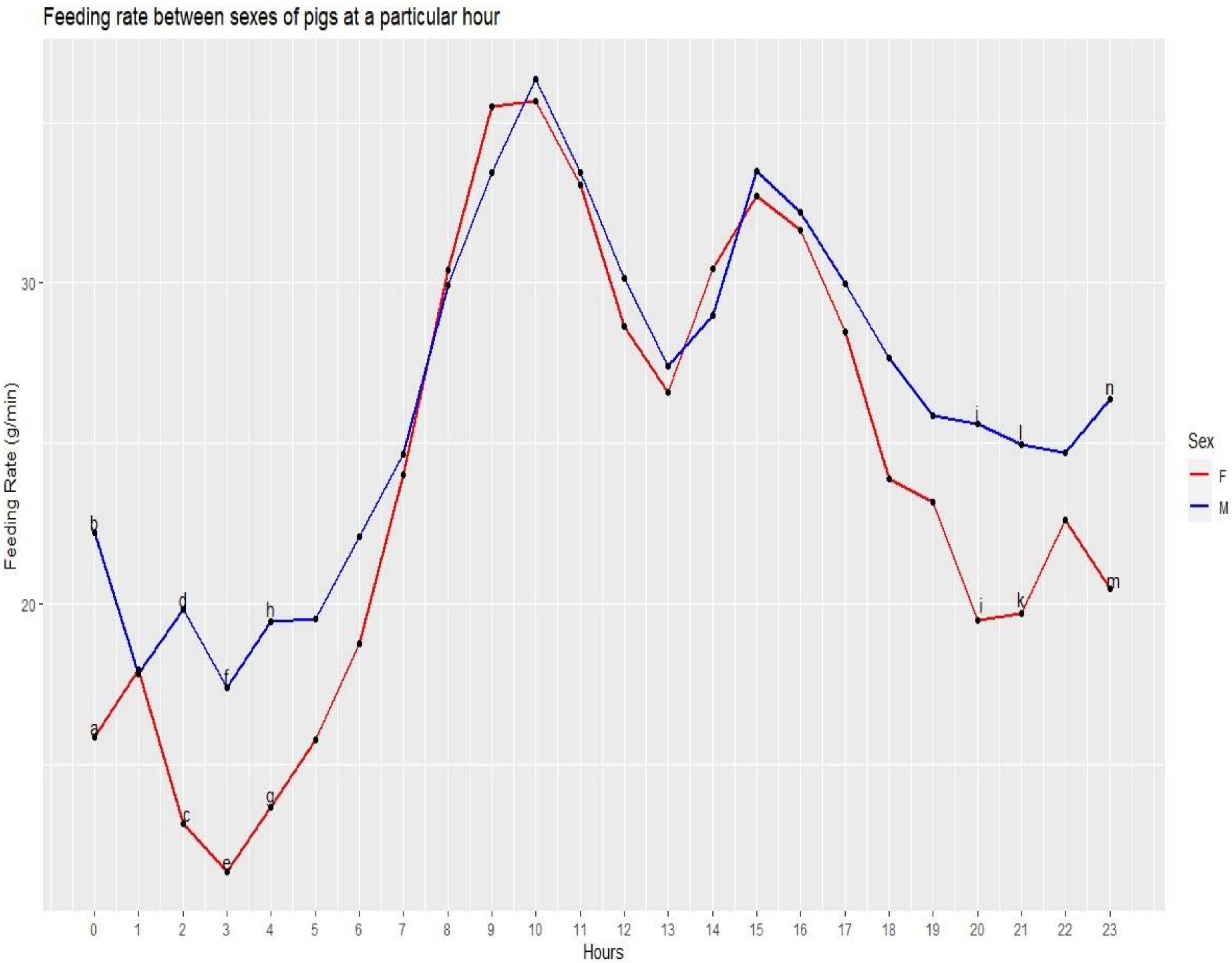

Figure 35: The significant difference in feeding rate between the two sexes at a particular.

Different alphabets indicate a significant difference in feeding rate between the two sexes at a particular hour of the day. The points in the graph with no alphabet showed no significant difference in feeding rate between sexes at that hour.

4.6.6 The effect of the pig's group on the feeding rate at a particular time of the day

As time progressed, the pig's group affected the hourly feeding rate. Similarly, the result of this study showed that growing-finishing pigs belonging to either group 1 or group 2 had a significantly ($P<0.05$) different feeding rate at a particular hour of the day (Figure 36).

Also, from 4 pm to 3 am for the group 1 pigs and 4 pm to 5 am for those in group 2, the feeding rate showed a decreasing trend. During this period, especially at a certain time of the day (from 1 am to 2 am), the feeding rate was significantly ($P<0.05$) different between the two groups. The group 2 pigs had a higher feeding rate than those in group 1. However, this changed at 4 pm, and the group 1 pigs had a higher feeding rate than the group 2 pigs (34.794 g/min vs 29.062 g/min; $P=0.033$).

As the morning progressed, for the group 1 pigs, an increasing trend in feeding rate began at 4 am with 13.806 g/min until it peaked at 10 am with 39.775 g/min. On the other hand, for the group 2 pigs, the increasing trend in feeding rate began from 6 am with 17.940 g/min to 10 am with 32.227 g/min. At 4 am, the group 2 pigs had a higher feeding rate than the group 1 pig (19.348 g/min vs 13.806 g/min; $P=0.0392$). However, this trend changed from 7 am to 10 am, with the group 1 pigs overtaking the group 2 pigs, thereby having a significantly ($P<0.05$) higher feeding rate.

After the peak feeding rate in the morning is later followed by a decline in feeding rate when the time of day progressed from 10 am to 11 am between both groups of pigs. This drop-in feeding rate was significant ($P=0.0072$) between the groups. The group 1 pigs had a higher feeding rate than the group 2 pigs (36.857 g/min vs 29.627 g/min). This is later followed by another round of increase in the afternoon feeding rate, which peaked at 3 pm for both groups of pigs (Figure 36). At 3 pm, the feeding rate between the two groups of pigs was significantly ($P=0.0078$) different. The group 1 pigs had a higher feeding rate than the group 2 pigs (36.682 g/min vs 29.528 g/min).

Also, a total of the feeding rate for the significant hours throughout the day showed that the group 1 pigs had a higher feeding rate when compared to those in group 2 (290.229 g/min vs 258.314 g/min; P<0.05). Overall, the group 2 pigs had a significantly (P<0.05) higher feeding rate at night than the group 1 pig. However, as the morning progressed, the trend changed from 7 am to 11 am and later in the afternoon from 3 pm to 4 pm. The group 1 pigs significantly (P<0.05) had a higher feeding rate than the group 2 pigs.

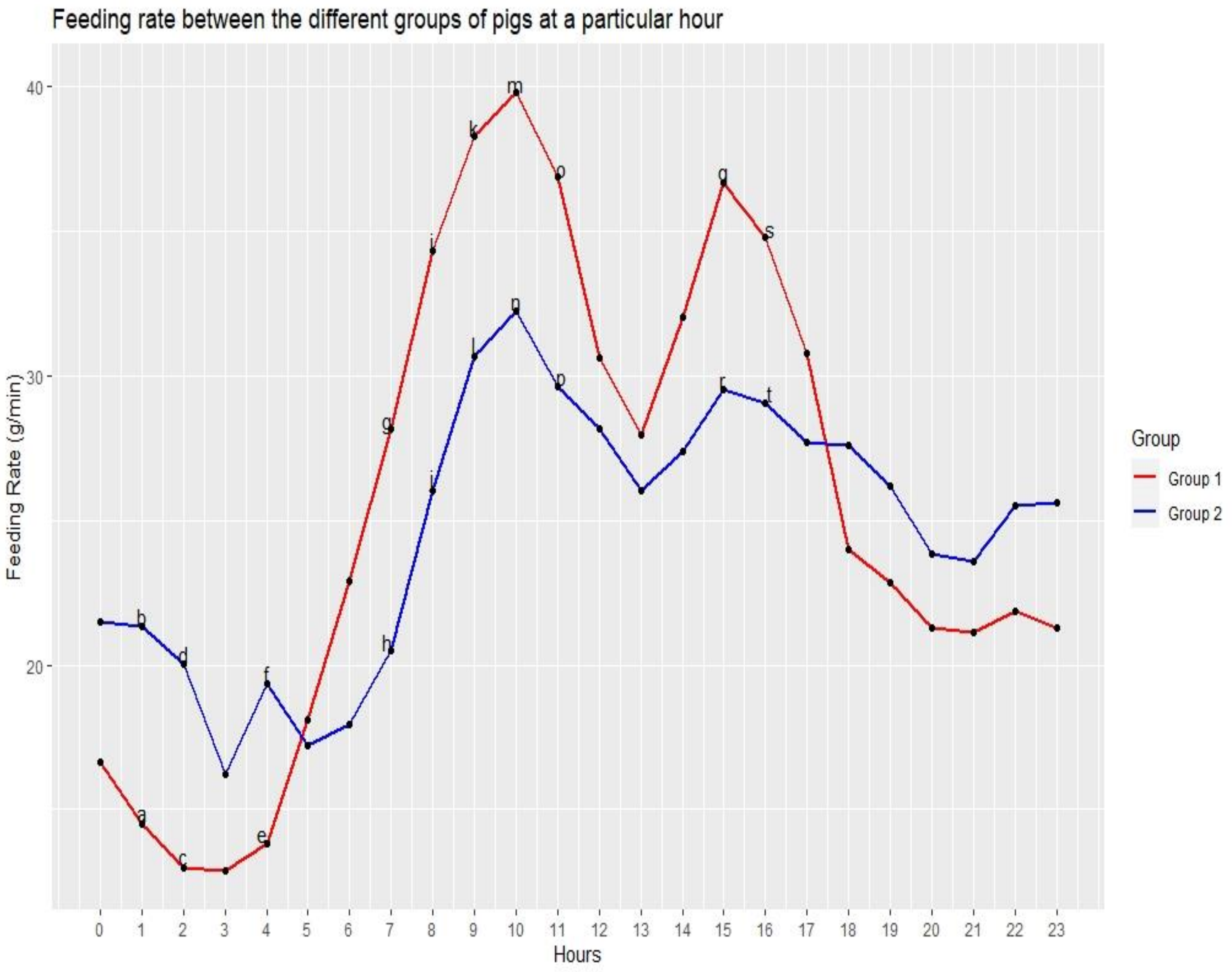

Figure 36: Difference in feeding rate between the different groups of pigs.

Different alphabets indicate a significant difference in feeding rate between the two groups at a particular hour of the day. The points in the graph with no alphabet showed no significant difference in feeding rate between the two groups at that hour.

4.6.7 The effect of the growth stage of the pig on feeding rate at a particular time of the day

As the time of the day progressed, the growth stage of the pig had a significant ($P<0.0001$) effect on the hourly feeding rate. Similarly, this study showed that at any hour of the day, the feeding rate of the pigs was significantly affected when the pigs were at either the growing or finishing phase (Figure 37).

As the morning progressed, an increasing trend in feeding rate was observed. The increase began at 4 am for both the growing and finishing pigs. The increasing trend in feeding rate continued until it peaked at 10 am for the growing and finishing pigs. During this period, the feeding rate increased from 13.371 g/min to 27.417 g/min for the growing pigs and from 16.948 g/min to 44.584 g/min for the finishing pigs. For all the hours during this period (4 am to 10 am), the finishing pigs had a higher feeding rate compared to the growing pigs ($P<0.05$).

After the peak of both phases, it is followed by a declining feeding rate trend until noon with 22.650 g/min for growing pigs and 1 pm with 36.123 g/min for the finishing pigs. During these hours (10 am to 1 pm), the feeding rate between the two growth phases was significant ($P<0.05$). The pigs during their finishing phase had a higher feeding rate compared to the growing phase. Subsequently, the feeding rate increased at 1 pm with 22.782 g/min for the growing pigs before it peaked at 3 pm with 23.896 g/min. The feeding rate began to increase at 2 pm with 36.454 g/min for the pigs at the finishing stage of growth, and then it peaked at 3 pm with 42.314 g/min. For all the hours during this period (1 pm to 3 pm), the finishing pigs had a higher feeding rate compared to the growing pigs ($P<0.05$; Figure 37).

Subsequently, After the peak of both phases in the afternoon, a declining trend in feeding rate was generally observed from 4 pm to 3 am for both growing and finishing pigs. For all the hours during this period (4 pm to 3 am), the feeding rate was significantly affected by the pig's growth stage. The pigs in the finishing phase consumed more feed over a shorter feeding duration (or high feeding rate) compared to when they were in a growing phase ($P<0.05$). Overall, a total of the feeding rate for the significant hours throughout the day showed that the pigs had a higher feeding rate during the finishing phase than what they consumed during their growing phase (732.477 g/min vs 474.732 g/min;

P<0.05). Therefore, finishing pigs would consume more feed over a shorter feeding duration than their growing phase.

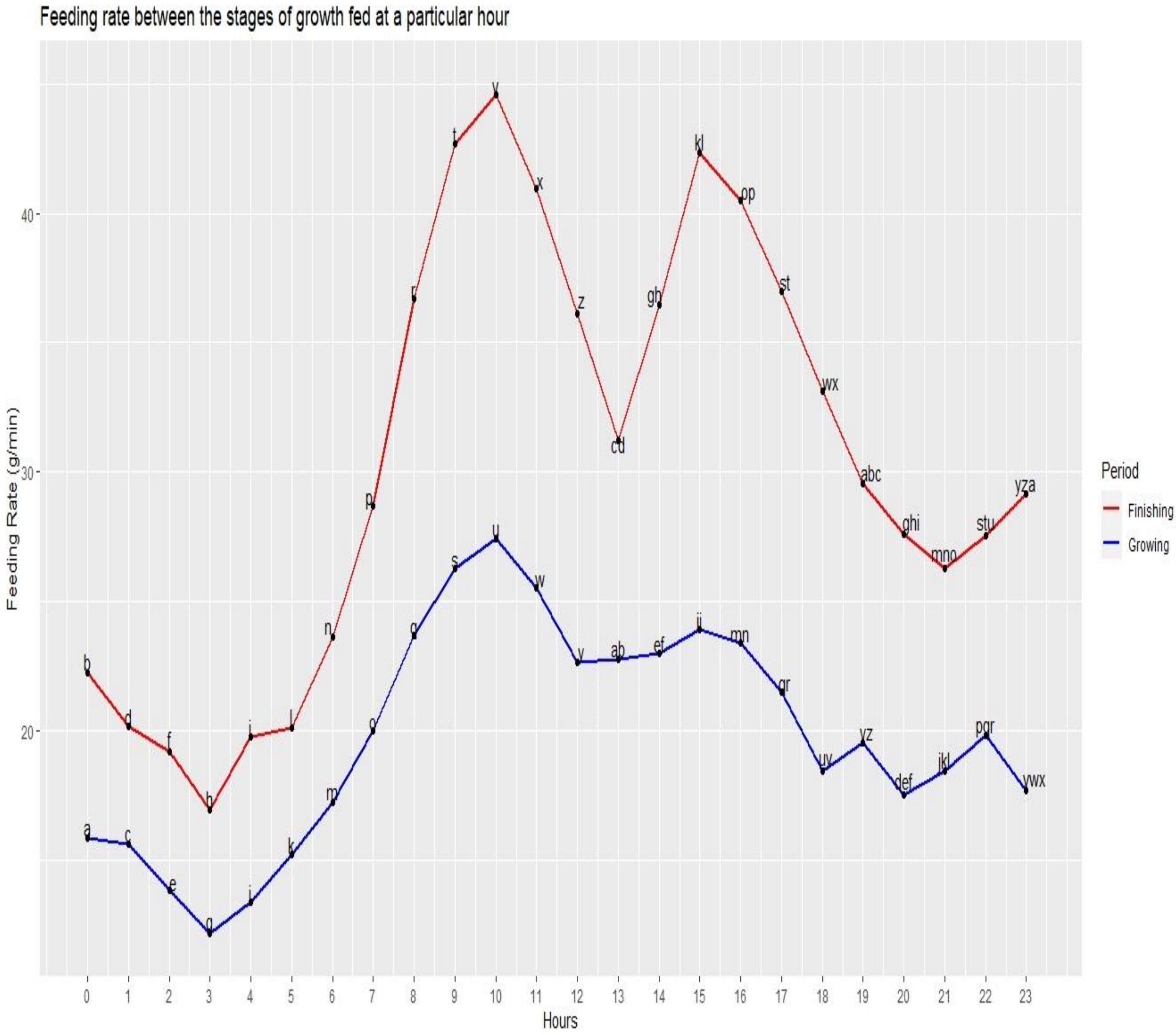

Figure 37: Difference in feeding rate between the different growth stages of the pigs.

Different alphabets indicate a significant difference in feeding rate between the two growth stages at a particular hour of the day. The points in the graph with no alphabet showed no significant difference in feeding rate between growth stages at that hour.

4.6.8 The effect of the group type and sex of the growing pigs on the feeding rate at a particular time of the day

Figure 38 showed that the group type of the growing pigs had no significant effect on their hourly feeding rate at all times of the day. The hourly feeding rate for group 1 and group 2 pigs was the same throughout the growing phase. Similarly, the feeding rate for male and female growing pigs was the same (Figure 39).

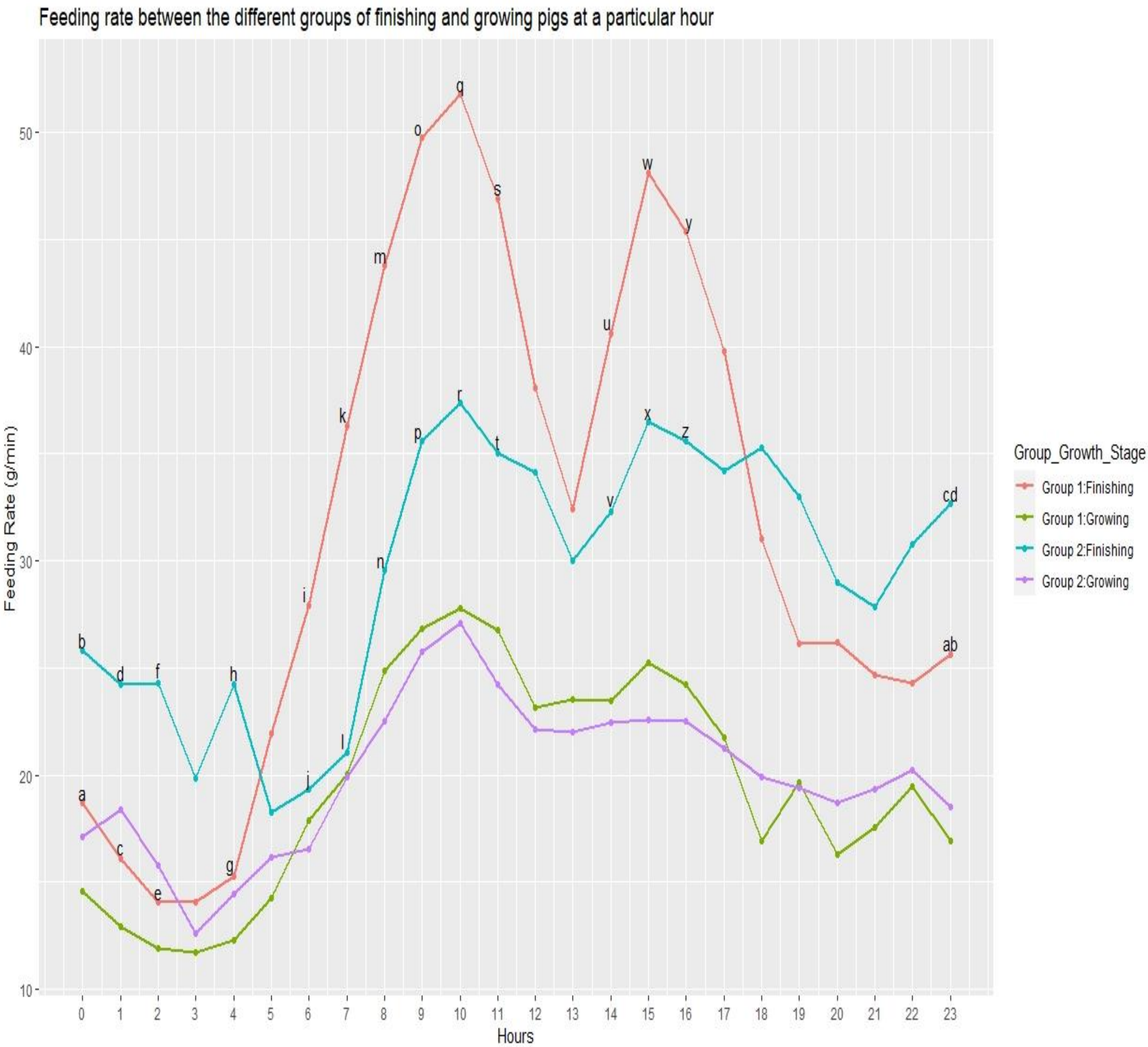

Figure 38: The significant difference in feeding rate between the different groups of finishing and growing pigs.

Different alphabets indicate a significant difference in feeding rate between the two groups of finishing pigs at a particular hour of the day. The points in the graph with no alphabet showed no significant difference in feeding rate between the groups of pigs at that hour.

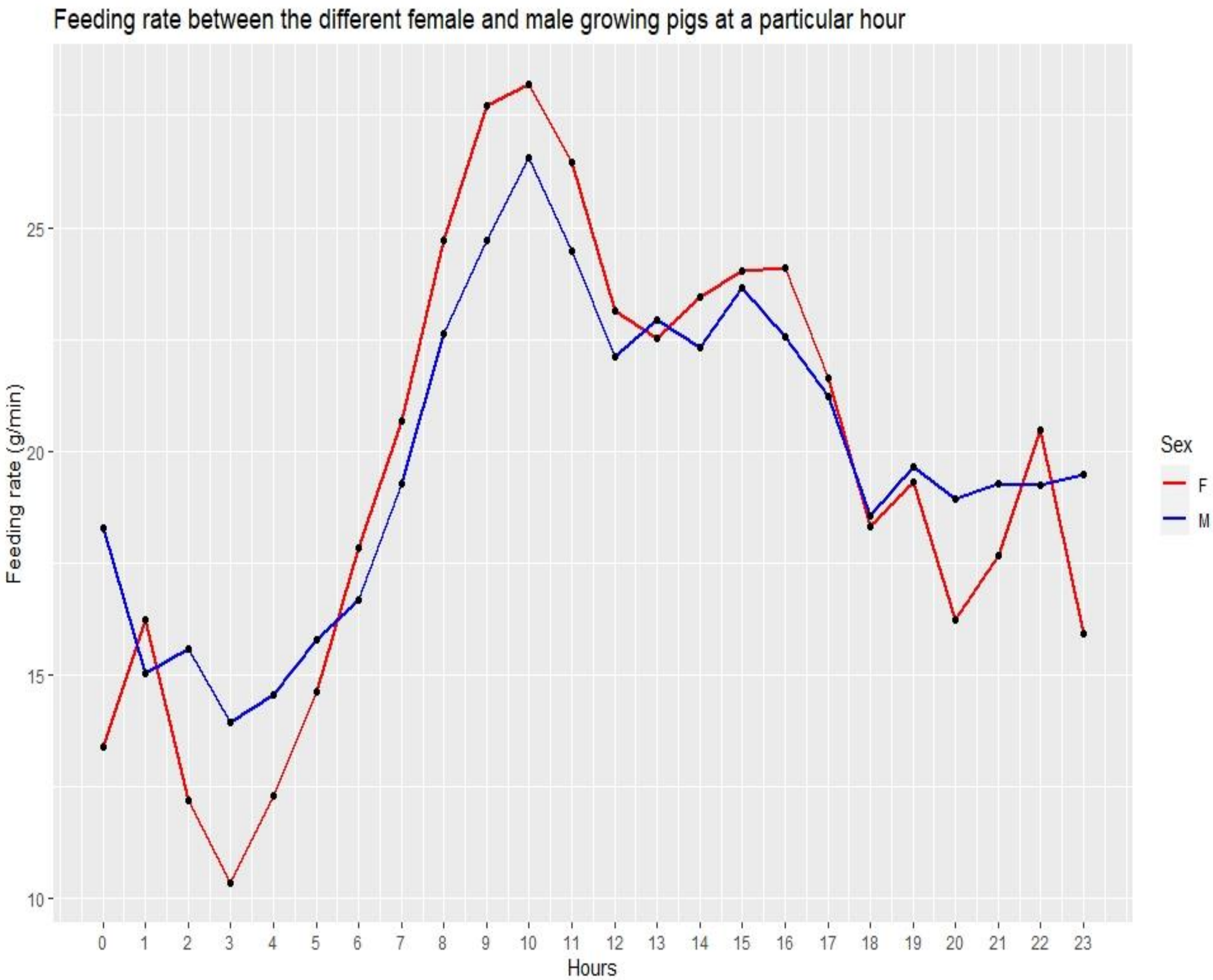

Figure 39: Difference in feeding rate between the female and male growing pigs.

4.6.9 The effect of the group type of the finishing pigs on the feeding rate at a particular time of the day

At certain hours of the day, the group type of the finishing pigs had a significant ($P<0.0001$) effect on their hourly feeding rate. Overall, a total of the feeding rate of the significant hours throughout the day showed that the group 1 finishing pigs generally consumed more ($P<0.05$) feed over a short feeding duration (high feeding rate) compared to group 2 finishing pigs (480.404 g/min vs 413.666 g/min).

As the morning progressed, an increasing trend in feeding rate was observed. The increase in feed intake began at 4 am for the group 1 finishing pigs and 6 am for the group 2 finishing pigs. The increasing trend in feeding rate continued until it peaked at 10 am for both groups of finishing pigs. During this period, the feeding rate increased from 15.304 g/min to 51.775 g/min for the group 1 pigs and from 19.308 g/min to 37.394 g/min for the group 2 finishing pigs. At certain hours of the morning (such as from 6 am to 10 am), group 1 finishing pigs had a higher feeding rate than group 2 finishing pigs. On the other hand, at 4 am, the group 2 pigs had a higher feeding rate compared to the group 1 pig (24.261 g/min vs 15.304 g/min; $P=0.0108$; Figure 38).

After the morning peak of both groups of pigs, it is followed by a declining feeding rate trend until 1 pm with 32.399 g/min for group 1 finishing pigs and 1 pm with 30.034 g/min for group 2 finishing pigs. The feeding rate between the two groups of finishing pigs was significantly ($P=0.0007$) different at 11 am. The group 1 pigs consumed more feed than the group 2 pigs (46.914 g/min vs 35.017 g/min). For the group 2 finishing pigs, the feeding rate began to increase again at 2 pm with 32.304 g/min and peaked again at 3 pm with 36.490 g/min. For the group 1 finishing pigs, the increasing trend in feeding rate began at 2 pm with 40.604 g/min before it peaked at 3 pm with 48.139 g/min (Figure 38). From 2 pm to 3 pm, the group 1 pig consumed more feed in a relatively shorter time compared to the group 2 pigs ($P<0.05$).

Subsequently, after the peak of both groups in the afternoon, a declining trend in feeding rate was generally observed from 4 pm with 45.353 g/min to 3 am with 14.067 g/min for the group 1 finishing pigs, and from 4 pm with 35.604 g/min to 5 am with 18.247 g/min for the group 2 finishing pigs. During this period, at certain hours of the day (such as at 11 pm and from 12 am to 3 am), there was a significant ($P<0.05$) difference between the two groups. The group 2 finishing pigs had a higher feeding rate than the group 1 finishing pigs. However, at 4 pm, the group 1 finishing pigs had a significantly higher feeding rate compared to the group 2 finishing pigs (45.353 g/min vs 35.604 g/min; P=0.0055)

Overall, during late in the night and very early in the morning, group 2 finishing pigs generally had a higher feeding rate than group 1 finishing pigs. On the other hand, group 1 finishing pigs had a higher feeding rate during the morning and afternoon.

4.7 The effect of the growth stage on the feeding rate of the group 1 pigs at a particular time of the day

Figure 40 showed that, at certain times of the day, the growth stage of the group 1 pigs had a significant effect on their feeding rate. At all the times of the day that the feeding rate was significant (such as from 5 am to 11 pm; $P<0.05$), the group 1 pigs during the finishing phase had a higher feeding rate compared to during its growing phase (Figure 40). The feeding rate peaked at 10 am for the group 1 pigs during the growing and finishing phase. The peak feeding rate was at 3 pm for the group 1 pigs during the growing and finishing phase in the afternoon. Overall, during the finishing phase, the group 1 pigs consumed more feed over a shorter feeding duration (higher feeding rate) than when they were growing.

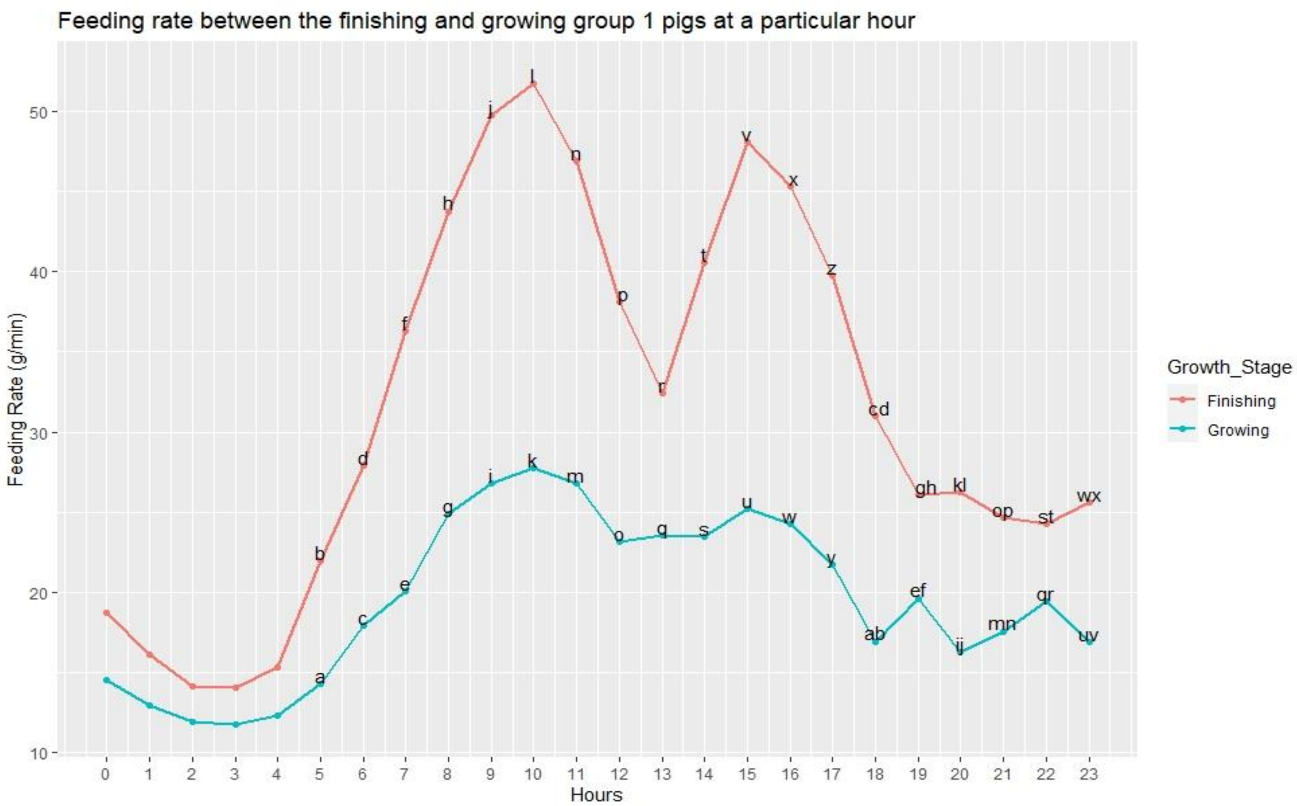

Figure 40: The difference in feeding rate between the growing and finishing growth stage of the group 1 pigs.

Alphabet indicates a significant difference in feeding rate between the growing and finishing group 1 pigs.

The points in the graph with no alphabet showed no significant difference in feeding rate between the growing and finishing group 1 pigs.

Chapter 5

Discussion

Only the results with no confounding effect of the diet fed (or group type) would be discussed for brevity.

5.1 The effect of the interaction between sex and group type of the pigs on the *ad libitum* feeding behaviour.

The number of feeder visits and feeding rate were the same for the female and male group 1 basally fed growing-finishing pigs. However, a significant difference in feed intake between the male and female group 1 growing-finishing pig fed the basal diet was observed. The male group 1 pigs consumed more feed than the female group 1 pigs (Table 4.5.4). De Haer & de Vries (1993) reported a similar result: the boar had a higher feed intake than the gilt. In their study, Gonyou et al. (1992) and Hyun (1997) also confirmed that barrow ate more than gilt. Also, differences in feed intake between barrows and gilts have been reported in studies conducted by Campbell & Taverner (1988) and Fuller et al. (1995).

Data presented by Cole & Chadd (1989) in their literature review on voluntary feed intake of growing pigs were contrary to this study. They reported that boars and gilts had similar feed intake. Likewise, Hyun et al. (1997) reported no difference in daily feed intake between barrows, boars, and gilts. Hyun et al. (1997) attributed the lack of difference in feed intake among the sexes in their study to the feeder design and the size and sex composition of groups used. This may have restricted access to the feeder and could have reduced the feed intake of barrows relative to the other two sexes. Feeding duration was the same in this study for the male and female group 1 growing-finishing pigs. This agrees with Hyun et al. (1997), who highlighted no difference in feeding duration between barrows, boars, and gilts. In contrast, Brown-Brandl et al. (2013) reported that barrows spent more time feeding than the gilts.

Also, it is important to highlight that the feeding behaviour for the female and male group 2 growing-finishing pigs will not be discussed. This is because of the confounding effect of two different diets (basal diet during the growing period and test diet during the finishing period) fed to the group 2 growing-finishing pigs.

5.2 The effect of the group type on the hourly feeding behaviour of the growing-finishing pigs

The interaction between group type and growth stage on the feeding behaviour of pigs will be discussed under the following subsections.

5.2.1 The effect of the group type on the hourly feeding behaviour of growing pigs

Hourly feeding rate for group 1 and group 2 pigs was the same during the growing phase because both groups of pigs were fed the same basal diet (Figure 38). However, for the other feed behaviour parameters, the group 2 pigs had higher feeding visits, spent more time feeding and consumed more feed than the group 1 pigs during their growing phase (Figure 14, 22 and 30).

It was expected that during the growing phase, other hourly feeding behaviour parameters, just like the feeding rate, would be the same between group 1 and group 2 pigs because both groups of pigs were fed the same basal diet. Therefore, this significant difference in the hourly feeding visit, hourly feeding duration and hourly feed intake reported between the two groups of growing pigs could not be due to the diet. Instead, this significant difference may be ascribed to the intrinsic differences between the pigs (such as sex).

5.2.2 The effect of the group type on the hourly feeding behaviour of finishing pigs

The type of diet fed to the different groups of finishing pigs influenced their hourly feeding behaviour. It is worthy to note during the finishing phase of growth, the group 1 pigs were fed the basal diet, and the group 2 pigs were fed the fibre-rich test diet. Therefore, any significant difference in the hourly feeding behaviour between the different groups could be ascribed to the diet.

The feed intake and feeding rate for the group 2 finishing pigs were usually reduced compared to the group 1 finishing pigs during the day (Figure 30 and 38). This low feed intake can be explained by the high fibrous nature of the test diet fed to the group 2 finishing pigs. Nyachoti et al. (2004) reported that the ability of the pigs to achieve gut fill depends on the bulkiness of the feed. The fibre-rich diet has increased gut fill due to its bulky nature (Kyriazakis & Emmans, 1995; Owusu-Asiedu et al., 2006; Ndou et al., 2013). Physicochemical properties such as their coarse structure and high water-holding capacity contribute to the bulky nature of the dietary fibre (de Leeuw et al., 2008). Similarly, studies have reported that dietary fibre boosts satiety in pigs which significantly reduces feed and energy intake (Pereira & Ludwig, 2001; Gerstein et al., 2004; de Leeuw et al., 2008; Bolhuis et al., 2010; Wanders et al., 2011; Agyekum & Nyachoti, 2017). Therefore, satiety and reduced feed intake of the group 2 finishing pigs were caused by the bulky and fibrous component of the test diet. Similarly, other studies have shown that the inclusion of fibre in the diet elicits a decrease in feed intake (Stein & Shurson, 2009; Gutierrez et al., 2013; Agyekum et al., 2012; 2014; 2015).

The high fibre content (of the test diet) fed to the group 2 finishing pigs means they attain satiety faster due to its physico-chemical properties. In the stomach, the presence of fibre in the diet triggers an increase in the retention time of the digesta, thereby leading to satiety or reduced feed intake (Wenk, 2001). Feed intake in pigs is influenced by the pig’s desire to meet its nutrient demands (Nyachoti et al., 2004). Feed intake in pigs is regulated based on its ability to meet its first limiting nutrient, especially the energy-yielding nutrients (Cole et al., 1968; Henry, 1985; NRC, 1998; McNeilage, 1999).

Fibre has been reported in some studies to dilute the available energy concentration of the diet (Noblet & Le Golf, 2001; Wenk, 2001). The overall effect shows a negative influence of dietary fibre on the pig’s energy metabolism (Agyekum & Nyachoti, 2017). For instance, energy digestibility was reduced due to lignin in the fibre of the diet (Wenk, 2001). Kyriazakis & Emmans (1995) also showed the connection between energy dilution of fibre-rich diet on feed intake. Their study reported that growing pigs offered feeds of increasing bulk could compensate for the nutrient dilution by increasing their intake. Only at very high levels of bulk did the daily energy intake decrease due to limiting gut capacity.

Therefore, as an adaptation mechanism to compensate for the low dietary available energy content of the test diet, the group 2 finishing pigs visited the feeder more often than the group 1 finishing pigs (Figure 14) throughout the day (24 hours) and continuously attempted to eat more feed to achieve a constant energy intake (Nyachoti et al., 2004). However, the physical feed intake capacity of the group 2 finishing pigs to consume large feed is limited by gut fill due to the bulky nature of the test diet-fed (Cole et al., 1971). As a result, they consume a smaller amount of the test diet per-hourly visit. This is why the group 2 finishing pig (fed the test diet) had a significantly higher feeding visit but had low feed intake (especially during the day) than the group 1 pig fed the basal diet (Figure 14 and 30). The continuous process of visiting the feeder cumulatively increases the feeding duration of the group 2 pigs (especially late at night and early in the morning) than the group 1 pigs (Figure 22). The extended time feeding could also be explained by the fact that the pig spends more time eating to compensate for the dilution effect of the fibre in the diet (Schrama et al., 1998; Kallabis et al., 2012). In a study conducted by Konstanze & Kaufmann (2012), a similar result of an increase in the feeding duration of pigs fed a high fibre diet was reported. Other authors have reported an increase in feeding duration for pigs fed a high fibre diet (Robert et al., 1997; Ramonet et al., 1999; Danielsen & Vestergaard, 2001; Robert et al., 2002).

The group 2 finishing pigs ate a smaller quantity of the feed per visit than the group 1 finishing pigs due to the satiating effect of the fibrous diet. The bulky nature of the test diet reduced feeding motivation and increased mastication time (or feeding duration) by stimulating mechanoreceptors in the gastrointestinal tract (sensory-specific-satiety (Paintal, 1954; Rolls & Rolls, 1997)). This process reduced the feeding rate of group 2 finishing pigs by stimulating satiation, thereby promoting meal termination (or reduced feed intake) over an extended mastication (or feeding duration) time (Cummings & Overduin, 2007; Figure 38). These findings were consistent with Konstanze & Kaufmann (2012), who reported a reduced feeding rate for pigs fed a fibre-rich diet. Other authors have also reported a decrease in the feeding rate for pigs fed a high fibre diet (Ramonet et al., 1999; Meunier-Salaun et al., 2001; Whittemore et al., 2002).

The feed intake pattern for the group 1 finishing pigs fed the basal diet was observed to have two definite peak times. Therefore, this means that when their energy intake has been met at a peak time, they rest for some hours before they resume another round of feeding. However, for the group 2 finishing pigs, there was a continuous consumption of feed throughout the 24 hours to compensate for the diluted energy intake of the fibre-rich diet (Nyachoti et al., 2004). This is why at night and early in the morning, when the group 1 finishing pigs were resting because their energy intake has been met, the group 2 finishing pigs have a significantly higher feeding visit, feeding duration, feed intake and feeding rate (Figure 14, 22, 30 and 38). The difference in the hourly feed intake and feeding duration pattern between the group 1 and group 2 finishing pigs further confirms the influence of the different diet-fed (Figure 22 and 30). While group 1 finishing fed the basal diet had two definite peaks (one in the morning and another in the afternoon), the group 2 pigs fed the test diet had a patternless feeding pattern. The hourly feeding duration for the group 2 pigs also exhibited similar patternless behaviour as the hourly feed intake (Figure 22 and 30).

Similarly, the hourly feed intake and feeding duration pattern of the group 2 pigs during their growing phase differed compared to their finishing phase. The hourly feed intake and feeding duration pattern for the group 2 growing pigs (that were fed the basal diet) looked defined (Figure 22 and 30) with two pronounced peak points (one in the morning and the other in the afternoon). On the other hand, during the finishing phase, when the fibre-rich diet was introduced to the group 2 finishing pigs, the hourly feed intake and feeding duration pattern for the group 2 pigs looked patternless and peaked more than twice (Figure 22 and 30). The change in the feeding duration and feed intake pattern of the group 2 finishing pigs represent an adaptation to the energy intake constraint placed by the fibre-rich test diet fed to them (Nyachoti et al., 2004).

5.2.3 The effect of the group type on the peak time of feeding behaviour of finishing pigs

Peak feeding behaviour is exhibited at a different time of the day. The difference in the peak feeding behaviour time (except feeding rate) observed between group 1 and group 2 finishing pigs may be attributed to the different diets fed to the pigs. Feeding visits peaked at 10 am for group 1 finishing pigs, and 9 am for group 2 finishing pigs (Figure 14). Similarly, the morning peak feeding duration was at 8 am for the group 1 finishing pigs. The group 2 finishing pigs spent most of the time feeding at 8 am and later at 11 am. The morning peak feed intake and feeding duration time were similar for group 1 and group 2 finishing pigs (Figures 30 and 22). The peak feeding rate time in the morning (10 am) was the same for group 1 and group 2 finishing pigs (Figure 38).

In the afternoon, the peak time for feeding duration and feed intake for group 1 and group 2 finishing pigs was different. The difference in the peak time for the feeding duration and feed intake time observed between group 1 (4 pm) and group 2 finishing pigs (5 pm) may be attributed to the different diets fed to the pigs (Figures 22 and 30). Feed intake and feeding duration had the same feeding pattern and the peak time for group 1 and group 2 finishing pigs (Figures 22 and 30). The peak time (3 pm) for feeding visits and feeding rate in the afternoon for group 1 and group 2 finishing pigs was the exact (Figures 14 and 38).

5.2.4 The effect of the growth stage on the hourly feeding behaviour of the group 1 pigs

The growth stage (or age) of the group 1 pigs (fed the basal diet) influenced their hourly feeding behaviour. This study observed that pigs fed the standard compound diet (group 1) consumed more feed during their finishing phase than their growing phase. As the pig grew (or age), the liveweight increased. Studies have reported a linear increase in feed intake as the pig grew (Bigelow & Houpt, 1988; Hyun et al., 1997). This can be explained by the increase in gut sizes as the pig age. During the growing phase, the basally fed group 1 pigs gut capacity to consume food was limited (due to its small size) compared to their finishing phase. As a result, the growing group 1 pigs frequently visited the feeder more often to compensate for their inability to eat a large feed per visit. (Figure 17 and 31). This agreed with the study conducted by Auffray & Marcilloux (1980) and Lebroue et al. (1994). The continuous feeding visitation and the inability to eat fast due to the small gut of the growing group 1 pigs cumulatively increased their time spent feeding (Figure 23). That is, the growing pigs were observed to have spent longer time feeding compared to finishing pigs. The finding of this study was consistent with that of Hyun et al. (1997). Hyun et al. (1997) reported a decline in the feeder visits per day from 7.5 to 6 as the pig aged and the weight increased. Also, Hyun et al. (1997) reported that as the pig ages and the live weight increased from 27 to 82 kg, the duration of time spent feeding decreases. These findings were consistent with those found in this study. Therefore, this study confirmed that the feeding duration required to achieve daily voluntary feed intake decreases with age or liveweight.

On the other hand, the finisher group 1 pigs visited the feeder less frequently for food than the grower group 1 pigs but ate a large quantity of feed per visit. This is because finisher pigs typically weigh more than grower pigs. Finishing pigs places a greater need for dietary nutrients compared to growing pigs. Therefore, they need to consume more feed to meet their daily nutrient requirements (Nyachoti et al., 2004). The study conducted by Hyun et al. (1997) confirmed the result of this trial. In their study, feed intake for pigs with live weight from 27 to 82 kg increased linearly with increasing body weight (from growing to finishing pigs). Auffray & Marcilloux (1980) and Bigelow & Houpt (1988) also reported the same findings. Similarly, the capacity of the group 1 pigs' mouth size and its gut size increased as it aged (Illius & Gordon, 1987; Nyachoti et al., 2004). Therefore, the group 1 finishing pig can consume a larger quantity of feed over a short feeding duration. Therefore, the group 1 finishing pig had a higher feeding rate than when it was growing (Figure 40). Hyun et al. (1997) also reported a similar increase in feeding rate as the pig ages with the live weight increasing from 27 (for the growing pigs) to 82 kg (finishing pigs). The studies conducted by Hsia & Wood-Gush (1984), Bigelow & Houpt (1988), Labroue et al. (1994) and Nielsen et al. (1995) reported similar findings that as the pig aged, the feeding rate increased.

5.3 The effect of the interaction between the group type and sex on the *ad libitum* feeding behaviour of the growing-finishing pigs

The growing-finishing pigs' group type and sex interaction were insignificant for feeding behaviour parameters such as the number of feeder visits, feeding duration, and feeding rate. However, the sex and diet fed to the different group types of the growing-finishing pigs influenced the hourly feed intake.

The sex of the growing-finishing pigs affected the hourly feed intake of the group 1 pigs. This study indicates that the male pigs consumed more feed for the group 1 pigs fed the basal diet than the female pigs during the growing phase. The same effect was observed for the group 1 pigs during the finisher phase. The male finishing pigs fed the basal diet (group 1) had a higher feed intake than the female group 1 finishing pigs (Table 4.5.6). Therefore, for the group 1 growing-finishing pigs fed an equivalent of a standard compound diet (basal), the male pigs had a higher feed intake than the female pigs. This finding was consistent with that of other studies discussed in section 5.1.

On the other hand, the sex of the growing-finishing pig did not affect the feed intake of the group 2 pigs. During the growing and finishing phase, the male and female group 2 pigs had the same feed intake (Table 4.5.6). The group 2 pigs during the growing phase were fed the basal diet, and in the finishing phase was fed the fibre-rich test diet. There was no effect on feed intake for the female growing pigs belonging to either group 1 or group 2 pigs. Similarly, the feed intake for group 1 and group 2 male growing pigs was the same. This non-significant effect can be explained because the group 1 and group 2 pigs were fed the same basal diet during the growing phase.

The group type (or type of diet fed) influenced the hourly feed intake of the finishing pigs. The group 1 male finishing pigs consumed more feed compared to the group 2 male finishing pigs. This difference is attributed to the type of diet fed to the different pig's groups. The male group 1 finishing pigs were fed the basal diet, and the male group 2 finishing pigs were fed the fibre-rich test diet. This finding agrees with those studies discussed in section 5.2.2. The physico-chemical properties of the bulky fibre-rich test diet fed to the male group 2 finishing pigs caused early satiation, restricting further feed intake compared to the less fibrous basal diet fed to the group 1 pigs (Table 4.5.6). Also, Section 5.2.2 further explained how fibre influenced the feeding behaviour (especially feed intake) in pigs. In contrast, female group 1 and group 2 finishing pigs had the same feed intake. Therefore, the nature of the diet fed did not affect the feed intake of the female finishing pig in this study. The male and female group 2 finishing pigs had a similar feed intake because the same fibre-rich test diet was fed (Table 4.5.6).

The growth stage of the pig affected the quantity of feed consumed. The result from this study confirmed this. During the finishing phase, the female pigs fed the basal diet (group 1) had a higher hourly feed intake than what they consumed when growing. Similarly, the male pigs fed the basal diet (group 1) had a higher hourly feed intake during their finishing phase than the growing phase (Table 4.5.6). As the pig grows, the requirement to meet its nutrient intake to support bodily function such as maintenance and accretion increases (Nyachoti et al., 2004). Therefore, the finisher pig consumed more feed to meet their nutrient needs. However, unlike the finisher pigs, the ability of the growing pigs to meet up with this function is limited due to the restriction placed by its small gut size. Therefore, as the pig grows, the gut size increases, increasing the quantity of feed consumed. Details on how the growth stage (or age) changes the feed intake pattern of the pigs had been discussed in section 5.2.4.

It is noteworthy to highlight that the effect of the growth stage of the group 2 male and female pigs on feed intake will not be discussed. This is because of the confounding effect of two different diets (basal diet during the growing period and test diet during the finishing period) fed to the group 2 pigs.

5.4 The effect of the interaction between the group type and sex on the hourly feeding behaviour of the pigs

The sex of the pig does affect the feed behaviour of growing-finishing pigs on an hourly basis. This study reported that the female group 1 pig (fed the basal diet) had a lower feed intake than the male group 1 pig. This finding agreed with those studies discussed in section 5.1. Furthermore, while female group 1 growing-finishing pigs visited the feeder more than the male group 1 growing-finishing pig, they consumed little quantity of the feed per visit, thereby spending little time feeding in the process (Figure 16, 25 and 33). On the other hand, the male group 1 growing-finishing pigs visited the feeder less frequently. Still, they consume a larger quantity of feed at each visit over an extended feeding time than the female group 1 growing-finishing pigs (Figure 16, 25 and 33).

The female and male group 1 growing-finishing pig typically spent most time feeding and consumed more food in the morning (8 am) and in the afternoon (4 pm). Also, the female and male growing-finishing pig mostly visits the feeder at 10 am. In the afternoon, the female and male group 1 growing-finishing pigs typically visit the feeder for food at 3 pm and 4 pm.

This study also shows that for the pig fed the basal diet (group 1), visiting the feeder the most at a particular time of the day does not mean that most feed consumption happens at that hour. Similarly, the sex of the growing to finishing group 1 pigs did not affect the time of the day when the pig consumed most of its feed and how long it takes to consume it (Figure 33 and 25). The feeding duration and feed intake peak time for the group 1 growing-finishing pig is typically the same. That is, the female and male group 1 pigs had similar peak feeding duration and feed intake time. This means that as group 1 (or basally fed), pigs consumed a proportional amount of feed similar to their time eating. If the group 1 pig consumed little feed, it spent a shorter time feeding in the process.

A similar effect was observed for the peak morning feeding visit, but it changed during the afternoon (Figure 16). That is, male and female pigs visited the feeder the most in the morning at 10 am. The female visited the feeder the most in the afternoon at 3 pm while the male at 4 pm. The sex of the growing-finishing pigs did not affect the feeding rate. The feeding rate for the female and male pigs fed the standard compound diet (group 1) was the same in this study.

5.5 The effect of the interaction between the group type and the growth stage of the pigs on the *ad libitum* feeding behaviour

Hourly feeding behaviour was the same for the group 1 and group 2 growing pigs. The non-significant difference in the hourly feeding behaviour is attributed to the fact that the group 1 and group 2 pigs were fed the same basal diet during the growing phase. Similarly, there was no significant difference in the hourly feeding behaviour between the group 1 pigs (fed the basal diet) and the group 2 pigs (fed the fibre-rich test diet) during the finisher phase.

Feeding visit, feeding duration and feed intake were the same for the group 1 pigs during their growing and finisher growth stage. However, the effect of the growth stage of the pig affected the feeding rate of the group 1 pigs. During the finishing stage of growth, the group 1 pigs (fed the basal diet) had a higher feeding rate than their growing period. This finding agreed with those studies discussed in section 5.2.4. Also, section 5.2.4 further demonstrates how the growth stage (or age/weight) influenced pigs' feeding behaviour (especially feeding rate).

It is noteworthy to highlight that the effect of the growth stage of the group 2 pigs on feeding behaviour will not be discussed. This is because of the confounding effect of two different diets (basal diet during the growing period and test diet during the finishing period) fed to the group 2 pigs.

Chapter 6

Conclusion

In summary, this study confirmed that marked changes occur in the feeding behaviour of pigs depending on factors such as their sex and the growth stage (age). Sex affected the feeding behaviour of growing-finishing pigs (fed a standard compound or basal diet) on an hourly basis differently. The female basally fed pigs frequently visited the feeder more often but spent a shorter feeding time because they only ate smaller feed quantities. However, the male basally fed pigs visited the feeder less often but spent more time feeding because of the large quantity of feed it consumed. Similarly, the pig's growth stage (or age/weight) influenced their behavioural feeding pattern. Therefore, to compensate for their reduced feed intake and feeding rate, growing pigs fed the basal diet were observed to have an extended feeding time because of their frequent feeding visits. On the other hand, finishing pigs fed the basal diet had a higher feed intake and feeding rate. Therefore, as the pig aged, the number of feeder visits and feeding duration reduced as the quantity of feed consumed and how fast it consumed it increased.

Many factors, including diet, can influence feeding behaviour. The composition of the diet could also affect the feeding behaviour of pigs. This study further indicates that a diet rich in fibre is likely to change the feeding behaviour pattern of the pigs. The physico-chemical properties of the fibre (such as bulkiness) can influence satiety through gut fill and mastication time. Satiety is shown to influence *ad libitum* feed intake in pigs. As a result, the fibre-rich diet changed the pigs' hourly feed intake and feeding duration pattern graph in this study. Overall, finishing pigs fed the fibre-rich diet exhibited reduced hourly feed intake, and feeding rate than pigs fed the standard (basal) compound diet. In contrast, the pigs fed the fibre-rich diet's hourly feeding duration and feeding visit was increased than the pigs fed the standard compound diet.

References

Abu, O., Olaleru, I., Oke, T., Adepegba, V., & Usman, B. (2015). Performance of broiler chicken fed diets containing cassava peel and leaf meals as replacements for maize and soya bean meal. *International Journal of Science and Technology* 4: 169-173.

Aerni, V., El-Lethey, H., & Wechsler, B. (2000). Effect of foraging material and food form on feather pecking in laying hens. *British Poultry Science*, *41*(1), 16-21.

Agyekum, A. K., & Nyachoti, C. M. (2017). Nutritional and metabolic consequences of feeding high-fibre diets to swine: a review. *Engineering*, *3*(5), 716-725.

Agyekum, A. K., Regassa, A., Kiarie, E., & Nyachoti, C. M. (2016). Nutrient digestibility, digesta volatile fatty acids, and intestinal bacterial profile in growing pigs fed a distillers dried grains with solubles containing diet supplemented with a multi-enzyme cocktail. *Animal Feed Science and Technology*, *212*, 70-80.

Agyekum, A. K., Sands, J. S., Regassa, A., Kiarie, E., Weihrauch, D., Kim, W. K., & Nyachoti, C. M. (2015). Effect of supplementing a fibrous diet with a xylanase and β-glucanase blend on growth performance, intestinal glucose uptake, and transport-associated gene expression in growing pigs. *Journal of Animal Science*, *93*(7), 3483-3493.

Agyekum, A. K., Slominski, B. A., & Nyachoti, C. M. (2012). Organ weight, intestinal morphology, and fasting whole-body oxygen consumption in growing pigs fed diets containing distillers dried grains with solubles alone or in combination with a multienzyme supplement. *Journal of Animal Science*, *90*(9), 3032-3040.

Agyekum, A. K., Woyengo, T. A., Slominski, B. A., Yin, Y. L., & Nyachoti, C. M. (2014). Effects of formulating growing pig diet with increasing levels of wheat-corn distillers dried grains with solubles on digestible nutrient basis on growth performance and nutrient digestibility. *Journal of Animal Physiology and Animal Nutrition*, *98*(4), 651-658.

Amerah, A. M., Ravindran, V., & Lentle, R. G. (2009). Influence of insoluble fibre and whole wheat inclusion on the performance, digestive tract development and ileal microbiota profile of broiler chickens. *British Poultry Science*, *50*(3), 366-375.

Anguita, M., Gasa, J., Nofrarias, M., Martín-Orúe, S. M., & Pérez, J. F. (2007). Effect of coarse ground corn, sugar beet pulp and wheat bran on the voluntary intake and physicochemical characteristics of digesta of growing pigs. *Livestock Science*, *107*(2-3), 182-191.

Anugwa, F. O., Varel, V. H., Dickson, J. S., Pond, W. G., & Krook, L. P. (1989). Effects of dietary fiber and protein concentration on growth, feed efficiency, visceral organ weights and large intestine microbial populations of swine. *The Journal of Nutrition*, *119*(6), 879-886.

AOAC International. (2005). *Official methods of analysis of AOAC International*. AOAC International.

Asp, N. G. (1996). Dietary carbohydrates: classification by chemistry and physiology. *Food Chemistry*, *57*(1), 9-14.

Auffray, P., & Marcilloux, J. C. (1980). Analysis of porcine feeding patterns from weaning to adulthood. *Reproduction, Nutrition and Development*, *20*(5B), 1625-1632.

Auffret, A., Barry, J. L., & Thibault, J. F. (1993). Effect of chemical treatments of sugar beet fibre on their physico-chemical properties and on their in-vitro fermentation. *Journal of the Science of Food and Agriculture*, *61*(2), 195-203.

Auffret, A., Ralet, M. C., Guillon, F., Barry, J. L., & Thibault, J. F. (1994). Effect of grinding and experimental conditions on the measurement of hydration properties of dietary fibres. *LWT-Food Science and Technology*, *27*(2), 166-172.

Baidoo, SK, McIntosh, MK, & Aherne, FX (1986). Selection preference of starter pigs fed canola meal and soybean meal supplemented diets. *Canadian Journal of Animal Science*, *66* (4), 1039-1049.

Bakare, A. G., Ndou, S. P., & Chimonyo, M. (2013). Influence of physicochemical properties of fibrous diets on behavioural reactions of individually housed pigs. *Livestock Science*, *157*(2-3), 527-534.

Beattie, V. E., O'connell, N. E., & Moss, B. W. (2000). Influence of environmental enrichment on the behaviour, performance and meat quality of domestic pigs. *Livestock Production Science*, *65*(1-2), 71-79.

Beaulieu, A. D., Williams, N. H., & Patience, J. F. (2009). Response to dietary digestible energy concentration in growing pigs fed cereal grain-based diets. *Journal of Animal Science*, *87*(3), 965-976.

Bedford, M. A., & Schulze, H. (1998). Exogenous enzymes for pigs and poultry. *Nutrition Research Reviews*, *11*(1), 91-114.

Benelam, B. (2009). Satiation, satiety and their effects on eating behaviour. *Nutrition Bulletin*, *34*(2), 126-173.

Bergeron, R., Bolduc, J., Ramonet, Y., Meunier-Salaün, M. C., & Robert, S. (2000). Feeding motivation and stereotypies in pregnant sows fed increasing levels of fibre and/or food. *Applied Animal Behaviour Science*, *70*(1), 27-40.

Bergner, H. (1980). Chemical basis of straw digestion in the pellet press. *Archives of Animal Nutrition*, *30* (1-3), 239-256.

Bigelow, J. A., & Houpt, T. R. (1988). Feeding and drinking patterns in young pigs. *Physiology & Behavior*, *43*(1), 99-109.

Bindelle, J., Leterme, P., & Buldgen, A. (2008). Nutritional and environmental consequences of dietary fibre in pig nutrition: a review. *Biotechnologie, Agronomie, Société et Environnement*, *12*, 69-80.

Black, J. L., Williams, B. A., & Gidley, M. J. (2009). Metabolic regulation of feed intake in monogastric mammals. In *Voluntary Feed Intake in Pigs* (pp. 187-211). Wageningen: Wageningen Academic Publishers.

Black, J.L., Campbell, R.G., Williams, I.H., James, K.J., & Davies, G.T. (1986). Simulation of energy and protein utilization in the pig. *Res. Dev. Agric.* 3, 121–145.

Blundell, J., De Graaf, C., Hulshof, T., Jebb, S., Livingstone, B., Lluch, A., Mela, D., Salah, S., Schuring, E., Van der Knaap, H., & Westerterp, M. (2010). Appetite control: methodological aspects of the evaluation of foods. *Obesity Reviews*, *11*(3), 251-270.

Bolhuis, J. E., van den Brand, H., Bartels, A. C., Oostindjer, M., van den Borne, J. J., Kemp, B., & Gerrits, W. J. (2010). Effects of fermentable starch on behaviour of growing pigs in barren or enriched housing. *Applied Animal Behaviour Science*, *123*(3-4), 77-86.

Bornett, H. L. I., Morgan, C. A., Lawrence, A. B., & Mann, J. (2000). The effect of group housing on feeding patterns and social behaviour of previously individually housed growing pigs. *Applied Animal Behaviour Science*, *70*(2), 127-141.

Botermans. J. A. M., Svendsen, J., Westrom, B., Bottcher, R. W., & Hoff. S. J. (1997). Competition at feeding of growing-finishing pigs. Pages 591–598 *in* R.W. Bottcher, ed. Proceedings of the 5th *International Symposium on Livestock Environment.*

Brachet, M., Arroyo, J., Bannelier, C., Cazals, A., & Fortun-Lamothe, L. (2015). Hydration capacity: a new criterion for feed formulation. *Animal Feed Science and Technology*, *209*, 174-185.

Brooks, P. H. (2005). Effect of diet on the behaviour and welfare of pigs. In *Proceedings of the Manitoba Swine Seminar. Retrieved October* (Vol. 21, p. 2013).

Brooks, P. H., Russell, S. J., & Carpenter, J. L. (1984). Water intake of weaned piglets from three to seven weeks old. *Veterinary. Record*, *115*(20), 513-515.

Brouns, F., Edwards, S. A., & English, P. R. (1994). Effect of dietary fibre and feeding system on activity and oral behaviour of group housed gilts. *Applied Animal Behaviour Science*, *39*(3-4), 215-223.

Brouns, F., Edwards, S. A., & English, P. R. (1995). Influence of fibrous feed ingredients on voluntary intake of dry sows. *Animal Feed Science and Technology*, *54*(1-4), 301-313.

Brown-Brandl, T. M., Rohrer, G. A., & Eigenberg, R. A. (2013). Analysis of feeding behaviour of group housed growing-finishing pigs. *Computers and Electronics in Agriculture*, *96*, 246-252.

Brownlee, I. A. (2011). The physiological roles of dietary fibre. *Food Hydrocolloids*, *25*(2), 238-250.

Brunsgaard, G. (1998). Effects of cereal type and feed particle size on morphological characteristics, epithelial cell proliferation, and lectin binding patterns in the large intestine of pigs. *Journal of Animal Science*, *76*(11), 2787-2798.

Buraczewska, L., Święch, E., Tuśnio, A., Taciak, M., Ceregrzyn, M., & Korczyński, W. (2007). The effect of pectin on amino acid digestibility and digesta viscosity, motility and morphology of the small intestine, and on N-balance and performance of young pigs. *Livestock Science*, *109*(1-3), 53-56.

Burton-Freeman, B. (2000). Dietary fiber and energy regulation. *The Journal of Nutrition*, *130*(2), 272S-275S.

Büttner, D. (2006). Fibres for fertility; the inclusion of raw fibre in sow diets has many positive effects. *Feed Mix*. The Netherlands: Misset International; p. 18–21.

Cadden, A. M. (1987). Comparative effects of particle size reduction on physical structure and water binding properties of several plant fibers. *Journal of Food Science, 52*(6), 1595-1599.

Campbell, G. L, & Bedford, M. R. (1992). Enzyme applications for monogastric feeds: A review. *Canadian Journal of Animal Science*, *72* (3), 449-466.

Campbell, R. G. (1988). Nutritional constraints to lean tissue accretion in farm animals. *Nutrition Research Reviews*, *1*(1), 233-253.

Campbell, R. G., & Taverner, M. R. (1988). Genotype and sex effects on the relationship between energy intake and protein deposition in growing pigs. *Journal of Animal Science*, *66*(3), 676-686.

Canibe, N., & Bach Knudsen, K. E. (2002). Degradation and physicochemical changes of barley and pea fibre along the gastrointestinal tract of pigs. *Journal of the Science of Food and Agriculture*, *82*(1), 27-39.

Casey, D. (2003). The use of electronic feeders in genetic improvement programs for swine [PhD dissertation]. *Ames: Iowa State University*.

Champ, M., Langkilde, A. M., Brouns, F., Kettlitz, B., & Le Bail-Collet, Y. (2003). Advances in dietary fibre characterisation. 2. Consumption, chemistry, physiology and measurement of resistant starch; implications for health and food labelling. *Nutrition Research Reviews*, *16*(2), 143-161.

Chaplin, M. F. (2003). Fibre and water binding. *Proceedings of the Nutrition Society*, *62*(1), 223-227.

Chesson A. (1995). Dietary fiber. *In:* Stephen A.M. *Food Polysaccharides and their Applications.* New York: Marcel Dekker, 547-576.

Cho, S., Devries, J. W., & Prosky, L. (1997). The physiochemical properties of dietary fiber. *Dietary Fibre Analysis and Applications, Gaithersburg, MD: AOAC International*, 119-138.

Close, W. H. (1993). Fibrous diets for pigs. *BSAP Occasional Publication*, *16*, 107-117.

Clutter, A. C., Jiang, R., McCann, J. P., & Buchanan, D. S. (1998). Plasma cholecystokinin-8 in pigs with divergent genetic potential for feed intake and growth. *Domestic Animal Endocrinology*, *15*(1), 9-21.

Coffey, R. D., & Cromwell, G. L. (1995). The impact of environment and antimicrobial agents on the growth response of early-weaned pigs to spray-dried porcine plasma. *Journal of Animal Science*, *73*(9), 2532-2539.

Cole, D. J. A., & Chadd, S. A. (1989). Voluntary food intake of growing pigs. *BSAP Occasional Publication*, *13*, 61-70.

Cole, D. J. A., Duckworth, J. E., Holmes, W., & Cuthbertson, A. (1968). Factors affecting voluntary feed intake in pigs. 3. The effect of a period of feed restriction, nutrient density of the diet and sex on intake, performance and carcass characteristics. *Animal Science*, *10*(4), 345-357.

Cole, D. J. A., Hardy, B., & Lewis, D. (1971). Nutrient density of pig diets. In *Pig Production, Proceedings of the Eighteenth Easter School in Agricultural Science*, University of Nottingham, Butterworths, London, 243.

Cöp, W. A. G., & Buiting, G. A. J. (1977). Feed intake in six lines of pigs and its influence on growth and carcass traits 1. Feeding twice daily for 20 min per session. *Animal Science*, *25*(3), 291-304.

Correa-Matos, N. J., Donovan, S. M., Isaacson, R. E., Gaskins, H. R., White, B. A., & Tappenden, K. A. (2003). Fermentable fiber reduces recovery time and improves intestinal function in piglets following Salmonella typhimurium infection. *The Journal of Nutrition*, *133*(6), 1845-1852.

Cummings, D. E., & Overduin, J. (2007). Gastrointestinal regulation of food intake. *The Journal of clinical investigation*, *117*(1), 13-23.

Cummings, J. H., & Englyst, H. N. (1995). Gastrointestinal effects of food carbohydrate. *The American Journal of Clinical Nutrition*, *61*(4), 938S-945S.

da Silva, C. S., Bolhuis, J. E., Gerrits, W. J., Kemp, B., & van den Borne, J. J. (2013). Effects of dietary fibers with different fermentation characteristics on feeding motivation in adult female pigs. *Physiology & Behavior*, *110*, 148-157.

da Silva, C. S., van den Borne, J. J., Gerrits, W. J., Kemp, B., & Bolhuis, J. E. (2012). Effects of dietary fibers with different physicochemical properties on feeding motivation in adult female pigs. *Physiology & Behavior*, *107*(2), 218-230.

Danielsen, V., & Vestergaard, E. M. (2001). Dietary fibre for pregnant sows: effect on performance and behaviour. *Animal Feed Science and Technology*, *90*(1-2), 71-80.

Danielsen, V., Eggum, B. O., Jensen, S. K., & Sørensen, H. (1994). Dehulled protein-rich rapeseed meal as a protein source for early weaned piglets. *Animal Feed Science and Technology*, *46*(3-4), 239-250.

Darzi, J., Frost, G. S., & Robertson, M. D. (2011). Do SCFA have a role in appetite regulation? *Proceedings of the Nutrition Society*, *70*(1), 119-128.

Day, J. E. L., Kyriazakis, I., & Lawrence, A. B. (1996a). An investigation into the causation of chewing behaviour in growing pigs: the role of exploration and feeding motivation. *Applied Animal Behaviour Science*, *48*(1-2), 47-59.

Day, J. E. L., Kyriazakis, I., & Lawrence, A. B. (1996b). The use of a second-order schedule to assess the effect of food bulk on the feeding motivation of growing pigs. *Animal Science*, *63*(3), 447-455.

de Haer, L. C. M., & de Vries, A. G. (1993). Effects of genotype and sex on the feed intake pattern of group housed growing pigs. *Livestock Production Science*, *36*(3), 223-232.

de Lange, C. F. M., Nyachoti, C. M., & Verstegen, M. W. A. (2000a). The significance of antinutritive factors in feedstuffs for monogastric animals. Pages 169–188 in *Feed Evaluation: Principle and Practices.* P. J. Moughan, M. W. A. Verstegen, and M. I. Visser-Reyneveld, ed. Wageningen Pers, Wageningen, The Netherlands.

de Lange, C. F. M., Rutherfurd, S. M., & Moughan, P. J. (2000b). Overview of determinants of the nutritional values of feed ingredients. Pages 17–32 in *Feed Evaluation: Principle and Practices.* P. J. Moughan, M. W. A. Verstegen, and M. I. Visser-Reyneveld, ed. Wageningen Pers, Wageningen, The Netherlands.

de Leeuw, J. A., Bolhuis, J. E., Bosch, G., & Gerrits, W. J. J. (2008). Effects of dietary fibre on behaviour and satiety in pigs: symposium on 'Behavioural nutrition and energy balance in the young'. *Proceedings of the Nutrition Society*, *67*(4), 334-342.

de Leeuw, J. A., Jongbloed, A. W., & Verstegen, M. W. (2004). Dietary fiber stabilizes blood glucose and insulin levels and reduces physical activity in sows (Sus scrofa). *The Journal of Nutrition*, *134*(6), 1481-1486.

de Leeuw, J. A., Jongbloed, A. W., Spoolder, H. A. M., & Verstegen, M. W. A. (2005). Effects of hindgut fermentation of non-starch polysaccharides on the stability of blood glucose and insulin levels and physical activity in empty sows. *Livestock Production Science*, *96*(2-3), 165-174.

De Silva, A., & Bloom, S. R. (2012). Gut hormones and appetite control: a focus on PYY and GLP-1 as therapeutic targets in obesity. *Gut and liver, 6*(1), 10.

D'Eath, R. B., Tolkamp, B. J., Kyriazakis, I., & Lawrence, A. B. (2009). 'Freedom from hunger and preventing obesity: the animal welfare implications of reducing food quantity or quality. *Animal Behaviour*, *77*(2), 275-288.

Dégen, L., Halas, V., & Babinszky, L. (2007). Effect of dietary fibre on protein and fat digestibility and its consequences on diet formulation for growing and fattening pigs: A review. *Acta Agriculturae Scand Section A*, *57*(1), 1-9.

Delzenne, N. M., & Cani, P. D. (2005). A place for dietary fibre in the management of the metabolic syndrome. *Current Opinion in Clinical Nutrition & Metabolic Care*, *8*(6), 636-640.

Dierick, N. A., Vervaeke, I. J., Demeyer, D. I., & Decuypere, J. A. (1989). Approach to the energetic importance of fibre digestion in pigs. I. Importance of fermentation in the overall energy supply. *Animal Feed Science and Technology*, *23*(1-3), 141-167.

Dikeman, C. L., & Fahey Jr, G. C. (2006). Viscosity as related to dietary fiber: a review. *Critical Reviews in Food Science and Nutrition*, *46*(8), 649-663.

Dilger, R. N., Sands, J. S., Ragland, D., & Adeola, O. (2004). Digestibility of nitrogen and amino acids in soybean meal with added soyhulls. *Journal of Animal Science*, *82*(3), 715-724.

Drochner, W., & Coenen, M. (1986). Vegetable structural substances in pig nutrition. *Übers. Tierernährg* , *14* , 1-50.

Eastwood, M. A., Robertson, J. A., Brydon, W. G., & MacDonald, D. (1983). Measurement of water-holding properties of fibre and their faecal bulking ability in man. *British Journal of Nutrition*, *50*(3), 539-547.

Ettle, T., & Roth, F. X. (2004). Specific dietary selection for tryptophan by the piglet. *Journal of Animal Science*, *82*(4), 1115-1121.

FAO (2009). How to feed the world 2050: Global agriculture towards 2050. Rome: Food and Agriculture Organization of the United Nations (FAO). p. 12–3.

FAO, (2011). World Livestock 2011 – Livestock in Food Security. Food and Agriculture Organization of the United Nations (FAO), Rome.

FAO, (2014). Pigs and Animal Production. Food and Agriculture Organization of the United Nations. Available at: http://www.fao.org/ag/againfo/themes/en/pigs/production.html.

Fowler, V. R. (1985). The importance of voluntary feed intake in pigs. *Proceedings of the Nutrition Society*, *44*(2), 347-353.

Frost, G., Sleeth, M. L., Sahuri-Arisoylu, M., Lizarbe, B., Cerdan, S., Brody, L., Anastasovska, J., Ghourab, S., Hankir, M., Zhang, S., Carling, D., & Bell, J. D. (2014). The short-chain fatty acid acetate reduces appetite via a central homeostatic mechanism. *Nature Communications*, *5*(1), 1-11.

Fuller, M. F., Franklin, M. F., McWilliam, R., & Pennie, K. (1995). The responses of growing pigs, of different sex and genotype, to dietary energy and protein. *Animal Science*, *60*(2), 291-298.

Gao, L., Chen, L., Huang, Q., Meng, L., Zhong, R., Liu, C., ... & Zhang, H. (2015). Effect of dietary fiber type on intestinal nutrient digestibility and hindgut fermentation of diets fed to finishing pigs. *Livestock Science*, *174*, 53-58.

Georg Jensen, M., Pedersen, C., Kristensen, M., Frost, G., & Astrup, A. (2013). Efficacy of alginate supplementation in relation to appetite regulation and metabolic risk factors: evidence from animal and human studies. *Obesity Reviews*, *14*(2), 129-144.

Gerstein, D. E., Woodward-Lopez, G., Evans, A. E., Kelsey, K., & Drewnowski, A. (2004). Clarifying concepts about macronutrients' effects on satiation and satiety. *Journal of the American Dietetic Association*, *104*(7), 1151-1153.

Gill, B. P., Brooks, P. H., & Carpenter, J. L. (1986). The water intake of weaned pigs from 3 to 6 weeks of age. *Proceedings of the British Society of Animal Production (1972)*, *1986*, 125-125.

Girard, C. L., Robert, S., Matte, J. J., Farmer, C., & Martineau, G. P. (1995). Influence of high fibre diets given to gestating sows on serum concentrations of micronutrients. *Livestock Production Science*, *43*(1), 15-26.

Gloaguen, M., Le Floc'H, N., Brossard, L., Barea, R., Primot, Y., Corrent, E., & van Milgen, J. (2011). Response of piglets to the valine content in diet in combination with the supply of other branched-chain amino acids. *Animal*, *5*(11), 1734-1742.

Gonyou, H. W. (1999). Feeder and pen design to increase efficiency. Pages 103–113 *in* Advances in pork production. Vol. 10. *Banff Pork Seminar*.

Gonyou, H. W., Chapple, R. P., & Frank, G. R. (1992). Productivity, time budgets and social aspects of eating in pigs penned in groups of five or individually. *Applied Animal Behaviour Science*, *34*(4), 291-301.

Goodlad, R. A., Ratcliffe, B., Lee, C. Y., & Wright, N. A. (1995). Dietary fibre and the gastrointestinal tract: differing trophic effects on muscle and mucosa of the stomach, small intestine and colon. *European Journal of Clinical Nutrition*, *49*, S178-S181.

Graham, H., Hesselman, K., & Åman, P. (1986). The influence of wheat bran and sugar-beet pulp on the digestibility of dietary components in a cereal-based pig diet. *The Journal of Nutrition*, *116*(2), 242-251.

Grieshop, C. M., Reese, D. E., & Fahey Jr, G. C. (2001). Non-starch polysaccharides and oligosaccharides in swine nutrition. Pages 107–130 in *Swine Nutrition*. A. J. Lewis, and L. L. Southern eds. CRC Press, Boca Raton, FL.

Gu, Y., Schinckel, A. P., Forrest, J. C., Kuei, C. H., & Watkins, L. E. (1991). Effects of ractopamine, genotype, and growth phase on finishing performance and carcass value in swine: II. Estimation of lean growth rate and lean feed efficiency. *Journal of Animal Science*, *69*(7), 2694-2702.

Gutierrez, N. A., Kerr, B. J., & Patience, J. F. (2013). Effect of insoluble-low fermentable fiber from corn-ethanol distillation origin on energy, fiber, and amino acid digestibility, hindgut degradability of fiber, and growth performance of pigs. *Journal of Animal Science*, *91*(11), 5314-5325.

Han, Y. K., Thacker, P. A., & Yang, J. S. (2006). Effects of the duration of liquid feeding on performance and nutrient digestibility in weaned pigs. *Asian-Australasian Journal of Animal Sciences*, *19*(3), 396-401.

Hancock, J., & Behnke, K.C. (2001). Use of ingredient and diet processing technologies (grinding, mixing, pelleting, and extruding) to produce quality feeds for pigs. In: Lewis, A.J., Southern, L.L. (Eds.), *Swine Nutrition*., 2nd edition. CRC Press, Boca Raton, FL, USA, pp. 469–497.

Hanson, A. R., Wang, L., Johnston, L. J., Baidoo, S. K., Torrison, J. L., Chen, C., & Shurson, G. C. (2015). Effect of feeding peroxidized dried distillers' grains with solubles to sows and progeny on growth performance and metabolic oxidative status of nursery pigs. *Journal of Animal Science*, *93*(1), 135-146.

Harper, A.E. (1959). Amino acid balance and imbalance. *Journal of Nutrition*. 68, 405–418.

Hasan, M.R. (2007). Economics of aquaculture feeding practices in selected Asian countries. FAO Fisheries Technical Paper 505. FAO, Rome, Italy.

Henry, Y. (1979). Feed intake regulation for growth in the pig. *Wiss. Z. Wilhelm Pieck Univ., Restock*, *28*, 2-129.

Henry, Y. (1985). Dietary factors involved in feed intake regulation in growing pigs: a review. *Livestock Production Science*, *12*(4), 339-354.

Henry, Y. (1995). Effects of reduced dietary lysine level on voluntary feed intake and growth performance in finishing pigs. In *Annales de Zootechnie (France)*.

Higgins, J. A. (2004). Resistant starch: metabolic effects and potential health benefits. *Journal of AOAC International*, *87*(3), 761-768.

Ho, I. H., Matia-Merino, L., & Huffman, L. M. (2015). Use of viscous fibres in beverages for appetite control: a review of studies. *International Journal of Food Sciences and Nutrition*, *66*(5), 479-490.

Hoebler, C., Guillon, F., Darcy-Vrillon, B., Vaugelade, P., Lahaye, M., Worthington, E., ... & Barry, J. L. (2000). Supplementation of pig diet with algal fibre changes the chemical and physicochemical characteristics of digesta. *Journal of the Science of Food and Agriculture*, *80*(9), 1357-1364.

Högberg, A., & Lindberg, J. E. (2004). Influence of cereal non-starch polysaccharides on digestion site and gut environment in growing pigs. *Livestock Production Science*, *87*(2-3), 121-130.

Hopwood, D. E., Pethick, D. W., Pluske, J. R., & Hampson, D. J. (2004). Addition of pearl barley to a rice-based diet for newly weaned piglets increases the viscosity of the intestinal contents, reduces starch digestibility and exacerbates post-weaning colibacillosis. *British Journal of Nutrition*, *92*(3), 419-427.

House, J. (2003). In search of a magic bullet! Strategies for dealing with Fusarium-contaminated grains in the swine industry. In *Proceedings of the 2003 Manitoba Swine Seminar* (Vol. 17, pp. 133-144).

House, J. D., Abramson, D., Crow, G. H., & Nyachoti, C. M. (2002). Feed intake, growth and carcass parameters of swine consuming diets containing low levels of deoxynivalenol from naturally contaminated barley. *Canadian Journal of Animal Science*, *82*(4), 559-565.

Howarth, N. C., Saltzman, E., & Roberts, S. B. (2001). Dietary fiber and weight regulation. *Nutrition Reviews*, *59*(5), 129-139.

Hsia, L. C., & Wood-Gush, D. G. M. (1984). The temporal patterns of food intake and allelomimetic feeding by pigs of different ages. *Applied Animal Ethology*, *11*(3), 271-282.

Hyun, Y. (1997). *Nutritional and environmental factors affecting feed intake level and pattern in growing and finishing pigs*. University of Illinois at Urbana-Champaign.

Hyun, Y., Ellis, M., McKeith, F. K., & Wilson, E. R. (1997). Feed intake pattern of group-housed growing-finishing pigs monitored using a computerized feed intake recording system. *Journal of Animal Science*, *75*(6), 1443-1451.

Illius, A. W., & Gordon, I. J. (1987). The allometry of food intake in grazing ruminants. *The Journal of Animal Ecology*, 989-999.

Jarrett, S., & Ashworth, C. J. (2018). The role of dietary fibre in pig production, with a particular emphasis on reproduction. *Journal of Animal Science and Biotechnology*, *9*(1), 1-11.

Jenkins, D. J., Jenkins, A. L., Wolever, T. M., Collier, G. R., Rao, A. V., & Thompson, L. U. (1987). Starchy foods and fiber: reduced rate of digestion and improved carbohydrate metabolism. *Scandinavian Journal of Gastroenterology*, *22*(sup129), 132-141.

Jensen, G.M, Kristensen, M., Belza, A., Knudsen, J. C., & Astrup, A. (2012). Acute effect of alginate-based preload on satiety feelings, energy intake, and gastric emptying rate in healthy subjects. *Obesity*, *20*(9), 1851-1858.

Jin, L., Reynolds, L. P., Redmer, D. A., Caton, J. S., & Crenshaw, J. D. (1994). Effects of dietary fiber on intestinal growth, cell proliferation, and morphology in growing pigs. *Journal of Animal Science*, *72*(9), 2270-2278.

Johansen, H. N., Knudsen, K. B., Sandström, B., & Skjøth, F. (1996). Effects of varying content of soluble dietary fibre from wheat flour and oat milling fractions on gastric emptying in pigs. *British Journal of Nutrition*, *75*(3), 339-351.

Jondreville, C., & Dourmad, J. Y. (2005). Phosphorus in pig nutrition. *INRA Production Animal*, *18*, 183-192.

Jørgensen, H., Lindberg, J. E., & Andersson, C. (1997). Diurnal variation in the composition of ileal digesta and the ileal digestibilities of nutrients in growing pigs. *Journal of the Science of Food and Agriculture*, *74*(2), 244-250.

Jørgensen, H., Zhao, X. Q., & Eggum, B. O. (1996). The influence of dietary fibre and environmental temperature on the development of the gastrointestinal tract, digestibility, degree of fermentation in the hind-gut and energy metabolism in pigs. *British Journal of Nutrition*, *75*(3), 365-378.

Kallabis, K. E., & Kaufmann, O. (2012). Effect of a high-fibre diet on the feeding behaviour of fattening pigs. *Archives Animal Breeding*, *55*(3), 272-284.

Kanis, E. G. B. E. R. T., & Koops, W. J. (1990). Daily gain, food intake and food efficiency in pigs during the growing period. *Animal Science*, *50*(2), 353-364.

Khokhar, S. (1994). Dietary fibers: their effects on intestinal digestive enzyme activities. *The Journal of Nutritional Biochemistry*, *5*(4), 176-180.

Kil, D. Y., Sauber, T. E., Jones, D. B., & Stein, H. H. (2010). Effect of the form of dietary fat and the concentration of dietary neutral detergent fiber on ileal and total tract endogenous losses and apparent and true digestibility of fat by growing pigs. *Journal of Animal Science*, *88*(9), 2959-2967.

Kim, B. G., Lindemann, M. D., Cromwell, G. L., Balfagon, A., & Agudelo, J. H. (2007). The correlation between passage rate of digesta and dry matter digestibility in various stages of swine. *Livestock Science*, *109*(1-3), 81-84.

Kim, J. H., Heo, K. N., Odle, J., Han, I. K., & Harrell, R. J. (2001). Liquid diets accelerate the growth of early-weaned pigs and the effects are maintained to market weight. *Journal of Animal Science*, *79*(2), 427-434.

Knap, P. W. (2009). Voluntary feed intake and pig breeding. Voluntary feed intake in pigs. *Wageningen Academic Publisher, Wageningen*, 13-31.

Knudsen, K. E. B. (2001). The nutritional significance of "dietary fibre" analysis. *Animal Feed Science and Technology*, *90*(1-2), 3-20.

Knudsen, K. E. B. (2011). Triennial growth symposium: effects of polymeric carbohydrates on growth and development in pigs. *Journal of Animal Science*, *89*(7), 1965-1980.

Knudsen, K. E. B., & Hansen, I. (1991). Gastrointestinal implications in pigs of wheat and oat fractions: 1. Digestibility and bulking properties of polysaccharides and other major constituents. *British Journal of Nutrition*, *65*(2), 217-232.

Knudsen, K. E. B., Hedemann, M. S., & Lærke, H. N. (2012). The role of carbohydrates in intestinal health of pigs. *Animal Feed Science and Technology*, *173*(1-2), 41-53.

Knudsen, K. E. B., Jensen, B. B., & Hansen, I. (1993). Digestion of polysaccharides and other major components in the small and large intestine of pigs fed on diets consisting of oat fractions rich in β-D-glucan. *British Journal of Nutrition*, *70*(2), 537-556.

Kristensen, M., & Jensen, M. G. (2011). Dietary fibres in the regulation of appetite and food intake. Importance of viscosity. *Appetite*, *56*(1), 65-70.

Kumar, V., Sinha, A. K., Makkar, H. P., de Boeck, G., & Becker, K. (2012). Dietary roles of non-starch polysachharides in human nutrition: a review. *Critical Reviews in Food Science and Nutrition*, *52*(10), 899-935.

Kyriazakis, I., & Emmans, G. C. (1995). The voluntary feed intake of pigs given feeds based on wheat bran, dried citrus pulp and grass meal, in relation to measurements of feed bulk. *British Journal of Nutrition*, *73*(2), 191-207.

Kyriazakis, I., & Emmans, G. C. (1995). The voluntary feed intake of pigs given feeds based on wheat bran, dried citrus pulp and grass meal in relation to measurements of feed bulk. *British Journal of Nutrition*, *73*(2), 191-207.

Labroue, F., Guéblez, R., Marion, M., & Sellier, P. (1995). Influence of breed on the feeding behavior of growing pigs reared in groups. *Journal of Pig Research, France*, *27* , 175-182.

Labroue, F., Guéblez, R., Sellier, P., & Meunier-Salaün, M. C. (1994). Feeding behaviour of group-housed Large White and Landrace pigs in French central test stations. *Livestock Production Science*, *40*(3), 303-312.

Laitat, M., Antoine, N., Cabaraux, J. F., Cassart, D., Mainil, J., Moula, N., Nicks, B., Wavreille, J., & Philippe, F. X. (2015). Influence of sugar beet pulp on feeding behavior, growth performance, carcass quality and gut health of fattening pigs. *Society of Biotechnology, Agronomy and Environment*, *19*(1), 20-31.

Langhans, W. (1999). Appetite regulation. In: Lobley, G.E., White, A., MacRae, J.C. (Eds.), Protein Metabolism and Nutrition, EAAP publication no. 96, Wageningen Pers., The Netherlands, 225–252.

Langlois, A., Corring, T., & Fevrier, C. (1987). Effects of wheat bran on exocrine pancreas secretion in the pig. *Reproduction Nutrition Development*, *27*(5), 929-939.

Laurinen, P., Siljander-Rasi, H., Karhunen, J., Alaviuhkola, T., Näsi, M., & Tuppi, K. (2000). Effects of different grinding methods and particle size of barley and wheat on pig performance and digestibility. *Animal Feed Science and Technology*, *83*(1), 1-16.

Le Bellego, L., & Noblet, J. (2002). Performance and utilization of dietary energy and amino acids in piglets fed low protein diets. *Livestock Production Science*, *76*(1-2), 45-58.

Le Dividich, J., Noblet, J., & Bikawa, T. (1987). Effect of environmental temperature and dietary energy concentration on the performance and carcass characteristics of growing-finishing pigs fed to equal rate of gain. *Livestock Production Science*, *17*, 235-246.

Le Gall, M., Warpechowski, M., Jaguelin-Peyraud, Y., & Noblet, J. (2009). Influence of dietary fibre level and pelleting on the digestibility of energy and nutrients in growing pigs and adult sows. *Animal: An International Journal of Animal Bioscience, 3*(3), 352.

Le Goff, G., & Noblet, J. (2001). Comparative total tract digestibility of dietary energy and nutrients in growing pigs and adult sows. *Journal of Animal Science*, *79*(9), 2418-2427.

Le Goff, G., van Milgen, J., & Noblet, J. (2002). Influence of dietary fibre on digestive utilization and rate of passage in growing pigs, finishing pigs and adult sows. *Animal Science*, *74*(3), 503-515.

Lee, B. H., Bello-Pérez, L. A., Lin, A. H. M., Kim, C. Y., & Hamaker, B. R. (2013). Importance of location of digestion and colonic fermentation of starch related to its quality. *Cereal Chemistry*, *90*(4), 335-343.

Li, Q., & Patience, J. F. (2017). Factors involved in the regulation of feed and energy intake of pigs. *Animal Feed Science and Technology*, *233*, 22-33.

Lindberg, J. E. (2014). Fiber effects in nutrition and gut health in pigs. *Journal of Animal Science and Biotechnology*, *5*(1), 1-7.

Lobley, G. E., Milne, V., Lovie, J. M., Reeds, P. J., & Pennie, K. (1980). Whole body and tissue protein synthesis in cattle. *British Journal of Nutrition*, *43*(3), 491-502.

Low, A. G. (1989). Secretory response of the pig gut to non-starch polysaccharides. *Animal Feed Science and Technology*, *23*(1-3), 55-65.

Lucas, J.S., & Southgate, P.C. (2012). Farming aquatic animals and plants. John Wiley and Sons, Chichester, UK, 648 pp.

Lunn, J., & Buttriss, J. L. (2007). Carbohydrates and dietary fibre. *Nutrition Bulletin*, *32*(1), 21-64.

Makkar, H. P. S., Tran, G., Henze, V., & Ankers, P. (2014). State-of-the-art on use of insects as animal feed. *Animal Feed Science and Technology*, *197*, 1-33. 10.1016.

Marciani, L., Gowland, P. A., Spiller, R. C., Manoj, P., Moore, R. J., Young, P., & Fillery-Travis, A. J. (2001). Effect of meal viscosity and nutrients on satiety, intragastric dilution, and emptying assessed by MRI. *American Journal of Physiology-Gastrointestinal and Liver Physiology*, *280*(6), G1227-G1233.

Mateos, G. G., Martin, F., Latorre, M. A., Vicente, B., & Lazaro, R. (2006). Inclusion of oat hulls in diets for young pigs based on cooked maize or cooked rice. *Animal Science*, *82*(1), 57-63.

Mavromichalis, I., Hancock, J. D., Senne, B. W., Gugle, T. L., Kennedy, G. A., Hines, R. H., & Wyatt, C. L. (2000). Enzyme supplementation and particle size of wheat in diets for nursery and finishing pigs. *Journal of Animal Science*, *78*(12), 3086-3095.

McCann, M. C., & Roberts, K. (1991). Architecture of the primary cell wall. In '*The Cytoskeletal Basis of Plant Growth and Form*'.(Ed. CW Lloyd) pp. 109–129.

McDougall, G. J., Morrison, I. M., Stewart, D., & Hillman, J. R. (1996). Plant cell walls as dietary fibre: range, structure, processing and function. *Journal of the Science of Food and Agriculture*, *70*(2), 133-150.

McLeese, J. M., Tremblay, M. L., Patience, J. F., & Christison, G. I. (1992). Water intake patterns in the weanling pig: effect of water quality, antibiotics and probiotics. *Animal Science*, *54*(1), 135-142.

McNeilage, E. M. (1999). Effects of feed enzyme and feeding regimens on growth, digestibility, organ weight, and meat quality in finishing pigs. MSc. Thesis, *University of Guelph, Guelph, ON.*

Mertens, D. R. (2003). Challenges in measuring insoluble dietary fiber. *Journal of Animal Science*, *81*(12), 3233-3249.

Metzler, B. U., & Mosenthin, R. (2008). A review of interactions between dietary fiber and the gastrointestinal microbiota and their consequences on intestinal phosphorus metabolism in growing pigs. *Asian-Australasian Journal of Animal Sciences*, *21*(4), 603-615.

Meunier-Salaün, M. C., Edwards, S. A., & Robert, S. (2001). Effect of dietary fibre on the behaviour and health of the restricted fed sow. *Animal Feed Science and Technology*, *90*(1-2), 53-69.

Michel, P., & Rérat, A. (1998). Effect of adding sugar beet fibre and wheat bran to a starch diet on the absorption kinetics of glucose, amino-nitrogen and volatile fatty acids in the pig. *Reproduction Nutrition Development*, *38*(1), 49-68.

Missotten, J.A.M. (2010). Fermented Liquid Feed for Piglets. Ghent University, Ghent, Belgium.

Montagné, L., Piel, C., & Lallès, J. P. (2004). Effect of diet on mucin kinetics and composition: nutrition and health implications. *Nutrition Reviews*, *62*(3), 105-114.

Montagne, L., Pluske, J. R., & Hampson, D. J. (2003). A review of interactions between dietary fibre and the intestinal mucosa, and their consequences on digestive health in young non-ruminant animals. *Animal Feed Science and Technology*, *108*(1-4), 95-117.

Moore, R. J., Kornegay, E. T., Grayson, R. L., & Lindemann, M. D. (1988). Growth, nutrient utilization and intestinal morphology of pigs fed high-fiber diets. *Journal of Animal Science*, *66*(6), 1570-1579.

Mosenthin, R., Sauer, W. C., & Ahrens, F. (1994). Dietary pectin's effect on ileal and fecal amino acid digestibility and exocrine pancreatic secretions in growing pigs. *The Journal of Nutrition*, *124*(8), 1222-1229.

Mount, L. E., Holmes, C. W., Close, W. H., Morrison, S. R., & Start, I. B. (1971). A note on the consumption of water by the growing pig at several environmental temperatures and levels of feeding. *Animal Science*, *13*(3), 561-563.

Naatjes, M., Htoo, J. K., Walter, K., Tölle, K. H., & Susenbeth, A. (2014). Effect of dietary tryptophan to lysine ratio on growth of young pigs fed wheat–barley or corn based diets. *Livestock Science*, *163*, 102-109.

National Research Council, (NRC). (1998). *Nutrient requirements of swine*. 10th ed. National Academy Press, Washington, DC.

National Research Council, (NRC). (2012). *Nutrient requirements of swine*. National Academies Press.

Ndou, S. P., Gous, R. M., & Chimonyo, M. (2013). Prediction of scaled feed intake in weaner pigs using physico-chemical properties of fibrous feeds. *British Journal of Nutrition*, *110*(4), 774-780.

Nielsen, B. L. (1999). On the interpretation of feeding behaviour measures and the use of feeding rate as an indicator of social constraint. *Applied Animal Behaviour Science*, *63*(1), 79-91.

Nielsen, B. L., Lawrence, A. B., & Whittemore, C. T. (1995). Effect of group size on feeding behaviour, social behaviour, and performance of growing pigs using single-space feeders. *Livestock Production Science*, *44*(1), 73-85.

Nienaber, J. A., & Leroy Hahn, G. (1984). Effects of water flow restriction and environmental factors on performance of nursery-age pigs. *Journal of Animal Science*, *59*(6), 1423-1429.

Noblet, J., & Knudsen, KB (1997, May). Comparative digestibility of wheat, maize and sugar beet pulp non-starch polysaccharides in adult sows and growing pigs. In *7. International Symposium* (No. 88). EAAP.

Noblet, J., & Le Goff, G. (2001). Effect of dietary fibre on the energy value of feeds for pigs. *Animal Feed Science and Technology*, *90*(1-2), 35-52.

Noblet, J., & Shi, X. S. (1993). Comparative digestibility of energy and nutrients in growing pigs fed ad libitum and adults sows fed at maintenance. *Livestock Production Science*, *34*(1-2), 137-152.

Nørgaard, J. V., Pedersen, T. F., Soumeh, E. A., Blaabjerg, K., Canibe, N., Jensen, B. B., & Poulsen, H. D. (2015). Optimum standardized ileal digestible tryptophan to lysine ratio for pigs weighing 7–14 kg. *Livestock Science*, *175*, 90-95.

Nyachoti, C. M., & Patience, J. F. (2003). Impact of water quality on poultry and pork production. Presented at a Symposium on Livestock Production and Water Resources: Impacts and Implications at the 2003 Annual Meeting of the *Canadian Society of Animal Science*, Saskatoon, SK.

Nyachoti, C. M., De Lange, C. F. M., McBride, B. W., Leeson, S., & Schulze, H. (2000). Dietary influence on organ size and in vitro oxygen consumption by visceral organs of growing pigs. *Livestock Production Science*, *65*(3), 229-237.

Nyachoti, C. M., Lange, C. D., McBride, B. W., & Schulze, H. (1997). Significance of endogenous gut nitrogen losses in the nutrition of growing pigs: A review. *Canadian Journal of Animal Science*, *77*(1), 149-163.

Nyachoti, C. M., Zijlstra, R. T., De Lange, C. F. M., & Patience, J. F. (2004). Voluntary feed intake in growing-finishing pigs: A review of the main determining factors and potential approaches for accurate predictions. *Canadian Journal of Animal Science*, *84*(4), 549-566.

Oakenfull, D. (2001). Physical chemistry of dietary fiber. Pages 33–47 in *Dietary Fiber in Human Nutrition*. 3rd ed. G. A. Spiller, ed. CRC Press, Boca Raton, FL.

Oresanya, T. F., Beaulieu, A. D., Beltranena, E., & Patience, J. F. (2007). The effect of dietary energy concentration and total lysine/digestible energy ratio on the growth performance of weaned pigs. *Canadian Journal of Animal Science*, *87*(1), 45-55.

Owen, J. B., & Ridgman, W. J. (1967). The effect of dietary energy content on the voluntary intake of pigs. *Animal Science*, *9*(1), 107-113.

Owusu-Asiedu, A. J. F. J., Patience, J. F., Laarveld, B., Van Kessel, A. G., Simmins, P. H., & Zijlstra, R. T. (2006). Effects of guar gum and cellulose on digesta passage rate, ileal microbial populations, energy and protein digestibility, and performance of grower pigs. *Journal of Animal Science*, *84*(4), 843-852.

Paintal, A. S. (1954). A study of gastric stretch receptors. Their role in the peripheral mechanism of satiation of hunger and thirst. *The Journal of Physiology*, *126*(2), 255.

Patience, J. F., & Petry, A. L. (2019). Chapter 5 - Susceptibility of fibre to exogenous carbohydrases and impact on performance in swine. In *The Value of Fibre: Engaging the Second Brain for Animal Nutrition* (pp. 99-115). Wageningen Academic Publishers.

Patience, J. F., Thacker, P. A., & de Lange, C. F. M. (1995). Swine Nutrition Guide. Prairie Swine Centre. *Inc., University of Saskatchewan, Saskatoon*.

Pereira, M. A., & Ludwig, D. S. (2001). Dietary fiber and body-weight regulation: observations and mechanisms. *Pediatric Clinics of North America*, *48*(4), 969-980.

Pérez, J. F., & Roura, E. (2017). Modulation of feed intake in pigs and chickens: Preface. *Animal Feed Science and Technology*, *233*, 1-2.

Pond, W. G., Varel, V. H., Dickson, J. S., & Haschek, W. M. (1989). Comparative response of swine and rats to high-fiber or high-protein diets. *Journal of Animal Science*, *67*(3), 716-723.

Prosky, L., Asp, G. N., Furda, I., de Vries, J.W., Schweizer, T.F., & Harland, B.F. (1984). Determination of total dietary fibre in foods, food products, and total diets: Interlaboratory study. *Journal of Association of Analytical Chemistry*. 67:1044–1052.

Quiniou, N., Dubois, S., & Noblet, J. (2000). Voluntary feed intake and feeding behaviour of group-housed growing pigs are affected by ambient temperature and body weight. *Livestock Production Science*, *63*(3), 245-253.

Quiniou, N., Dubois, S., Le Cozler, Y., Bernier, J. F., & Noblet, J. (1999). Effect of growth potential (body weight and breed/castration combination) on the feeding behaviour of individually kept growing pigs. *Livestock Production Science*, *61*(1), 13-22.

Ramonet, Y., Meunier-Salaün, M. C., & Dourmad, J. Y. (1999). High-fiber diets in pregnant sows: digestive utilization and effects on the behavior of the animals. *Journal of Animal Science*, *77*(3), 591-599.

Ramonet, Y., Robert, S., Aumaitre, A., Dourmad, J. Y., & Meunier-Salaün, M. C. (2000). Influence of the nature of dietary fibre on digestive utilization, some metabolite and hormone profiles and the behaviour of pregnant sows. *Animal Science*, *70*(2), 275-286.

Ratanpaul, V., Williams, B. A., Black, J. L., & Gidley, M. J. (2019). Effects of fibre, grain starch digestion rate and the ileal brake on voluntary feed intake in pigs. *Animal*, *13*(11), 2745-2754.

Renaudeau, D., Weisbecker, J. L., & Noblet, J. (2003). Effect of season and dietary fibre on feeding behaviour of lactating sows in a tropical climate. *Animal Science*, *77*(3), 429-437.

Revell, D. K., & Williams, I. H. (1993). A review-Physiological control and manipulation of voluntary food intake. In *Manipulating Pig Production IV* (pp. 55-80). Australasian Pig Science Association.

Rijnen, M. M. J. A., Heetkamp, M. J. W., Verstegen, M. W. A., & Schrama, J. W. (1999). Effects of dietary fermentable carbohydrates on physical activity and energy metabolism in group-housed sows. *Journal of Animal Science*, *77*(suppl. 1), 182-182.

Rinaldo, D., & Le Dividich, J. (1991). Assessment of optimal temperature for performance and chemical body composition of growing pigs. *Livestock Production Science*, *29*(1), 61-75.

Robert, S., Bergeron, R., Farmer, C., & Meunier-Salaün, M. C. (2002). Does the number of daily meals affect feeding motivation and behaviour of gilts fed high-fibre diets? *Applied Animal Behaviour Science*, *76*(2), 105-117.

Robert, S., Matte, J. J., Farmer, C., Girard, C. L., & Martineau, G. P. (1993). High-fibre diets for sows: effects on stereotypies and adjunctive drinking. *Applied Animal Behaviour Science*, *37*(4), 297-309.

Robert, S., Rushen, J., & Farmer, C. (1997). Both energy content and bulk of food affect stereotypic behaviour, heart rate and feeding motivation of female pigs. *Applied Animal Behaviour Science*, *54*(2-3), 161-171.

Robertson, J. A., de Monredon, F. D., Dysseler, P., Guillon, F., Amado, R., & Thibault, J. F. (2000). Hydration properties of dietary fibre and resistant starch: a European collaborative study. *LWT-Food Science and Technology*, *33*(2), 72-79.

Robinson, D. W. (1975). Food intake regulation in pigs. IV. The influence of dietary threonine imbalance on food intake, dietary choice and plasma acid patterns. *British Veterinary Journal*, *131*(5), 595-600.

Rolls, E. T., & Rolls, J. H. (1997). Olfactory sensory-specific satiety in humans. *Physiology & Behavior*, *61*(3), 461-473.

SAS. (2016). SAS/STAT® User's Guide, Version 9.4. SAS Institute Incorporated., Cary, North Carolina.

Schiavone, A., De Marco, M., Martínez, S., Dabbou, S., Renna, M., Madrid, J., Hernandez, F., Rotolo, L., Costa, P., Ga, F., & Gasco, L. (2017). Nutritional value of a partially defatted and a highly defatted black soldier fly larvae (Hermetia illucens L.) meal for broiler chickens: apparent nutrient digestibility, apparent metabolizable energy and apparent ileal amino acid digestibility. *Journal of Animal Science and Biotechnology*, *8*(1), 1-9.

Schneeman, B. O., & Gallaher, D. (1985). Effects of dietary fiber on digestive enzyme activity and bile acids in the small intestine. *Proceedings of the Society for Experimental Biology and Medicine*, *180*(3), 409-414.

Schrama, J. W., Bosch, M. W., Verstegen, M. W. A., Vorselaars, A. H. P. M., Haaksma, J., & Heetkamp, M. J. W. (1998). The energetic value of nonstarch polysaccharides in relation to physical activity in group-housed, growing pigs. *Journal of Animal Science*, *76*(12), 3016-3023.

Schulze, H., Van Leeuwen, P., Verstegen, M. W. A., Huisman, J., Souffrant, W. B., & Ahrens, F. (1994). Effect of level of dietary neutral detergent fiber on ileal apparent digestibility and ileal nitrogen losses in pigs. *Journal of Animal Science*, *72*(9), 2362-2368.

Serena, A., Hedemann, M. S., & Bach Knudsen, K. E. (2008). Influence of dietary fiber on luminal environment and morphology in the small and large intestine of sows. *Journal of Animal Science*, *86*(9), 2217-2227.

Serena, A., Jørgensen, H., & Bach Knudsen, K. E. (2009). Absorption of carbohydrate-derived nutrients in sows as influenced by types and contents of dietary fiber. *Journal of Animal Science*, *87*(1), 136-147.

Shi, X. S., & Noblet, J. (1993). Contribution of the hindgut to digestion of diets in growing pigs and adult sows: effect of diet composition. *Livestock Production Science*, *34*(3-4), 237-252.

Slavin, J., & Green, H. (2007). Dietary fibre and satiety. *Nutrition Bulletin*, *32*, 32-42.

Slavin, J.L. (2010). Dietary fibre and satiety—not all fibre is alike. In: Williams PA, Phillips GO, editors. Gums and Stabilisers for the Food Industry 15: *Proceedings of the 15th Gums and Stabilisers for the Food Industry Conference*; 2009 Jun 22–26;Wrexham, United Kingdom. Cambridge: Royal Society of Chemistry; p. 333.

Sleeth, M. L., Thompson, E. L., Ford, H. E., Zac-Varghese, S. E., & Frost, G. (2010). Free fatty acid receptor 2 and nutrient sensing: a proposed role for fibre, fermentable carbohydrates and short-chain fatty acids in appetite regulation. *Nutrition Research Reviews*, *23*(1), 135-145.

Souffrant, W. B. (2001). Effect of dietary fibre on ileal digestibility and endogenous nitrogen losses in the pig. *Animal Feed Science and Technology*, *90*(1-2), 93-102.

Stanogias, G., & Pearcet, G. R. (1985). The digestion of fibre by pigs: 1. The effects of amount and type of fibre on apparent digestibility, nitrogen balance and rate of passage. *British Journal of Nutrition*, *53*(3), 513-530.

Stark, A., Nyska, A., Zuckerman, A., & Madar, Z. (1995). Changes in intestinal tunica muscularis following dietary fiber feeding in rats. *Digestive Diseases and Sciences*, *40*(5), 960-966.

Stein, H. H., & Shurson, G. C. (2009). Board-invited review: The use and application of distillers dried grains with solubles in swine diets. *Journal of Animal Science*, *87*(4), 1292-1303.

Stephen, A. M., & Cummings, J. H. (1979). Water holding by dietary fibre in vitro and its relationship to faecal bulking in man. *The Proceedings of the Nutrition Society*, *38*(2), 55A-55A.

Story, J. A. (1985). Dietary fiber and lipid metabolism. *Proceedings of the Society for Experimental Biology and Medicine*, *180*(3), 447-452.

Svihus, B., & Hervik, A. K. (2019). Chapter 7 The influence of fibre on gut physiology and feed intake regulation. In *The Value of Fibre: Engaging the Second Brain for Animal Nutrition* (pp. 683-689). Wageningen Academic Publishers.

Swanepoel, F. J. C., Stroebel, A., & Moyo, S. (2010). The role of livestock in developing communities: Enhancing multifunctionality. University of the Free State/CTA.

Tabeling, R., Schwier, S., & Kamphues, J. (2003). Effects of different feeding and housing conditions on dry matter content and consistency of faeces in sows. *Journal of Animal Physiology and Animal Nutrition*, *87*(3-4), 116-121.

Takahashi, T., & Sakata, T. (2002). Large particles increase viscosity and yield stress of pig cecal contents without changing basic viscoelastic properties. *The Journal of Nutrition*, *132*(5), 1026-1030.

Takahashi, T., Furuichi, Y., Mizuno, T., Kato, M., Tabara, A., Kawada, Y., Hirano, Y., Kubo, K., Onozuka, M., & Kurita, O. (2009). Water-holding capacity of insoluble fibre decreases free water and elevates digesta viscosity in the rat. *Journal of the Science of Food and Agriculture*, *89*(2), 245-250.

Terlouw, E. M. C., Lawrence, A. B., & Illius, A. W. (1991). Influences of feeding level and physical restriction on development of stereotypies in sows. *Animal Behaviour*, *42*(6), 981-991.

Thacker, P. A. (2001). Water in swine nutrition. Pages 381–398 *in* A. J. Lewis and L. L. Southern, ed. *Swine nutrition*. 2nd ed. CRC Press, New York, NY.

Theander, O., Åman, P., Westerlund, E., & Graham, H. (1994). Enzymatic/chemical analysis of dietary fiber. *Journal of AOAC International*, *77*(3), 703-709.

Thibault, J. F., Lahaye, M., & Guillon, F. (1992). Physico-chemical properties of food plant cell walls. In *Dietary Fibre—a Component of Food* (pp. 21-39). Springer, London.

Tolhurst, G., Heffron, H., Lam, Y. S., Parker, H. E., Habib, A. M., Diakogiannaki, E., Cameron, J., Grosse, J., Reimann, F., & Gribble, F. M. (2012). Short-chain fatty acids stimulate glucagon-like peptide-1 secretion via the G-protein–coupled receptor FFAR2. *Diabetes*, *61*(2), 364-371.

Torrallardona, D., & Roura, E. (2009). Voluntary feed intake in pigs. Wageningen Academic Publishers, Wageningen, The Netherlands.

Urriola, P. E., & Stein, H. H. (2010). Effects of distillers dried grains with solubles on amino acid, energy, and fiber digestibility and on hindgut fermentation of dietary fiber in a corn-soybean meal diet fed to growing pigs. *Journal of Animal Science*, *88*(4), 1454-1462.

Urriola, P. E., Cervantes-Pahm, S. K., & Stein, H. H. (2012). 11 Fiber in Swine Nutrition. *Sustainable Swine Nutrition*.

USDA, (2016). USDA Agricultural Projections to 2025. Available at: http://www.usda.gov/oce/commodity/projections.

Van der Meulen, J., & Bakker, J. G. M. (1991). Effect of various sources of dietary fibre on chemico-physical characteristics of digesta in the stomach and the small intestine of the pig. *Digestive Physiology in Pigs (Ed. MWA Verstegen, J. Huisman and LA den Hartog). Pudoc Wageningen. Netherlands*, 440-445.

Van Huis, A. (2013). Potential of insects as food and feed in assuring food security. *Annual Review of Entomology*, *58*, 563-583.

Van Soest, P. V., & Wine, R. H. (1967). Use of detergents in the analysis of fibrous feeds. IV. Determination of plant cell-wall constituents. *Journal of the Association of Official Analytical Chemists*, *50*(1), 50-55.

Van Soest, P. V., Robertson, J. B., & Lewis, B. A. (1991). Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science*, *74*(10), 3583-3597.

Van Soest, P.J. (1963). Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fibre and lignin.

Vanhoof, K., & De Schrijver, R. (1996). Availability of minerals in rats and pigs fed non-purified diets containing inulin. *Nutrition Research*, *16*(6), 1017-1022.

Varel, V. H., & Yen, J. T. (1997). Microbial perspective on fiber utilization by swine. *Journal of Animal Science*, *75*(10), 2715-2722.

Veldkamp, T., & Bosch, G. (2015). Insects: a protein-rich feed ingredient in pig and poultry diets. *Animal Frontiers*, *5*(2), 45-50.

Vicente, B., Valencia, D. G., Pérez-Serrano, M., Lázaro, R., & Mateos, G. G. (2008). The effects of feeding rice in substitution of corn and the degree of starch gelatinization of rice on the digestibility of dietary components and productive performance of young pigs. *Journal of Animal Science*, *86*(1), 119-126.

Wanders, A. J., van den Borne, J. J., de Graaf, C., Hulshof, T., Jonathan, M. C., Kristensen, M., Mars, M., Schols, H.A., & Feskens, E. J. (2011). Effects of dietary fibre on subjective appetite, energy intake and body weight: a systematic review of randomized controlled trials. *Obesity Reviews*, *12*(9), 724-739.

Webb, A. J. (1989)**.** Genetics of food intake in the pig. Pages 41–50 in J. M. Forbes, M. A. Varley, and T. L. J. Lawrence, eds. The voluntary feed intake of pigs. *Proceedings of the British Society of Animal Production*, Edinburgh, UK.

Wenk, C. (2001). The role of dietary fibre in the digestive physiology of the pig. *Animal Feed Science and Technology*, *90*(1-2), 21-33.

Whittemore, C. (1998). *The Science and Practice of Pig Production* (No. Ed. 2). Blackwell Science Ltd.

Whittemore, E. C., Emmans, G. C., & Kyriazakis, I. (2003). The relationship between live weight and the intake of bulky foods in pigs. *Animal Science*, *76*(1), 89-100.

Whittemore, E. C., Kyriazakis, I., Tolkamp, B. J., & Emmans, G. C. (2002). The short-term feeding behavior of growing pigs fed foods differing in bulk content. *Physiology & Behavior*, *76*(1), 131-141.

Wilfart, A., Montagne, L., Simmins, H., Noblet, J., & van Milgen, J. (2007a). Digesta transit in different segments of the gastrointestinal tract of pigs as affected by insoluble fibre supplied by wheat bran. *British Journal of Nutrition*, *98*(1), 54-62.

Wilfart, A., Montagné, L., Simmins, P. H., van Milgen, J., & Noblet, J. (2007b). Sites of nutrient digestion in growing pigs: Effect of dietary fiber. *Journal of Animal Science*, *85*(4), 976-983.

Williams, K. C., & Blaney, B. J. (1994). Effect of the mycotoxins, nivalenol and zearalenone, in maize naturally infected with Fusarium graminearum on the performance of growing and pregnant pigs. *Australian Journal of Agricultural Research*, *45*(6), 1265-1279.

Williams, N. H., Stahly, T. S., & Zimmerman, D. R. (1997). Effect of level of chronic immune system activation on the growth and dietary lysine needs of pigs fed from 6 to 112 kg. *Journal of Animal Science*, *75*(9), 2481-2496.

Wondra, K. J., Hancock, J. D., Behnke, K. C., & Stark, C. R. (1995b). Effects of mill type and particle size uniformity on growth performance, nutrient digestibility, and stomach morphology in finishing pigs. *Journal of Animal Science, 73*(9), 2564-2573.

Wondra, K. J., Hancock, J. D., Behnke, K. C., Hines, R. H., & Stark, C. R. (1995a). Effects of particle size and pelleting on growth performance, nutrient digestibility, and stomach morphology in finishing pigs. *Journal of Animal Science*, *73*(3), 757-763.

Woyengo, T. A., Beltranena, E., & Zijlstra, R. T. (2014). Nonruminant nutrition symposium: Controlling feed cost by including alternative ingredients into pig diets: A review. *Journal of Animal Science*, *92*(4), 1293-1305.

Yen, J. T. (1997). Oxygen consumption and energy flux of porcine splanchnic tissues. In *Digestive physiology in pigs: proceedings of the VIIth International Symposium on Digestive Physiology in Pigs*. Saint Malo, France: Institut National de la Recherche Agronomique.

Yen, J. T., Nienaber, J. A., Hill, D. A., & Pond, W. G. (1989). Oxygen consumption by portal vein-drained organs and by whole animal in conscious growing swine. *Proceedings of the Society for Experimental Biology and Medicine*, *190*(4), 393-398.

Young, R. J., & Lawrence, A. B. (1994). Feeding behaviour of pigs in groups monitored by a computerized feeding system. *Animal Science*, *58*(1), 145-152.

Zaczek, V., Jones, E. K. M., Macleod, M. G., & Hocking, P. M. (2003). Dietary fibre improves the welfare of female broiler breeders. *British Poultry Science, 44*(S1), 30-31.

Zebrowska, T. (1985). The influence of the level and source of fibre in the diet on the exocrine pancreatic secretion in growing pigs. *Beretning fra Statens Husdyrbrugsforsoeg (Denmark)*.

Zebrowska, T., Low, A. G., & Zebrowska, H. (1983). Studies on gastric digestion of protein and carbohydrate, gastric secretion and exocrine pancreatic secretion in the growing pig. *British Journal of Nutrition*, *49*(3), 401-410.

Zhou, J., Hegsted, M., McCutcheon, K. L., Keenan, M. J., Xi, X., Raggio, A. M., & Martin, R. J. (2006). Peptide YY and proglucagon mRNA expression patterns and regulation in the gut. *Obesity*, *14*(4), 683-689.

Zijlstra, R. T., Ekpe, E. D., Casano, M. N., & Patience, J. F. (2001). Variation in nutritional value of western Canadian feed ingredients for pigs. In *Proceedings. 22nd Western Nutrition Conference., Saskatoon*, *SK* (pp. 12-24).

Zijlstra, R. T., Lange, C. D., & Patience, J. F. (1999). Nutritional value of wheat for growing pigs: chemical composition and digestible energy content. *Canadian Journal of Animal Science*, *79*(2), 187-194.