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THE EFFECTS OF HOUSING SYSTEMS AND PROVISION OF MAIZE SILAGE ON PIG PERFORMANCE AND PORK MEAT QUALITY

by

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At no time during the registration for the degree of Research Masters has the author been registered for any other University award without prior agreement of the Doctoral College Quality Sub-Committee.

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NICHOLAS PURDUE

EFFECTS OF HOUSING SYSTEMS AND PROVISION OF MAIZE SILAGE ON PIG PERFORMANCE AND PORK MEAT QUALITY

Abstract

Concerns over animal welfare within pig production, the flavour of the meat produced, environmental considerations and food safety worries have led consumers to question the merits of current production systems. The study set out to investigate the effects of outdoor rearing and the offering of farm produced forage on the growth rate of pigs and the eating quality of the pork produced. Experiment 1: 2 groups of British Lop X Welsh finishing pigs were housed either in indoor straw bedded pens with access to an outside yard (YA) or in outdoor accommodation with a simple shelter (OA). All pigs were offered the same pelletized diet, restricted to be approximately equivalent to appetite, in order to explore the feed conversion efficiency of pigs within the two housing systems. No difference was found in the growth rates of animals finished on the two housing systems. It was found that pigs in the OA group took a mean of 10 days longer to fatten, incurring the associated additional costs which was in agreement with other studies. Experiment 2: 2 groups of British Lop X Welsh finishing pigs were offered a diet pelletized cereal based feed (PD) or a diet in which 40% of the pelletized feed were substituted with maize silage (FD). In the FD diet 1 Kg of pelletized feed was substituted with 2.5 Kg maize silage. No difference in growth rate was found, however animals offered the FD took 17.5 days longer to finish. The comparison of growth rates between the two groups established that the FD pigs were able to utilise 2.98 MJ/ Kg of maize silage fed (fresh weight) equating to an ME 8.5MJ/ Kg on a dry matter basis. A preference taste test was conducted with members of the general public using the pork produced in Experiment 2. A clear preference was demonstrated for the pork produced from FD pigs ($P<0.01$), however the result was not consistent across all age groups. Benefits of feeding a fibrous diet were identified, in regard to flavour and cost, however better understanding of the most suitable forages is required to maintain production levels and carcass quality.

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Table 1: Table of Abbreviations

DLWG	Daily live weight gain
LWG	Live weight gain
TLWG	Total live weight gain
Kg	Kilogram
MJ	Megajoule
MM	Millimetre
OA	Outdoor Accommodation
YA	Yard Accommodation
PD	Pelletized Diet
FD	Fibre Diet
FCR	Feed conversion ratio
DE	Digestible energy
ME	Metabolizable energy
ME_m	Metabolizable energy for maintenance
FHP	Fasting Heat Production
KJ	Kilojoule
BW	Body weight
h	Head
d	Day
P	Pig

1. Introduction

Pigs have traditionally been an integral part of farming systems in many parts of the world, often consuming waste and surplus products to produce meat with little cost to the whole farm system (Bellis, 1968; Blaxter and Robertson, 1995; Woods 2012). In the UK, pig production systems started to develop into larger more structured units at the beginning of the 20th Century (Blaxter and Robertson, 1995; Woods, 2012). Improvement in the understanding of animal nutrition and increased financial returns led to the development of outdoor systems on arable land (Woods, 2012).

Increased pressures on cereal production in the UK during the First World War led to an increase in indoor systems, with greater feed efficiency, however this created an increased problem with disease (Mae *et al*, 2000; Gardner *et al*, 2002; Woods, 2019). The availability of antibiotics to treat these diseases in the late 1940s (Bud 2007), along with government incentives, led to an increase in production and individual herd sizes, with more animals being reared on specialised units. This trend has been mirrored in many other countries, world production has increased from 376 million head in 1961 to over 1,486 million head in 2017 (FAO STAT, 2019), approximately half of all European pork currently being reared in herds larger than 7,000 head (SEGES, 2018). This has led to increased disease management and welfare implications associated with housing large numbers of similar animals together (Mae *et al*, 2000; Woods, 2019).

Large mechanised units, gaining economies of scale by minimising labour and variable costs, have led to a production system greatly influenced by the price of grain (Ptak-chmielewska, 2017). This has created a cyclic boom and bust industry with the wholesale price of pork lagging behind that of their feed (Coase and Fowler, 1935; Holst and von Cramon-Taubadel, 2012).

Pigs in the wild are forest grazer foragers which live in moderately sized extended family groups (Leaper *et al*. 1999; Sodeikat and Pohlmeyer, 2003; Keuling 2008a). They are predominantly nocturnal, spending a large proportion of their time searching for and consuming a fibre rich diet (Graves 1984; Massei, Genov and Staines, 1996). Conversely commercial pigs are kept in large groups, often on concrete slats, given high levels of concentrated cereal based feed low in fibre and have little opportunity to forage (Houston, 2013; SEGES, 2018). While the modern pig is far removed from its forest dwelling ancestors in terms of carcass conformation, leanness and food conversion ratios, it has been shown to retain many behavioural traits from its past (Petersen, Simonsen and Lawson, 1995; Van De Weerd, *et* al, 2005).

The lack of opportunity to demonstrate many natural behaviours, in particular those associated with foraging, has created significant welfare implications for the industry (Stolba and Wood-Gush, 1984 and 1989; Van de Weerd and Ison, 2019). The main concerns being increased boredom and aggression, which can manifest itself into stereotypic behaviours including pacing vacuum chewing and in severe cases tail biting (Scipioni *et al*, 2010). The increased incidence of detrimental stereotypic activity within the industry has led to intervention practices, which includes the routine tail docking of young pigs, being common practice (Jensen *et al*, 2012).

Concerns raised by welfare groups across Europe, highlighting the flaws in modern pork production, have led to increased concerns from the consumer regarding environmental implications, animal welfare and general food safety (Mellor and Webster, 2014; Van de Weerd and Ison, 2019). The high level of antibiotics use to combat increased levels of disease associated with more intensive husbandry has also been identified as a problem (Tilman *et al.*, 2002; Veissier *et al.*, 2008; Krystallis *et al.*, 2009). This has increased the perception, within Europe, that pork is not a healthy food (Kanis, Groen and De Greef, 2003; Verbeke *et al.*, 2010).

Ethical concerns have also been raised in relation to the type of diet currently fed to pigs in modern rearing systems, where some cereals currently being used for meat production could be utilised more effectively to feed the growing human population (Smil, 2002; Tilman *et al.*, 2002; Davis *et al.*, 2016). World pork production stands at approximately 108 Million tonnes (FAO STAT 2019). Using a kill out ratio of 75% (AHDB, 2017), it is calculated that between 4 and 4.5 kg of pig feed is required to produce 1 kg of dressed pork (Losinger, 1998).

2. Review of current literature

An analysis of literature was completed on the performance of pigs reared in modern production systems. The effects of housing type and the level of fibre in the diet were examined along with how they may have influenced the health and welfare of the animals, production efficiency, carcass composition and meat quality.

2.1 Types of pig housing in the UK

There are three main alternatives for the housing of fattening pigs under modern intensive systems.

1. Indoor intensive housing. Pigs are kept in purpose designed buildings in pens with slatted floors, which allow for the removal of urine and faeces. These animals do not have straw or other substrate.

This accounts for 33.5% of the UK rearing and fattening herd (DEFRA, 2010). While this system has higher capital costs than the others discussed it has a low labour demand and little food waste.

2. Indoor straw yards. Pigs are kept in simple buildings with a solid floor, animals are in pens which have straw or other substrate covering part of the floor, dung and urine have to be removed.

This accounts for 64% of the UK growing and fattening herd (DEFRA, 2010), having increased in recent years at the expense of indoor intensive systems. Setup costs are lower but there is a higher demand for labour and a cost for bedding.

3. Outdoor rearing systems. Pigs are kept in outdoor areas in paddocks, often on cereal stubble, with simple, portable shelters from the weather.

This accounts for only 2.5% of the UK growing and fattening herd (DEFRA, 2010). Setup costs are low, providing suitable well drained land is available but labour costs are higher than the other systems. It should be noted that the proportion of the total pig herd kept outside is far larger than that for this class, with almost half of all dry sows and in pig gilts being kept in this way (DEFRA, 2010)

2.2 The effects of types of housing on pork production and productivity

Studies comparing pigs reared inside and those in outdoor conditions have, in the main, found little or no effect on growth rate in cool temperate climates (Andresen, Ciszuk and Ohlander, 2001; Gustafson and Stern, 2003). This is not universally true, studies by Olsson *et al.* (2003) and Gentry *et al.* (2002, 2004), showed an increase in growth rate for animals reared outdoors, at all times throughout the year, while studies by Enfält *et al*, (1997) and Sather *et al.* (1997) demonstrated a decreased growth rate for both summer and winter.

In warmer climates a lower growth rate has been observed in outdoor reared pigs, which was attributed to a lower appetite (Edwards, 2005), this was more pronounced when insufficient shade was provided. In colder conditions the pig requires additional energy to maintain thermostasis (Close and Poornan 1993; Millet *et al.* 2005), although this is has been shown to be compensated for by higher feed intakes (Strudsholm and Hermansen, 2005; Kelly *et al*, 2007) sustaining growth rates.

Many of the studies carried out have been using animals offered an *ad-libitum* diet, using live weight gain as the measure of performance. Studies that looked at food intake as well as weight gain (Gentry *et al*, 2004; Kelly *et al,* 2007), demonstrated that feed intake increased by 11 to 15 % for animals reared outside. The increased feed consumption was not fully reflected in improvements in live weight gain, indicating a reduction in food conversion efficiency. Gentry *et al.* (2004) and Kelly *et al*. (2007) demonstrated a decrease was 11% and 13% respectively in their studies. The variation demonstrated within these studies has largely been attributed to differing climatic conditions and their effect on both appetite and the maintenance requirements.

Increased activity of outdoor reared animals has also been cited as a factor contributing to decreased feed conversion efficiency (Petley and Bayley, 1988;

Noblet *et al,* 1994). Presto *et al*. (2013) demonstrated that pigs with the opportunity to forage were significantly more active than those housed on straw, with those kept on slats being the least active. This observation was not universal, studies by Guy *et al*. (1994, 2002) found no increase in the activity of pigs kept outdoors. Increases in activity in indoor housed pigs was observed in many studies where forage or substrate was available, (Beattie *et al*, 2000; Scott *et al*, 2006; Morrison *et al*, 2007),

Hunger has been strongly linked with increased activity (Ewbank 1974) and more recently it has been shown that the concentration of protein in the diet has a large effect on foraging (Jensen *et al*, 1993; Jakobsen *et al*, 2015). Pigs offered a diet which is low in protein foraged significantly more than those offered a balanced diet, demonstrating the ability to select high protein components from the forage (Kyriazakis and Emmans, 1991; Riart, 2001; Jakobsen *et al*, 2015).

Studies investigating the growth performance of pig breeds under alternative rearing systems have, in the main, demonstrated that traditional breeds perform better in outdoor systems (Webber 1989; Edwards *et al*, 1991; Edwards and Zanella, 1996; Edwards 2005). This is not universal, a study by Kelly *et al*, (2007) examining traditional breeds, cross breeds and hybrids found that accommodation type did not significantly affect growth rate or carcass composition.

Studies that have compared the performance of slatted floor rearing systems with straw yards and other forms of enrichment, have found little or no difference in growth rate and food conversion ratio (Bettie *et al*, 2000; Van de Weerd *et al,* 2005; Scott *et al*, 2006; Trickett *et al*, 2009; Averós *et al*, 2010). Increased costs related to bedding and labour (Redman, 2018) and a lower recommended stocking rate (The pigsite, 2019), associated with straw yards, may be offset against identified health benefits (Mouttotou *et al*, 1999; Maes *et al*, 2000 Gentry *et al*, 2002) for these rearing systems.

No difference in growth rate or feed conversion ratio (FCR) was demonstrated when comparing slatted floor pens to straw yards (Lambooij *et al,* 2004; Averós *et al,* 2010), however additional labour and material costs associated with straw bedding systems would have to be considered (Redman, 2018). Outdoor systems show a more mixed picture when compared to indoor ones, showing both higher and lower growth rates (Table 2). Studies which examined FCR universally found poorer results for outdoor reared pigs (Gentry *et al*, 2004; Kelly *et al,* 2007).

Table 2: Summary of results from studies into the effects of housing on pig performance

Type of housing	Daily gain	Backfat thickness	Meat percentage	Author
Outdoor paddocks/straw yards	↑	Straw yards highest		Guy *et al.* (2002)
Outdoor rearing	=	↑	=	Bridi *et al.* (1998)
Outdoor rearing	↓	↓	↑	Enfalt *et al.* (1997)
Outdoor rearing during summer	↓	↓	=	Lebret *et al.* (2002)
Outdoor housing			↓	Gandemer *et al.* (1990)
Outdoor Housing	↓	↑		Gentry *et al.* (2004)
Outdoor Housing	↓	=		Kelly *et al.* (2007)
Pigs in an outdoor paddock		↓		Warriss *et al.* (1989)
Free-range pigs		Trend to higher values	↓	Van der Wal *et al.* (1993)
Straw bedding/free-range housing		= /=		Lambooij *et al.* (2004)
Pigs born and finished outdoors	↑	↓	↑	Gentry *et al.* (2002)
Indoor-born pigs finished outdoors during winter	=	=	=	Gentry *et al.* (2002)
Straw Yards	=			Averós *et al.* (2010)
Free-range pigs	↓	↓	↑	Hoffman *et al.* (2003)

2.3 The effects of housing on the health and welfare of growing pigs

Welfare within different housing systems for pigs has been a subject of discussion both for the general public (Krystallis *et al.*, 2009; Thorslund *et al.*, 2016) and government organisations including the EU, DEFRA and farm assurance schemes including RSPCA Assured and Red Tractor.

Millet *et al.* (2005) identified the following 8 measures of poor animal welfare; Increased mortality, Impaired growth or breeding ability, External/internal lesions and/or pain, Disease, Immunosuppression, Profound physiological changes, Expression of few or no species specific behaviours, Occurrence of behavioural abnormalities. Lack of expression of 'normal' behaviours and the occurrence of abnormal or stereotypic behaviours which are commonly used as animal-based animal welfare indicators (Waran and Randle, 2016), such as inactivity, bar biting, rooting bare floor, vacuum chewing and tail biting in pigs (Lawrence and Terluw 1993).

The lack of physical stimulus for pigs kept on bare floors without substrate has been identified as a principal factor in the occurrence of stereotypic behaviours (Wemelsfelder *et al*, 2000; Tuyttens, 2005; Averós *et al*, 2010). There are both EU directives (Directive2001/93/EU) and farm assurance scheme requirements (RSPCA, 2016; Red Tractor, 2020) in place with the intention of mitigating these problems, stating that all pigs must have 'access to straw or other malleable materials or objects to satisfy their behavioural needs'.

The interaction with various toys in slatted systems, either on the ground or suspended, was found to be very low in pigs after initial placement. (Heizmann *et al*, 1988; Blackshaw *et al*, 1997; Van de Weerd *et al*, 2003 and 2009; Scott *et al*, 2006, 2007; Averós *et al*, 2010). However some studies have demonstrated positive effects on social behaviour with these types of enrichment (Pearce and Paterson, 1993; Guy *et al*, 2002). The properties of the material used for enrichment products has been shown to influence the degree of interaction demonstrated (Van de Weerd *et al*, 2003; Bracke *et al*, 2006, 2008), with metal chains being least suitable and chewable items of greatest value to pigs (Hill *et al*, 1998; Feddes and Fraser, 1994).

The use of malleable substrates, either as bedding or offered in a trough, have been shown to be much more suitable for pig enrichment with up to 20 times the level of interaction, compared to 'toys' in a barren environment (Fraser, 1985; Lyons et al, 1995; Kelly *et al*, 2000; Scott *et al*, 2006, 2007; Van de Weerd *et al*, 2006). The presence of substrates promotes foraging and chewing activities (Fraser, 1985; Fraser *et al*, 1991) and reduces aggressive behaviour towards pen mates, as indicated by side lesions and tail biting (Beattie *et al*, 1995; Petersen *et al*, 1995; Kelly *et al*, 2000; Guy *et al*, 2002). One experiment, looking into the effects of enrichment on the development of harmful social behaviours in pigs with intact tails (Van de Weerd *et al*, 2005), observed that groups of animals which had to be removed from slatted floor pens on welfare grounds during the trial, due to excessive tail biting, stopped expressing further antisocial behaviours when bedded with straw. Scott *et al,* (2006), when comparing straw yards with fully slatted pens, found no difference in these indicators.

Substrate presented on the floor, opposed to in troughs, occupied pigs for a higher proportion of their time (Fraser, 1985; Scott *et al*, 2007). Scott *et al*, (2007) observed that the manipulation of straw bedding occupied 21% of pigs' time compared with less than 2% interacting with suspended toys.

Straw is the most popular substrate to be used in observations, although Beattie *et al*. (1995) showed that pigs demonstrate an even greater preference for peat, mushroom compost and sawdust.

The levels of observed rooting activity for pigs bedded on straw has been shown to be comparable with the activity shown in outdoor systems (Guy *et al*, 1994, 2002), however a study by Presto *et al*, (2013) demonstrated significantly higher levels of activity in outdoor reared pigs. As mentioned previously this may have been a result of diet.

The effects of increased enrichment on performance have been varied, while some have shown an increase in growth rate (Beattie *et al*, 2000; Gentry *et al,* 2002; Olsson *et al,* 2003; Millet *et al*, 2005), others have observed no difference (Lewis *et al,* 1989; Beattie *et al,* 1996; Klont *et al,* 2001), (Table 3).

Table 3: Summary of results from studies into the effects of enrichment on pig performance

Type of housing	Daily gain	Backfat thickness	Meat percentage	Author
Deep bedding	↑	↓		Gentry *et al.* (2002)
Organic housing	↑	↑	=	Millet *et al.* (2004)
Organic pigs	↑	↑	↓	Olsson *et al.* (2003)
Enriched housing	↑ from 55-100Kg	↑		Beattie *et al.* (2000)
Enriched housing	=			Beattie *et al.* (1996)
Effect of training		=	=	Enfält *et al.* (1993)
Enriched housing	=	=	=	Klont *et al.* (2001)
Exercise	=	↑		Lewis *et al.* (1989)
Environmental enrichment/isolation	Treatment × genotype	Lower in isolated animals	Higher in isolated animals	Hill *et al.* (1998)

The incidence of foot lesions in pigs bedded on straw yard and concrete slats has been shown to differ, with those kept on straw being significantly lower (Gentry *et al*, 2002; Scott *et al*, 2006), with a study by Lyon *et al.* (1995) demonstrating that the prevalence of adventitious bursitis was lower in the hocks of pigs kept on straw. The study by Gentry *et al*, (2002) demonstrated a higher incidence of foot lesions in pigs kept on slats, 55% of animals in group compared to 32% of those on straw. The severity of lesions, however, was shown to be greater in animals bedded on straw, with 31% of cases being classified as severe compared to 9% of cases from pigs kept on slatted floors. The escalation in severity of the injuries in the group kept on straw was attributed to poor hygiene and areas of wet bedding causing secondary infections (Gentry *et al*, 2002; Van de Weerd and Day, 2009)

A study by Mouttotou *et al*. (1999) identified that the type of floor contributes to the position of the lesion on damaged feet. Straw bedding being associated more with problems in the toe, while heal lesions are more likely to occur in pigs kept on concrete slats.

The effects of straw bedding on the respiratory systems of pigs have been investigated, with the speculation being that animals on straw based systems have increased incidence of lung lesions, due to increased presence of pathogens and dust (Arey, 1993). Scott *et al*, (2006), in a study of over 4000 pigs, found an increased incidence of respiratory problems requiring veterinary treatment within the straw housed animals, but a lower number from that group needing to be removed from the study on health grounds, post mortem lung lesion scores were the same for both groups. Gentry *et al*. (2002) found no difference in the overall incidence of lesions, however the numbers developing severe lung damage was almost double for the animals housed on slatted floors. The design of the two housing systems differed greatly in the experiment by Gentry *et al*. (2002) with increased floor space and air flow being influencing factors (Mae *et al*, 2000).

Evidence demonstrate a clear benefit to welfare for pigs reared outside compared to those housed on slatted floors, in regard to opportunity to exhibit natural behaviour and a reduction in detrimental habits associated with frustration and boredom (Scott *et al*, 2007; Averós *et al*, 2010). This remains true when suspended 'toys' for the pigs in slatted floor pens. Similar benefits to those of outdoor systems have been witnessed in indoor housing when pigs are bedded on straw or other suitable substrate (Guy *et al*, 1994, 2002).

When examining evidence on health in relation to lameness and respiratory problems in relation to the two indoor systems, overall the greatest benefits were gained from straw based housing, although stocking density and unit biosecurity could play a significant part (Mae *et al*, 2000; Gardner *et al*, 2002).

2.4 The effects of high fibre diets on the performance and growth of pigs

Studies examining the inclusion of fibre into pig diets can be split into three main groups.

- The addition of refined fibre, ground and added to the cereal based meal, offered to pigs in the conventional manner.
- Pigs being offered natural forms of fibre such as from grass or cereal silage in addition to an *ad-libitum* conventional cereal diet
- Pigs on a restricted cereal diet with additional fibrous feed offered.

Studies looking at the inclusion of additional fibre within formulated feed (Noblet *et al*, 2001; Takahashi and Horiguchi, 2005; and Zanfi and Spanghero, 2012) have taken the form of digestibility trials on individual animals. Total nutrient intake and the nutrient content of excreta were measured to determine accurate utilisation of the feedstuff, with animals' movement being restricted during the studies. Experiments were carried out over short periods, ranging from 10 to 28 days, resulting in relatively small changes in growth rate and carcass quality.

The ability for pigs to utilize crude fibre has been shown to decrease as the level of fibre in the diet increased (Takahashi *et al,* 1988; Hata & Koizumi, 1995; Takahashi and Horiguchi, 2005). It has been demonstrated that appetite decreases significantly as the level of fibre inclusion in the diet was increased (Takahashi and Horiguchi, 2005). Noblet *et al*. (2001), using surgically prepared ileo-rectally anatomized animals, showed that most fibre digestion takes place in the large intestine and that pigs overall ability to utilize energy from the diet decreased as the fibre content was increased (Noblet *et al*, 1994).

Studies offering fibre in addition to conventional feed (Mowat *et al*, 2001; Edwards 2003; Kelly *et al,* 2007), have universally found intake of the fibre to be low with little or no effect on FCR or carcass composition.

A trial carried out by Kelly *et al*. (2007) also considered the effect of breed. Animals on the trial were offered fibre in the form of grass/clover silage and pea/wheat silage in addition to their feed. Kelly *et al.* (2007) explored the hypothesis that the more traditional breeds of pig, with a natural tendency to grow more slowly would be more suited to diets containing fibre (Edwards *et al,* 1991). Using traditional breeds, crossbreeds and modern hybrid animals, Kelly *et al.* (2007) found no difference in intake of fibre or FCR between the breeds. This would indicate that genotype was not a variable when exploring fibre utilization, however fibre uptake was low for all animals in the study, only 4% of total dry mater intake.

Experiments carried out of animals on a restricted diet, being offered additional fibre, have looked at grazing pigs (Edwards, 2003; Oksbjerg *et al*, 2005; Jakobsen *et al*, 2015) and conserved forages including grass/ clover silages, and whole crop cereal silages (Danielsen *et al*, 1999; Hansen *et al*, 2006; Presto, Rundgren and Wallenbeck, 2013)

Studies comparing the intake of forage by animals on a cereal based diet restricted to 80% of their expected appetite, compared to those offered an *Ad lib.* diet, showed significantly higher levels of fibre intake from restricted animals (Danielsen *et al*, 1999; Edwards, 2003; Oksbjerg *et al*, 2005; Hansen *et al*, 2006; Presto, Rundgren and Wallenbeck, 2013; Jakobsen *et al*, 2015)

In grazing experiments the increased uptake of fibre was between 5 to 60 % compared to observations of animals fed to appetite (Edwards, 2003; Stern and Andresen, 2003; Jakobsen *et al*, 2015). Jakobsen *et al.* (2015) examined the effects of grazing material on the habits and performance of pigs fed on an 80% restricted diet. Increased grazing activity and significantly higher pasture utilization was observed in animals on lucerne paddocks compared to grass/ clover paddocks. It has been shown that pigs can be selective grazers, able to select the more digestible parts of the lucerne sward (Gustafson & Stern, 2003), possibly explaining the differences observed in intake (Jakobsen *et al,* 2015). Reducing the protein level in the supplementary feed was shown to have no significant effect on grazing activity (Jakobsen *et al*, 2015), however significantly increase rooting activity was witnessed on grass paddocks, but not on lucerne. This would infer that pigs on grass paddocks were seeking to supplement their deficient diet with roots and invertebrates, re-enforcing the hypothesis that protein is a driver for foraging activity (Jensen *et al,* 1993; Jakobsen *et al,* 2015).

A study by Andersen & Redbo (1999) did not support these findings, showing no change in foraging activity in pigs fed different levels of crude protein.

The study by Stern and Andresen, (2003) demonstrated no nutritional gain form grazed forage consumed in respect to FCR, experiments observing a higher intake of grazed forage (Edwards, 2003; Jakobsen *et al*, 2015), showed an improvement in FCR in relation to cereal based portion of their diet, however overall productivity was still below those animals on an *Ad lib.* diet, indicating the level of fibre utilization did not fully compensate for the reduced ration.

Pigs fed on a 70% restricted cereal diet and offered *Ad lib* fresh cut or conserved forage demonstrated increases in fibre intake of 25 to 50% compared to animals on an *Ad lib.* diet (Danielsen *et al*, 1999; Hansen *et al*, 2006; Presto, Rundgren and Wallenbeck, 2013). The growth rate of the pigs on the restricted diets were reduced by 11 to 16%, however this demonstrated an improved FCR. Danielsen *et al.* (1999), when investigating uptake of fresh and conserved grass/ clover, observed that uptake of fresh fibre was lower than that of conserved silage, although the performance of animals of both diets remained the same, implying that the pigs were better able to utilize fresh grass. A Study examining the utilization of cereal forage silage and clover grass silage by pigs (Hansen *et al.* 2006), demonstrated similar results, with pigs on a 70% restricted diet showing a 22% decrease in weight gain. While both groups of animals performed similarly, the uptake of grass clover/ silage, at 8% was over double that of pea/ barley silage, indicating a difference in the ability of the pigs to utilize the energy within the fibre portion of different diets.

There is no evidence of production benefits to offering pigs fibre in addition to an *Ad lib*. diet (Table 4). When animals are fed a restricted diet and offered additional fibrous feed there is a clear negative effect on DLWG, however there is also a decrease in body fat and an increase in meat content (Table 4). There is evidence of improved FCR in those animals on restricted diets indicating the opportunity to reduce overall production costs.

Table 4: Summary of results from studies into the effects offering fibre in a pigs diet on pig performance

Type of diet	Daily gain	Backfat thickness	Meat percentage	Author
Offered additional fibre to diet	=	=		Kelly et al (2007)
Offered additional fibre to diet	=	=		Edwards (2003)
Offered additional fibre to diet	=	=		Mowat et al (2001)
Portion of feed substituted for fibre	↓	↓	↑	Danielsen (2005)
Portion of feed substituted for fibre	↓	↓	↑	Strudsholm & Hermansen (2005)
Portion of feed substituted for fibre	↓	↓		Hansen (2006)

2.5 The influence of diet and housing on carcass composition and eating quality

Quantitative factors identified as having an influence on the eating quality of pork (Rincker *et al*, 2008; Lee *et al,* 2012). These include intramuscular fat levels (marbling), genotype and the physical properties of the carcass including pH and the tenderness of the flesh, measured by shearing force (Wood *et al*, 2004; Millet *et al,* 2005; Rincker *et al*, 2008). In addition to these primary qualities, a group of secondary, qualitative factors have been identified as influencing the overall quality of the meat (Edwards, 2003), these include flavour and consumer perception in regard to animal welfare, food safety and environmental concerns (Krystallis *et al*, 2009; Thorslund *et al*, 2016; Muringai *et al*, 2017).

2.5.1 Primary attributes of meat quality

Studies comparing the carcass composition of pigs reared either indoors or outside have, in the main, found no significant difference in backfat thickness (Gentry *et al*, 2000; Gentry and McGlone, 2003; Hansen *et al*, 2006; Kelly *et al*, 2007), although some studies have observed a decrease in fat levels of those housed outdoors (Strudsholm and Hermansen, 2005; Hansen *et al*, 2006). The reduction being attributed to an increase in activity and a raised demand for energy to maintain body temperature (Strudsholm and Hermansen, 2005). Gentry *et al.* (2004) showed an increase in back fat but a reduction in intramuscular fat in animals kept outdoors, attributed to favourable climatic conditions.

A study which investigated at the size of joints on the carcass (Hansen *et al,* 2006), found no significant difference between animals permanently housed and those with access to outdoors, with the exception of larger leg muscles for those animals not fully housed.

When comparing indoor straw based systems with slatted floor pens the level of carcass backfat was found to be the same (Lyons *et al*, 1995; Klont *et al*, 2001; Guy *et al*, 2002; Van de Weerd *et al*, 2005), however Gentry *et al.* 2002 did observe an increase in backfat in pigs reared in straw pens.

A study examining the effects of feeding fibre as part of the diet on carcass composition observed that the overall lean meat content was lower for the animals a 100% cereal ration, compared to these on a restricted 70% ration with access to forage silage (Hansen *et al*, 2006). There was a correspondingly lower level of intramuscular fat in these animals. The carcasses of pigs given the restricted diet and offered forage, while having a greater overall fat content, contained 2% less saturated fat, showing an equivalent increase in polyunsaturated fat content (Hansen *et al*, 2006). These findings are supported by studies carried out by Danielsen *et al*. (1999) and Strudsholm & Hermansen (2005). The study by Hansen *et al*. (2006) looked at the yields from different joints on the carcass, observing animals on the fibre diet produced significantly heavier loins and less belly pork, qualities which would increase the value of the carcass.

2.5.2 Secondary attributes of meat quality

Batcher and Dawson (1960) identified at strong correlation between intramuscular fat and palatability, in terms of tenderness and flavour, this was well supported (Kauffman *et al*, 1964; Davis *et al*, 1975; Ellis *et al,* 1996; Wood *et al*, 2004; Fortin *et al*, 2005). Other studies have only identified very weak correlations (Wood *et al*, 1979; Lentsch *et al*, 1992). Rincker *et al*. (2008) while investigating the effects of the level of intramuscular fat on tenderness and flavour of pork, using an untrained consumer panel, also supported this finding over a range of cooking times. The same study (Rincker *et al,* 2008) provided contradictory results when using a trained panel of tasters, identifying no correlation between tenderness and fat levels as cooking time increased. Consumers did not identify any improvements in the samples at the highest level of fat (Rincker *et al,* 2008), this supports speculations by Göransson *et al*. (1992) that there is an upper limit of intramuscular fat, beyond which tenderness may deteriorate.

Genotype has been shown to have an influence on eating quality (Chang *et al*, 2003; Wimmer *et al*, 2008). The proportions of muscle fibres of different types affects the tenderness and flavour of pork from different breeds, irrespective of overall fat levels (Müller *et al*, 2002; Chang *et al*, 2003; Lefaucheur *et al*, 2004).

The higher levels of intramuscular fat in certain types of fibre, has been identified as the explanation for improved eating quality(Essen-Gustavsson *et al*, 1994; Fiedler *et al*, 2003).

Carcasses produced outdoors were found to be of similar in composition to those of housed animals (Essen-Gustavsson *et al*, 1988; Petersen *et al*, 1995; Sather *et al*, 1997; Enfält *et al,* 1997; Gentry *et al*, 2002; Olsson *et al,* 2003), implying that the environment has little effect on juiciness, tenderness and flavour. Many observations supported this (Essen-Gustavsson *et al.*, 1988; Petersen *et al.*, 1995; Gentry *et al.*, 2002), however the findings were not universal when considering meat tenderness. Studies by Sather *et al*. (1997), Enfält *et al.* (1997) and Olsson *et al.* (2003) found tenderness to decrease, by up to 18%, with animals reared outside. An explanation for this was the increase in levels of certain types of muscle fibre, which have been shown to affect eating quality (Chang *et al,* 2003; Wimmer *et al*, 2008), the proliferation of different muscle fibres having been shown to vary between individual animals as well as between genotypes.

Studies examining the effects of exercise on the toughness of meat have, in the main, found no effect on tenderness with the levels associated with outdoor production systems (Hawrysh *et al*, 1973; Essen-Gustavsson *et al*, 1988 Peterson *et al*, 1997), however increased levels of toughness have been demonstrated in a study by O'Halloran et al (1997) which examined very high levels of exercise.

When examining the effects of diet on eating quality, the majority of studies, it is carcass composition and in particular fat content which is being examined (Danielsen *et al,* 2000; Jonsäll *et al,* 2000). The levels of fat within a carcass, both subcutaneous and intermuscular, have been shown to be strongly influenced by the levels of protein in the diet (Wood *et al.* 1979 and 2004). This trait is more strongly observed in modern breeds which have been developed to utilize high levels of protein, having an increased capacity for muscle growth (Andersen and Nannerup, 2004; Kelly *et al*, 2007). Diets high in fibre tend to be lower in available protein, leading to greater levels of fat being deposited in the carcass (Wood *et al.* 1979 and 2004). The implication that pork produced on a high fibre diet would be juicier and more tender, due of increased fat levels is well supported. (Kauffman *et al*, 1964; Davis *et al*, 1975; Ellis *et al,* 1996; Fortin *et al*, 2005). This has not been a universally observation, some studies offering high fibre diets have produced leaner carcasses (Danielsen *et al.*, 1999; Strudsholm and Hermansen, 2005; Hansen *et al.*, 2006).

2.6 Establishing the maintenance requirement of the pigs on the trial

The energy required for the maintenance of an animal can be determined in one of three ways; calculating the fasting metabolism, by linear regression of an animal with an energy retention of zero with no weight gain or loss, or from examining the relationship between energy intake and protein and fat deposition (Close and Fowler 1984).

The first two methods of establishing the metabolizable energy requirement for maintenance (ME_m) are not suitable for studying growing animals as energy retention is not zero (Close and Fowler 1984). The dynamic flux of deposition and breakdown of proteins, even when animals are in stasis, has to be considered in any calculations (Fuller *et al.* 1976, Close *et al.* 1978). This could represent as much as 25 to 30% of the total maintenance requirement.

Investigations conducted to establish the maintenance requirement by examining the relationship between intake and growth, have demonstrated that energy requirement expressed in terms of body weight $Kg^{0.60}$ was more accurate when describing fast growing modern hybrid and improved native breeds of pig, than body weight $Kg^{0.75}$ which was traditionally used for slower growing animals (Norbet *et al*, 2003; Everts, 2015). A wide range of values for the maintenance requirements of pigs had been established through experimentation (Table 5).

Table 5: Proposed Maintenance Requirement Coefficients for pigs
Reproduced from 'Energy Requirements for Maintenance in Growing Pigs' (Everts, 2015)

NEm ($kJ/BW^{0.60}$)	**Remarks**	**Study**
749	Regression of RE on ME	Noblet *et al*, 1989b
962	FHP, corrected for activity	Van Milgen *et al*, 1998
630-730	Data set of Noblet et al. 1999	Van Milgen and Noblet, 1999
765	FHP, corrected for activity	Noblet *et al*, 2001
750	Data set of Noblet et al., 2001	Le Bellego *et al*, 2001
734-798	FHP, corrected for activity	Van Milgen *et al*, 2001
711-743	FHP, corrected for activity	Le Goff *et al*, 2002
661-774	FHP, corrected for activity	Noblet *et al*, 2003
609-729	FHP, extrapolated plateau	De Lange *et al*, 2006

(FHP = Fasting heat production)

The variation in results may be explained by differences in genotype (Müller *et al*, 2002; Chang *et al*, 2003), level of activity (Petley and Bayley, 1988; Noblet *et al,* 1993), environmental conditions (Millet *et al.* 2005) and the dynamic flux of deposition and breakdown of proteins, which could represent as much as 25 to 30% of the total maintenance requirement (Fuller *et al.* 1976, Close *et al.* 1978). Diet may also be an influencing factor, evidence indicates that the digestion of a higher fibre diet requires more energy, increasing the maintenance requirement, this appears more pronounced in growing pigs (Noblet and Le Goff, 2001)

The large range calculated values for maintenance requirement for a kilogram of metabolic live weight of growing pigs presents a problem when investigating the utilization of a novel diet. The two extremes within the findings, 609 KJ Kg/ME_m (De Lange *et al*, 2006) and 962 KJ Kg/ME_m (Van Milgen *et al*, 1998) would produce the following requirement for a 50 Kg Pig.

$$ME_m = 609KJ \times 50Kg^{0.60} = 6.37MJ / day$$

$$ME_m = 962KJ \times 50Kg^{0.60} = 10.06MJ / day$$

These values are at the extremes of the general consensus, (Everts, 2015). It was decided to use the mean of the values presented in Table 4, 739 KJ Kg/ME_m, to use for the investigation into pigs ability to utilize the energy from maize silage.

2.7 Summary of current literature

Clear welfare benefits were demonstrated when housed pigs were given access to fibrous bedding. The opportunity to demonstrate natural behaviours, such as foraging, greatly reducing the incidence of antisocial behaviours. Straw and other substrates out preformed enrichment objects, such as balls and chains, in terms of uptake and level of activity. Little or no difference in levels of activity and natural behaviours was observed between pigs housed in loose pens on straw and those in outdoor production systems.

When examining growth performance, outdoor rearing systems carried a clear penalty in terms of feed conversion ratio, animals kept outdoors requiring 10 to 15% more feed to finish, although intake was shown to have increased to maintain growth rate. .

The voluntary uptake of fibrous feeds, including grass, lucerne and conserved forage, was shown to be very low, with little effect on performance. Studies using animals on a restricted diet demonstrated a marked increase in uptake of fibrous feed. Higher levels of fibre intake were shown to have a detrimental effect on growth rate and feed conversion ratio, however performance data on offering high fibre diets to pigs was scarce.

The level of intramuscular fat was shown to be of greatest influence on meat quality, although genotype and the ratio of different muscle fibres types was shown to affect tenderness flavour and juiciness. The effects of housing on fat levels in carcasses was variable. Little or no difference was shown in animals housed inside, whether bedded on straw or in slatted floor pens. Pigs reared outside were leaner in the majority of studies, however this was far from a universal result. Climatic conditions and breed being cited as reasons for variation.

3. Introduction to Current Study

Little information is currently available on pigs' ability to utilise the energy from forages offered. A better understanding of nutrient uptake would provide scope to develop high fibre rations which are less detrimental in terms of production performance while improving animal welfare through promoting natural behaviours. Climate and location have been shown to have an effect the growth performance observed in pigs reared outside.

It was the intention of this study to examine the economic viability of producing pork in a high welfare environment using farm conserved forage. The performance indicators examined were growth rate, feed utilization and the flavour of the meat produced. This took the form of two separate experiments. Experiment 1, investigating growth rates of animals reared in outdoor pens compared to those housed in straw pens with access to outside yards. Experiment 2, investigating the growth rate of animals with a portion of their diet substituted with maize silage, compared to those on a wholly cereal based diet. A consumer taste test was carried out on the pork produced in Experiment 2.

4. Experiment 1: An investigation into the influence of accommodation on the performance of growing pigs

4.1 Materials and Methods

4.1.1 Introduction

The following study was undertaken to investigate the effects on growth rate of two types of rearing accommodation for pigs. The study compared animals housed outside in pig arks with access to an earth paddocks with those in traditional buildings with access to an outside concrete yard.

4.1.2 Location of study

The experiment was conducted at Duchy College's West Combs Head Farm, Callington, Cornwall, PL17 8PB. in 2016. The animals used were farm produced British Lop cross Welsh pigs.

All pigs were kept in accordance with Code of Recommendations for the Welfare of Livestock: Pigs (DEFRA 2003) and with respect for the five animal needs. Every effort was made to avoid distress in the handling and caring for the animals used. Health and welfare was be monitored daily by independent professional practitioners experienced in managing pigs and pig welfare. Any animals adversely affected by treatments would have been removed from the experiment.

4.1.3 Animals used

A group of 17 farm bred British Lop cross Welsh piglets, born on the 1st December 2015, from two litters (totalling 8 males and 9 females), were used for this study. They were selected to be as genetically and physiologically similar as possible, both litters being born on the same day, both litters sired by the same boar, from sows of the same genetic line. All piglets were treated the same from birth, reared by their mothers until weaning at six weeks of age. Weaned piglets were commingled and reared together, fed *Ad lib.* BOCM Farm Gate Sow and Weaner 16% protein pellets (Appendix 1), in accordance with West Coombs Head farm's usual practice.

At 100 days of age the piglets were weighed and allocated to one of two treatment groups, according to sex and live weight to ensure that the groups were similar. This was achieved by allocating the heaviest male to group 1 and the second heaviest to group 2, working through the piglets until all the males had been allocated, followed by the females. The piglets were placed into one group of eight and one group of nine, as there was an odd number of animals and a single piglet could not be reared by its-self outside of the experiment. The larger group was assigned the outdoor accommodation, where there was more space so a lesser likelihood of any impact on the study, there were five females and four entire males (OA group). Four females and four entire males were assigned the yard accommodation (YA group).

4.1.4 Animal Nutrition

All weaned pigs were offered BOCM Farm Gate Sow and Weaner 16% protein pelleted feed twice daily, ensuring there was sufficient trough space for all animals to eat at the same time. It was intended to feed a near appetite restricted diet to ensure both groups received the same quantity of feed with no waste and minimal effects on growth rate. As the animals grew the quantity of feed offered was increased to accommodate increased appetite, feed was split into two equal feeds fed morning and evening.

Table 6: Quantity of feed given to individual pigs during Experiment 1

Age of animals (Days)	Weight of feed (kg/h/d)
101	1.6
134	2
186	2.5

4.1.5 Description of housing treatments

The farmyard is at an altitude of 160 M, with an annual rainfall of 1375 mm, the soil type is clay loam over shillet.

Treatment I. Yard Accommodation

The YA group were housed in traditional pig pens (Figure 1). These consisted of a stone house approximately 3 meters by 4 meters, with concrete floor and an outside yard 3 meters by 7.5 meters concrete yard with an automatic water trough and access to approximately 2.4 meters of feed trough. Straw bedding was supplied for the housed area and the pigs had unrestricted access to all areas of their accommodation. The pen was secure, free from hazards and suitable for the class of stock. The yards were cleaned daily and waste removed, the housed area was cleaned as required and fresh straw added weekly.

Figure 1: Indoor pig accommodation

Treatment 2. Outdoor Accommodation

The OA group were kept in an earth floored pen, with a pig ark for shelter (Figure 2). The outdoor pen was approximately 12 meters by 20 meters, had regularly been used for keeping pigs and contained no vegetation with the exception of trees forming a natural shelter. It was assumed that there was no nutritional advantage to the gained by the pigs on Treatment 2. The pen was bordered by a stock-net fence with a strand of electric fence run around the base of it to prevent the pigs damaging it. The pen was level, secure, free from hazards and suitable for the class of stock. The pig ark was 2.5 meters by 2.5 meters, of curved corrugated steel construction and had a wooden floor to ensure the bedding remained dry. Straw bedding was supplied in the ark, it was not necessary to clean out the ark and straw was only added once a month.

Figure 2: Outdoor pig accommodation

4.1.6 Management of the treatment groups

The day to day management of the pigs was carried out by college staff and students as part of their practical duties, overseen by experienced farm staff. All codes of practice in regard to husbandry and welfare (DEFRA 2003) were adhered to. Provision was in place to remove any sick or injured animals from the experiment and take appropriate actions.

Twelve weeks into the experiment, when the animals were 24 weeks of age, both groups were split according to sex to prevent any unwanted mating. A second identical pen was set up for each treatment to ensure that the study was unaffected, all feeding and husbandry was continued as described in Table 1.

On achieving slaughter weight, males 90 kg, females 100 kg, individual animals were removed from the study and sent to the abattoir, The Cornish Farmhouse Bacon Company, Whitstone, Holsworthy, EX22 6LE. They were transported by farm staff in a livestock box, in accordance with existing animal movement and transportation regulations. The journey of 19 miles to the abattoir took approximately 40 minutes.

The feed for the remainder of the group was adjusted to maintain specified individual diets.

4.1.7 Live-weight recording and carcass quality

Pigs were weighed individually on a weekly basis from the start of the experiment. To minimise any stress caused by the weighing process the pigs were weighed in their enclosures. Weighing was carried out by the same person each time to ensure consistency. Wherever possible pigs were weighed at the same time, mid-morning, after their first feed. All measurements were carried out using an analogue Avery sheep and pig weigh scale (accurate to 0.5 Kg). This was checked for accuracy before every weighing using bags of animal feed of a known weight.

Individual animals were weighed immediately before being loaded onto transport to the abattoir using a digital Avery calf scales (accurate to 0.1 Kg), this weight, along with the cold slaughter weight from the abattoir was taken to calculate kill out percentage on individual pigs.

At the abattoir an optical probe was used to measure back fat and rind thickness of the carcass at the P2 position (AHDB, 2018). The following formula was used to estimate the percentage lean in the carcass from the P2 fat probe reading.

$$L = 66.5 - 0.95P_2 + 0.068Cw$$

(United Kingdom Protocol, 1994)

Where L is the estimated percentage lean meat

P_2 is mm fat read using the probe at the P2 position

Cw is the Cold carcass weight in Kg

4.1.8 Statistical analysis

The weekly live weight gain data obtained from the study were analysed using the Minitab Version [18] (2018) statistical package. Data were found not to be normally distributed and were transformed using the Johnson Transformation. An analysis of variance, using the general linear model, was performed on the modified data to investigate the effect accommodation type had on daily live weight gain. Sex was also included in the model, however treatment differences due to sex were minimal.

4.2 Observations

While there were no structured observations of behaviour during the study, the groups of animals were observed at various times of day while on the experiment. The following were noted.

Both groups spent a large proportion of the day at rest. Both groups were more active prior to feeding. Outside of feeding times the quantity of activity was influenced by the weather, in dry conditions pigs spent outside time manipulating tactile materials. Although the pigs in the outdoor areas had considerably more space and greater opportunity to demonstrate natural foraging behaviours, activity levels were similar for both groups. Neither group demonstrated stereotypic behaviours associated with stress.

4.3 Results

The data demonstrated that in this experiment the OA pigs took an average of 10 days longer to fatten (Table 7). This resulted in an additional 25 kg of feed being consumed per animal, along with additional costs associated with keeping the pigs for a longer period. An analysis of variance performed on the transformed daily live weight gain (DLWG) data for the two types of housing found there to be no significant difference in this result (Table 8). The influence of the sex of the animals was not significant.

The kill-out percentage for the pigs on the two treatments was very similar. Small group sizes prevented this figure from being analysed. Back-fat data was incomplete preventing this information from being used in the comparison.

Table 7: Performance data from Experiment 1

Treatment Group	OA	YA
Number in group	9	8
Liveweight at slaughter (kg)	99.6	99.4
Kill out %	73.5	75.5
Days on trial	158	148.5
Total feed consumed (kg)	300	276

Table 8: Analysis of variance data from Experiment 1

Term	Coefficient	SE Coefficient	T-Value	P-Value	VIF
Constant	-0.0227	0.0554	-0.41	0.682	
Sex	0.0627	0.0554	1.13	0.259	1.01
Housing	0.0892	0.0554	1.61	0.109	1.01
Housing*Sex	0.0336	0.0554	0.61	0.545	1.02

The results indicate, due to the high standard error in relation to the effects of the coefficients, that there is no significant effect due to either sex or housing. The descriptive data (Appendix 2) shows that, while not statistically significant, there was a measurable difference in daily live weight gain between housing systems. The daily live weight gain of the YA animals was 0.52 kg/d, compared to 0.48 kg/d for the OA group.

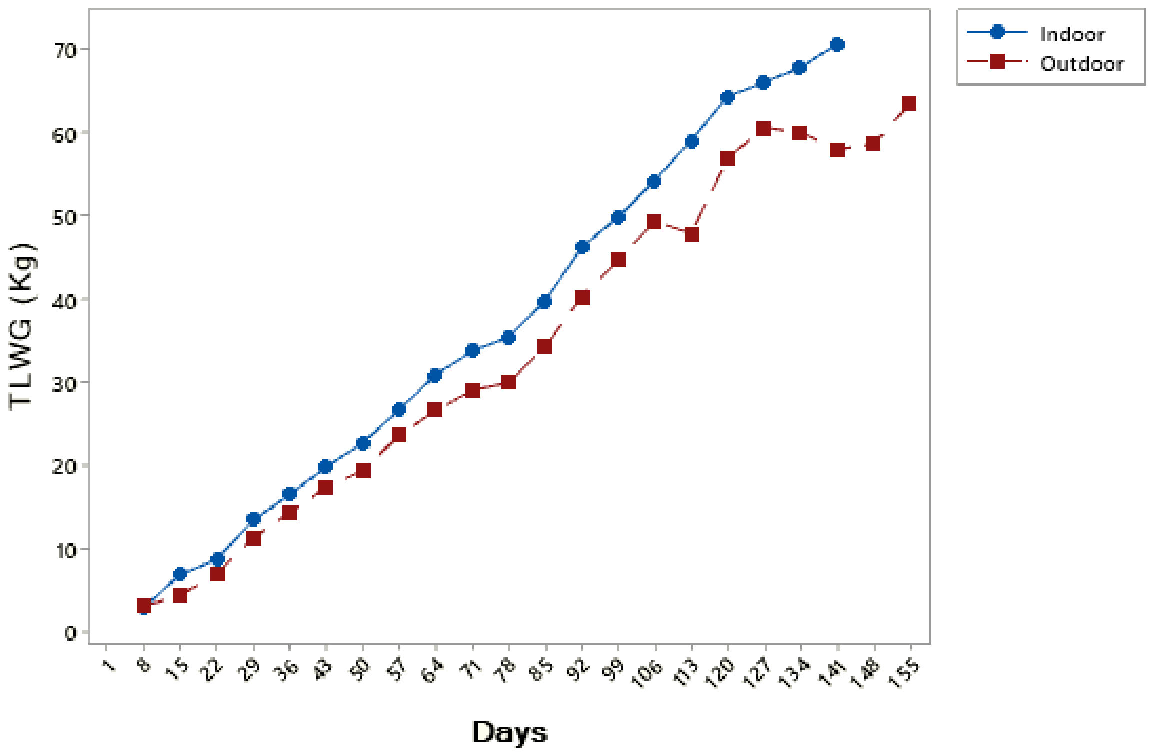


Figure 3: The effect of housing type on the mean weight gain of finishing pigs
* means were calculated from animals within the same group

4.4 Discussion

When investigating the growth rate of pigs kept outdoors and in high welfare traditional straw pens with access to outside, the results demonstrated that there was no significant effect on growth rates between treatments. However it should be noted that the data in this study was collected from a single group for each treatment, to draw conclusions replication of the experiment would be required. When examining how closely the data are fitted to the regression line using R-squared, the proportion of total variation explained by the model, the value was very low (R-sq = 1.26%). The poorness of fit of the model along with uneven spread of observed values on the regression model of the transformed data support the need for the study to be repeated for its findings to be of merit.

There was an increased finishing time of 10 days for pigs reared outdoors. This would incur an additional requirement of 25kg of feed per animal, representing a 9% increase in feed intake. This is approximately in line with other studies investigating the performance of outdoor reared pigs (Gentry *et al.* 2004; Kelly *et al.* 2007). The increase in feed required to finish OA animals in this study is slightly lower than that of the others reported. This is possibly due to the YA group also having access to an outside area with additional maintenance costs associated with activity and thermoregulation. This could also have been an indication that the breed being used was of a higher genetic suitability for outdoor rearing (Kelly *et al.* 2007).

The additional feed cost, and the associated increased labour costs of the extended rearing period for OA pigs would have a marked effect on the profitability of an outdoor rearing enterprise. Across the UK pig industry feed cost represents 80% of variable costs and 64% of total production costs (Davis, 2017).

The increased feed cost would, to some extent be offset by savings elsewhere in the production system. The extent to which these influenced overall profitability would depend greatly on individual unit criteria. There is a lower initial capital investment expenditure, in terms of buildings and waste management, and subsequent depreciation cost associated with outdoor systems (Thornton, 1988). The inclusion of pigs as part of an arable rotation has been shown to increase soil fertility and reduce the requirement for artificial nitrogen fertilizer in subsequent crops (Williams *et al*, 2005), however nitrogen leaching can be a problem if not appropriately managed.

This small scale study demonstrated a reduced labour requirement for pigs kept outside, the animals housed inside required cleaning out on a daily basis and fresh straw weekly, which amounted to approximately two additional hours of labour a week. The design of commercial outdoor units does not lend its self to the high levels of mechanisation seen in indoor units (Honeyman, 2005), with an increased labour cost associated with feeding, monitoring and handling compared to modern indoor facilities.

Considerations would have to be made in relation to environmental factors and typography (Danks and Worthington, 1997). The suitability of the farm to accommodate a large scale outdoor rearing unit would influence its financial viability.

With regard to animal welfare, clear advantages are demonstrated in both systems when compared to intensively reared pigs housed on concrete slats, advantages when comparing outdoor systems to keeping pigs in high welfare straw yards are less identifiable. It has been observed that animals kept in both systems demonstrate similar levels of natural behaviours including rooting and manipulating bedding (Guy *et al*, 2002). Animals in both groups demonstrated 'foraging' activity, this was mostly spent outside in fine weather and indoors in inclement conditions, however all animals spent a large portion of their day at rest. One reason for this general low level of activity observed could be the plane of nutrition the animals were on. Pigs in both groups were being given at diet designed to meet appetite, so the drive to root and search for additional food in their environment was diminished (Ewbank, 1974). Another factor influencing this may have been that all observations took place during working hours in the daytime. Domesticated pigs are descended predominantly from Eurasian wild boar (*Sus. Scrofa Scrofa*), although other species were domesticated (Oliver, Brisbin & Takahashi, 1993). These boar inhabit wooded and shady areas and being most active at dusk and dawn. While adaptive, it has been shown that modern domesticated pigs maintain a preference for low levels of light, being more active and less stressed under these conditions (Taylor, 2010).

The findings of this trial were generally in line with others previously conducted (Gentry *et al*, 2004; Kelly *et al*, 2007), while not significant, there was a penalty in terms of feed conversion to rearing animals outdoors and this would have a noticeable financial cost to the farmer. The ability to recoup this by way of selling the pork at a premium for being 'High Welfare' or 'Free Range' is unclear. Studies on consumer opinion have indicated a strong drive towards healthy high welfare pork, however the same study has shown that the level to which this opinion is supported by additional spending is considerably lower (Krystallis *et al,* 2009).

The availability of suitable land is another consideration influencing the extent of take up of outdoor rearing enterprises. Most of the land of this type in pig producing areas is already being used for dry sows and outdoor breeding systems, these enterprises possibly being more suited to this type of production as the animals are not in the growing phase and are fed a maintenance diet for much of this period.

Both the rearing systems examined demonstrate similar levels of animal welfare in regard to previously described indicators (Millet *et al.* 2005) and there is little evidence of production or financial advantage to outdoor rearing over animals kept in straw yards. There is potential to educate the consumer as to the benefits of both of these systems over intensively reared pork in terms of animal welfare, changes in consumer opinion and trust in the product could increase their willingness to pay a premium (Muringai *et al*, 2017).

5. Experiment 2: An investigation into the utilization of maize silage incorporated into the diet of pigs and its effect on growth performance.

5.1 Materials and Methods

5.1.1 Introduction

The following study was undertaken to investigate the effects on growth rate on rearing pigs given two different diets. The study compared animals on a diet of pelletized sow and weaner compound feed with those given a ration where 40% of the pelletized feed had been substituted for maize silage, on a dry matter basis.

5.1.2 Location of study

The experiment was conducted at Duchy College's West Combs Head Farm, Callington, Cornwall, PL17 8PB. in 2017. The animals used were farm produced British Lop cross Welsh pigs.

All pigs were kept in accordance with Code of Recommendations for the Welfare of Livestock: Pigs (DEFRA 2003) and with respect for the five animal needs. Every effort was made to avoid distress in the handling and caring for the animals used. Health and welfare will be monitored daily by independent professional practitioners experienced in managing pigs and pig welfare, close attention was paid to the pigs at the start of the study to ensure the experimental diet had no adverse effects. Any animals adversely affected by treatments would have been removed from the experiment.

5.1.3 Animals used

A group of 17 farm bred British Lop cross Welsh piglets, from two litters, born on 27^{th} October and 25^{th} November 2016, (totalling 8 males and 9 females), were used for this study. All animals were genetically similar, both litters sired by the same boar, from sows of the same genetic line. All piglets were treated the same from birth, reared by their mothers until weaning at six weeks of age. Weaned piglets were fed *Ad lib* BOCM Farm Gate Sow and Weaner pellets, in accordance with the practices of the farm. When the younger group had reached 8 weeks of age the two litters of pigs were mixed, they continued to be fed *Ad lib*.

On 24^{th} March 2017 the piglets were weighed and allocated to one of two treatment groups, according to sex and live weight to ensure that the groups were similar. This was achieved by allocating the heaviest male to group 1 and the second heaviest to group 2, working through the piglets until all the males had been allocated, followed by the females. The piglets were placed into one group of eight and one group of nine, as there was an odd number of animals and a single piglet could not be reared by its-self outside of the experiment. The larger group was assigned the all pelletized diet, there were five females and four entire males (PD group). Four females and four entire males were assigned the high fibre diet containing maize silage (FD group).

5.1.4 Animal Nutrition

Both groups of pigs were initially offered 2.5 kg per head per day of BOCM Farm Gate sow and weaner pelletized feed, split into two meals. One week into the experiment, when the groups had settled, one kg of pelletized feed was substituted for 1 kg of farm produced maize silage, on a dry matter basis, for animals in the FD group. The diet of the PD group was not altered. The ration for both groups was split into two feeds and remained unchanged for the duration of the experiment. The pelletized feed was offered in a trough and the silage was placed in a half barrel feeder. The silage and the pelletized feed were allocated at the same time.

The inclusion rate for maize silage used in the diet of FD group was decided upon after the following considerations were taken into account.

- The level of nutrients, in particular protein, in the diet must not drop to a level which would have a detrimental effect on the health of the animals;
- Maintenance requirements for energy must be exceeded throughout the trial; and
- The intake of fibre should be sufficiently high to be able to make observations on its utilization within the diet.

Silage was substituted on a dry matter basis, thus ensuring maximum uptake of the silage, driven by dry-mater intake, while minimising the opportunity for the animals to select the grains out of the silage in preference to the more fibrous components (Table 9). The nutrient density of the two diets used (Table 10), met the recommended energy requirements for growing pigs, however the high fibre diet was lower in protein and lysine than recommended (Table 11).

Table 9: Nutrient Composition of Feedstuffs used in Experiment 2

Feed	BOCM Farm Gate Sow and Weaner Pellets	Farm Produced Maize Silage
Dry Mater Content	86%	35%
Protein	16%	8.50%
Energy	13MJ DE (12.48 MJ ME)*	11.5MJ ME

*Approximated using conversion ratio 0.96 (Noblet *et al*, 1994; NRC, 1998)

Table 10: Nutrient content of diets used in Experiment 2

		Pelletized Diet (PD)	High Fibre Diet (FD)
Sow & Weaner Pellets (Kg Wet weight)		2.5	1.5
Maize Silage (Kg Wet weight)		-	2.5
Total Energy	MJ ME	26.8	26.2
Total Protein	g CP	344	281

Table 11: Nutrient composition of feeds used in Experiment 2

(Per Kg DM)	Recommendations for growing pigs	BOCM Sow and Weaner Pellets	Maize Silage	High fibre diet fed to FD group
Digestible Energy	11.6MJ	13.0MJ	12.0MJ	12.6MJ
Crude Protein	15.50%	16%	8.50%	13%
Lysine	0.95%	0.75%	0.20%	0.53%
Methionine	0.28%	0.28%	0.12%	0.22%

Recommendations taken from Newcastle Handbook of Feeding Organic Pigs (Edwards, 2002) and adjusted to a dry mater basis

5.1.5 Management of the treatment groups

The day to day management of the pigs was carried out by college staff and students as part of their practical duties, overseen by experienced farm staff. All codes of practice in regard to husbandry and welfare (DEFRA 2003) were adhered to, close attention being paid to the pigs at the start of the trial to ensure the experimental diet had no adverse effects. Provision was in place to remove any sick or injured animals from the experiment and take appropriate actions. Feeding was carried out morning and evening, at approximately the same time each day, care being taken to make sure all pigs had equal access to the troughs. Fresh water was available at all times. The pigs were monitored on a daily basis in respect to welfare and if there were any concerns action was taken immediately.

Four weeks into the trial both groups were split according to sex to prevent any unwanted mating. A second identical pen was set up for each treatment to ensure that the trial was unaffected, all feeding and husbandry was continued as previously described.

5.1.6 Live-weight recording and carcass quality

Pigs were weighed individually on a weekly basis from the start of the trial using the same protocols set out in experiment 1 using the same equipment.

When individual animals reached slaughter specification, in excess of 90 kg for males and 100 kg for females, they were removed from the trial and sent to the abattoir. The feed for the remainder of the group was adjusted to maintain the same individual diets.

Pigs ready for slaughter were treated in the same way as those in experiment 1, being weighed before leaving the farm and transportation being undertaken by farm staff with all regulations being adhered to. The P2 fat probe measurement was collected from the abattoir.

5.1.7 Statistical analysis

The data obtained for total growth and weekly growth were analysed using the Minitab [18] statistical package to establish whether it was normally distributed. The data was found to be not normally distributed and a Kruskal- Wallis test was used to investigate the effect diet type had on daily live weight gain. Sex was also included in the model, however treatment differences due to sex were minimal.

5.1.8 Interpretation of the level of energy utilization from the high fibre diet

Live weight gain data collected from the two groups of animals was used to determine the level of utilisable energy available to the pigs in the FD group from maize silage portion of their diet. The following presumptions were made in order to calculate this:-

- The maintenance requirement for animals in both groups was the same.
- All energy from the diets surplice to maintenance was used for growth, as determined by weight gain.
- The energy required for one kg of gain was the same for animals in both groups.

The energy required for maintenance was calculated using the following formula. Maintenance energy requirement = 739 kilojoules per kilogram of metabolic weight, this being the mean of the values found by experimentation, discussed in the literary review.

Having established the maintenance requirement for the animals in the PD group, the energy required to produce 1 kg of live weight gain was calculated by dividing the surplus energy in the diet by the LWG of the animals. This figure was then used to calculate the total available energy in the diet of the FD group.

5.2 Observations

It was observed that shortly after the trial diet had been introduced. The pigs in the FD group adopted different feeding habits. Several of the pigs in the group leaving the pelletized feed and going to the maize silage on its arrival and selecting the kernels in preference. Other pigs ran from one feed to the other and back, while others remained with the pelletized feed until it was completely consumed before eating any silage. This behaviour was not expected and may have been a result of one or a combination of factors.

- Different levels of dominance of individuals within the group. Those of a lower status being pushed away from the pelletized feed.
- Individual pigs selecting the high energy kernels from the maize silage. The energy density of maize grains is 14.5MJ (Edwards, 2002), this is higher than that of the pelletized feed given, however the protein level is lower.

The group was not monitored regularly enough during the feeding period to establish whether these observations related to specific individuals or were random occurrences. The status of individuals within the group was not established.

The silage component of the feed took longer for the group to eat, with some of the more fibrous components remaining uneaten.

At feeding times no one group appeared more hungry than the other with both groups calling for their feed. Other behaviours were similar in both groups, although due to the nature of the fibre diet, the pigs in the FD group took longer to consume their feed and remained active for longer after feeding time. It was observed that the pigs on this diet would periodically get up on an individual basis and root through the fibrous silage which had been left. This could have been searching for additional sustenance, or demonstrating natural foraging behaviours.

5.3 Results

The summary of data (Table 12) demonstrates that individual pigs in the FD group ate approximately 60 kg less pelletized feed over the course of the trial than those in the PD group, they also ate 250 kg of maize silage per head. The pigs in the FD group took 18 days longer to finish than those in the PD group.

Table 12: Mean performance data from Experiment 2

	PD Group	FD Group
Number in group	9	8
Liveweight at slaughter (Kg)	100.9	96.9
Kill out %	75.4	74.4
Days on trial	84.9	102.5
Total feed concentrates (Kg)	212.2	153.8
Total Feed Maize (Kg)	_	256.3

When examining the data for individual animals (Appendix 3) in regard to kill-out and carcass composition it should be noted that pig No.148 in the FD group had an exceptionally low back fat reading. The pig also lost 5 kg between its final weekly weighing and the weight recorded on the day of slaughter. This may indicate an underlying condition in that animal’s health which, while showing no clinical signs, caused the animal to lose weight in the form of body fat in the last week before slaughter. Pig No. 143 in the PD group also had an uncharacteristically low back fat measurement. Taking out these atypical results, the level of back fat is 1.5 mm greater in pigs fed on the diet containing maize than in pigs fed conventionally, this equates to an 11% difference. The kill-out percentages of animals in both groups were very similar, was be noted that the both animals with unusually low back fat measurements had a high kill-out percentage.

The LWG data collected from experiment 2, having been shown to be non-parametric, was analyses using the Kruskal-Wallis Test to determine whether the medians of the two growth rates of the groups differed, using diet as covariate. The results indicate that there was no significant difference in the LWG of the pigs in the two groups (P=0.078), therefore it is concluded that the type of diet had no effect on the growth rate in this study.
The P value was slightly lower when adjustments were made for results with the same value, however the value not adjusted for ties was used for these results. The Z-value of those animals in the FD was negative, indicating that the group's mean rank was lower than the overall average rank, similarly the PD group's average rank was above that of the overall. This indicates, that while not statistically significant, the animals on the fibre diet did not perform as well as those on the pelletized. This is demonstrated in the descriptive data (Appendix 3) which showed a DLWG of 0.54 Kg/d for the PD group and 0.42 Kg/d for the FD group. As pigs are selected for slaughter the mean total weight gain for the remaining animals in the group is affected, resulting in the fluctuations seen towards the end of the experiment (Figure 4 and 5).

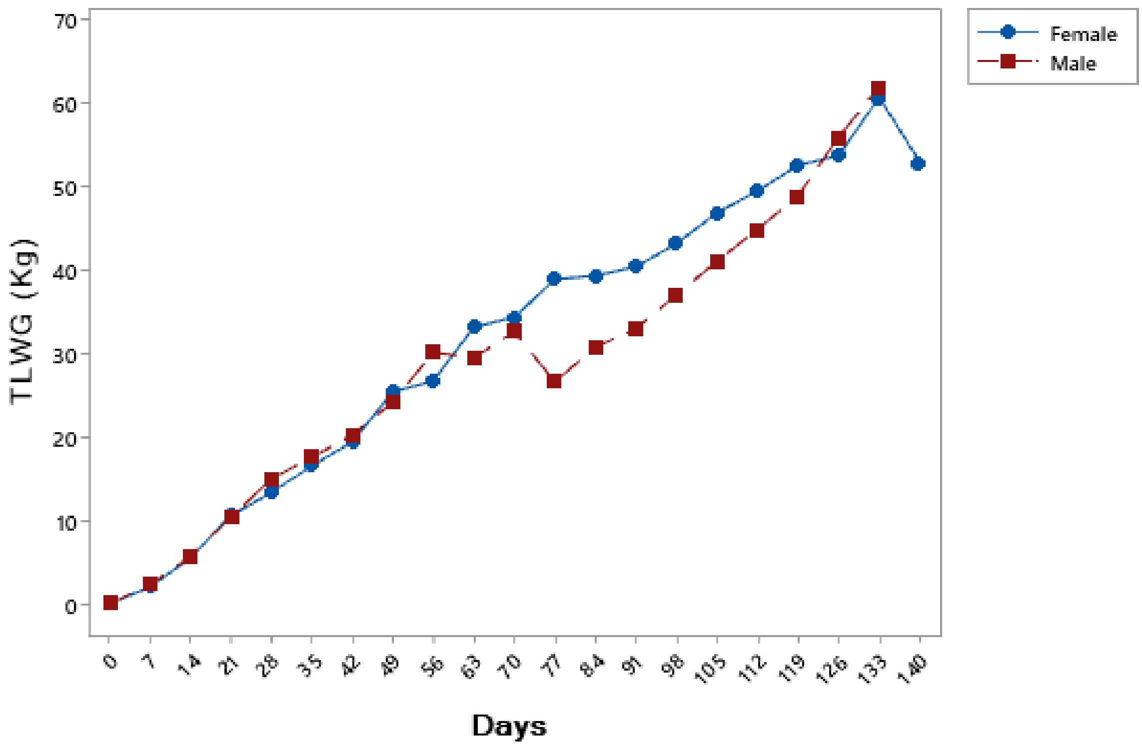


Figure 4: Mean total live weight gain of animals in Experiment 2 in relation to sex * means were calculated from animals within the same group

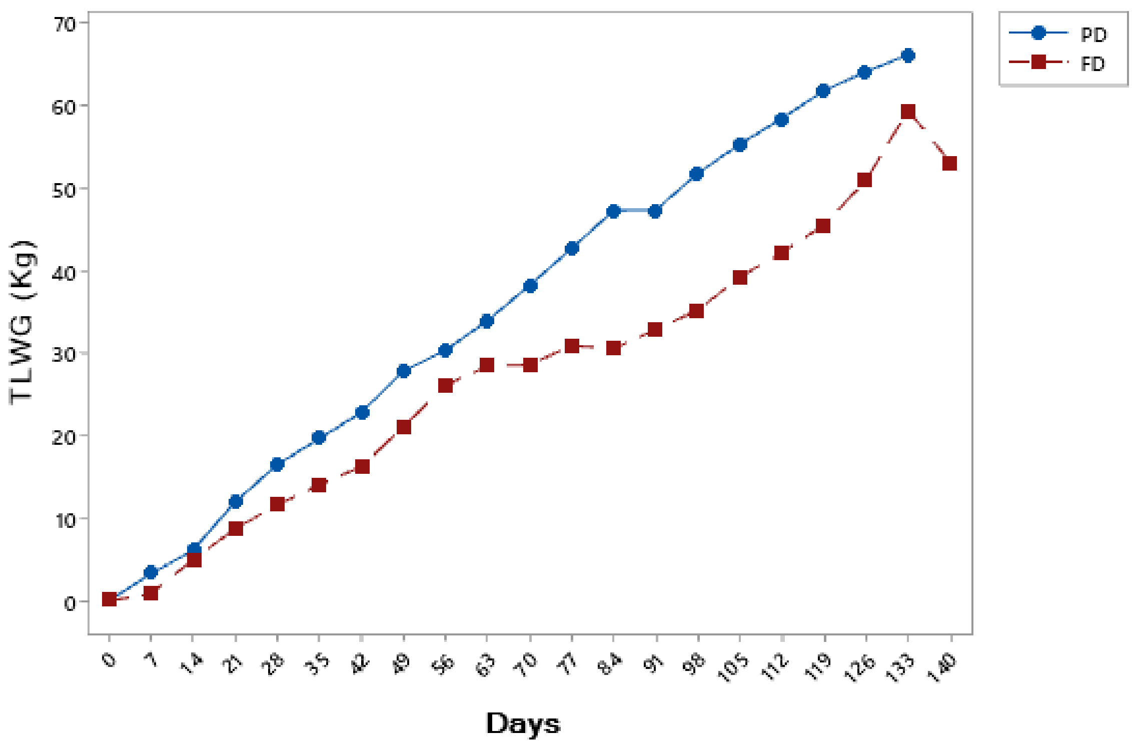


Figure 5: Mean total live weight gain of animals in Experiment 2 in relation to diet * means were calculated from animals within the same group

5.4 Calculations for the utilization of energy from the maize silage portion of the diet of pigs fed the high fibre diet.

The following formula was used to calculate the maintenance requirement for the pigs in experiment 2.

$$ME_m = 739\ KJ \times Kg\ Liveweight^{0.60}$$

The surplus energy in the diet of the PF group, along with the group's total LWG was used to calculate that 33.59 MJ metabolic energy was required to produce 1 kg of live weight gain for animals in this group. This figure was used to calculate the total utilizable energy derived from the maize silage portion of the diet in the FD group (Table 13). The assumptions were made that the surplus energy in the diet was used exclusively for growth and that the energy required for LWG was the same for animals in both groups.

Table 13: Calculated surplus energy and total weight gain for both feed groups

	PD Group	FD Group
Total Energy from pelletized Feed	20,500 MJ	13,202 MJ
Total Energy for Maintenance	7,435 MJ	7,802 MJ
Energy Surplus to Maintenance	13,065 MJ	5,400 MJ
Total Live Weight Gain	389 Kg	343 Kg
Energy Required for 1 Kg of LWG	33.59 MJ	
Weight Gain Attributed to Pelletized Feed	389 Kg	160.8 Kg
Weight Gain Attributed to Maize Silage	-	182.2 Kg

A total of 182.2 Kg of live weight gain could be attributed to the maize silage portion of the diet, this equated to 6,117.9 MJ of ME. The group consumed a total of 2,050 Kg of fresh silage. The pigs were able to utilize 2.98MJ ME /Kg of fresh maize silage. This equated to a utilizable ME 8.5MJ /Kg maize silage, on a dry matter basis.

5.5 Discussion

5.5.1 Effect of diet on growth rates and carcass composition

The investigation into the effects on growth of pigs given an alternative higher fibre diet containing maize silage and pelletized feed, demonstrated that there was no significant difference in performance compared to that of animals on a diet comprising solely of pelletized feed. This result differed from previous studies into pigs which have had a portion of the pelletized diet substituted with high fibre forage (Danielson *et al*, 1999; Hansen *et al,* 2006), which demonstrated a significant decrease if LWG. Dietary fibre having been shown to depress appetite (Takehashi and Horiguchi, 2005), as well as decreasing the animal's ability to utilize energy and protein from within the diet (Takehashi *et al*, 1988; Noblet *et al*, 1994; Hata and Koizumi, 1995).

One explanation for this is that pig are better able to utilize the nutrients from maize silage than they are from grass and cereal silages used in previous studies. The analysis of energy yield from the high fibre diet indicated that the pigs in the FD group were able to utilize 74% of the available metabolisable energy from the maize silage. However the group sizes used in this experiment must be considered as an influencing factor, while there was no statistical difference, the empirical data indicated a 20% decrease in LWG, broadly in line with studies by Danielson *et al*, (2000), Strudsholm and Hermansen, (2005) and Hansen *et al,* (2006).

5.5.2 Extraneous factors which may have influenced maintenance requirements and growth of pigs in both groups

In examining the validity of the comparisons made between the performances of the two groups of pigs, factors outside of diet which could affect the nutritional or maintenance requirement of the animals were identified and the possible influence examined.

The assumption was made that the energy requirements for maintenance and growth were identical for all the pigs in both groups. The two groups of animals were genetically very similar, however differences between individual animals may have influenced results, the group sizes were small and although variation was low, the potential for individual animals to perform differently, irrespective of diet, is a real one (Rehfeldt and Kuhn 2006). Environmental and husbandry factors were standardised to minimise any influence on performed throughout the experiment.

Different diets have been shown to directly affect the maintenance requirements of pigs. Evidence shows that high fibre diets have a higher energy requirement for digestion than compound feeds (Wiseman and Cole, 1985) along with a depressed level of nutrient utilization (Takehashi *et al*, 1988; Noblet *et al*, 1994; Hata and Koizumi, 1995). The presence of additional fibre in the diet of pigs depress appetite (Takehashi and Horiguchi, 2005). Additional incremental increases in the energy required to digest the diet along with lower utilization and feed intake, were not taken into account in this study, however as the experiment was examining net utilization in relation to LWG, these factors would be taken into account within overall performance of animals in the FD group.

The pelletized feed, while not all being from a single batch, was all produced by one manufacturer and was presumed to be consistent in nutritional constituents. The nutrient value of the maize silage was likely to be less consistent. Small quantities of silage were fed over the duration of the study, coming from different areas of the clamp which was also being used to feed dairy cattle. This was likely to cause small variations in the energy density of this feed, this was not adjusted for in the calculations.

Animals were fed at a constant rate throughout the experiment. As the animals gained weight, their requirements of maintenance increased, reducing the surplus energy within their diet correspondingly. It has been shown that feed conversion efficiency increases as total surplus energy decreases in the diet (Close and Fowler, 1985). This would have influenced the animals in the FD group to a greater extent than those in the PD group as available nutrients in their diet were already lower (Takehashi *et al*, 1988; Noblet *et al*, 1994; Hata and Koizumi, 1995), increasing their feed conversion efficiency and potentially increasing LWG.

Consumption was consistent throughout the experiment, all concentrated pig feed was consumed at all times and while a small portion of the silage was left, this quantity was constant throughout, and presumed to be the least palatable portion.

5.5.3 The validity of calculated energy requirement for maintenance and growth

As discussed in the review of literature, there are many variations on the formula used for calculating the maintenance requirement for growing pigs (Everts, 2015). The figures used in this experiment were the mean of those put forward in current thinking. The wide range of values proposed through the studies summarised in Table 5 would indicate a high opportunity for the calculations used in this experiment to be different from actual values for maintenance requirement and tissue production. Any inaccuracies in calculations, as the same figures were used for both groups, would not affect the proportion of contribution made by the maize silage to the diet, only the absolute value of the energy gained from it.

5.5.4 Comparing energy requirement of live weight gain

In calculating the energy required for live weight gain it was presumed that the body composition of the animals in both groups was identical. At the start of the experiment, the animals were selected from two litters in a way which would support this assumption. At the end of the experiment the composition of carcasses of the animals in the two groups was not the same. The total lean content of the pigs in the FD group was 2% lower than those in the PD group, extrapolated from the P2 fat probe readings. Taking the proportion of bone and internal organs to be similar for animals in both groups, those in the FD group laid down more fat during the trial. More energy is required to lay down 1 Kg of fat compared to 1 Kg of lean tissue, 53.5 MJ ME and 43.9 MJ ME respectively

(Close and Fowler, 1985). Animals in the FD group would have required more energy to produce 1 KG of live weight gain. This was not allowed for in the calculations and may indicate that total energy utilization from the maize silage was higher than calculated using this direct comparison model.

While the factors discussed highlight the opportunities for errors and inaccuracies in the results, most would be small or cancel each other out. The calculation of total energy utilisation from the feed being the sum of energy required for maintenance and that used for tissue production in terms of LWG was a valid approximation to examining the total energy available to the pigs fed on the diet including maize silage.

5.5.5 Calculating the feed value of maize silage

Each kilogram of fresh silage provided 2.98 MJ of utilisable energy to the diet. This equates to 8.51 MJ per Kg DM, indicating that the animals were able to utilise 74.1% of the total metabolic energy available in the silage.

The level of utilization of the silage was not constant throughout the experiment. In week one the maize silage had a negative effect on total energy utilized from the high fibre diet. As the experiment continued the pigs' ability to take advantage of the energy in the diet increased (Appendix 5).

The initial negative affect can be explained by the sudden change in diet as the experiment started. The apparent increase in utilization during the trial could be influenced by two main factors. As stated previously utilization of feed increases as overall total available energy after maintenance decreases (Close and

Fowler, 1985), a condition which applied to the animals in this study. The second factor to be considered is that of microbial digestion, or fermentation was taking place in the large intestine (Varel and Yen, 1997). This would have taken time to establish, and as the gut fauna developed, the ability for the animal to breakdown cellulose, turning it into useable energy, would increase. The scatter plot (Figure 6) demonstrated a moderate increase in the efficiency of energy utilisation. It should be noted that the error range is high, with variable results for individual animals on the plot. The group size was too small to allow any further analysis of this observed trend. The affect is most likely to have been caused by a combination of an increased efficiency due to lower nutritional status and an increase in microbial digestion.

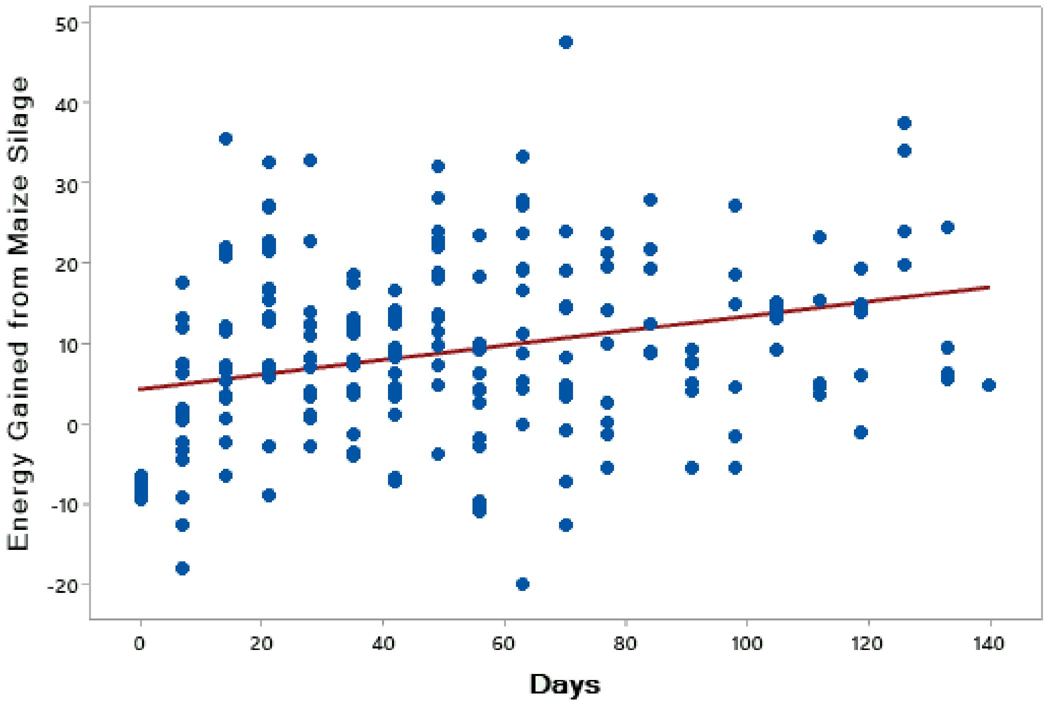


Figure 6: Energy gained from silage in diet as experiment progresses

5.5.6 The economic implications of feeding maize silage to pigs

As stated in the introduction, the single largest factor influencing the profitability of pork production is the cost of feed, being 87% of variable costs (Redman, 2018). This experiment has been established that 2.5 Kg of maize silage (fresh matter) had the equivalent feed value as 0.73 Kg of sow and weaner nuts (fresh matter). Using current UK farm management data (Redman, 2018), the comparative costs of the two diets has been calculated (Table 14). The daily cost per animals of the two diets was 68.75p for the PD group and 47p for the FD group. This equates to a saving of approximately 32%. When the extended finishing time was considered, the overall saving in feed cost was17.2% per pig in the FD group (Table 15).

Table 14: Equivalent costs of feeds used in Experiment 2

	Price per Tonne	**Price per Kg**	**Equivalent Prices**
Sow and Weaner Nuts	£275	27.5p	0.73 x 27.5p = 20.07p
Farm produced Maize silage (including fixed costs)	£23.41	2.3p	2.5Kg x 2.3p = 5.8p

(Costings data from Farm Management Pocket Book (Redman 2018))

Table 15: Comparison of costs of the two diets used in Experiment 2

	Pigs in PD Group	Pigs in FD Group
Total Concentrates Consumed	212.2Kg	153.8Kg
Total Maize Silage Consumed	-	256.3Kg
Cost of Concentrates	£58.36	£42.30
Cost of Maize Silage	-	£6
Total cost of feed	£58.36	£48.30

Commercially there would be a financial penalty for the increased levels of fat seen on the carcasses of animals fed the high fibre diet. Marketing meat produced this way may be difficult as consumers selecting on appearance have been shown to choose leaner, darker joints with lower levels of fat (Brewer *et al*, 2001; Rincker *et al,* 2008).

The addition of fibre to the diets of pigs has been shown to have a positive effect in regard to digestive health and a reduction in nitrogen emissions (Wang *et al*, 2018). The increase the population of ‘good’ bacteria in the ileum, reducing the incidence of more detrimental microorganisms such as e-coli (Yang and Liao, 2019), giving the scope to reduce the levels of antibiotics used in the rearing process.

While the financial advantages shown are clear, the performance of the pigs on this trial was lower than comparable commercial systems in regard to growth rate and lean tissue production. Reasons for the lower level of production overall for animals on the trial have been identified as breed and activity levels, however the further decreases seen in the group fed maize silage are assumed to be a result of the diet.

The main factors which influence growth and lean tissue production, relating to diet, in growing pigs are energy and protein (CAB 1981). Studies have shown that the carcasses of animals fed a low protein diet contain higher levels of both intermuscular and intramuscular fat (Castell *et al*, 1994; Carpenter, O'Mara and O'Doherty, 2004), this however is not conclusive (Kerr *et al*, 2003). The diets used in this trial were formulated to balance dry matter content, not protein or energy, this was to ensure a high level of intake of the fibrous feed.

The two feeds used balanced in terms of energy and are in line with recommendations for growing pigs (Table 10), however when looking at protein levels the high fibre diet is considerably lower than both the concentrate diet and the recommended level. The level of lysine in the diet is approximately half the recommended level, although it should be noted that the concentrate diet is also below recommended levels (Edwards, 2002). Low levels of essential amino acids in the diet lead to poor utilization of protein to manufacture lean tissue, lysine is often the first limiting amino acid in a pig's diet. This would explain the high fat content in the carcases of the animals fed the high fibre diet, surplus energy which cannot be used for protein synthesis is used to lay down fat (Zhang et al, 2011).

There is some evidence that the small intestine of the pig, as well as being a major site for the absorption of dietary amino acids, is also a site for the absorption of microbial proteins from the gut itself. While this is a possible source of additional amino acids, including lysine, from non-protein nitrogen in the diet, this effect has been shown to be relatively small (Dai et al, 2011; Liao, Regmi and Wu, 2018). Any increase in this effect through the feeding of a diet high in digestible fibre and subsequent changes in microbial populations in the gastrointestinal tract of the pig are unproven.

The utilization of energy from the maize silage in the fibrous diet was high (74%), however there is scope for improving lean tissue synthesis. The inclusion of different whole crop silages higher in available protein, such as those containing peas or beans, or the addition of a high protein supplement to the diet at lower levels, have the potential to improve both carcass composition and growth rate while still being able to reduce overall feed costs. These theoretical benefits are yet to be tested.

6. Investigating the effect of a high fibre feed on the taste of prepared pork, using a simple preference test.

6.1 Materials and Methods

6.1.1 Tasting protocol

A comparison taste test was conducted on pork produced from animals reared on the two different diets in Experiment 2 using untrained members of the public. Participants were asked to identify which of two prepared meat samples they preferred or to register that they could detect no difference between them.

The tasting was carried out at an open day and food festival held at Duchy College, Callington, Cornwall, PL17 8PB on 24th June 2017. The event was attended by approximately 1,500 members of the public. The selection of participants was completely voluntary. It was not possible to perform the sampling under controlled conditions free from noise smell or distraction, as set out in BS 5929 Part2 1982 Sensory Analysis of Food Part 2 Paired Comparison Test. Efforts were made to minimise any variation in conditions for individual participants while the test was taking place. The sampling was carried out in a single fixed location in the hall and the tasking took place over a single two hour period. It was felt that the deviation from the protocol was compensated for by the large number of participants of both sexes across a wide age range provided by the venue.

6.1.2. Selection of animals used

The two animals selected for the tasting, No.147 from the PD group and No.136 from the FD group, were both male, weighed 57 kg when they entered the trial and both were on the trial for 75 days. At slaughter the carcasses were of similar weight, however their composition differed, the FD animal had a lower killing out percentage (72% compared to 74%) and a higher fat probe reading at the P_2 position (18 mm compared to 16 mm). Meat from the shoulder of both pigs was used.

6.1.3 Preparation of Meat

The two selected animals were slaughtered at the Cornish Bacon Company on14th June 2017, ten days before the taste test. The following week the carcasses were sent to the butcher where two shoulder joints, on the bone, were prepared. The two joints were roasted in the same oven together by members of Duchy Colleges catering staff the day before the tasting. The joints of meat were allowed to cool, trimmed to remove excess subcutaneous fat and diced. The meat was labelled and kept refrigerated until needed for the taste test the following day.

6.1.4. Carrying out the tasting

A table was set up close to one end of the food hall and an information poster was displayed explaining the background to the feed trial, the diets the two pigs had been on and the rational for carrying out the taste test (Appendix 6). The composition of the sample group included a broad range of ages across both sexes, as reported in the results, however the ethnicity of those participating was almost exclusively White British, this was a fair reflection of those attending the event. Clear instructions were displayed on the table stating the correct way to carry out a comparison test. The instructions stated;

First Take a Sip of Water

Then Try one sample of pork

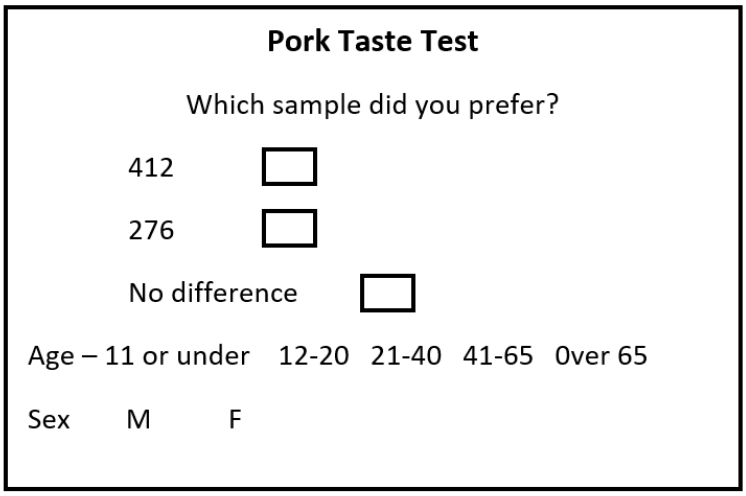
Take a second sip of water

Try the second sample of pork

Record your preference on the form provided.

Still spring water was provided, along with disposable glasses, to cleanse the palate. Wooden cocktail sticks were used by the participants to select the samples. The pieces of pork could be selected in any order. A portion of the samples were presented on two metal trays, each identified by a random three digit number. As the tasting progressed more samples were collected from the fridge and this continued until there were insufficient samples left to offer to the public. A simple form was used to record their preferences (Figure 7). The form additionally required that the participants' record their sex and which age category they were in.

Verbal instructions were given where appropriate to participants and completed forms were removed from the table and stored out of sight so as not to influence the decisions of others.



Pork Taste Test

Which sample did you prefer?

412 ☐

276 ☐

No difference ☐

Age – 11 or under 12-20 21-40 41-65 0ver 65

Sex M F

Figure 7: Sample form used for taste test

6.1.5 Statistical Analysis

The data obtained from the taste test were analysed to determine the influence of age and sex of the participants on choice, using Pearson’s Chi Square (Appendix 7).

The results were assessed using a two sided paired comparison test set out in the British Standards Institute ‘Methods for sensory analysis of food’ (BSI 1982), to determine whether a significant preference was detected between the pork samples.

6.2 Observations

All participants, including young children took the activity seriously, accurately following the protocol and giving their answers consideration. It was also observed that while some stated that the samples were similar and it was difficult to choose a preference, others commented that there was a large difference in the samples.

In preparing the two joints for the test it was observed that one of the samples, the one fed maize silage, had notably more subcutaneous fat. This was removed post cooking when the meat from both shoulders of pork were trimmed and samples were prepared for the tasting.

6.3 Results

One hundred and ninety members of the public took part in the tasting, comprising of 105 females and 85 males of varying ages. Of those who participated 107 preferred the pork from animals fed maize silage in their diet, 66 preferred the pork from conventionally fed animals while 17 could detect no difference. The preference for the two samples was broken down in respect to age and sex of participants (Table 16).

Table 16: Preference for samples, split by sex and age of participants

		Preference			**Total**	
Age (years)	**Sex**	Pelletized Diet	Fibre Diet	No Preference		
≤11	Female	9	10	5	24	42
	Male	8	7	3	18	
12-20	Female	3	6	1	10	19
	Male	6	2	1	9	
21-40	Female	11	8	0	19	38
	Male	3	15	1	19	
41-65	Female	15	21	3	39	66
	Male	5	20	2	27	
>65	Female	5	8	0	13	25
	Male	1	10	1	12	
Total		66	107	17		190

A Pearson's Chi Square test was carried out on the results to ascertain whether any one subset of participants exerted more influence on the results than the others (Appendix 7). The distribution of choices between the sexes of the different age groups was as predicted using the Pearson's Chi Square test, indicating that the sex of the participants had no influence on the result across all age groups. The preference selections made within age groups did not always follow predictions. While some categories followed the prediction closely, the results from the lower two age groups differed considerably. The 11 and under had a ‘no preference’ tally twice as high as predicted, they also had an identical tally for the pork from the PD and FD animals, the figure for the FD pork being a third lower than expected.

In order to analyse the data and ascertain any significance from the results of the taste test, those participants identifying no preference were discarded. The low number of these responses, 9%, was an indicator that the samples had a detectably different flavour.

The adjusted results were analysed using the paired comparison test set out in the methodology to ascertain the existence of a preference for pork fed on one of the two diets. The analysis concluded that a preference was identified for the meat produced from the FD animal ($P<0.001$).

When the results were broken down into their age groups a reduced preference was demonstrated in some groups, in particular younger participants did not show as strong a preference, with those 11 years and under showing no preference at all.

When the results from individual age groups are looked at, using the same rules, candidates 21 years and over demonstrated the same preference at the 5% level. The candidates in the youngest two age groups did not identify a significant preference. It should be noted that when carrying out individual age groups analysis, the sample sizes became smaller, making identifying a significant outcome more difficult.

Removing 11 and under group from the sample, for the reasons covered in the discussion, the remainder of the cohort demonstrated a stronger preference for the pork produced from the FD animal, with 90 of the remaining 139 participants selecting this sample.

6.4 Discussion

During the taste test a clear preference was shown for the pork produced from the animals offered the fibre. Of those participants detecting a difference between the samples 107 selected the FD pork compared to 66 selecting the pork from PD animal.

6.4.1 The influence of participants on the result

As stated in the methodology, the taste test was not carried out in the controlled conditions laid down in BS5929 part 2, members of the public attending a college open day and food festive were used. Participants self-selected to be involved, having seen the stand or read the information poster. The sampler had firstly chosen to attend the event and secondly to participate in the tasting. This selection did not ensure a fair representation of the British public, however there was a large number of recipients across a good range of ages. Any influence this process may have had on results would need to be considered along with the following points.

The breakdown of the sexes within each age band closely matched the predicted values, using Pearson's Chi Square, indicating that sex was not an influencing factor in the tasting. When looking at the distribution of choices made within each age group the results differed considerably from those predicted figures. The distribution of responses from the two youngest groups differed considerably from the predictions made using Pearson's Chi Square. The participants in the group11 years and under had a high number of tasters who detected no difference between the two samples, 20%, over twice the rate demonstrated by the group as a whole, with the remainder split evenly between the two samples. The group 12 to 20 years was the only age range to show a preference for the PD pork. These two groups represented almost a third of the total number of participants and they produced a different result from the overall population.

One possible explanation for this is that taste changes with age. The human taste sense is functional from birth with the ability to detect the full range of flavour (Steiner, 1973), however there is evidence that preferences change and develop with age (Cowart, 1981). As a child preference is shown towards sweet and low levels of salt (Mennella, 2018; Cowart, 1981), with a discrimination away from spicy complex flavours (Rozin, 1976). With age the preference switches towards less sweet foods and a greater tolerance for salt and bitter flavours is demonstrated (Desor and Beauchamp, 1987; Mennalla *et al*, 2011).

As the samples were prepared in a plain manner, with no added flavourings or salt, the samples would have been neither sweet nor bitter and differences may have been more difficult to distinguish for these younger participants. This is highlighted by the group of participants aged 11 or under, they showed equal preference for either sample with a large portion detecting no difference.

6.4.2 Factors which may have affected the taste of the samples

6.4.3 The selection of the sample animals

As stated the two joints meat were taken from animals which were as similar as possible within the trial. Both animals were from the same sire, eliminating any effects of breed and genotype (Müller *et al*, 2002; Chang *et al*, 2003; Lefaucheur *et al*, 2004; Wood, 2004). The two selected pigs entered the experiment at the same weight (57 kg), were kept identically in every way except diet, had both spent 75 days in the experiment and were transported to slaughter together on the same day. The meat for both samples was prepared stored and cooked in a similar manner, both samples coming from the shoulder and being cooked on the bone. All animals are individual and while efforts were made to keep differences to a minimum, there was opportunity for genetic differences in the individual sample animals to influence the result (Chang *et al*, 2003; Wimmer *et al*, 2008).

The two pigs selected came from different litters, although genetically similar as the two sows were closely related, however they were different ages. The animal offered the pelletized diet was born on 25th November 2016, while the one offered the fibre diet was born some four weeks earlier on 27th October 2016. Both animals were the same weight at the start of the study, indicating that the older pig did not perform as well during the pre-experiment period. Once on the trial both animals demonstrated the same growth rate. The improvement in performance of the FD pig may have been due to reduced competition at feed time, with silage and concentrates being offered at the same time, or the animals' genetic make-up favouring the utilisation of maize silage (Kelly *et al*, 2007; Edwards *et al*, 1991).

6.4.4 Carcass composition

The two animals were slaughtered at the same weight, however there were differences in carcass composition. The animal on the high fibre diet had a lower kill out percentage, 72%, compared with 74% for the conventional animal. This was broadly in line with the other animals on the experiment, those in the FD group having an average kill-out 1% lower than the PD animals. The dressed carcass of a pig includes head, full limbs including trotters and skin (AHDB, 2018). Differences in kill-out must be a result of increased weight of gut and organs removed and gut fill. This variation was assumed to be a result of a more bulky diet and unlikely to affect the eating quality of the meat.

The two carcasses had differing levels of subcutaneous fat present, as determined by a fat probe at the P2 position. The measurement was 2 mm thicker, at 18 mm, on the pig from the FD group compared to the animal from the PD group. The increased fat level was consistent with observations seen on carcasses of animals from this group in experiment 2. Using the formula set out in the methodology the total lean composition of the two carcasses was calculated. The PD carcass was 56.25% lean and the carcass from the FD animal 54.30%, these being classified as E and U respectively on the European EUROP classification scale (AHDB, 2018). The difference in the level of fat present in the two samples may have influenced the preference demonstrated by the participants, with many studies demonstrating a strong correlation between levels of intramuscular fat and improved tenderness and flavour

(Batcher and Dawson, 1960; Kauffman *et al*, 1964; Davis *et al*, 1975; Ellis *et al,* 1996; Wood *et al*, 2004; Fortin *et al*, 2005). This has not been found to be universal with some studies finding only a weak correlation (Wood *et al*, 1979; Lentsch *et al*, 1991). When using an untrained consumer panel to taste pork with different levels of marbling, Rincker *et al*. (2009) detected no change in flavour between samples and only a slight increase in tenderness and juiciness with an increase in intramuscular fat, however this declined again at the high levels of fat.

The difference between the level of fat in the two test joints of meat is likely to be a factor which would have affected the taste and texture of the samples (Batcher and Dawson, 1960; Kauffman *et al*, 1964; Davis *et al*, 1975; Ellis *et al,* 1996; Wood *et al*, 2004; Fortin *et al*, 2005). How much influence this had is not easy to ascertain as joints were taken from carcasses which were of a markedly higher fat content to those normally produced in the UK.

The animals used for the trial were being produced for a specialist butcher who had requested a high level of fat on the carcass. The average 60 to 80 Kg carcass presented in the UK in 2017 had a P2 back fat reading of 10.2 mm (AHDB, 2018) and an estimated lean content of 61.57%. The animals used in this tasting had a 5% and 7% lower level of lean content. The 2% difference in lean content between the two samples used is relatively small when compared to the deviation from the national average and there is some evident that very high levels of fat have no additional effect on flavour (Ricker *et al*, 2009)

It should be noted that these calculations for comparative fat content were taken from a single probe point and rely on the fat distribution within the body being similar between the two animals used.

When preparing the samples for the taste test, it was observed that the pig on the fibrous diet had visibly more fat trimmed during preparation. This may indicate that there was a greater difference in the fat content of the two samples than indicated by the probe reading (United Kingdom Protocol, 1994). Leaving the two joints untrimmed during the cooking process allowed any influences the different fat levels, both subcutaneous and intermuscular, may have had on flavour to be fully demonstrated (Davis *et al*, 1975; Fortin *et al*, 2005; Rincker *et al,* 2009). The joints of pork were both trimmed when taste samples were prepared to investigate these effects on the flesh. The different levels of total fat within the two sample joints was likely to have had an influence on the difference in flavour detected.

6.4.5 The effects age of carcass may have on eating quality

The pig selected from the FD group for the tasting was approximately one month older than the animal used from the PD group, although the two animals were on the trial for the same length of time and had similar kill-out and carcass weights. studies have reported that carcasses decrease in moisture and increase in intramuscular fat with age (Latorre *et al*, 2003), with effects being observed at age differences as low as 15 days. The level of effect on this trial is likely to be small, due to the high levels of fat present in both carcasses used for the tasting (Rincker *et al,* 2008), however the ages of these animals differed by 29 days. Any increase in intramuscular fat is likely to have a positive influence on flavour, (Kauffman *et al*, 1964; Davis *et al*, 1975; Ellis *et al,* 1996; Wood *et al*, 2004; Fortin *et al*, 2005), while a decrease in moisture was likely to have a negative effect on tenderness and juiciness (Fortin *et al*, 2005). The effect of age is likely to have been small but has to be considered as an influencing factor.

6.4.5 Husbandry slaughter and preparation of samples

The pigs from both groups were treated identically both before and during Experiment 2. They were fed their respective diets twice daily at the same time, all routine handling, husbandry and weighing was carried out consistently for both groups. When selected for slaughter both animals were transported to the abattoir in the farm's livestock box, in separate compartments to reduce stress caused by mixing animals. The journey was approximately 40 minutes without stops and the abattoir used is small with a minimum of waiting time pre slaughter.

Post slaughter the two carcasses were treated in an identical way, being hung for 2 days at the abattoir before collection by the butcher where they were hung for a further 3 days before being butchered, the two joints were collected from the butcher's cold room taken to the college catering department where they were kept refrigerated until prepared for the taste test. The two shoulder joints were roasted in the same over for the same length of time the day before the trial. They were allowed to cool, the excess fat was trimmed off and the meat cut into equal sized cubes approximately 2 cm across, the samples were stored in two separate labelled containers in the fridge until required for the sampling.

The husbandry of the animals, their slaughter, the method of preparation of the samples and their subsequent storage until use was unlikely to have a direct affected the eating quality of the samples. The exception to this being the level of fat trimmed from the joints, post cooking, in their preparation for tasting, this has been discussed previously.

6.4.6 The tasting

While the tasting did not take place in a distraction free environment as recommended in the protocol (BSI 1982) as it took place during a food festival in a hall with numerous other food stalls, many other members of the public and distractions in the form of noise and smells. It was felt that the environment was similar for all participants, the stall being set up in a single place near one of the entrances and took place over a short period of time. Completed result sheets were removed from the tasting area as completed, so that previous results could not influence decision making. It was considered that the similarity of distractions for all those taking part in the trial, while not being ideal, can be discarded as a factor effecting the result of the trial.

Most variables within rearing, preparing and tasting were kept to a minimum by the methodology. It was identified that the main difference between the two samples tested, beyond the diets offered, was the level of fat present. To a lesser extent the age of the animals sampled also gave opportunity to influence the result. Neither the level of intramuscular fat nor the total fat level of the animals was quantitatively assessed, however the level of subcutaneous fat in the animal reared on the silage diet was observed to be higher. The fat was retained during the cooking process and only removed in preparation for the sampling. The levels of both intermuscular and intramuscular fat are likely to have had a positive effect on flavour, juiciness and tenderness (Kauffman *et al*, 1964; Davis *et al*, 1975; Ellis *et al,* 1996; Wood *et al*, 2004; Fortin *et al*, 2005), while high level witnessed in the FD sample may have had a negative effect (Göransson *et al,* 1992; Rinker *et al*, 2008). The pig fed the novel diet was also the older of the two animals, this would have reduced the tenderness and juiciness of the pork, while having a positive influence on flavour (Latorre *et al*, 2003).

There was a clear preference for the sample which was reared on the maize silage diet. This could be taken as a positive endorsement for this method of rearing. However more work would be required to confirm this. The samples were taken from a single animal in each cohort and either or both may not be representative of the group. The level of fat was identified the most likely factor effecting flavour, however total fat content and distribution were not analysed in this study. While fat levels were approximated using a fat probe at the P2 position, observations indicated that the diets may have influenced fat distribution, invalidating these readings. To better establish the influence of diet on the flavour of pork produced, the levels of fat, its distribution and its possible effect on meat flavour would need to be studied in greater detail.

7. Summary

This study indicates that both the finishing of pigs outdoors and the feeding of a diet which included 40% maize silage had no significant detrimental effect on performance, in regard to daily live weight gain. This goes against observations in previous studies, both examining outdoor rearing (Gentry *et al*, 2004; Kelly *et al,* 2007) and those looking at substituting high fibre feeds into pig diets (Danielsen *et al*, 1999; Edwards, 2003; Hansen *et al*, 2006; Presto *et al,* 2013; Jakobsen *et al*, 2015; Oksbjerg *et al*, 2016). Only one replication of each treatment was conducted within each experiment, with small group sizes, possibly explaining the differences seen in these results. To draw any conclusions from the findings, further replications of both experiments would need to be carried out.

Housing

There was clear indication that animals outdoors require more feed to finish. This increase in variable costs would have a large impact on the profitability of pork produced in this way (Redman 2018). Health benefits, in terms of enrichment and reduced stereotypic behaviours, have been shown to be significant when comparing outdoor rearing to intensive systems with no substrate (Kelly *et al,* 2000; Scott *et al,* 2005, 2007; Van de Weerd *et al*, 2005; Averós *et al,* 2010). There is little evidence of similar benefits when comparing outdoor reared pigs and those in straw pens (Guy *et al.* 1994, 2002).

No production benefit to outdoor rearing was identified. This in line with other studies, (Enfalt *et* al, 1997; Birdi *et al*, 1998; Gentry *et al*, 2002; Hoffman *et al*, 2003) and while some identified increases in growth rate, (Olsson *et al*, 2003;

Gentry *et al*, 2002, 2004). Those monitoring feed intake noted a similar increase for animals reared outside as those observed in this study (Gentry *et al*, 2004; Kelly *et al*, 2007). There may be some scope for increased revenue through higher prices for the pork produced, if correctly marketed. Public perception is that outdoor rearing and free range production systems are healthier and have increased animal welfare, as a result products may realise a premium (Lassen *et al*, 2006; Krystallis *et al*, 2007; Thorslund, 2016). However studies have shown that consumers show a reluctance to invest in products of perceived higher welfare in regards to pork (Muringai *et al*, 2017). A campaign to highlight the benefits of loose housing over slatted floor systems, in regards to welfare, may be more advantageous in regard to improving consumer awareness and improving pig welfare through consumer pressure.

Diet

When examining the benefits of feeding farm produced maize silage based diet, this study demonstrated no decrease in growth rate and clear financial benefits. This goes against the findings of previous studies which have all demonstrated a reduction in growth rate (Danielsen *et al*, 1999; Edwards, 2003; Hansen *et al*, 2006; Presto *et al,* 2013; Jakobsen *et al*, 2015; Oksbjerg *et al*, 2016). As stated this study was small with only one replication, however while the indicite data showed a simmilar trend to previous studies it also demonstrated a clear financial saving in regard to overall feed cost.

The animals on Experiment 2 demonstrated a strong ability to utilize the energy from the silage, however the diet of the FD group was deficient in both protein and lysine. This may have explain the increased level of fat observed in animals in the FD group, which goes against previous observations (Danielsen *et al*, 1999; Strudsholm & Hermansen, 2005; Hansen *et al*, 2006)

There is scope to improve the performance of pigs fed on fibrous diets, through offering a diet more suited to their needs (Edwards 2002). The use of additional or alternative cereal/ pulse silages which would be more in balance with the nutritional requirements of growing pigs. Alternatively high protein supplements to boost crude protein intake may allow for the complete replacement of compound feeds. A diet formulated with higher levels of protein may improve the carcass composition, by increasing the deposition of lean tissue, and improve food conversion ratios (Wood *et al,* 1979, 2004; Close and Fowler, 1885; Andersen and Nannerup, 2004; Kelly *et al*, 2007)

Tasting

The taste test demonstrated a clear preference to the pork produced on the fibrous diet, this most likely being a result of the high levels of fat, both intermuscular and intramuscular, present in the sample (Batcher and Dawson, 1960; Kauffman *et al*, 1964; Davis *et al*, 1975; Ellis *et al,* 1996; Wood *et al*, 2004; Fortin *et al*, 2005) It may be possible to utilise this improvement in flavour to increased revenue in niche markets, however consumers have been shown to select against higher levels of fat when purchasing pork (Ricker *et al,* 2008), and fatter carcasses are penalised in commercial production (AHDB, 2017).

There is clear scope for improving the profitability of pork production, while maintaining or improving animal welfare, through the feeding of fibrous diets although this area requires further investigation to establish the best diet in terms of productivity and profitability.

8. Appendices

Appendix 1: Composition of BOCM Farm Gate Sow and Weaner Pellets

Analytical Constituents

Crude Oils & Fats	4.00%
Crude Protein	16.00%
Crude Fibre	6.50%
Crude Ash	5.50%
Calcium	0.90%
Phosphorus	0.52%
Sodium	0.17%
Moisture	13.80%
Vitamin E	86 iu/Kg
Lysine	0.75%
Methionine	0.28%

Digestible Energy 13MJ/Kg

Composition

Barley, Wheat, Wheat Feed, Sunflower Seed Meal, Rapeseed Meal, EU Distillers Dried Grains, Palm Kernel Expellant, Calcium Carbonate, Vegetable Oil & Fat, Sodium Chloride, Fish Oil.

Additives (per Kg)

Vitamins

Vitamin A	10000 IU	Vitamin D3	2000 IU

Compounds of Trace Elements

Calcium Iodate anhydrous	1.6	mg
Cupric sulphate pentahydrate	60	mg
Ferrous sulphate monohydrate	323	mg
Manganous oxide	81	mg
Sodium selenite	0.67	mg
Zinc oxide	139	mg

Digestibility Enhancer

3 – Phytase 500 FTU

Appendix 2: Descriptive summary of the results obtained from individual animals in Experiment 1

Table 17: Summary of data from Experiment 1

	Outdoor Group									Group Mean
Tag No.	76	77	79	81	82	84	87	88	89	
Sex	M	F	M	F	F	M	F	F	M	
Days on trial	146	174	139	174	132	132	139	132	109	141.9
LW (start) Kg	29	32	28	32	34	29	29	33	34	31.1
LW (end) Kg	95	107	91	110	99	96	101	104	93	99.6
DLWG Kg/d	0.45	0.43	0.45	0.45	0.51	0.51	0.52	0.54	0.54	0.48
Dead Weight	69.6	75.3	66.3	82.9	74.7	71.7	75.1	78.2	66.7	73.4
Kill Out %	73	70	73	75	75	75	74	75	72	73.5
Fat Probe (P2) MM	10	12	14	14	14	14	13	15	13	13.2
Total Feed Kg	309	379	292	379	274	274	292	274	221	300

	Indoor Group								Group Mean
Tag No.	73	74	75	78	80	83	85	86	
Sex	M	M	F	F	M	F	F	M	
Days on trial	130	130	146	139	109	130	146	133	132.9
LW (start) Kg	29	27	31	33	32	30	29	35	30.8
LW (end) Kg	92	93	99	105	94	103	102	107	99.4
DLWG Kg/d	0.48	0.51	0.47	0.52	0.57	0.56	0.50	0.55	0.52
Dead Weight	67.4	71.8	74.7	78.3	69.0	80.9	78.6	80.0	75.0
Kill Out %	73	77	75	75	73	79	77	75	75.5
Fat Probe (P2) MM	*	*	10	13	14	*	15	*	13
Total Feed Kg	269	269	309	292	222	269	309	269	276

* Fat probe not available

Appendix 3: Descriptive summary of the results obtained from individual animals in Experiment 2

Table 18: Summary of data from Experiment 2

	Pelletized Diet									Group Mean
Tag No.	134	135	138	141	143	146	147	149	150	
Sex	F	F	F	M	F	F	M	M	M	
Days on trial	82	136	124	75	68	82	75	54	68	84.9
LW (start) Kg	50	38	46	54	67	60	57	65	58	55
LW (end) Kg	104	103	109	94	103	99	99	97	100	100.9
DLWG Kg/d	0.66	0.48	0.51	0.67	0.53	0.48	0.56	0.59	0.62	0.54
Dead Weight Kg	76.4	78.3	86.4	68.9	80.2	77.2	72.8	71.0	74.7	76.2
Kill Out %	73	76	79	73	78	78	74	73	75	75.4
Fat Probe (P2) MM	*	17	15	16	11	*	16	15	16	15.1
Total Pelletized Feed Kg	205	340	310	188	170	205	188	135	170	212

	Indoor Group								Group Mean
Tag No.	136	137	139	140	142	144	145	148	
Sex	M	F	F	M	F	M	M	F	
Days on trial	75	145	136	136	82	54	68	124	102.5
LW (start) Kg	57	40	50	38	61	72	61	52	53.9
LW (end) Kg	96	96	103	98	97	95	95	95	96.9
DLWG Kg/d	0.52	0.39	0.39	0.44	0.44	0.43	0.50	0.35	0.42
Dead Weight	69.3	72.3	77.0	72.0	72.0	71.5	70.5	72.9	72.2
Kill Out %	72	75	75	73	74	75	74	77	74.4
Fat Probe (P2) MM	18	17	17	17	*	18	17	8	16
Total Feed Kg	113	218	204	204	123	81	102	186	153.8
Total Maize Silage Kg	188	363	340	340	205	135	170	310	256.3

* Fat probe not available

Appendix 4: Calculations of Maintenance energy of PD animals in Experiment 2

Table 19: Maintenance energy requirements and energy surpluses of animals in PD group

Week of Trial	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
Pigs in group	9	9	9	9	9	9	9	9	8	8	6	4	2	2	2	2	2	2	1
Mean Weight (Kg/P)	56.6	59.6	64.0	69.0	72.8	76.1	80.2	83.3	85.7	88.2	89.8	89.4	88.5	91.3	95.3	98.5	101.8	102.8	103.0
Group weight gain (Kg)	28.0	27.0	51.0	40.0	29.0	29.0	45.0	19.0	30.0	26.0	15.0	12.0	2.0	9.0	7.0	6.0	7.0	5.0	2.0
Mean weight gain (Kg/P)	**3.1**	**3.0**	**5.7**	**4.4**	**3.2**	**3.2**	**5.0**	**2.4**	**3.8**	**4.3**	**3.8**	**6.0**	**1.0**	**4.5**	**3.5**	**3.0**	**3.5**	**5.0**	**2.0**
Energy from pelletized feed (MJ/P/d)	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8
Energy for maintenance (MJ/P/d)	8.3	8.6	9.0	9.4	9.7	9.9	10.3	10.5	10.7	10.9	11.0	10.9	10.9	11.1	11.4	11.6	11.8	11.9	11.9
Surplus energy (MJ/P/d)	18.5	18.2	17.9	17.5	17.1	16.9	16.6	16.3	16.2	16.0	15.9	15.9	15.9	15.7	15.5	15.2	15.0	14.9	14.9

Appendix 5: Calculations of energy utilized from maize silage

Table 20: Maintenance energy requirements and energy surpluses of animals in FD group

Week of Trial	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Pigs in group	8	8	8	8	8	8	8	8	7	7	6	5	4	4	4	4	4	4	3	3
Mean Weight (Kg/P)	54.2	56.6	60.4	63.5	66.1	68.3	71.7	73.4	75.1	77.1	76.5	75.7	76.4	78.8	82.0	85.5	88.6	92.5	96.5	95.7
Group weight gain (Kg)	5.0	33.0	28.0	22.0	19.0	17.0	37.0	12.0	32.0	13.0	13.0	16.0	9.0	10.0	16.0	12.0	13.0	23.0	11.0	2.0
Mean weight gain (Kg/P)	**0.6**	**4.1**	**3.5**	**2.8**	**2.4**	**2.1**	**4.6**	**1.7**	**4.6**	**2.2**	**2.6**	**4.0**	**2.3**	**2.5**	**4.0**	**3.0**	**3.3**	**7.7**	**3.7**	**2.0**
Energy from pelletized feed (MJ/P/d)	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1
Energy for maintenance (MJ/P/d)	8.1	8.3	8.7	8.9	9.1	9.3	9.6	9.7	9.9	10.0	10.0	9.9	10.0	10.1	10.4	10.7	10.9	11.2	11.5	11.4
Surplus energy (pig/day)	8.0	7.8	7.4	7.2	7.0	6.8	6.5	6.4	6.2	6.1	6.1	6.2	6.1	6.0	5.7	5.4	5.2	4.9	4.6	4.7
Surplus energy (MJ/P/d)	447.5	435.7	417.0	402.1	390.2	379.8	364.4	356.7	305.4	297.8	257.3	216.5	171.8	166.6	159.7	152.3	145.8	137.9	97.3	98.6
Predicted weight gain (Kg/P)	**1.9**	**1.9**	**1.8**	**1.7**	**1.7**	**1.6**	**1.6**	**1.5**	**1.3**	**1.3**	**1.1**	**0.9**	**0.7**	**0.7**	**0.7**	**0.6**	**0.6**	**0.6**	**0.4**	**0.4**
Additional gain	-1.3	2.3	1.7	1.0	0.7	0.5	3.1	0.2	3.3	0.9	1.5	3.1	1.5	1.8	3.3	2.4	2.6	7.1	3.3	1.6

Appendix 6: Information poster displayed at tasting

Figure 8: Poster displayed at pork tasting

Appendix 7: Pearson's Chi Square analysis of taste test results

Table 21: Distribution of group in relation to sex and age compared to predicted tally using Chi Square Test

Age		Female	Male	Total
11 or under		24	18	42
	Predicted	**23.21**	**18.79**	
12-20		10	9	19
	Predicted	**10.50**	**8.50**	
21-40		19	19	38
	Predicted	**21**	**17.00**	
41-65		39	27	66
	Predicted	**36.47**	**29.53**	
0ver 65		13	12	25
	Predicted	**13.82**	**11.18**	
Total		105	85	190

Likelihood Ratio Chi-Square = 1.038, DF = 4, P-Value = 0.904

Table 22: Results in relation to age group compared to predicted tally using Chi Square test

Age		No Difference	Silage Fed	Conventional Fed	Total
11 or under		8	17	17	42
	Predicted	**3.76**	**23.65**	**14.59**	
12-20		2	8	9	19
	Predicted	**1.70**	**10.70**	**6.60**	
21-40		1	23	14	38
	Predicted	**3.40**	**21.40**	**13.20**	
41-65		5	41	20	66
	Predicted	**5.91**	**37.17**	**22.93**	
0ver 65		1	18	6	25
	Predicted	**2.24**	**14.08**	**8.68**	
Total		17	107	66	190

Likelihood Ratio Chi-Square = 13.873, DF = 8, P-Value = 0.085

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