Growth Performance and Pork Quality of Two New Zealand Pig Genotypes

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ABSTRACT

In the pig industry, feed is a major cost which contributes 60 - 80% of production costs, thus it is important that feed specifications reflect the needs for modern genotypes to express their genetic growth potential. The major genetic drivers for growth are the minimum whole body lipid to protein ratio (Minlp) and the upper limit to protein deposition (Pdmax). The objective of the present study was to evaluate the growth performance potential and pork quality of two genotypes (G1 and G2) commonly used in New Zealand.

Sixty four pigs were reared indoors for 12 weeks, and fed two diets to slaughter. The first diet was limited in energy (to provide expression of Minlp); and the second was not limited in energy or protein/amino acids (to provide expression of Pdmax). After slaughter, carcass measurements were recorded and pork quality was tested.

During the Minlp and Pdmax diet phases the key overall findings were that G1 had improved average daily gain (940 vs. 890 g/d) and feed conversion ratio (1.75 vs. 1.87), had lower calculated Minlp slope (i.e., 0.0248, 0.0327) and greater Pdmax values (i.e., 226 vs. 204 g/d) compared to G2. No difference was found for daily feed intake.

For carcass traits G1 had the lower backfat thickness. There was no difference found for dressing % or carcass weight. For pork quality, G2 had the lower pH and also had greater thawloss % compared to G1.

In conclusion G1 had overall better growth performance and were leaner than G2. The pork from both G1 and G2 was not found to have pale soft and exudative (PSE) quality and was considered to be very tender.

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α	Slope
a*	Relative redness
ADFI	Average daily feed intake
ADG	Average daily gain
AI	Adequate intake
b*	Relative yellowness
BF	Backfat
BFA	Backfat surface area
BW	Body weight
CP	Crude protein
DEI	Digestible energy intake
DFD	Dark firm dry
DM	Dry matter
EJL	Expressed juice loss
FCR	Feed conversion ratio
FI	Feed intake
G	Genotype
GE	Gross energy
G*S	Genotype*sex interaction
He-Ne	Helium-neon
HI	Heat increment
kcal	Kilocalories

KJ	Kilojoules
L*	Relative lightness
Ld	Lipid deposition
LM	Longissimus muscle
LA	Longissimus dorsi surface area
LSMeans	Least squares means
LW	Live weight
ME	Metabolisable energy
ME_m	Metabolisable energy for maintenance
MFI	Myofibrillar fragmentation index
Minlp	Minimum Ld to Pd ratio
MIRINZ	Meat Industry Research Institute of New Zealand
N	Newton
n	Sample size
NDF	Neutral-detergent fibre
NRC	National Research Council
Pd	Protein deposition
Pdmax	Protein deposition maximum
pHu	Ultimate pH
PSE	Pale soft and exudative
S	Sex
SD	Standard deviation
SEM	Standard error of the mean

SL	Sarcomere length
Target L/P	Target lipid to protein ratio
WBSF	Warner-Bratzler shear force
WHC	Water holding capacity

CHAPTER 1: INTRODUCTION

The global increase in meat production from 1987 to 2007 (Table 1.1) was due to an increased human population, increased urbanisation and economic growth especially within developing countries (FAO, 2009).

Table 1.1. Comparison of production of four main meat groups between 1987 and 2007 by region and world. Modified from FAO (2007).

Region/world	Pig		Poultry		Cattle		Sheep and Goat	
	1987 (million tonnes)	2007 (million tonnes)	1987 (million tonnes)	2007 (million tonnes)	1987 (million tonnes)	2007 (million tonnes)	1987 (million tonnes)	2007 (million tonnes)
Developed Countries	37.1	39.5	22.9	37.0	34.1	29.4	3.7	3.2
Developing Countries	26.6	76.0	13.0	49.8	16.9	32.5	5.0	10.8
World	63.6	115.5	35.9	86.8	50.9	61.9	8.6	14.0

The USDA (2006) has also reported an increased trend for meat production and consumption when they compared beef, pork and poultry from major world traders from 2001 - 2006 (Table 1.2).

Table 1.2. Major world traders of beef, pork and poultry from 2001-2006. Modified from USDA (2006).

Production	2001	2002	2003	2004	2005 (p)	2006 (f)
Beef and Veal[a]	49,646	51,241	50,095	51,327	52,247	53,592
Pork[a]	83,881	86,802	89,231	91,393	94,202	97,207
Broiler and Turkey[b]	57,237	59,173	59,218	60,845	63,599	65,768
Total	190,764	197,216	198,544	203,565	210,048	216,567
Consumption						
Beef and Veal[a]	48,708	50,265	49,017	49,817	50,274	51,743
Pork[a]	83,703	86,679	89,097	90,829	93,254	96,209
Broiler and Turkey[b]	55,637	57,623	57,640	58,928	61,639	63,543
Total	188,075	194,567	195,754	199,574	205,167	211,495

(p) preliminary; (f) forecast.
[a]1,000 metric tons (carcass weight equivalent).
[b]1,000 metric tons (ready to cook equivalent).

"Note to readers: totals include only those countries that make up the USDA's official PSD database. This means totals do not encompass all production, consumption, and trade, but rather the sum of those countries reported in the USDA's database, which represent the most important players in the world meat PSD situation. In an attempt to capture these major players the list of countries reported changes periodically" (USDA, 2006).

Pork was reported by Orr and Shen (2006) to be 'the meat of choice' worldwide. The global consumption of pork increased by 27% between 1995 and 2005 (Orr

& Shen, 2006).Global consumption of pork in 2005 was more than 93 million metric tonnes (USDA, 2006) (Table 1.2). According to Warris (2000), the cost of producing pigs and poultry is cheaper than producing sheep or cattle. The feed is a major cost for producing grower-finisher pigs (Heuven et al., 2003; Kyriazakis & Whittemore, 2006; Mullan et al., 2011; Payne & Zijlstra, 2007). The total production costs for feed ranges between 65-75% for grower-finisher pigs in Australia (Mullan et al., 2011), and in New Zealand (NZ) the total production costs ranged between 60-80% (NZPork, 2011).In order to meet the increased demand for pork and increasing costs for production (e.g., rising feed prices), reducing the production costs or improving the pork yield is vital to meet the world's pork demand.

Over the last 20 years improvements for desired traits such as heavier carcass weights, leanness, feed efficiency and meat quality have been achieved (Heuven et al., 2003; Kyriazakis & Whittemore, 2006) by traditional and molecular (genetic) breeding (Heuven et al., 2003). The problem is that the current feed specifications for protein and amino acids requirements are based on research done more than 20 years ago (Black et al., 1986; Fuller et al., 1989; NRC, 1998) and are not specifically tailored to meet the different nutritive requirements of modern pig genotypes to express their genetic growth potential (Mullan et al., 2011). Thus, knowledge for growth potential amongst different pig genotypes which may increase pork yield and/or reduce production costs would be advantageous to the farming enterprise to help them increase their profits.

Growth performance is determined by average daily gain (ADG), feed conversion ratio (FCR) and daily feed intake (FI). Experimental studies also use the terms minimum lipid deposition (Ld) to protein deposition (Pd) ratio (Minlp) and upper limit to Pd (Pdmax) for the assessment of growth performance as they can be used to predict Pd and or Ld rates(de Lange et al., 2008).

Recent trials to improve growth performance for grower-finisher pigs have found that the external and internal environments can have positive and negative consequences for growth (Kyriazakis & Whittemore, 2006). The external environment consists of (but is not limited to): housing and space requirements; ambient temperature, relative humidity and social behaviours (e.g., mixing)

(Kyriazakis & Whittemore, 2006). The internal environment may include: the physiological state of the animal; the genetic make-up of each pig; and interactions of the different dietary constituents within the diet which may interfere with metabolic processing of nutrients during digestion and absorption (Kyriazakis & Whittemore, 2006).

The Pork Cooperative Research Centre (CRC) was established in Australia in 2005, and it funds research to enhance Australia's ability to be able to compete in overseas and domestic pork markets without reducing the pigs welfare (PorkCRC, 2011).The purpose of the current trial is to evaluate growth performance and pork quality from two New Zealand genotypes of grower-finisher pigs. Specifically, the objectives are:

- to establish growth performance of two New Zealand pig genotypes (i.e., G1 and G2) using both entire male and female pigs.
- to evaluate Minlp and Pdmax values expressed within these two genotypes using a growth model retrospectively from data gathered from the growth trial.
- To assess the pork quality by empirical tests to ensure consumer acceptance of the end product.

Based on these results, PorkCRC will be able to compare growth performance (FI, ADG, FCR, Minlp and Pdmax) and pork quality from these two genotypes used in this thesis with the genotypes in Australia. However, this will not be addressed within this thesis.

CHAPTER 2: REVIEW OF LITERATURE

2.1 Background

Feed is a major cost for producing grower–finisher pigs for the pork industry. The feed composition and intake are both essential for growth to occur by supplying adequate nutrients (i.e., carbohydrates, protein/amino acids, fat, vitamins and minerals) (NRC, 1998). According to NRC (1998) guidelines, the composition and quantity of the feed was estimated generally for all pig genotypes when written. However, these specifications most likely do not allow modern genotypes to express their genetic growth potential (Mullan et al., 2011).

This review will focus on the current understanding for predicting growth performance in grower-finisher pigs using mathematical models, and meat quality assessments to assess the pork quality. Also included is a brief description for growth characteristics and energy partitioning concepts.

Note: The term grower-finisher pigs refers to LW range for grower pigs of 20 - 50kg (Mullan et al., 2008), and finisher pigs 50 - 90kg LW (Kyriazakis & Whittemore, 2006; Mullan et al., 2008).

2.2 Growth characteristics and energy partitioning in grower-finisher pigs

For grower-finisher pigs, the main desired body tissue to increase in size (i.e., cell number and/or cell volume) is skeletal muscle (i.e., lean tissue) (Kyriazakis & Whittemore, 2006). The two main feed constituents which have both been the major focus of research trials on grower-finisher pigs are energy and protein/amino acids (de Lange et al., 2008; Kyriazakis & Whittemore, 2006; NRC, 1998; Wellock et al., 2004).

2.1.1 Energy for maintenance

According to the National Research Council (NRC) (1998), for growth to occur the energy intake must exceed the metabolisable energy (ME) required for body maintenance (ME_m). The mean ME_m is estimated to be 106kcal (equivalent to 444KJ) per kilogram (kg) body weight $(BW)^{0.75}$ per day (d). Energy for maintenance, can also be expressed as digestible energy intake (DEI) i.e., 110kcal DEI (461KJ)/kg $BW^{0.75}$/d (NRC, 1998). ME_m can vary due to the heat

increment (HI) i.e., heat produced from digestion and metabolism; excretion of waste products (e.g., urine and faeces); thermogenesis and the pig's level of physical activity (Kyriazakis & Whittemore, 2006; NRC, 1998; Van Milgen & Noblet, 2003).

Note: The term body weight is equivalent to live weight (LW); but the term LW will be used for the remainder of this thesis.

2.1.2 Protein

Protein is also essential for growth. Although ingested protein contributes to the ME intake, if a portion of the ingested protein (i.e., amino acids) is used for Pd, energy is not released from that portion of protein and can not contribute to available net energy (NE). This separates protein from energy 'under specific conditions' to promote growth (Wellock et al., 2004).

There are reported to be nine essential amino acids and two semi-essential amino acids for pigs which must be supplied in the pig's diet (de Lange & Whittemore, 2006). The essential amino acids are: lysine, methionine, threonine, tryptophan, histidine, isoleucine, leucine, phenylalanine, and valine. The semi-essential amino acids are classed as such because they can be synthesised from only one essential amino acid, when required. These two are cysteine and tyrosine. Cysteine can be synthesised from methionine, and tyrosine from phenylalanine (de Lange & Whittemore, 2006). If any of the essential amino acids are lacking in the diet, then protein is catabolised from retained body protein to provide the limiting amino acid(s) accordingly to sustain vital body functions (Wellock et al., 2004).

2.3 Energy partitioning for growth in grower-finisher pigs

Energy partitioning for growing pigs refers to how energy above ME_m is retained between Pd and Ld (de Lange et al., 2008; Kyriazakis & Whittemore, 2006; Whittemore & Fawcett, 1976). Pd and Ld both approximately represent skeletal muscle and adipose tissue respectively (de Lange et al., 2008), although protein and energy are also stored amongst other major growing tissues of the pig's empty body weight (EBW) i.e., where the EBW = LW less the gut fill (the gut fill is ~ 5%) (de Lange et al., 2003). Other tissues of the EBW include: visceral and reproductive organs, bone, blood and skin (de Lange et al., 2003).

According to de Lange et al. (2003) 45 - 60% of total body protein mass is stored in lean tissue, and about 15% is stored within the visceral and reproductive organs. Energy is suggested to be the most limiting factor for Pd when the pigs are small (LW < 20kg), stressed or when the feed is bulky due to high fibre content (Whittemore &Fawcett, 1976).

A review written by de Lange et al. (2008) has found that six basic principles must be present to provide a framework for energy partitioning between Pd and Ld. These are: (1) Pd and Ld are influenced by the intake of energy yielding nutrients and balanced protein only; (2) pigs have a daily upper limit to Pd (Pdmax); (3) the pigs desired feed intake is determined based on meeting nutrient requirements for body functions first, then Pd and Ld; (4) dietary intakes for energy yielding nutrients and balanced protein have independent effects on Pd; (5) there is a maximum marginal efficiency of utilising metabolically available balanced protein for Pd, which is independent of LW and pig genotype/type; and (6) the marginal energetic efficiencies of using dietary nutrients for Pd and Ld are not influenced by LW or pig genotype but by dietary nutrient source. These principles were found to be adequate to predict marginal Ld and marginal Pd when the pig's available energy or available balanced amino acids intakes are changing. However, these principles were not sufficient to predict marginal Pd and marginal Ld when energy intake determines Pd. Under these circumstances, some rules are needed to represent energy partitioning for Ld and Pd. To predict absolute Ld and Pd responses, estimates are needed for the maintenance requirements of the pigs (de Lange et al., 2008).

2.3.1 Protein deposition

As excess protein cannot be stored within the body, and must contain balanced amino acids; Pd is dependent on the first limiting amino acid up to Pdmax (de Lange et al., 2008; Kyriazakis & Whittemore, 2006). Kyriazakis and Whittemore (2006) reports that Pdmax may only be expressed when nutritional and environmental conditions are not limiting, and Pdmax is ultimately genetically predetermined (de Lange et al., 2008).

Pd is paired with Ld when energy intake is above body maintenance requirements (Kyriazakis & Whittemore, 2006) and below Pdmax (de Lange et al., 2008). According to de Lange et al. (2008) the relationship between Pdmax and LW for young growing pigs is not fully known. Two relationships have been proposed one being sigmoidal and the other linear.

2.3.1.1 Sigmoidal theory of Pd

The sigmoidal relationship is plotted between protein mass and time. Protein mass has the fastest Pd rate up to the inflexion point within the sigmoid curve. Beyond the inflexion point the Pd rate declines as the pigs mature (de Lange et al., 2008).

The Pd rate (provided the diet is adequate in supplying balanced protein or amino acids, and the energy intake is above maintenance) both increases and decreases with increasing LW until maturity is reached (Black et al., 1986; Kyriazakis & Whittemore, 2006; Schinckel & De Lange, 1996). Thus, Pd is reported by Kyriazakis and Whittemore (2006) to have an asymptotic relationship with increasing LW as the pig's approach maturity in which the Pd rate gets closer to zero.

2.3.1.2 Linear theory of pd

The linear view shows that the relationship between Pd and daily ME intake (or DEI) is constant between 20kg LW until the pig starts to mature and is independent of LW and protein mass (de Lange & Fuller, 2000; de Lange et al., 2008). The relationship between energy intake and Pd is currently viewed by de Lange et al. (2008) as linear provided energy intake is above ME_m and below Pdmax for the energy dependent phase of growing pigs (Bikker, 1994; de Lange et al., 2008; Kyriazakis & Whittemore, 2006; Schinckel & De Lange, 1996). Once Pdmax is reached then any surplus energy above this limit is assumed to be deposited as fat (de Lange et al., 2008).

2.4 Modelling

The purpose of a mathematical model is to provide a tool to predict growth performance and/or body chemical composition in pigs (Black, 1995; Kyriazakis & Whittemore, 2006), although body composition can also be determined by

serial slaughter (Bikker et al., 1995; Moughan et al., 2006; Weis et al., 2004) and nitrogen balance studies (Moughan et al., 2006; Weis et al., 2004).

The modelling of pig growth requires appropriate input variables to allow sensible prediction of extent and composition of growth (de Greef, et al., 1992). The input variables are found to be characteristic to the animal, nutrients which may consist of the LW of the pig, digestible energy content of the feed consumed and ambient temperatures (de Greef & Verstegen, 1995). The output characterises growth performance such as ADG, Pd and Ld (de Greef & Verstegen, 1995). The input variables

Models which can be used to predict growth performance in pigs (Black, 1995; de Lange et al., 2008; Kyriazakis & Whittemore, 2006) have taken a static, dynamic, deterministic, stochastic, empirical and mechanistic approach (Black, 1995).

2.4.1 Static and dynamic models

Static models represent the state of the system at only one fixed point in time; and dynamic models are the opposite to static models in that it explains time explicitly over several time iterations (Black, 1995).

2.4.2 Empirical and mechanistic models

Empirical models are based on equations that describe associations and correlations between two or more variables (Black, 1995; Kyriazakis & Whittemore, 2006) which are based upon direct research trials but suggest nothing about the underlying biological mechanism controlling the operation for the system (Black, 1995). Mechanistic models represent the underlying biological mechanisms to predict growth (Black, 1995).

2.4.3 Deterministic and stochastic models

Deterministic models have only one outcome from a calculation. Stochastic models on the other hand have a range of possible outcomes representing natural variability and are suitable for predicting growth rates for pig populations. Sometimes stochastic elements are added to deterministic models to provide variability amongst the different animals. When stochastic elements

are added to the model output, a mean and variance are expressed for several important attributes which may impact on profitability, e.g., BF depth (Black, 1995).

2.4.4 Model framework

A framework for modelling nutrient partitioning for a simple pig growth model was described by de Lange (1995) to contain “Static, deterministic and mechanistic” elements. These three elements refer to nutrient partitioning for: one fixed point in time (static); deterministic in that the model generates outcomes for each individual animal, and the model is mechanistic in that growth is represented based on underlying biological rules (de Lange, 1995). According to Black et al. (1995) the model must contain seven features. These are: (1) initial body composition; (2) nutrient intake; (3) availability of nutrients for metabolism (energy and amino acids); (4) nutrients used for body maintenance; (5) nutrients used for growth; (6) efficiency of nutrients used; and, (7) final body composition. This is illustrated in a flow chart diagram in Figure 2.1.

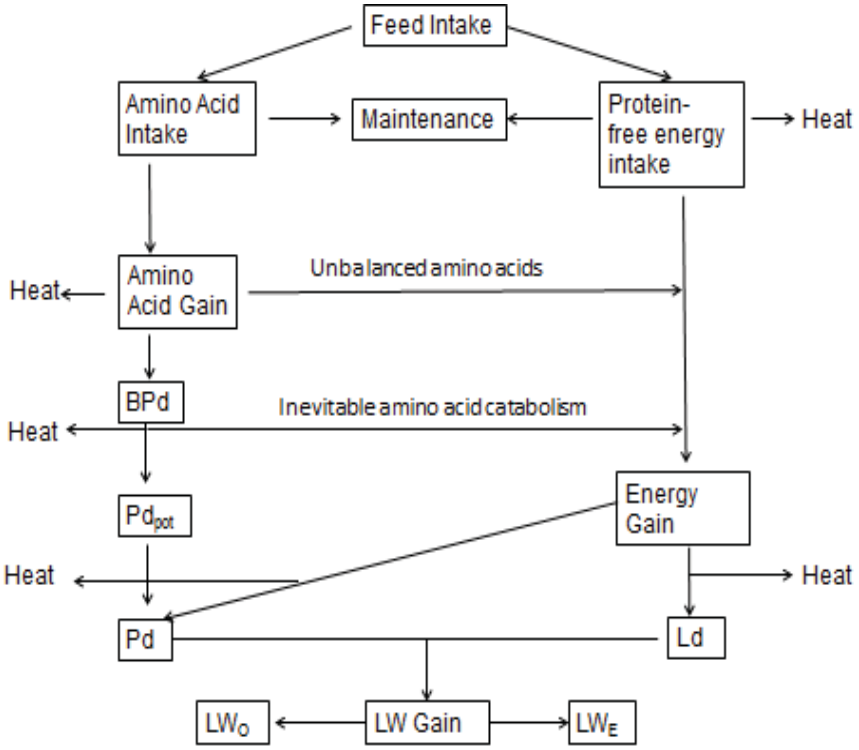

Figure 2.1. A flow chart showing the simple pig growth model for energy and protein partitioning from feed intake. Also shown is the relationship between energy gain and amino acid gain for Pd and Ld accordingly. Heat is liberated as a biproduct of metabolism when energy is used. *Abbreviations: BPd=balanced protein which may be used for protein deposition; Pd_{pot}=potential protein deposition rate; Pd= actual protein deposition rate; Ld= lipid deposition; LW=live weight; LW_O=initial LW; and LW_E=end LW.* Modified from de Lange (1995).

2.4.5 Modelling Growth Performance

Growth performance parameters which are used to predict Minlp and Pdmax according to de Greef et al. (1995) are LW gain, FCR and leanness of the carcass. Leanness of the carcass is determined in NZ by P2 back fat (BF) depth measured in millimetres (mm) (Honeyfield-Ross et al., 2009), although leanness can also be determined by muscle to bone ratio or expressed as whole body fat mass percentage (R. Purchas, Personal Communication).

Simulation models to predict porcine growth have progressed since work in the 1970's by Whittemore et al. (1976). Whittemore et al. (1976) proposed the Linear Plateau Concept. The Linear Plateau Concept states that a positive linear relationship exists between increasing Pd and increasing DEI up to

Pdmax for grower-finisher pigs. As long as the energy supplied in the feed is above maintenance requirements, it is assumed Pd is paired with Ld provided Pdmax is not reached (Figure 2.2).

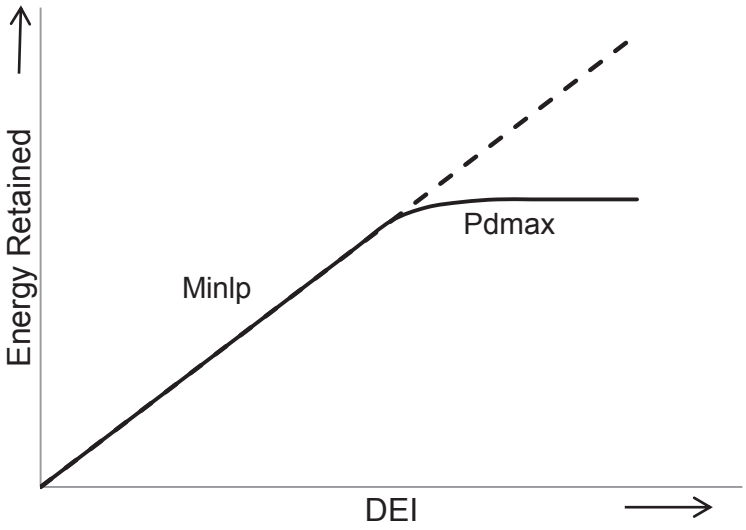

Figure 2.2. The Linear Plateau concept. Showing the partitioning of digestible energy intake (DEI) between retained energy [i.e., Ld ( ) and Pd (--)] when DEI is above body maintenance. Also shown are Minlp (the linear portion of the curve) and Pdmax (the plateau portion of the curve). Any surplus energy beyond Pdmax is assumed to be retained as Ld. Modified from Kyriazakis et al. (2006).

The linear portion of the curve refers to Minlp which under these conditions Minlp remains constant and found to be about 1:1 (variation of this ratio due to genotype and gender differences amongst pigs) (Kyriazakis & Whittemore, 2006).

Once Pdmax is reached (the point where the curve plateaus in Figure 2.2), surplus energy is assumed to be stored as Ld (de Greef et al., 1992; Kyriazakis & Whittemore, 2006). These two parameters (i.e., Minlp and Pdmax) are both used in recent trials (de Lange et al., 2008; Honeyfield-Ross et al., 2009) to predict whole body Ld to Pd ratio (Target L/P) based on the following equation: (de Lange et al., 2008).

$$Target\ L/P = \alpha \times DEI$$

α = slope (i.e. Minlp) which is specific to genotype

DEI = digestible energy intake (MJ / d) during energy dependant phase for Pd.

A serial slaughter study by Bikker et al. (1995) involved 28 commercial hybrid gilts which had a high genetic capacity for lean tissue gain found that a positive linear relationship existed between increasing energy intake and ADG, Pd and Ld up to a maximum feed intake for gilts between 20 - 45 kg LW. At the start of this trial 4 pigs were slaughtered at LW 20kg (to determine initial body composition), and the remaining 24 pigs were evenly assigned to being fed one of five different energy level diets (i.e., 1.7, 2.2, 2.7, 3.2 and 3.7 times MEm/day) plus one group being fed *ad libitum*. Thus, there were six different energy level diets in total. The water and protein content for body composition within the carcass, EBW and viscera all decreased while the fat content increased. In the empty body, the protein content decreased with increasing energy intake by 23 g/kg LW whereas lipid content increased with energy intake by 67g/kg LW between all energy levels from 1.7 times ME_m to ad libitum.

2.5 Restricted feeding vs. ad libitum feeding – effect on growth performance

In small pigs, it was found that gut capacity was the most important limiting physical factor which controls feed intake, and thus will have an impact on growth (Kyriazakis & Whittemore, 2006). For this reason, high energy dense feeds are more important to promote growth in small pigs. The problem with high energy dense feeds is that Ld continues once Pdmax is reached (Moughan et al., 2006; Schinckel & De Lange, 1996), thus decreasing the quality of the carcass (Moughan et al., 2006).

Restricted feeding may be defined as the pigs having a limited allowance to the amount of feed per day (Kyriazakis & Whittemore, 2006). Kyriazakis and Whittemore (2006) suggest maximum feed intake consumed per day may be achieved by allowing pigs to consume feed *ad libitum,* in which satiety is reached, per scheduled meal time (i.e., per 3 - 4 times per day) as opposed to having feed available ad libitum continuously. This effect may be due to the pigs

consuming more feed (i.e., gorging behaviour) to carry them through the subsequent fasting period between feeds.

Serrano et al. (2009) found that when Iberian pigs (i.e., entire and castrated males, entire and ovariectomised females) were restrictively fed 82% (days of age = 152 - 201) and then 72% (days of age = 202 - 263 of *ad libitum* feed intake). As expected the restrictive fed pigs consumed less feed, and had lower ADG compared to the *ad libitum* fed pigs. However, the carcasses were leaner and the ham yield as a percentage of carcass was greater for the restricted fed pigs. Similar findings were reported by Mullan et al. (2008) with decreased subcutaneous fat depth and reduced ADG were observed for restricted feeding when compared to *ad libitum* fed pigs. Mullan et al. (2008) also found that restrictive fed pigs took longer to reach the desired LW for slaughter.

2.6 Compensatory growth

Compensatory growth is rapid growth which follows a slow growth phase (Kyriazakis & Whittemore, 2006) which is usually a consequence of restricted feeding. Compensatory growth can be imposed by nutrient (protein or energy) restriction followed by realimentation (refeeding) phase (Kyriazakis & Whittemore, 2006). Some studies have found that compensatory growth may increase nutrient efficiency; growth performance (Martinez-Ramirez et al., 2008a); carcass attributes and meat tenderness (de Greef, et al., 1992; Martínez-Ramírez et al., 2008b). Some studies have found this phenomenon for improved FCR and enhanced Pd during the realimentation phase often initially reducing amino acid intake (de Greef, et al., 1992; Martínez-Ramírez et al., 2008b) and others haven not (Martinez-Ramirez et al., 2008a). According to Kyriazakis et al. (2006), the pig's preferred ratio for Ld/Pd is preset by genetics, so provided there is a nutrient deficiency which is followed by realimentation, initially the nutrient utilization efficiency improves up until the desired Ld or Pd is reached.

2.7 Carcass Traits and the influence of genotype

For fresh pork production, desired carcass traits are heavier carcass weights (CW), greater killing-out percentages and reduced fatness (and/or increased leanness). CW is defined in the following equation: CW = LW – (visceral and

thoracic organs + hair) where: CW, LW, visceral and thoracic organ weights, and hair are all expressed in kilograms (de Lange et al., 2003). The carcass traits of pigs of higher genetic merit for desirable carcass traits (post 2000) are compared against pigs in the 1980's which are shown in Table 2.1.The modern pigs are leaner with reduced backfat (BF) depths, greater loin areas and a greater carcass weight (Figure 2.2).

Table 2.1. Comparison of carcass traits for slaughter generation pigs from 1978, 1989, 2008 and 2011.

		Carcass Traits					
	Genotype	**Slaughter weight, Kg**	**Carcass weight, Kg**	**Carcass Length, cm**	**BF depth, mm**	**Loin Area, cm^2**	**Reference**
Pre 2000	Yorkshire / Landrace [c]	97.6	n/a	78.1	31.7	33.1	Bereskin & Davey, 1978
	Yorkshire / Landrace [d]	97.6	n/a	75.6	43.3	29.9	
	Duroc / Yorkshire[a]	114.4	81.2	n/a	31.0	28.7	Seideman et al., 1989
	Duroc / Yorkshire[b]	105.1	81.8	n/a	69.3	17.1	
Post 2000	Duroc-cross[e]	101.3	80.00	n/a	11.9	40.3	Janz et al., 2008a
	Duroc-cross[e]	101.7	80.60	n/a	12.2	39.3	
	Duroc-cross[e]	102.8	80.80	n/a	12.1	40.8	
	Duroc-cross[e]	101.8	79.30	n/a	11.1	40.7	
	Berkshire	110	n/a	n/a	23.39	47.78	Lee et al., 2011
	Duroc	110	n/a	n/a	23.21	41.16	
	Landrace	110	n/a	n/a	21.08	51.35	
	Yorkshire	110	n/a	n/a	21.75	41.42	

[a] *Mean values for equal numbers of Duroc and Yorkshire genotypes for lean group within this trial.*
[b] *Mean values for equal numbers of Duroc and Yorkshire genotypes for obese group within this trail*
[c] *Mean values for equal numbers of Yorkshire and Landrace genotypes for low fat group within this trial.*
[d] *Mean values for equal numbers of Yorkshire and Landrace genotypes for Control within this trial.*
[e] *Four different diet treatments within this trial.*
n/a = no data available.

The trend for heavier carcass weights from 1975 - 2010 for New Zealand pigs is shown in Figure 2.3.

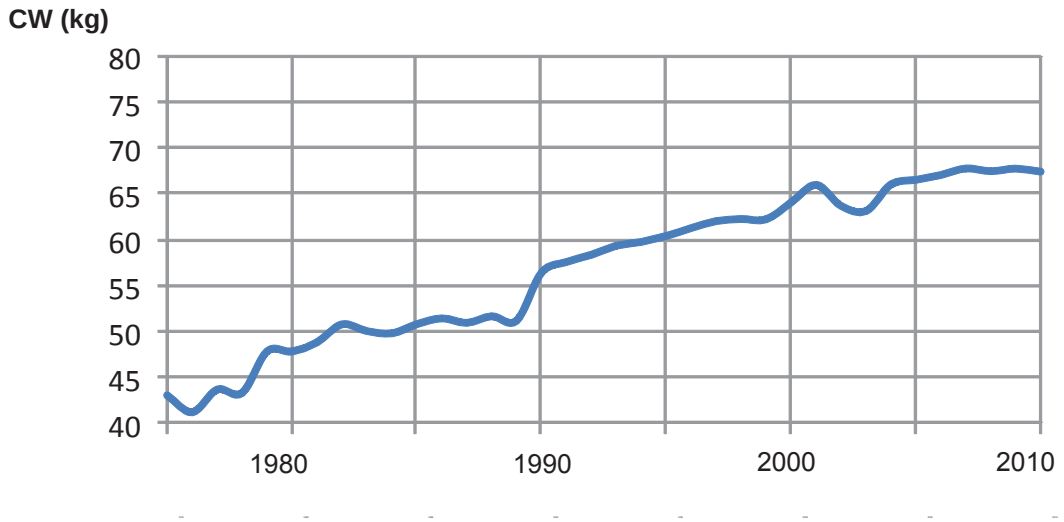

Figure 2.3. Carcass weight trend of New Zealand domestic pigs from 1975 - 2010. Adapted from NZPork (2010).

2.7.1 Fatness

Leanness in New Zealand is determined by backfat (BF) depth measured at the P2 site by a Hennessy Grading Probe in millimetres (mm) (Honeyfield-Ross et al., 2009). According to Kyriazakis and Whittemore (2006), the ideal P2 BF depth (to maximise the profit of the carcass) at slaughter ranges between 8 - 12mm. In New Zealand, if the BF depth is > 12mm the price per kg of pork decreases accordingly (interest.co.nz, 2011). See Table 2.2 for the recent pork and bacon pricing schedule in NZ.

Table 2.2. Recent pricing schedule from NZ pork and bacon. Modified from interest.co.nz (2011).

Pricing Schedule	BF depth, mm	CW range, kg								
		<40	40.1-45	45.1-50	50.1-55	55.1-60	60.1-65	65.1-70	70.1-75	75.1-80
Pork[a], NZ cents/kg	5-9	345	415	415	415	400	375	365	365	360
	10-12	335	415	415	415	400	375	365	365	360
	13-15	205	225	225	265	335	335	335	335	330
	16-18	145	165	165	165	235	245	245	245	240
	>18	125	145	145	145	165	185	185	185	180
Bacon[a], NZ cents/kg	5-9	335	380	380	380	375	370	365	365	360
	10-12	325	380	380	380	375	370	365	365	360
	13-15	205	225	225	265	330	335	335	335	330
	16-18	145	165	165	165	235	245	245	245	240
	>18	125	145	145	145	165	185	185	185	170

[a]prices for boars across all weight ranges = 125c/kg, prices for sows across all weight ranges = 185c/kg for both pork and bacon pricing schedules (not shown in table).
NZ = New Zealand.

Common lean genotypes used for grower-finisher pigs in developed countries are: Landrace, Large White, Hampshire, Pietrain, Duroc and crosses between these genotypes (Switonski et al., 2010). Examples of genotypes with greater fatness are: Zlotnicka Spotted, Iberian pigs and Mangalica (Switonski et al., 2010).

Entire male pigs are reported to be leaner but are prone to boar taint compared to castrated males and females within the same genotype (Kouba et al., 1999; Kouba & Sellier, 2011; Kyriazakis & Whittemore, 2006). Fatness for castrated males lies between entire males and females (Kouba & Sellier, 2011). An example of gender differences for total fat mass (including subcutaneous fat, intermuscular fat and kidney fat) in Large White pigs in which the values were adjusted to 46.9kg of EBW were: entire males = 7.25kg, castrated males = 8.31kg and females = 8.31kg (Kouba et al., 1999).

2.8 Pork quality

The quality of pork and pork-related products is influenced by: (1) the genetic make-up of the pig, (2) the way the pigs are handled on the farm pre and during slaughter (Lawrie, 1998; Rosenvold & Andersen, 2003), and (3) handling of the

carcasses post slaughter (Lawrie, 1998; Maltin et al., 2003; Rosenvold & Andersen, 2003). Pigs have been specifically bred to improve the quality of pork and pork related products (Sellier & Monin, 1994) as well as for growth performance (Heuven et al., 2003).

Meat quality was defined by Lee et al. (2011) as “A combination of properties, including technological quality attributes, consumer acceptance and credence characteristics of safety and health, as well as more intangible features such as the cleaning, green or welfare status of the production system.” Of these properties, consumer acceptance and technological quality characteristics have a strong impact on consumer perception of meat. Consumer acceptance refers to the appearance and palatability of the meat that is sensed, and enjoyed by the consumer. These senses involved in consumer acceptance of meat may include: colour, smell, flavour, texture (Lee et al., 2011) and juiciness of the meat (Lawrie, 1998). An undesirable flavour found in entire male pigs is boar taint. The incidence of boar taint increases once the LW > 100kg in entire males due to increasing levels of androgens (Kyriazakis & Whittemore, 2006). Consumer acceptance is an important property of meat quality which may have a positive or negative impact on repeat meat purchases by the consumer (Lee et al., 2011).

The technological quality attributes refers to traits such as: leanness, water holding capacity (WHC), colour, tenderness and ultimate pH ((normal pH range 5.5 - 6.5 (Sellier & Monin, 1994)) which are reported affected by biological processes (Lee et al., 2011). In research trials, the technological quality attributes were usually determined on the *longissimus dorsi* muscle 24 hours post slaughter (Kyriazakis & Whittemore, 2006). The relationship between post-mortem pH changes from muscle to pork quality is shown in Figure 2.4.

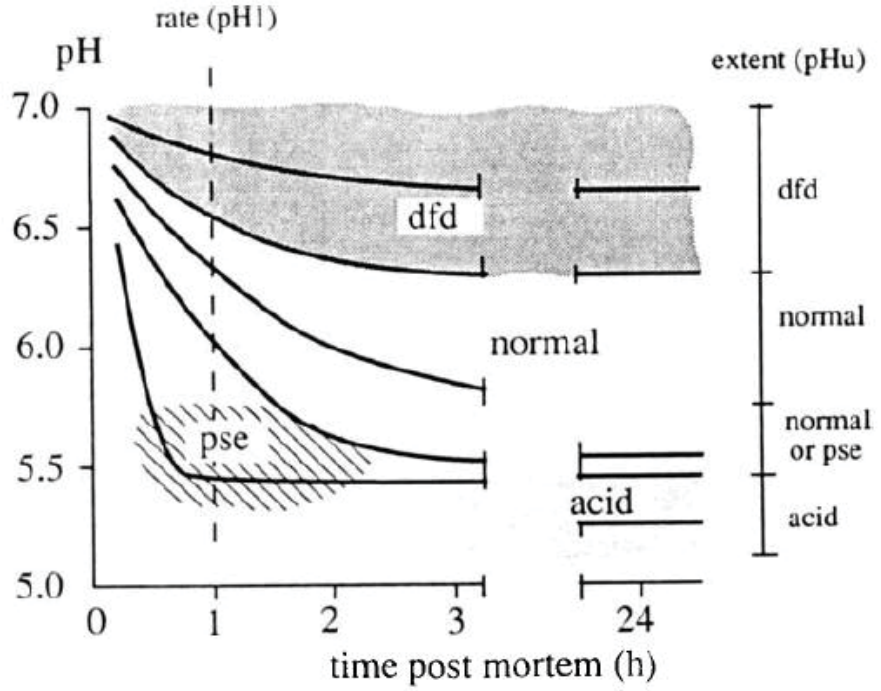

Figure 2.4. Relationship between patterns of post-mortem changes in pH of muscle and pork quality. This graph shows the pH changes which occur from 0-3 hours post slaughter and also ultimate pH at 24 hours. *Abbreviations: dfd = dark firm dry meat, pse = pale soft and exudative meat and pHu = ultimate pH.* Adapted from Sellier and Monin (1994).

2.8.1 Tenderness

Post-mortem events were the main factors which impact on tenderness, although the handling of the animals immediately before slaughter has also been found to affect tenderness (Maltin et al. (2003). Some of these conditions that may increase toughness are: (1) if the pigs have high stress levels or low/depleted muscle glycogen levels immediately before slaughter (Kouba & Sellier, 2011); (2) cold and hot muscle shortening (i.e., shortened sarcomere lengths) from hanging the carcasses in sub-optimal temperatures outside the range of 10 - 15ºC directly after slaughter (Maltin et al., 2003) (see Figure 2.5); and, (3) rapid drop in pH (i.e., PSE meat - refer to Figure 2.4).

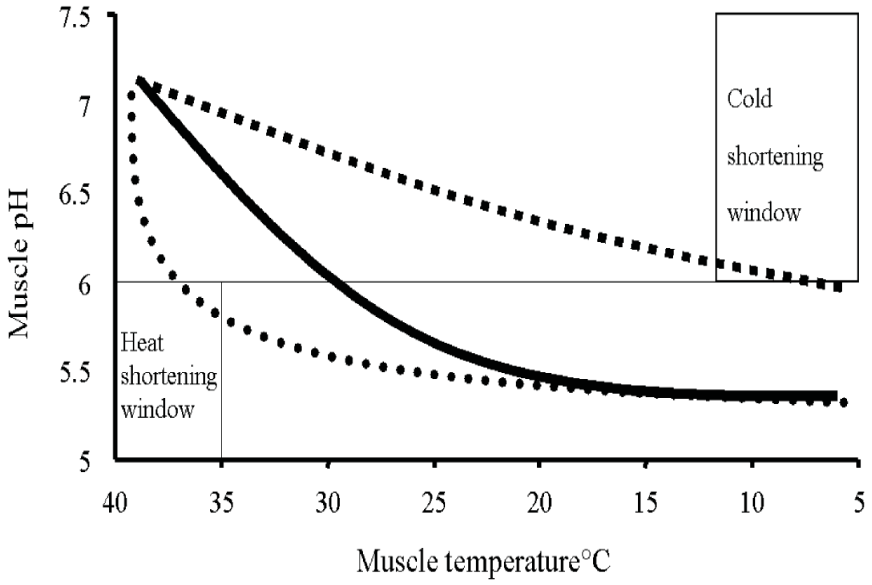

Figure 2.5. Comparison of muscle pH vs. muscle temperature by Meat Standards Australia for optimal pH rate of decline (solid line), cold shortening (dashed line) and heat shortening (dotted line). Adapted from (Thompson, 2002).

Maltin et al. (2005) suggested that muscle fibre type and also dry firm and dark (DFD) meat (pH > 6.5) may increase toughness but the evidence is unclear as some studies have found this relationship and others have not.

Maltin et al (2003) and Karlsson et al (1999) both have found that domestic pigs which are bred for increased lean tissue growth efficiency have a higher proportion of glycolytic muscle fibres compared to slow twitch fibres of wild boars. According to Warris (2000), was meat is toughest between pH 5.8 - 6.2 and becomes more tender outside of this range and report a curvilinear relationship exists between pH and tenderness. This is illustrated in Figure 2.6.

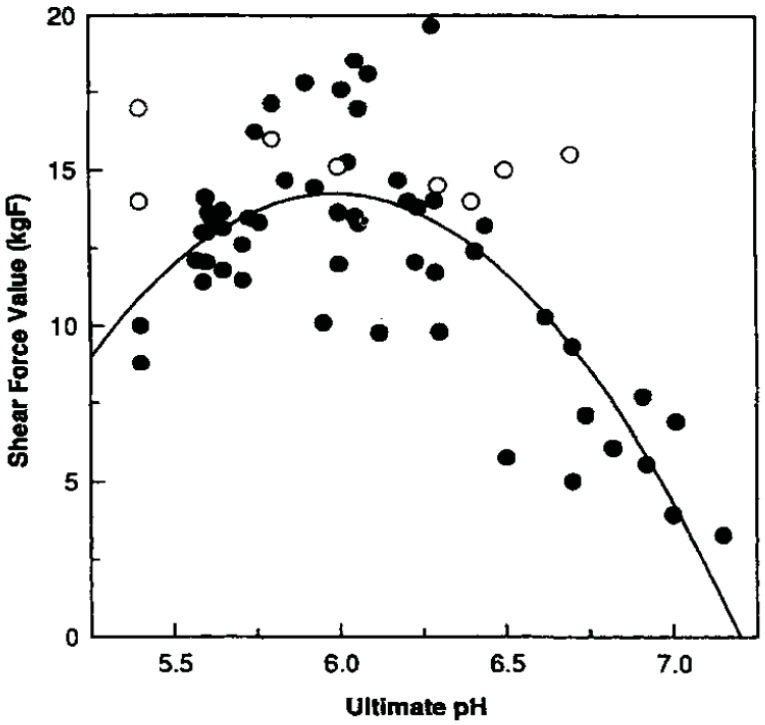

Figure 2.6. Relationship between ultimate pH and shear force values from sheep loins treated with zinc chloride (○) and without zinc chloride (●). Adapted from Watanabe et al (1996).

In a study when pig genotypes with muscles having greater type 1 (oxidative) fibre content was compared to type 2 fibres (glycolytic), the type 1 fibres had greater triacyglyerceride (TAG) content and were more tender than the type 2 fibres. The pig genotypes examined for this trial were Swedish Landrace, Hampshire and Yorkshire. The findings were that the Swedish Landrace and Hampshire genotypes were more tender than Yorkshire pigs due to having different muscle fibre types (Essén-Gustavsson & Fjelkner-Modig, 1985; Karlsson et al., 1999).

2.8.2 Water holding capacity

Water holding capacity (WHC) was reported to be one of the most important meat characteristics which may be detected before and after cooking by the consumer (Lawrie, 1998). WHC refers to the meat's ability to retain moisture and can be measured by drip (or weep) losses; cooking losses and expressed juice loss (Lawrie, 1998). The relationship between WHC and ultimate pH of beef is shown in Figure 2.7. The lowest water holding capacity is found to be ~

pH5 due to proteins getting close to their isoelectric point and thus losing their ability to bind water.

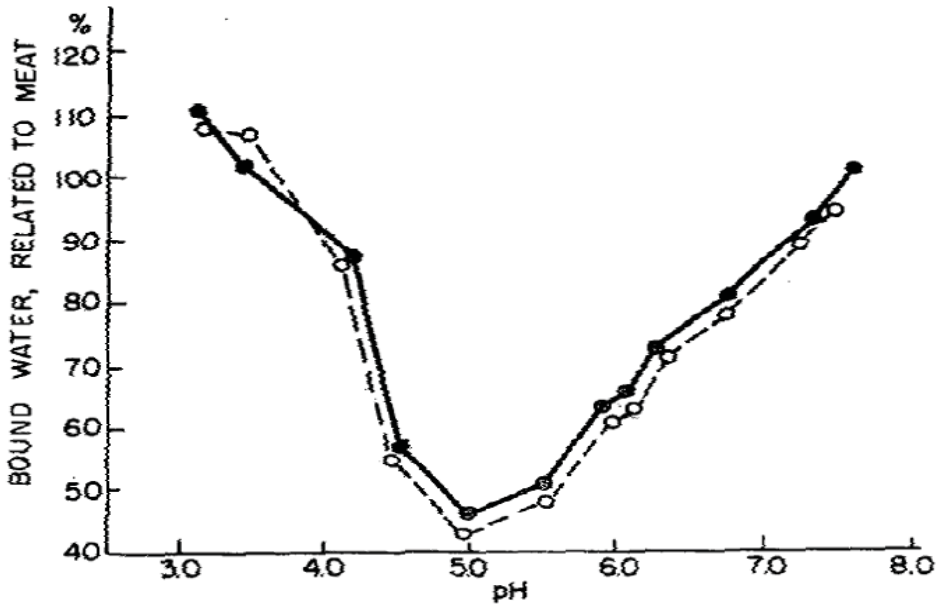

Figure 2.7. Comparison of the relationship between bound water and ultimate pH for beef between fresh meat (●) and the same meat after freezing and thawing (○). Adapted from Deatheridge and Hamm (1960).

2.8.3 Colour

The importance of colour is that it provides aesthetics to the consumer. The colour of meat provides a visual cue of the quality of meat whether it be of poor quality (PSE/DFD) or normal (Warris, 2000). A comparison between various traits including colour (lightness) and pork quality are compared in Table 2.3.

Table 2.3. Summary of colour and loss of exudate in pork longissimus dorsi muscle of pork from quality. Modified from Warris (2000).

Trait	extreme DFD	Slight DFD	Normal	Slightly PSE	Extreme PSE
L*, Lightness	42	48	54	60	66
Hue (°)	1	22	38	48	53
Saturation, chroma	3	5	7	9	12
Reflectance, EEL	20	32	44	56	67
Driploss 48hr, %	0	5	10	13	15

Abbreviation: EEL = Electron energy loss.

2.8.4 Other factors which may affect meat quality traits

2.8.4.1 Juiciness

The juiciness of the meat is affected by WHC and intramuscular fat (Warris, 2000). Greater WHC and increased intramuscular fat (IMF) content are both found to increase meat juiciness (Warris, 2000). Lawrie (1998) reported that two components of juiciness are initial wetness and sustained juiciness during mastication. These components refer to the quick release of fluids from the first few chews for initial wetness, while the latter is related to the release of fat stimulating salivary secretion (Lawrie, 1998). The extremes of juiciness are reported to be succulence and dryness, which is determined upon mastication by consumers or sensory panels in research trials. Dryness is related to the meat having low WHC and/or low IMF content. A low IMF content can be related to leaner pig genotypes (Warris, 2000) and or younger animals (Lawrie, 1998).

2.8.4.2 Flavour

Flavour consists of odour, taste, texture, temperature and pH components (Lawrie, 1998). Of these components, the odour is found to be the most important. If the odour is lacking, then one or more of the four fundamental tastes (salty, sour, sweet and bitter) will predominate (Lawrie, 1998). There is a recent fifth taste called umami which senses monosodium glutamate (a.k.a. meaty taste) (Dransfield, 2008). Raw meat has very little flavour but cooked meat has greater flavour. This difference may be due to volatile substances being released upon cooking (Warris, 2000). The odour is detected by olfactory receptors located within the nasal passage from volatile substances from the

meat (especially during and after cooking) (Lawrie, 1998). With cooked meat there are two types of flavour, i.e., non-species dependant and species dependant (Lawrie, 1998). The non-species dependant flavour is the meaty flavour which may relate to texture and juiciness of the meat; and the species dependant flavour discriminates the meat flavour between different animal species e.g., lamb, beef, pork or chicken (Warris, 2000). Flavour is found to be difficult to quantify mainly due to variation among consumers for flavour preference, however, it is quantified in research trials usually by sensory panels (Warris, 2000).

2.8.4.3 Intramuscular fat

Greater intramuscular fat (IMF) content in pork has been associated by Karlsson et al. (1999) with increased sensory tenderness. The optimal IMF% was reported by Morel et al. (2010) to be ≥ 2.0%. IMF is defined as the entire lipid content found within and between skeletal muscle fibres (Karlsson et al., 1999; Kouba & Sellier, 2011), and also between the muscle fascicles (Karlsson et al., 1999). This may be due to IMF being softer than muscle tissue. A study which compared Meishan, Ming and Landrace x Duroc crossbred pigs found that the pork from the Meishan pig which had a greater percentage of IMF, was more tender than the Landrace x Duroc crossbred pigs (Suzuki et al., 1991). This is shown in Table 2.4 below.

Table 2.4. Comparison of intramuscular fat content for sensory evaluation of cooked pork from Meishan, Ming and Landrace x Duroc crossbred pigs (percent distribution of overall evaluation). Modified from Suzuki et al. (1991).

Parameter	Genotype		
	Meishan	Ming	Landrace x Duroc
IMF, %	4.25	6.17	3.36
Sensory Evaluation			
Boiling Water[a]			
Very Poor	0	1.3	0
Poor	10.4	13	19.5
Average	41.6	51.9	61
Good	45.4	31.2	18.2
Excellent	2.6	2.6	1.3
Grilled Over Burnt Charcoal[a]			
Very Poor	0	0	0
Poor	3.9	11.7	16.9
Average	46.7	33.8	51.9
Good	45.5	49.3	29.9
Excellent	3.9	5.2	1.3

[a]*Cooking method of pork*

"The cooked pork was evaluated for appearance, odour, taste, tenderness, and overall quality by panel members (10 women and 67 men). Per cent distribution of overall evaluations are based on the scores given to each parameter are shown in the table"(Suzuki et al., 1991).

2.8.4.4 Genes

Two genes have been identified which may negatively impact on pork quality. These are: HAL gene (Heuven et al., 2003; Sellier & Monin, 1994) and the rendement napole (RN^-) gene (Heuven et al., 2003; Moeller et al., 2003). Both are associated with PSE meat.

2.8.4.4.1 HAL Gene

The halothane (HAL) gene has been positively associated with improved carcass traits such as a blockier shape, leaner carcasses and reduced BF depths (Gispert et al., 2007), although it is also associated with poor pork quality by providing meat which may be pale soft and exudative (PSE) (Rosenvold & Andersen, 2003; Warris, 2000).

The halothane effect on pork was identified by Eikelenboom et al. (1974) in which malignant hyperthermia (MH) was triggered in pigs by halothane

anaesthesia in stress susceptible pigs. The HAL gene itself was identified in the 1990's (Sellier & Monin, 1994).

MH was previously referred to as Porcine Stress Syndrome. MH was reported by MacLennan et al. (1990) to be activated via rapid influx of Ca^{2+} from the sarcoplasmic reticulum into myoplasm which results in muscle contractions. The calcium channel was identified by using ryanodine alkaloid substrate from plants to activate this channel which consequently was named the ryanodine calcium channel. A single point mutation along chromosome 6p11-q21 by the ryanodine gene (RYR1) encodes for the ryanodine receptor protein which consequently is inserted into the calcium channel and results in rapid influx of Ca^{2+} resulting in MH upon slaughter (Fujii et al., 1991) This rapid influx of calcium results in muscle contractions which also liberates heat, increasing the temperature of the carcass, and uses both glycogen stores and ATP rapidly. This rapid depletion of glycogen results in increased levels of lactic acid formation, which causes the rapid drop in pH. The effect of MH negatively impacts on meat quality via excessive protein denaturation (via over activation of proteolitic enzymes by warm/hot carcasses), excessive exudation, very low pH and pale in colour (PSE meat).

The HAL gene is found in Pietrain and Landrace genotypes (Sellier & Monin, 1994). PSE meat is characterised by a rapid drop in pH (pH <5.5) detected at 45-60 minutes post slaughter (Sellier & Monin, 1994). PSE meat is attributed with excessive water loss, pale in colour and tough (Kyriazakis & Whittemore, 2006).

2.8.4.4.2 RN^- gene

RN^- gene is also known as 'the acid meat' gene (Heuven et al., 2003). Acid meat develops when the ultimate pH of the pork is very low (See Figure 2.5) (Sellier & Monin, 1994) although there is no rapid decline in pH as seen in PSE meat (Rosenvold & Andersen, 2003). The RN^- gene is found amongst Hampshire pigs (Moeller et al., 2003; Sellier & Monin, 1994). Comparison of the effects of the carriers for the RN- gene vs. non carriers for meat quality traits and glycolytic potential are shown below in Table 2.5.

Table 2.5. Comparison of the effects of RN^- genotype on pork quality traits and chemical composition of the longissimus dorsi muscle. Modified from Lebret et al. (1999).

Trait	rn^+/rn^+	RN^-/rn^+	RN^-/RN^-	P value
Glycolytic potential, µmol/g[a]	108	222	195	<0.001
Ultimate pH, 24h	5.74	5.54	5.52	<0.001
Lightness	47.8	50.3	51.2	<0.001
Dry matter, %	24.6	23.6	23.7	<0.001
IMF, %	1.42	1.31	1.36	0.630
Protein, %	22.2	20.5	20.6	<0.001

rn^+/rn^+ = control; RN^-/rn^+=carrier; and RN^-/RN^- =Carrier
[a]herititablility value used for calculation.
P value shows significant difference between non carriers and carriers for RN- gene (P ≤ 0.05)
Genotypes used in trial consisted of equal numbers for Hampshire, Pietrain and Large White and consisted of same numbers for females and castrated males.
The sensitive HAL gene was not detected at the HAL/RYR loci as determined by DNA base testing.
Initial LW and slaughter LW were 24 and 108 kg respectively.

2.8.5 Nutritive value of pork

Meat is an excellent source of balanced protein (essential amino acids) and micronutrients to the consumer (Lawrie, 1998). According to Lawrie (1998) the amino acid composition of meat varies very little between different animal species, genotypes or muscles. Refer to Lawrie (1998) for additional information.The purpose of the current trial is to evaluate growth performance and pork quality from two New Zealand genotypes of grower-finisher pigs. Specifically, the objectives are: (1) to establish growth performance of two New Zealand pig genotypes (i.e., G1 and G2) using both entire male and female pigs; (2) to evaluate Minlp and Pdmax values expressed within these two genotypes using a growth model retrospectively from data gathered from the growth trial and (3) to assess the pork quality by empirical tests to ensure consumer acceptance of the end product.

CHAPTER 3: MATERIALS AND METHODS

3.1 Animals

Sixty four pigs, 5-6 weeks of age, were selected from a total of 133 pigs from two Pig International Company boar hybrid genotypes identified as G1 and G2 for commercial reasons (Table 3.1). These pigs were sourced from a pig farming enterprise located on the North Island, New Zealand. Equal numbers of entire males and females were chosen. The mean LW for the pigs was 15.4 ± 2.6kg (LW ± standard deviation (SD)).

Table 3.1. The selection procedure for the pigs used in this trial.

Boar type	Sow line	Gender	Total pigs	Selected pigs for trial	Litters used in trial
G1	A46	M	24	8	5
	A46	F	24	9	5
	C46	M	15	8	3
	C46	F	10	7	3
G2	A46	M	10	7	2
	A46	F	12	7	2
	C46	M	21	9	5
	C46	F	17	9	4
		Total	133	64	29

Abbreviations: M = male; F = female.

The selected pigs were transported to the Massey University Pig Biology Unit in Palmerston North, New Zealand. Pigs were allocated to eight pigs per pen which was determined by gender and genotype (i.e., four pigs from G1 and four pigs from G2 genotypes per pen). These pigs had a one week acclimation period prior to the experiment commencing. During this week, the pigs were offered a base diet which was in agreement with the guidelines specified by NRC (1998), water and feed were provided *ad libitum* during this period.

Animal ethics was approved by the Massey University Animal Ethics Committee (MUAEC 10/60). The pigs were cared for according to the New Zealand Code of Practice for the Care and Use of Animals for Scientific Purposes.

3.2 Experimental design

The trial commenced one week after the pigs arrived at the Massey University piggery and went for 13 weeks. The pigs were weighed at the start of the trial (by walking onto a calibrated platform scale) after the morning feed (~30 minutes after feeding ended), and were weighed consequently at the start of each week thereafter until slaughter. They were fed twice daily (i.e., 8.00am and 3:00pm) within individual feeding cages (i.e., eight feeding cages per pen).

3.2.1 Diets

The pigs were fed two diets. The first diet was limiting in energy but not limiting in balanced protein or amino acids (Minlp), and the second diet was not limiting in either energy or protein or amino acids (Pdmax). Diet compositions follow the guidelines specified (NRC, 1998). The diet summaries are shown in Table 3.2.

Table 3.2. Diet composition summaries for Minlp and Pdmax diets.

Ingredients	Diet	
	Minlp	**Pdmax**
Barley	66.60	62.55
Fish meal	4.00	-
Soy bean meal	24.00	28.00
Soybean oil	1.00	5.00
Lysine	0.30	0.35
Methionine	0.30	0.30
Threonine	0.20	0.20
Tryptophan	0.05	0.05
Vitamin + mineral premix[a]	0.30	0.30
Dicalcium phosphate	3.00	3.00
Disodium phosphate	0.15	0.15
Sodium chloride	0.10	0.10
Total	100	100

[a]*Vitalean; Vitec Nutrition, 2/20 Kerwyn Avenue, East Tamaki, Auckland, New Zealand.*

The purpose for the first diet was to determine the expression of Minlp as described by Weis et al. (2004). Thus, Minlp is driving growth. Once these pigs LW were ≥ 49.5kg their diet was changed to the Pdmax diet.. On the Pdmax diet was limiting growth. These pigs remained on the Pdmax diet until slaughter. The day before slaughter, the pigs were fed 400 ± 5g of Pdmax diet at 4:00pm and were fasted for 16 hours (water still provided ad libitum) before being loaded onto a truck at 8:00am the following morning to be transported to the local abattoir (i.e., Landmeats Ltd, Wanganui). The pigs were slaughtered in three batches by electrical stunning and exsanguination followed by scalding, splitting and gutting of the carcasses during weeks 11-13 of the trial.

The day post slaughter, the left side of the carcass was weighed; the *longissimus* muscle plus the overlying fat and skin from the short loin were boned out, vacuum packed, taken back to Massey University, and stored for 7 days in the chiller 2ºC ± 1ºC and then transferred to the freezer -30ºC ± 2ºC until required for pork quality assessments to be conducted.

3.2.1 Feeding regimen

At feeding time, the gates at the back of the feeder were opened one at a time to allow each pig access to one of the eight feeders. After each pig walked into the feeder the gate was closed behind them, and their feed bucket was allocated to them by matching the pig number on the bucket with the corresponding number on the pig's ear tag. This was to ensure the pigs were fed the correct amount of feed. The amount of feed which was offered daily per pig was calculated based on formulas which provided under Section 3.2.3.

Approximately half of the allocated dry feed per pig per day was emptied from each feed bucket into the respective feeder for the first meal time. Water was added to make a 'porridge-like consistency' (this was to ensure maximum feed intake and reduce feed wastage). Any feed not consumed (i.e., refusal) was recorded and, a sample of the refusal (i.e., a measured scoop to provide a representative sample of the feed refusal) was placed into a sealed plastic bag for each pig/week accordingly. This refusal bag was stored at -20ºC ± 2ºC between each feeding time for each pig per week. At the end of each week, the refusal bag was stored frozen until further analysis was conducted for dry matter (DM).

3.2.2 Diets

On the first day of the trial, the pigs were all restrictively fed the MinIp diet. The intended amount of feed offered was calculated based on previous work from Weiss et al. (2004) according to the following equation:

$$1) \quad FI\,(g/d) = (LW * 0.21 + 10.5) / 13.85 * 1000$$

However, to reduce the refusals for the first 7 days of the trial, the pigs were fed less than equation 1 (above). Thus, the energy intake was reduced to 70% and then gradually increased over the remaining days of the first week to 100%

based on equation 1. From day 8 onwards Equation 1 was used at 100% of energy intake until pigs reached ≥ 49.5kg (42 – 56 days of trial). Thus, the overall equation during the whole Minlp diet phase (derived from a linear regression of DEI/d as a function of LW) is:

$$2)\ FI\ (g/d) = (LW * 0.26 + 9.1) / 13.85 * 1000\ (R^2 = 98.1\%)$$

Once each pig's LW reached ≥ 49.5kg, pigs were offered the Pdmax diet ad libitum per scheduled feeding. The amount of feed offered was calculated based on the equation:

$$3)\ FI\ (g/d) = LW^{0.75} * 0.11 * 1000$$

3.2.3 Diet analysis methodology

Both of these diets were analysed by the nutrition laboratory at IFNHH, Massy University for dry matter (DM), GE, protein and amino acid content, fat, ash and neutral detergent fibre (NDF).

The DM was assessed by drying a feed sample in a convection oven at 105°C (AOAC 930.15, 925). The GE was assessed by bomb calorimetry. Protein was assessed by Leco total combustion method (AOAC 968.06, N-P = 6.25). Fat was assessed using the Soxtec extraction method (AOAC 991.36). Ash was determined by placing a feed sample in a furnace at 550°C (AOAC 942.05). NDF was assessed by the Tecator Fibretic System (AOAC 2002.04). The amino acids were analysed by hydrochloric acid (HCl) hydrolysis, followed by high-performance liquid chromatography (HPLC) separation (AOAC 994.12). Cysteine and methionine were analysed by performic acid oxidation.

The digestible energy (DE), true digestible lysine and lysine:DE ratio for Minlp and Pdmax diets were calculated.

3.2.4 Dry matter intake

The refusal sample from each respective pig was thawed and homogenised in a mixing bowl. A 40g sample was taken (weight recorded), placed in a 100ml Pyrex beaker and placed in an oven at 105ºC for 16 - 17 hours. The dried sample was reweighed, and the DM for the refusal was calculated. Also DM

was determined on a sample of each batch of dry feed. The DM percentage was calculated using equation 4.

4) $\%DM = \frac{dry\ weight\ (g)}{weight\ weight\ (g)} * 100$

Once the DM was determined for the refusal and the feed offered, equations 5 and 6 were used to calculate the amount of DM consumed per pig per diet per week for the duration of the trial.

5) $DMr\ (g) = total\ wet\ weight\ of\ refusal\ per\ week\ (g)\ *\ \%\ DMr$

$DMf\ (g) = total\ weight\ of\ feed\ offered\ per\ pig\ per\ week\ (g)\ *\ \%\ DMf$

DMr = Dry matter of the refusal sample

DMf = Dry matter of the feed offered

6) $FI\ (g) as\ fed/week = DMf\ \ per\ week\ (g) - DMr\ (g)\ per\ week\ /\ \%Dmf$

3.2.5 Growth performance

The growth performance was assessed by comparing the average daily gain (ADG), feed conversion ratio (FCR) and the feed intake (FI) for each diet (i.e. Minlp and Pdmax) and overall performance (the total of ADG, FCR and FI over the whole trial). The LW was also compared at the start of the trial, the end of the Minlp diet (start of Pdmax diet) and the end of the trial (i.e., the slaughter weight). The ADG and FCR were calculated by the following equations:

7) $ADG\ (g) = \frac{LWE - LWI}{LWE}\ *\ 1000$

ADG = average daily gain expressed in grams

LWE = live weight at the end of each diet period expressed in kilograms

LWI = live weight at the start of each diet period expressed in kilograms

8) $FCR = \frac{FI}{ADG}$

FCR = feed conversion ratio

FI = feed intake consumed over the period (expressed in grams)

ADG = average daily gain over the period (expressed in grams)

The terms Minlp and Pdmax were determined for each individual pig in the respective Minlp and Pdmax diet phases. Pdmax and Minlp values were calculated by the Massey pig biological growth model (http://www.porkmaster.org). See also Appendix 1.

3.3 Carcass measurements

Once the pigs reached LW ~90kg, (92.9 ± 4.81kg mean ± SD), the pigs were transported to an abattoir (Landmeats Ltd, Wanganui). The BF depth, pH and CW measurements were recorded. The P2 BF was measured using a Hennessey Grading Probe approximately 30 mintues post slaughter (after scalding and gutting, and the carcass inspection), and the carcass weight (CW) were recorded. Both measurements were performed by the staff at the abattoir. The carcasses were then hung and transferred to the chiller (2ºC ± 1ºC). Forty five minutes post slaughter, the pH of the longissimus dorsi muscle was measured using a calibrated digital pH probe (pH Spear, Eutech Instruments, OAKLON®) in the chiller by a technician from Massey University. The pH probe was calibrated with pH standard solutions at pH 10.01, 7.01 and 4.01. The same technician performed all the carcass pH measurements at the abattoir. The carcasses were hung in the chiller for 20 hours post slaughter before being boned.

The day post slaughter, the head of each carcass was removed (C1), and were longitudinally split into two along the length of the spine. The left side of each carcass was cut into three between the 3rd to 4th rib and the last to 2nd last lumbar vertebrae providing three primal cuts referred to as shoulder middle and leg. Each of these three cuts were weighed separately. A short loin was prepared as the caudal part resulting from a cut through the middle between the last and 2nd to last rib. One photograph of the cranial face of each short loin (i.e., before bone and fillet were removed) were taken by a digital camera with a 30 cm ruler (with mm graduations) to provide a scale.

The killing out percentage was calculated by the following equation (Warris, 2000):

$$9)\quad Killing\ out\ \% = \frac{CW}{LWE} * 100$$

CW = carcass weight (kg)

LWE = final LW determined before slaughter (kg)

3.4 Pork quality assessments

3.4.1 Pork loin measurements

The parameters assessed from the pictures were: the BF depth (mm), width (cm); depth (cm) and the surface areas (cm^2) of the BF and the longissimus dorsi muscle. This is illustrated in Figure 3.1.

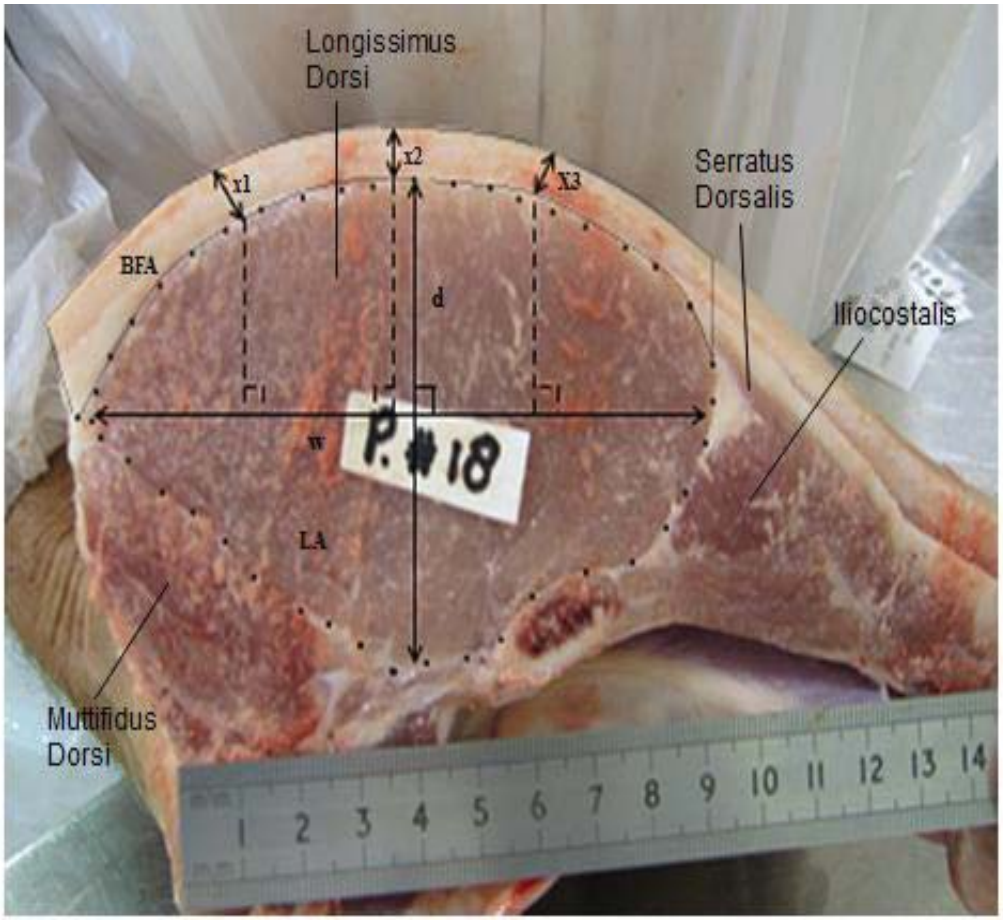

Figure 3.1. Shown where the measurements were taken from the picture of the pork loin chop. *Abbreviations: w = width (cm); d = depth (cm); LA = longissimus dorsi muscle area (cm^2) (inside ••• area); BFA = backfat surface area (cm^2) (inside area); x1-x3 = back ~~fa~~t depth (mm).*

The surface area was measured by tracing around the loin area and BF areas by a Placom Digital Planimeter KP-90N. The scale was adjusted by measuring the actual length of the ruler to provide a scale to calculate a conversion factor by dividing the length of the millimetric ruler in the picture by the actual length of the ruler.

3.4.2 Thaw loss

The pork loins were taken out of the freezer, removed from their vacuum-packed plastic bag, weighed and placed in a plastic bag and transferred to the chiller at 3ºC ± 1ºC for 24 hours to thaw. The sample was removed from the plastic bag, blotted on a paper towel and reweighed. Thaw loss was calculated by the following equation:

$$10) Thaw\ loss\ (\%) = \frac{Frozen\ weight\ (g) - thawed\ weight\ (g)}{Frozen\ weight\ (g)} * 100$$

3.4.3 Preparing the pork loin for pork quality

The overlaying skin and BF from the pork loin were removed manually with a boning knife. The cutting up procedure is shown in Figure 3.2.

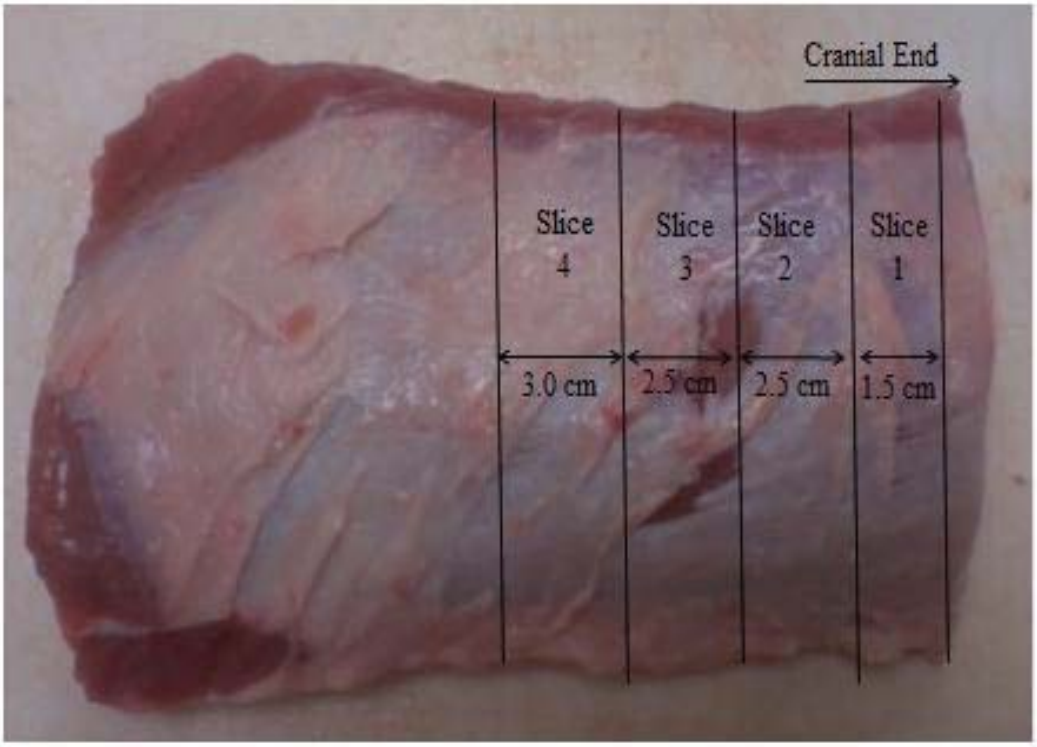

Figure 3.2. The cutting-up procedure of the pork loin. The BF and overlaying skin were removed with a knife prior to cutting (each cut is indicated by the solid line). The first cut was to square off the cranial end. Slice 1 was used for colour, sarcomere length, ultimate pH and expressed juice loss assessments. Slices 2 and 3 were used to measure cooking loss and shear force. Slice 4 was used for driploss and IMF assessments.

3.4.4 Colour

A sample was cut from the pale end of slice 1, placed in a sealed bag and stored frozen at -30°C. When required for testing, the samples were thawed in the chiller at 3°C (whilst still remaining in their sealed bags), then pulled out of the bag and cut in half with a knife to expose the internal surface to air at room temperature (18 - 20°C) for 30 minutes. A petri dish was then placed over the sample and lightly squashed on the upper surface of the sample. This was to keep the chromometer clean. Then each sample was measured twice (i.e., once on each slice) with a chromometer. The Minolta CR-200 chromometer had a 10mm diameter aperture and was calibrated against a white standard for values: lightness (L*) = 97.55, redness (a*) = - 0.52 and yellowness (b*) = 2.60

The petri dish was cleaned after every fifth sample with distilled water and dried with a paper towel.

3.4.5 Ultimate pH

The ultimate pH was measured with a digital pH meter with temperature compensation. The pH meter was calibrated for pH7 and pH4 with standard solutions which were 2ºC ± 1ºC prior to the first sample being measured. An internal (core) sample of 2.0 - 2.5g of pork was taken from slice 1 and homogenised in 10ml 150mM potassium chloride (KCl) as described by Purchas and Zou (2008). Once the sample was homogenised the pH was recorded.

3.4.6 Expressed juice loss

An internal single sample of 500 ± 20mg was taken from slice 1 and placed on a piece of Whatman number one filter paper (11cm diameter). The filter paper and sample were pressed between two Perspex plates and a 10kg weight was placed on top for 5 minutes. Once 5 minutes was reached the weight was removed, the area of the flattened pork was circumscribed with a pen and the area of the moisture on the paper was measured by a Placom Digital Planimeter KP-90N as described by Purchas (1990). The expressed juice loss was then calculated by the following equation:

$$11) Expressed\ juice\ = \frac{Outside\ wetted\ area\ (cm^2)}{Meat\ sample\ weight\ (g)}$$

3.4.7 Sarcomere length

A small sliver from the dark part of slice 1 was cut 8 - 10mm along the length of the muscle fibres and 1 x 1mm cross section with a scalpel blade. The sliver of tissue was flattened out with a scalpel blade to increase the surface area of the sample and then transferred to a microscope slide. About 2 - 3 drops of distilled water was added to the sample and a second microscope slide was pressed on top, squashing the sample between the two microscope slides. The microscope slide was then placed on the holder so that the sample was 100mm from a white surface. A helium-neon (He-Ne) laser was passed through the sample. The sample in the holder was rotated around until 3 bands were clearly visible. The distance between the first order diffraction bands was measured, and 12

measurements per sample were used to calculate the mean distance (mm). The following equation was then used to calculate the sarcomere length (SL) in micrometres (µm):

$$12) SL(\mu m) = 0.6328 * \frac{\left[\sqrt{\left(\left(\frac{x}{10*2}\right)^2 + 100\right)}\right]}{\frac{x}{10*2}}$$

x = *the calculated mean distance between the first-order diffraction bands (mm).*

3.4.8 Cooking losses and shear force measurement

Slices 2 and 3 (2.5cm thick) were placed into a 150 x 250ml plastic bag (which were unsealed) and weighed prior to cooking. The sample was then suspended in a water bath at 70ºC for 90min. Each sample was then drained of all visible moisture in the bag for 5 minutes, and placed in the chiller (2ºC) overnight (~ 20 hours). The following morning the sample was blotted on a paper towel and reweighed as described by Purchas et al. (2002). The following equation was used to calculate the cooking losses:

$$13) Cooking\ loss\ (\%) = \frac{Raw\ weight\ (g) - cooked\ weight\ (g)}{Raw\ weight\ (g)} * 100$$

The cooked samples were then subjected to a meat toughness test using the Warner-Bratzler Shear Force machine (WSFM). Six cores were prepared that ran parallel to the muscle fibres in length and with a 13 x 13mm cross section. Any cores which were not uniform in size or appearance were not used. Each of the six cores were sheared twice (i.e., 1/3 and 2/3 along the length of each cut) yielding a total of 12 shear values per sample as described by Purchas (1990).

3.4.9 Drip loss

An internal sample was cut into a cube shape measuring approximately 3 x 3 x 3cm from slice 4. The sample was weighed, put on a metal hook, placed in a 150 x 250mm plastic bag and hung in the chiller at 2ºC ± 1ºC. Each sample was reweighed at 24 and 48 hour intervals as described by Edens et al.(1996). Driploss was calculated by the following equation:

$$14) Driploss\ (\%) = \frac{Original\ weight\ (g) - end\ weight\ (g)}{Orignal\ weight\ (g)} * 100$$

end weight (g) = driploss weight (g) after either 24 hour or 48 hours.

3.4.10 Intramuscular Fat

A trimmed ~40g sample was taken from slice 4 of the loin and placed in a sealed plastic bag and stored in the freezer at -30°C. The frozen sample was minced with a knife, placed in a new sealed plastic bag and weighed before being freeze dried. The freeze dried weight sample was weighed and the fat content quantified by solvent extraction (petroleum ether, BP 40 - 60°C) using a Soxtec apparatus (AOAC 911.36).

3.5 Statistical analysis

A linear model using 2 x 2 fixed factorial design with boar genotype and sex as fixed effects and their interaction was fitted to the data. Significance given when $P < 0.05$. Difference between genotype*sex groups were tested with Fischer's least significant difference (LSD) test where appropriate.

CHAPTER 4: RESULTS

The data for growth performance, carcass traits and pork quality will be presented in separate tables below. All these tables display the effects (i.e. genotype (G), sex (S) and genotype*sex (G*S) interaction for least squares means (LSMeans) and P values. The goodness of fit of the model is represented by the residual standard deviation (RSD) and coefficient of determination (R^2).

4.1 Selected pigs

During the selection process, 14 pigs were not suitable for selection from the original pool of 133 pigs. This was due to eight pigs having joint infections and six pigs dying. Thus, 64 pigs were selected from a total of 119 pigs. All the pigs were born within seven days of each other.

The LW for the selected pigs (n = 64) was 15.4 ± 2.6kg, mean ± SD. Pigs were selected 2 weeks prior to the experiment commencing (this included the 1 week adjustment period when the pigs arrived at the Massey University Pig Biology Unit.

4.2 Diet analysis

Table 4.1 compares the chemical analyses between Minlp and Pdmax diets as analysed in the nutrition lab at IFNHH, Massy University.

Table 4.1. Laboratory analyses and predicted values of the Minlp and Pdmax diets based on dry matter basis.

Laboratory analysis	Diet	
	Minlp	**Pdmax**
DM, g/kg	895	885
GE, MJ/kg	16.22	17.03
Protein, g/kg	236	207
Fat, g/kg	25	65
Ash, g/kg	77	65
Neutral detergent fibre, g/kg	134	136
Aspartic acid, g/kg	19.8	18.7
Threonine, g/kg	9.8	8.6
Serine, g/kg	8.7	8.4
Glutamic acid, g/kg	39.1	37.2
Proline, g/kg	16.3	13.7
Glycine, g/kg	9.8	7.8
Alanine, g/kg	9.1	7.8
Valine, g/kg	11.4	10.5
Isoleucine, g/kg	9.2	8.6
Leucine, g/kg	15.4	14.4
Tyrosine, g/kg	6.6	6.2
Phenylalanine, g/kg	10.5	10.1
Histidine, g/kg	5.7	5.1
Lysine, g/kg	14.0	13.3
Arginine, g/kg	13.2	11.9
Cysteine, g/kg	3.5	4.0
Methionine, g/kg	6.1	6.0
Calculated[a]		
DE (MJ/kg)	13.85	14.81
True digestible lysine, g/kg	12.6	12.0
Lysine/DE ratio	0.91	0.81

[a]*The DE, true digestible lysine and lysine/DE ratio were calculated from Morel et al. (1999).*

4.3 Growth performance

Table 4.2 shows the growth performance for pigs fed Minlp and Pdmax diets, and overall growth performance.

Note: One of the male pigs from the G2 genotype was removed from the trial midway through the Pdmax diet phase because it had a pinched nerve on its hind legs and could not stand up. Thus, this pig's data was excluded from the Pdmax diet phase and overall performance.

4.3.1 Minlp diet

The G1 genotype had the greatest ADG and lowest FCR compared to G2 ($P < 0.001$). Males had the greatest ADG and lowest FCR compared to the females ($P < 0.001$) across both genotypes. The G1 males had the greatest ADG and the G2 females had the lowest ADG while G1 females and G2 males had similar ADG, The G2 females had the greatest FCR as were the only group that was different from the rest within the genotype*sex interaction.

The differences found for genotype and sex were both highly significant ($P < 0.001$) in which the G1 had the lowest Minlp value within genotype and males had the lowest within sex. The G2 females had the greatest Minlp value ($P = 0.016$) and were the only group which was different to the others within the G*S interaction.

4.3.2 Pdmax diet

The G1 genotype had the greatest ADG and lowest FCR compared to G2 ($P < 0.001$). The males had the greatest ADG and lowest FCR compared to the females ($P < 0.001$). The females had the greatest daily feed intake compared to the males during the Pdmax diet phase ($P = 0.040$). There were no differences found for the genotype*sex interaction for ADG, daily feed intake or FCR during this diet phase although the G2 females yielded the lowest absolute values for ADG and greatest absolute values for FCR (See Table 4.2).

G1 and males had the greatest Pdmax values within genotype and sex respectively ($P < 0.001$). No differences were found within genotype*sex interaction.

Table 4.2 Least squares means for growth performance data for genotype, sex and genotype*sex interaction for grower-finisher pigs.

Growth Data	Genotype (G)		Sex (S)		G1		G2		P Values			RSD[y]	R^2 %[y]
	G1	G2	F	M	F	M	F	M	G	S	G*S		
Minlp phase													
n[x], sample size	32	32	32	32	16	16	16	16					
LW start, kg	18.54	18.15	18.54	18.15	18.98	18.09	18.1	18.21	0.600	0.590	0.500	2.91	1.7
ADG, g	750	710	710	760	750[b]	760[b]	680[a]	750[b]	<0.001	<0.001	0.020	0.04	40.6
Feed intake, g/d	1230	1240	1240	1230	1240	1220	1240	1230	0.330	0.110	0.480	0.03	6.5
FCR	1.63	1.74	1.75	1.62	1.67[a]	1.60[a]	1.83[b]	1.65[a]	<0.001	<0.001	0.040	0.11	40.5
Minlp	0.0248	0.0327	0.0330	0.0245	0.0269[a]	0.0226[a]	0.0391[b]	0.0263[a]	<0.001	<0.001	0.016	0.01	46.4
LW diet change, kg	52.69	52.29	52.27	52.72	52.56	52.83	51.97	52.61	0.410	0.350	0.710	1.91	2.8
Pdmax phase[x]													
ADG, g	1200	1130	1088	1240	1135	1263	1041	1220	<0.001	<0.001	0.250	0.09	49.6
Feed Intake, g/d	2190	2210	2220	2190	2200	2180	2230	2190	0.150	0.040	0.460	0.05	10.8
FCR	1.85	1.98	2.06	1.77	1.96	1.74	2.16	1.81	<0.001	<0.001	0.110	0.16	52.0
Pdmax, g/d	226	204	193	237	208	245	178	229	<0.001	<0.001	0.303	25.74	50.4
LW slaughter, kg	93.27	91.57	91.68	93.16	92.98	93.56	90.38	92.76	0.100	0.150	0.380	4.09	8.6
Overall Performance[x]													
ADG, g	940	890	880	960	920[b]	970[c]	830[a]	940[b,c]	<0.001	<0.001	0.040	0.05	49.3
Feed Intake, g/d	1640	1650	1660[b]	1630	1670	1620	1660	1640	0.600	0.010	0.530	0.05	10.7
FCR	1.75	1.87	1.91	1.71	1.82[b]	1.67[a]	2.00[c]	1.74[a,b]	<0.001	<0.001	0.050	0.12	54.5

*[a,b,c]Least squares means within G*S without a common superscript letter within row are different (P ≤ 0.05).*

[x]the sample size was less for columns G2, male and G2 male groups for the Pdmax diet and overall performance due to one pig being removed from the trial during the Pdmax diet phase.

[y]the goodness of fit of the model by the residual standard deviation (RSD) and the coefficient of determination (R^2).

4.4 Carcass traits

The results for the carcass traits are shown in Table 4.3. G1 had the lowest P2BF depth compared to the ($P = 0.010$). There was no difference for sex for P2BF. The G1 females had the lowest P2BF, G2 females had the greatest ($P = 0.010$), while the G2 and G1 males were intermediate and not different from each other.

There were no differences for carcass weight or killing out percentages for genotype, sex or genotype*sex interaction. The G1 genotype had greatest shoulder mass (kg) compared to G2 ($P = 0.001$). The males also had greater shoulder mass (kg) compared to females ($P = 0.004$). There was no difference for G*S interaction. There were no differences found for middle or leg masses (kg) within genotype, sex or genotype*sex interaction.

The shoulder percentage was greatest in the G1 compared to G2 which was ($P < 0.001$). The males had the greatest shoulder percentage compared to the females ($P < 0.001$). There was no G*S interaction for shoulder percentage for.

The females had the greatest middle percentage compared to the males which ($P = 0.012$). No G*S interaction for middle percentages were found affect of genotype.

The G2 genotype had the greatest leg percentage compared to G1 ($P < 0.001$). No other differences were found for leg percentage within sex or G*S.

Table 4.3. Least squares means for slaughter and carcass measurements for genotype, sex and genotype*sex interaction.

Carcass Traits	Genotype (G)		Sex (S)		G1		G2		P Values			RSD[y]	R^2 %[y]
	G1	G2	F	M	F	M	F	M	G	S	G*S		
n[x]	32	31	32	31	16	16	16	15					
Hot carcass weight, kg	71.1	69.4	69.7	70.8	71.2	71.1	69.1	70.5	0.130	0.450	0.410	3.85	9.4
Killing-out, %	76.2	75.4	75.7	76	76.5	76	75.5	75.4	0.151	0.576	0.719	2.23	4.2
P2BF depth(mm)	8.9	9.8	9.4	9.3	8.4[a]	9.3[b]	10.3[c]	9.3[b]	0.010	0.880	0.010	1.34	21.0
Left side of carcass													
Shoulder, kg	10.18	9.66	9.71	10.13	10.06	10.30	9.35	9.96	0.001	0.004	0.192	0.56	29.7
Middle, kg	10.54	10.35	10.50	10.39	10.67	10.42	10.34	1.04	0.213	0.466	0.400	0.61	4.6
Leg, kg	10.69	10.86	10.74	10.82	1.74	10.64	10.73	11.00	0.361	0.672	0.331	0.75	3.2
Sum half, kg	31.4	30.9	31.0	31.3	31.5	31.4	30.4	31.3	0.190	0.345	0.224	1.62	6.7
Shoulder, %	32.4	31.3	31.4	32.3	32.0	32.9	30.8	31.8	<0.001	<0.001	0.735	0.95	40.1
Middle, %	33.6	33.6	34.0	33.2	33.9	33.2	34.0	33.1	0.957	0.012	0.714	1.24	10.5
Leg, %	34.0	35.2	34.7	34.5	34.1	33.9	35.2	35.1	<0.001	0.604	0.912	1.21	19.6

[a,b,c] *LSMeans within G*S without a common superscript letter within row were different (P ≤ 0.05).*

[x] *the sample size was less in the G2, male and G2 male groups due to one pig being removed from the trial.*

[y] *superscript shows the goodness of fit of the model by the residual standard deviation (RSD) and the coefficient of determination (R^2).*

4.5 Pork chop Image analysis

The results for the pork chop image analysis are shown in Table 4.4. G1 had the greatest width compared to G2 (P = 0.013). The females also had the greatest width compared to the males (P = 0.016). No difference was found within G*S interaction for width (P = 0.463). There were no differences found for depth. The G2 had the greatest BF depths compared to G1 (P < 0.001). The females tended to have the greatest BF depths compared to the males (P = 0.059). The G2 females had the greatest BF depths and G1 males and G1 females had the lowest BF, while the G2 males was the intermediate (P = 0.023). G1 had the greatest longissimus dorsi surface area (LA) compared to G2 (P = 0.011). The females tended to have the greatest LA (P = 0.056). No G*S interaction was found for LSA.

G2 had the greatest back fat area (BFA) compared to G1 (P = 0.002). Across genotypes, the females had the greatest BFA (P = 0.011). There was no G*S interaction. G1 had the greatest LA:BFA ratio compared to G2 which was (P < 0.001). There was no G*S interaction and no other differences within sex for LSA:BFA ratio.

Table 4.4. Least squares means for image analysis for the loin chop picture for genotype, sex and genotype*sex interaction.

Test	Genotype (G)		Sex (S)		G1		G2		P value			RSD[y]	R^2%[y]
	G1	G2	F	M	F	M	F	M	G	S	G*S		
n[x]	32	31	32	31	16	16	16	15					
Width, cm	10.0	9.7	10.0	9.7	10.2	9.8	9.8	9.6	0.013	0.016	0.463	0.52	18.3
Depth, cm	6.2	6.0	6.2	6.0	6.3	6.0	6.1	5.9	0.189	0.058	0.579	0.48	9.0
BF depth, mm	6.6	8.2	7.8	7	6.5[a]	6.6[a]	9.0[c]	7.3[b]	<0.001	0.059	0.023	1.58	31
LA, cm^2	44.3	41.2	43.9	41.6	46.2	42.4	41.6	40.8	0.011	0.056	0.215	4.71	17.3
BFA, cm^2	8.6	10.5	10.3	8.8	9	8.3	11.6	9.4	0.002	0.011	0.189	2.22	25.4
LA:BFA, Log10	0.724	0.605	0.644	0.685	0.731	0.717	0.557	0.653	<0.001	0.187	0.078	0.12	25.6

*[a,b,c] LSMeans within G*S without a common superscript letter within row were different (P = ≤0.05).*
[x]the sample size was less in the G2, male and G male groups due to one pig being removed from the trial.*
[y]the goodness of fit of the model by the residual standard deviation (RSD) and the coefficient of determination (R^2).
Abbreviations: BF = backfat; LA=Longissimus area; BFA = backfat area; LA:BFA = Longissimus area to backfat area ratio.

4.6 Pork quality analysis

Table 4.5 shows the results for pork quality. Differences were found for thawloss, ultimate pH and intramuscular fat (IMF) only. G2 had the greatest thawloss when compared to G1 (P = 0.027). There were no other differences found for sex or G*S.

G2 had the lowest pH when compared to G1 (P=0.005). No ultimate pH differences were found for sex or G*S.

The G2 females had the greatest IMF percentage when compared to G1 males, G2 females and G2 males (P = 0.017).

Table 4.5 Least squares means for pork quality tests performed for genotype, sex and genotype*sex interaction.

Pork quality test	Genotype (G)		Sex (S)		G1		G2		P Values			RSD[y]	R^2 %[y]
	G1	G2	f	m	f	m	f	m	G	S	G*S		
n[x]	32	31	32	31	16	16	16	15					
Thawloss, %	1.88	2.40	2.14	2.14	1.80	1.97	2.48	2.32	0.027	0.982	0.481	0.91	7.3
pH, 45 min PS	6.31	6.35	6.38	6.28	6.35	6.26	6.40	6.31	0.450	0.120	0.980	0.77	5.0
Ultimate pH	5.37	5.29	5.33	5.33	5.39	5.35	5.28	5.31	0.005	0.984	0.199	0.34	12.3
Driploss 24h, %	13.20	13.53	13.79	12.94	12.47	13.92	13.40	13.66	0.657	0.251	0.426	2.99	3.9
Driploss 48h, %[z]	16.77	16.09	16.80	16.06	16.25	17.28	15.87	16.32	0.310	0.260	0.660	2.61	3.8
Cooking loss, %	28.93	28.49	29.13	28.29	28.33	29.52	28.24	28.73	0.612	0.337	0.689	3.51	2.2
Expressed juice loss, $cm^2\ g^{-1}$	34.91	34.43	35.39	33.96	33.84	35.99	34.08	34.79	0.508	0.055	0.331	2.95	8.0
Sarcomere length (µm)[*]	1.60	1.62	1.61	1.61	1.60	1.60	1.62	1.62	0.210	0.890	0.975	0.07	3.4
IMF, %	0.80	0.89	0.90	0.79	0.78[a]	0.82[a]	1.02[b]	0.76[a]	0.159	0.080	0.017	0.24	16.1
Shear peak force, N	74.24	70.27	71.51	73	76.86	71.62	69.15	71.4	0.278	0.682	0.305	14.44	4.8
Colour Test													
L*, lightness	48.93	47.96	48.68	48.20	48.50	49.35	47.90	48.01	0.882	0.080	0.429	1.76	10.1
a*, redness	6.70	7.14	6.85	6.99	6.80	43.21	7.18	7.11	0.094	0.598	0.797	2.07	1.1
b*, yellowness	3.09	3.22	3.13	3.19	3.18	3.19	3.19	3.25	0.504	0.754	0.551	0.78	2.1

*[a,b,c] LSMeans within G*S without a common superscript letter within row were different (P < 0.05).*

[x] the sample size was less in the G2, male and G male groups due to one pig being removed from the trial.*

[y] the goodness of fit of the model by the residual standard deviation (RSD) and the coefficient of determination (R^2).

[z] one pig data was removed from G2, F and G2F columns due to being an outlier for driploss 48hr test. Thus sample size for these columns is: G2=30; F=31 and G2F=15.

[*] data from 3 pigs were removed from sarcomere length test due to being outliers (determined by Minitab®15.1.0.0 normality test). Sample sizes: G1=31; G2=29; F=30; M=30; G1F=15; G1M=16; G2F=15 and G2M=14.

CHAPTER 5: DISCUSSION

5.1 Growth performance

Traditionally, growth performance is determined by measuring LW, FI, ADG and FCR. These growth traits from the current trial are compared with other studies for the grower phase in Table 5.1 and the finisher phase in Table 5.2.

Table 5.1. Comparison of traditional growth performance traits for the grower diet[a] phase of the current trial with other recent trials.

Genotype	LW, kg	FI, g/d	ADG, g	FCR	Type of Study	Reference
G1 female	18.98 - 52.56	1240	750	1.67	Growth trial	Current trial
G1 male	18.09 - 52.83	1220	760	1.6	Growth trial	
G2 female	18.1 - 51.97	1240	680	1.83	Growth trial	
G2 male	18.21 - 52.61	1230	750	1.65	Growth trial	
Female	24.4 - 50.8	1324	678	1.96	Growth trial	CRC, unpublished
male	24.8 - 53.3	1324	628	2.11	Growth trial	
G1	31 - 34 weeks	1330	747	1.78	Growth trial	Honeyfield-Ross et al., 2009
G2	31 - 34 weeks	1338	707	1.89	Growth trial	
G3	31 - 34 weeks	1360	793	1.72	Growth trial	
G4	31 - 34 weeks	1359	692	1.96	Growth trial	
CM LW	n/a	n/a	n/a	n/a	SS	Quiniou et al., 1996
CM LW x Pt	n/a	n/a	n/a	n/a	SS	
Entire male LW x Pt	n/a	n/a	n/a	n/a	SS	
SSc	28 - 65	1937	1088	1.79	SS	de Greef, et al., 1992
SSt	28 - 66	1396	417	3.4	SS	
CSc	28 - 67	1952	1025	1.91	SS	
CSt	28 - 68	1415	430	3.35	SS	
LW x LR	20-45	1500	809	1.84	Growth trial	Campbell & Taverner, 1988
LW x LR	20-46	1500	750	2.02	Growth trial	
LW x LR	20 - 47	1510	670	2.25	Growth trial	

[a]*Grower phase term used to indicate the diets where energy but not protein is the limiting factor.*
Abbreviations CM = castrated male; CSc = commercial sire control; CSt = commercial sire treatment; LR = Landrace; LW = Large White; n/a = not available; Pt = Pietrain; SSc = synthetic sire control; SSt = synthetic sire treat; SS = serial slaughter.

Table 5.2. Comparison of traditional growth performance traits of the current trial with other recent trials for finisher diet[a] phase.

Genotype	LW, kg	FI, g/d	ADG, g	FCR	Type of Study	Reference
G1 female	52.72-93.16	2200	1135	1.94	Growth trial	Current trial
G1 male	52.56-92.98	2180	1263	1.73	Growth trial	
G2 female	52.83-93.56	2230	1041	2.14	Growth trial	
G2 male	51.97-90.38	2190	1220	1.8	Growth trial	
Female	50-90	2473	1039	2.38	Growth trial	CRC, unpublished
male	50-91	2522	1120	2.25	Growth trial	
G1	34 weeks - 73.5	2078	1104	1.88	Growth trial	Honeyfield-Ross et al., 2009
G2	34 weeks - 73.5	2040	989	2.06	Growth trial	
G3	34 weeks - 73.5	2113	1102	1.92	Growth trial	
G4	34 weeks - 73.5	2071	1033	2	Growth trial	
CM LW	42.6-100.5	2555	1032	2.48	SS	Quiniou et al., 1996
CM LW x Pt	45.6-101.6	2406	1032	2.33	SS	
Boar LW x Pt	41.5-101.9	2316	1078	2.15	SS	
SSc	65-105	2500	1105	2.26	SS	de Greef et al., 1992
SSt	65-105	2266	1305	1.74	SS	
CSc	65-105	2495	1158	2.15	SS	
CSt	65-105	2384	1288	1.85	SS	
LW x LR	45-90	2230	710	3.14	Growth trial	Campbell & Taverner, 1988
LW x LR	45-90	2460	866	2.84	Growth trial	
LW x LR	45-90	2700	1202	2.25	Growth trial	

[a]*Finisher phase term used to indicate diet not restricted in energy or protein/amino acids.*
See Table 5.1 for abbreviations.

During the Pdmax diet phase the current genotypes had improved FCR and ADG compared to older studies (Table 5.2). These findings indicate that G1 and G2 are more efficient at utilising the feed nutrients and have better growth performance compared to earlier genotypes.

There are many ways to describe the partitioning of energy retained between Pd and Ld for grower-finisher pigs. In the review written by de Lange et al. (2008), it was concluded that a simple linear relationship existed between DEI and Target L/P. This was sufficient to predict the effect of energy intake on body composition provided the diet is limiting in energy, but not limiting in protein/amino acids during the energy-dependant phase. This conclusion was made after re-analysing data from 13 different trials. The Minlp value (slope) ranged between 0.020 – 0.048 from 13 different studies. Target L/P can be calculated from LW during the energy-dependant phase of the growth trial (i.e.,

20 – 50kg LW of the current trial) from the equation: Target L/P = $\alpha \times$ DEI (see also Appendix 1). The Minlp values from the current thesis are within this range and are shown with the other genotypes from de Lange et al. (2008) in Figure 5.1.

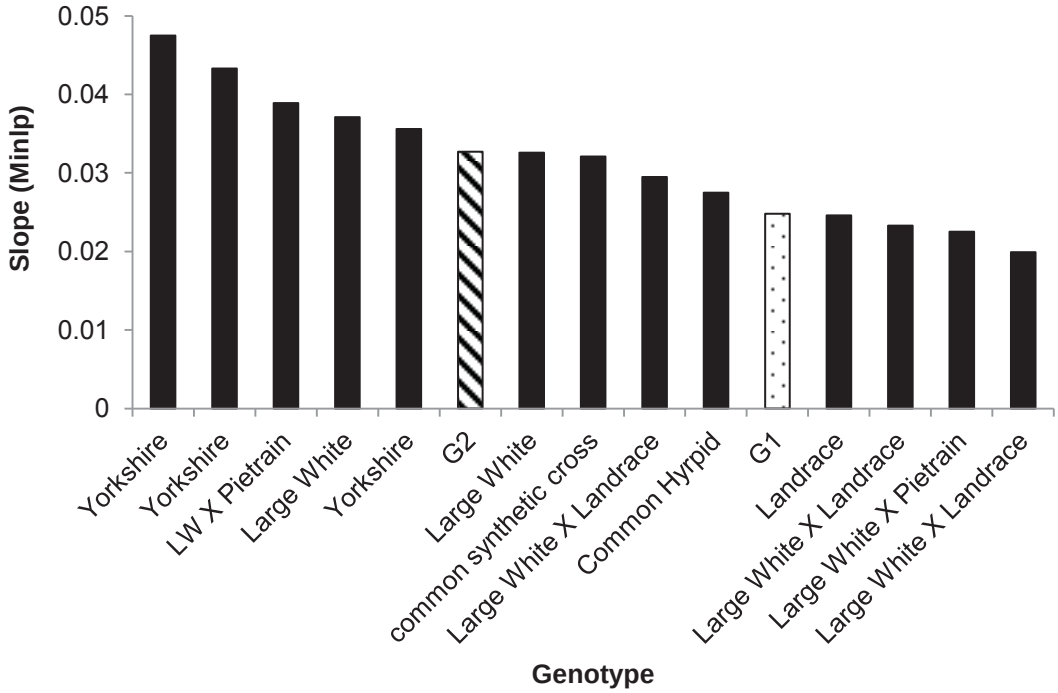

Figure 5.1. Comparison of the slope from G1 (dotted bar) and G2 (striped bar) against other genotypes during the energy dependant phase of the growth trial. The fattest genotypes are shown in descending order from the left hand side of the graph and the leanest genotypes are on the right hand side. The data from the other genotypes (i.e., excluding G1 and G2) were taken from Table 14.5 and the genotype names were retrieved from Table 14.2 Adapted from de Lange et al. (2008).

The purpose of the energy restricted diet phase for the current trial was to provide the expression of Minlp. G1 and G2 were found to be in the middle between the fattest and leanest genotypes reported by de Lange et al. (2008) (Figure 5.1.).

Although in other growth trials, Minlp was evaluated for different genotypes by using several diets which consisted of different energy level restrictions (but the diets were still adequate in protein/amino acids). For the current trial, the pigs were all fed the same diet restricted fed at a level which was calculated based

on an equation provided from Weiss et al. (2004). This earlier work by Weiss et al. (2004), and also the Minlp range reported by de Lange et al. (2008), both indicate that the pigs from the current trial were held at Minlp during the energy-dependant phase of the trial.

The Minlp value is unique to specific pig genotypes. Minlp is expected to be the lowest for entire males compared to females within the same genotype. This is because entire males are found to be more lean (or least fat) compared to females and castrated males. The findings of the current trial support this in which the males themselves and also within the G1 and G2 genotypes had the lowest Minlp values compared to the females within sex and genotype (see Table 4.2 in Chapter 4). However, no differences for Minlp were reported for sex effects by Honeyfield-Ross (2009) using a similar experimental group except the sample size was smaller for sex (i.e., n = 6) compared to the current trial (i.e., n = 32 per).

It is not known whether compensatory growth occurred or not with the current trial. This is because it was not measured directly (i.e., not controlled for).

Two studies which started off with a diet restricted in protein/amino acids using entire males and barrows, then fed a diet not limiting in neither protein or energy found that the pigs were held above Minlp during the grower phase (Martinez-Ramirez et al., 2008a; Martínez-Ramírez et al., 2008b). During the finisher phase of this trial pigs were found to be more efficient at depositing protein and argued that this effect may be due to compensatory growth (Martinez-Ramirez et al., 2008a; Martínez-Ramírez et al., 2008b). However, because the body's chemical composition is preset (Kyriazakis & Whittemore, 2006), the pig's in these two trials were tending towards greater Pd and a decrease in Ld to meet the preferred Ld:Pd ratio during the finisher phase.

Compensatory growth may have had an affect on the current trial on the nutrient utilisation during the Pdmax diet phase because the pigs were restricted fed a diet limiting in energy first, and then fed a diet not limiting in energy or protein/amino acids. However, the effect of compensatory growth may have been small because these pigs were held at Minlp during the grower phase as opposed the trials on entire males and barrows in which these pigs

were held above Minlp during the grower phase (Martinez-Ramirez et al., 2008a; Martínez-Ramírez et al., 2008b). Thus, the pigs body composition in the current trial may not have deviated far from the preferred Ld:Pd as described by Kyriazakis and Whittemore (2006). More research is required to evaluate the ability of compensatory growth to manipulate nutrient utilisation in pigs as a factor to improve performance in the pig industry.

Pdmax is reported to be unique to genotype and is constant between LW range from 20kg until the pigs start to mature after which Pdmax starts to decline (de Lange et al., 2008). The Pdmax and ADG values of the current trial are compared against eight other trials shown in Figure 5.2.

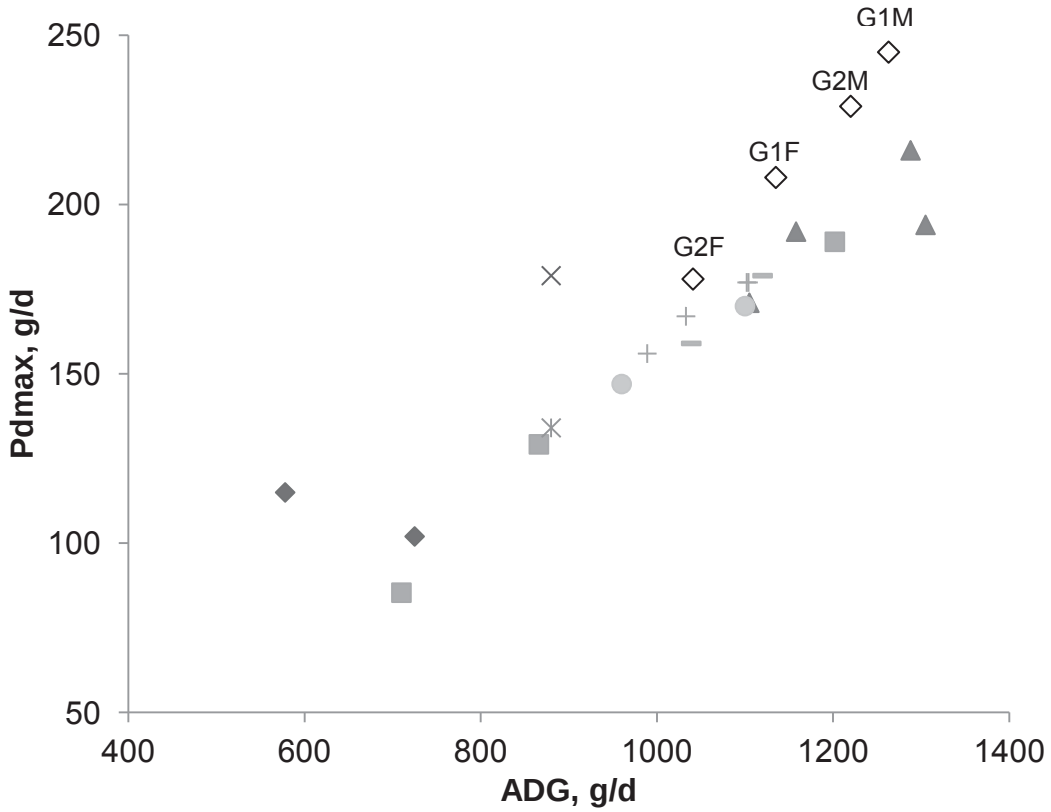

Figure 5.2. The relationship between Pdmax and ADG in the current trial against eight other trials. The linear equation is: y = 0.1815x – 19.81 and the coefficient of determination (R^2) = 78.5%. *Symbols: ◊ (Kerr, 2012); ♦ (Whittemore & Fawcett, 1974); ■ (Campbell & Taverner, 1988); ▲ (de Greef, et al., 1992); × (Rao & McCracken, 1992); ✳ (de Lange & Schreurs, 1995); + (Honeyfield-Ross et al., 2009); ● (Moughan et al., 2006) and – (CRC, unpublished).*

The Pdmax values calculated from the current trial are greater than the other trials shown in Figure 5.2. This is consistent with the trend that modern genotypes are leaner and have better growth performance traits compared to older genotypes (refer to Tables 5.1 and 5.2). This trend was also found by Knap et al. (2009) that Pdmax values were increasing from 1970 – 2004 where the lowest Pdmax value was 110g/d and the greatest was 230g/d, respectively.

Other trials which have evaluated Pdmax have done so using diets with lysine as the first limiting amino acid over several different levels in nitrogen balance, serial slaughter and growth trials. In the current trial, Pdmax was calculated (using some calculation rules provided in Appendix 1) using the Massey Pig Growth Model (www.porkmaster.org) from a growth trial in which all the pigs were offered the same diet which was not limiting in energy or protein/amino acids offered *ad libitum* per scheduled meal time.

5.2 Carcass traits

The carcasses from G1 yielded lower P2BF depths compared to G2. Also, the LA:BFA ratio provided an indication of leanness (although total fat free mass or muscle to bone ratio were not measured in this experiment) between these two genotypes. The findings from P2 BF and LA:BFA both suggest that G1 was leaner (or less fat) than G2 in this trial. These finding were also consistent with the claims made by the pig international company (PIC) which were that the 337 genotype (i.e., G1) have the greatest growth performance and are more lean than 356 genotype (i.e., G2) (PIC, 2011).

Although there was no difference found within sex effect for P2BF, the common trend within genotype was that entire males were leaner compared to females. This trend was also found by Rosenvold and Stuart. (2009) in which the females were fatter compared to boars (fat index 9.4 and 8.9, respectively) based on data obtained from four abattoirs of typical genotypes in NZ, although no mention of specific genotypes were given. This trend was also found within G2, but not in G1 of current trial.

An unusual finding was that the G1 females were as lean if not leaner than the G1 males shown by the low P2BF depths (see Tables 4.3 – 4.5 in Chapter 4). This does not follow the common trend which is that male pigs should be leaner

and less fat than females within the same genotype. It is unclear as to how this came about because the effects of the external environment were reduced as all the pigs were housed in the same facility under same conditions. The distribution of BF across the loin was not measured in the current trial.

Because the P2 BF depth was lower than the maximum allowance of 12mm (interest.co.nz, 2011; Kyriazakis & Whittemore, 2006) for G1 and G2 (see Table 5.1 and Table), this finding suggests that the target slaughter weight for both G1 and G2 genotypes may be increased > 90kg. However, New Zealand abattoirs do not allow CW > 80kg, and CW above 80kg results in a penalty on the pork and bacon price per kg(interest.co.nz, 2011) (see also Table 2.2 in Chapter 2). The carcass traits of the current trial are compared to other recent studies in Table 5.3.

Table 5.3. Comparison of carcass traits of the current trial with those from other recent trials.

Genotype	Slaughtered LW, kg	Carcass Traits				Reference
		Carcass Weight, kg	Killing-out, %[a]	Loin Area, cm^2	BF depth, mm[b]	
G1	93.27	71.10	76.2	44.30	8.90	Current Trial
G2	91.57	69.40	75.8	41.20	9.80	
Hybrid gilts[c]	88.10	70.50	79.57	n/a	10.30	Nuijten, 2010
Hybrid gilts[c]	89.00	70.80	79.52	n/a	10.30	
Hybrid gilts[c]	92.60	74.63	80.65	n/a	10.15	
Hybrid gilts[c]	89.90	72.05	80.14	n/a	10.70	
Hybrid gilts[c]	88.60	69.94	78.89	n/a	10.06	
Hybrid gilts[c]	93.50	74.70	79.89	n/a	10.10	
Zlotnicka White	~105	80.17	76.4	36.20	26.69	Grześkowiak & Borys, 2009
Zlotnicka Spotted	~105	78.32	74.6	26.05	25.95	
Berkshire	110, ±5kg	n/a	n/a	47.78	23.39	Lee et al., 2011
Duroc	110, ±5kg	n/a	n/a	41.16	23.21	
Landrace	110, ±5kg	n/a	n/a	51.35	21.08	
Yorkshire	110, ±5kg	n/a	n/a	41.42	21.75	
Duroc-cross[d]	101.3	80.00	79.0	40.3	11.9	Janz et al., 2008a
Duroc-cross[d]	101.7	80.60	79.3	39.3	12.2	
Duroc-cross[d]	102.8	80.80	78.6	40.8	12.1	
Duroc-cross[d]	101.8	79.30	77.9	40.7	11.1	
Duroc	107.4	84.4	78.5	40.1	13.89	Ball, 2000
Hampshire	105.1	83.0	78.9	45.6	13.21	
Landrace	107.1	84.9	79.0	41.3	13.83	
Yorkshire	105.4	84.1	79.5	42.9	12.88	

*[a]Killing-out, percentages were estimated for all these trials by the formula: Carcass weight/slaughter LW *100.*

[b]BF depths variable due to different techniques. BF measurements by Kerr, current trial (2012), Nuitjen (2010) and Janz, Morel et al (2008a) determined by Henessey grading probe at P2 site; slide callipers used by Grześkowiak et al. (2009) , average BF measured from XI and last rib by Lee et al. (2011); and BF technique not known from Ball (2000).

[c]six diet treatment groups used trial by Nuijten (2010).

[d]four diet treatment groups by Janz et al. (2008a).

Slaughter weights from Lee et al 2011 110kg, (gender effect castrated males for Berkshire and Yorkshire only; females for all four genotypes).

n/a = data not available.

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The G1 and G2 carcass weights and slaughter LW were less than the other studies (Table 5.3). However, the carcass weights were similar to values reported by Rosenvold and Stuart (2009) for typical genotypes in New Zealand.

The killing-out percentages are comparable against other recent trials in Table 5.3. Generally, the killing out percentage has been found to be greater in females than entire males (Wood & Whittemore, 2006). However no differences were found with the current trial. Babol and Squires (1995) report that females dressed 2 - 2.5 per cent greater than entire males. This is mainly due to the removal of the male reproductive tract (especially the testes and scrotum) which

reduces the carcass weight (Babol & Squires, 1995; Wood & Whittemore, 2006). This difference is found in larger slaughter weight pigs which may be due to the increase in proportional size of boar's testes.

A study by Cisneros et al. (1996) compared whole sale cut percentage between shoulder percentages between genotypes: commercial hybrid (BCH) vs. Yorkshire x Duroc dams bred with Hampshire sires (HYD) found that the BCH had the greatest shoulder percentage of 26.25% compared to HYD (25.45%). Between gilts and barrows, the gilts yielded the greatest ham per cent compared to the barrow (25.45%, 24.71% respectively) but the barrows had the greatest shoulder per cent (26.19, 25.51).

A study by Ball (2000) compared effects between barrows, gilts and boars (slaughter LWs of 105.5,103.8 and 109.4 kg, respectively) averaged across genotypes of Duroc, Hampshire, Landrace and Yorkshire. The findings were that the dressing percentages were greatest for the gilt (79.4%). The barrow (79.0%) and the boar (78.5%) were not significantly different from each other.

Beard et al. (2010) reported higher ham and loin percentages in gilts (18.9 and 25.0) compared to barrows 18.2 and 24.4%). Carcass yield tended to be greater (P = 0.08) in gilts vs barrows (80 vs. 79.4%) and there was no difference for shoulder percentage (12.3 vs. 12.0%, gilts vs. barrows).

The findings from the current trial, along with those of Cisneros (1996), Ball (2000) and Beard et al. (2010), suggest that the distribution of body mass amongst wholesale cuts differs between genotypes and sex. The Hampshire breed in studies by Cisneros (1996) and G2 in the current trial yielded lower shoulder percentages than BCH and G1, respectively. The entire males yielded greater shoulder percentages while females yielded greater leg or ham percentages.

5.3 Pork Quality

All the pork quality measurements, but for pH45, were done on samples which have been frozen. This should be kept in mind when comparing results from this study with other published data. There was no PSE pork found in the current trial as determined by measuring the pH of the longissimus dorsi muscle 45

minutes post slaughter. The ultimate pH was low for both G1 and G2 compared to other recent trials shown in Table 5.4. Low pH in G2 may have been because the G2 genotype was a cross between Hampshire and G1 (P. Morel, personal communication). The longissimus muscle of the Hampshire genotype is well documented to have low ultimate pH values which may result in acid meat quality (Sellier & Monin, 1994). This effect is due to the RN- gene which may be present in Hampshire pigs (Heuven et al., 2003; Moeller et al., 2003). According to Rosenvold and Andersen. (2003) the RN- gene does not result in a rapid decline in pH as observed with the HAL gene, which may explain why no rapid decline in pH was found for pH at 45 minutes with G2, but the ultimate pH was low compared to other studies (Janz et al., 2008a; Lee et al., 2011; Meinert et al., 2008) with different pig genotypes. Values in the current trial were similar to values reported by Brewer et al. (2002) in which Hampshire breeds were used (Table 5.4).

The ultimate pH for G1 and G2 were both lower compared with the other trials shown in Table 5.4. This may be because the other trials determined the ultimate pH 24 hours post slaughter, as opposed to the current trial in which the samples were vacuum packed and chilled for seven days and then frozen and subsequently thawed before pH testing. The ultimate pH for G1 and G2 were comparable to the ultimate pH which was determined under similar conditions by Nuijten (2010) with ultimate pH values ranging between 5.44 - 5.56 within Pig International Company (PIC) hybrid female pigs of unknown genotype (data not shown in Table 5.4).The ultimate pH values from the current trial were also similar to typical New Zealand boars and gilts with reported mean values of 5.43 and 5.42 from 4 different abattoirs within New Zealand (Rosenvold & Stuart, 2009). This suggests that the ultimate pH in pigs from New Zealand genotypes may be slightly lower than the ultimate pH from other genotypes overseas (Table 5.4).

Table 5.4. Comparing pork quality traits from the present trial with other recent trials.

Genotype	Meat quality traits											Reference
	pH, 45min	pHu	Lightness	Redness	Yellowness	Driploss 48h,%	IMF, %	Cooking loss, %	Shear, N[b]	Sarcomere length, µm	EJL, g/cm^2	
G1	6.31	5.37	48.93	6.70	3.09	16.77	0.80	28.93	74.24	1.60	34.91	Kerr, 2012
G2	6.35	5.29	47.96	7.14	3.22	16.09	0.89	28.49	70.27	1.62	34.43	
Zlotnicka White	6.38	5.53	43.88	6.27	4.95	3.36	1.87	27.62	n/a	n/a	29.88	Grześkowiak & Borys, 2009
Zlotnicka Spotted	6.32	5.56	47.97	4.73	5.01	3.41	2.04	29.36	n/a	n/a	32.07	
Berkshire	6.24	5.77	44.75	7.06	1.96	2.31	2.36	26.25	45.45	n/a	n/a	Lee et al., 2011
Duroc	6.34	5.60	48.99	6.04	2.90	3.40	2.89	29.46	58.91	n/a	n/a	
Landrace	6.12	5.58	48.06	6.62	2.40	4.56	1.6	35.54	61.84	n/a	n/a	
Yorkshire	6.14	5.65	45.47	7.14	2.48	3.14	1.70	31.28	65.66	n/a	n/a	
Duroc-cross[a]	6.41	5.54	49.10	6.04	3.20	6.08	n/a	29.5	72.22	n/a	37.7	Janz et al., 2008b
Duroc-cross[a]	6.51	5.42	50.50	6.16	3.30	6.37	n/a	29.4	59.84	n/a	40.6	
Duroc-cross[a]	6.42	5.57	49.20	5.52	3.09	6.24	n/a	29.9	75.34	n/a	38.5	
Duroc-cross[a]	6.39	5.53	49.00	5.93	3.08	5.77	n/a	29.4	81.62	n/a	40.5	
Hampshire	n/a	5.74	53.3	6.40	2.90	3.50	0.90	n/a	53.20	1.64	n/a	Meinert et al., 2008
Wild Pig	n/a	5.42	44.70	13.70	6.50	1.20	0.80	n/a	70.20	1.67	n/a	
Hampshire, (RN-)	n/a	5.37	44.11	9.24	7.76	n/a	n/a	21.36	56.71	n/a	n/a	Brewer et al., 2002
Hampshire (RN+)	n/a	5.33	44.62	10.23	8.14	n/a	n/a	21.64	57.98	n/a	n/a	

[a]Duroc crossbred gilts superscript refers four different diet treatment groups (Animal control, animal treatment, plant control and plant treatment respectively) used in trial only; driploss (%) by Janz et al. (2008b) reported for 96 hour time period only.

[b]all shear force data measured by Warner-Bratzler machine across all trials.

Brewer et al. (2010) pigs slaughtered 125kg.

Abbreviations: EJL = expressed juice loss, for determination of WHC, n/a = data not available, pHu = ultimate pH.

Samples from the G2 genotype had the greatest thaw loss for genotype. This difference may be attributed to the RN^- gene found amongst Hampshire pigs (Heuven et al., 2003; Sellier & Monin, 1994). However, this is unlikely to be the case in the current study as the PIC has removed the RN-gene from its Hampshire lines (PIC, personal communication). Thaw loss was measured after the meat samples were aged for seven days in the chiller (vacuum packed) and then frozen and subsequently thawed. The thawloss may be attributed to ice crystals forming within the meat fibres resulting in mechanical damage to the cellular membranes (Lawrie, 1998; Xia et al., 2009).

Driploss at 48 hours in the current trial was greater than that several other studies (Table 5.4). This may be because the other trials commenced their driploss 24 hours post slaughter as opposed to the current trial which had the effects of freeze-thawing of the sample first before drip loss commenced. Also G1 and G2 genotypes had much lower ultimate pH values when compared to other trials (Table 5.4). There was a relationship between ultimate pH vs. driploss. According to Lawrie (1998) when bound water of beef muscle was compared to ultimate pH, the lowest amount of water was bound between pH 5.0 - 5.2, and the bound water increases when above or below this range. This effect may be due to denaturation of sarcoplasmic and other myocellular proteins as the proteins get closer to their isoelectric point. The relationship between ultimate pH and driploss after 48 hours from the results shown in Table 5.4 is shown in Figure 5.3 along with the quadratic regression line. Although the effect of freeze-thawing also increases driploss, the data from G1 and G2 are consistent with other studies as they followed the quadratic trend of decreasing driploss as pH increases.

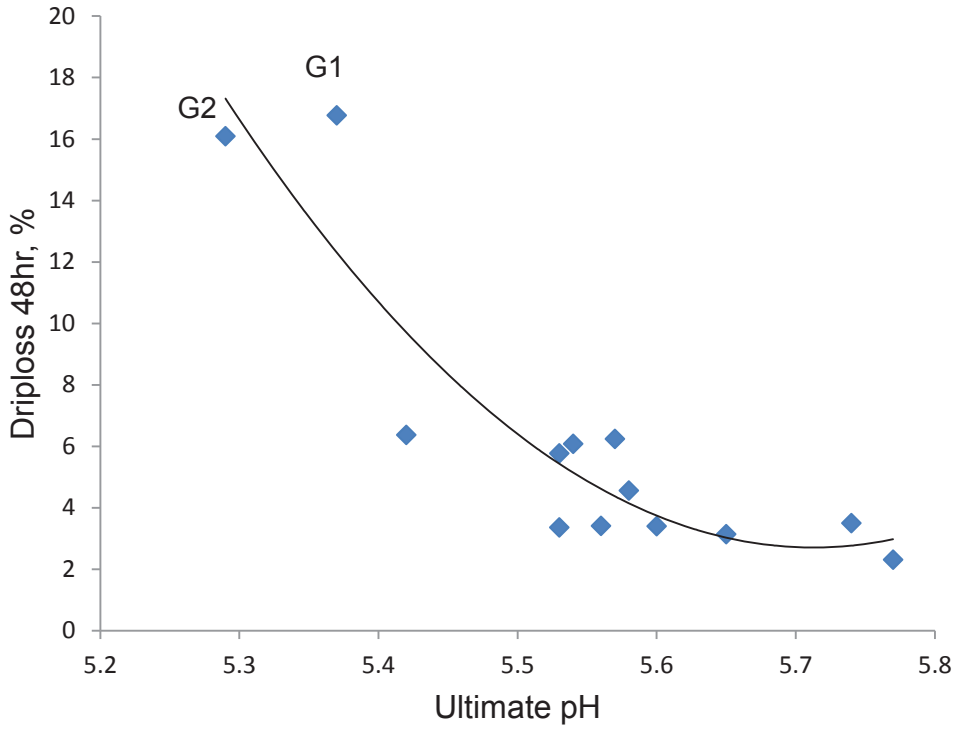

Figure 5.3. Relationship between driploss 48hr vs. ultimate pH from the data presented in Table 5.4 (except for Brewer et al. 2002) for the different genotypes including G1 and G2. The quadratic regression equation is: $y = 81.783x^2 – 934.39x + 2671.6$ and R^2 = 83.6%. The data from Wild Pig was excluded as was not bred for pork production.

Meat samples from the G1 and G2 groups had greater shear force values than other studies shown in Table 5.4 but were similar to Duroc cross-bred gilts (Janz et al., 2008b) and hybrid gilts which ranged between 59.55 - 70.12N (Nuijten, 2010). According to Rosenvold and Stuart. (2009), pork tenderness determined by MIRINZ tenderometer given the following tenderness scores: < 5 kgf was very tender; 5 - 7.9 kgf was tender; 8 - 10.9kgf was acceptable; 11 - 14.9 kgf was tough; and > 15kgf was very tough.

A study which compared the effects for toughness between WBSF and MIRINZ shear force in beef longissimus dorsi for bulls and steers found that the WBSF values were greater than MIRINZ (Purchas et al., 2002). Plotting the WBSF values vs. MIRINZ from Purchas et al. (2002) provided the following linear equation: MIRINZ (kgF) = 0.679 x WBSF - 0.4752 (R^2 = 99.9%) where: 1 kgF = 9.81N. By using this equation to predict what G1 and G2 would be in MIRINZ shear force values (kgf), the mean value for G1 was estimated to be 4.66 kgf

and G2 was 4.39 kgf. This suggests that 73% of the pork was very tender and 27% was tender from both genotypes in the current trial. These scores are comparable with scores reported by Rosenvold and Stuart (2009) from 400 pigs (i.e., 200 boars and 200 females) which were: 93% scored very tender or tender, 7% were acceptable and < 1 % were tough.

When comparing the BF depth and IMF with other recent trials (Tables 5.3 and 5.4), G1 and G2 from the current trial were found to be very lean and low in fat. This pork is less than the optimal IMF% of the longissimus muscle as it was < 2.0% (Morel et al., 2010). The optimal level of IMF% will influence pork appearance (i.e., marbling), juiciness, tenderness and flavour (Lawrie, 1998). The IMF range of the current trial was between 0.76 - 1.02% is below the optimal IMF%. These lower than optimal level of IMF may limit the acceptable sensory traits (i.e., appearance, flavour, juiciness and tenderness) of pork which can be achieved. The IMF% from G1 and G2 are comparable to IMF% reported by Morel et al. (2010) for modern genotypes from NZ pigs which was between 1.0 and 1.5%. This suggests that pork from these two genotypes would be a healthy food item. Although the fatty acid profile for IMF or BF was not determined in the current trial, it would be advantageous to have this information to evaluate the fatty acid profiles of New Zealand genotypes to compare with genotypes overseas.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

It is evident, from the current study, that G1 had the best growth performance traits compared to G2. This is because G1 was more efficient at using the nutrients within the feed and gained LW faster compared to G2 when both genotypes were offered the same feed. The effects of sex found that entire males also had better growth performance traits compared to females. G1 was found to be the leanest (or least fat) as shown by lowest P2BF depth, the greatest LA:BFA ratio, lowest Minlp value and had the greatest Pdmax value.

There were no differences found for hot CW or killing out percentage, however, there were differences found in the percentages for shoulder and leg. G1 had the greatest shoulder mass and also shoulder percentage, whereas G2 had the greatest leg percentage.

G2 had the greatest thawloss percentage and also had the lowest ultimate pH. There were no other statistical differences found for pork quality between genotype.

By combining all these findings together, it can be concluded that the G1 genotype overall had the greatest growth performance, were the most lean and the pork quality was similar to G2. No PSE pork was found, however, acid meat may be an issue (pH 5.28 - 5.39). The consumer acceptance of pork may be limited because the marbling was low (IMF 0.76 -1.2%). The pork from G1 and G2 were considered to be very tender or tender. The growth performance from G1 and G2 indicate that the current feed guidelines (NRC, 1998) need to be updated as they do not reflect the needs of modern genotypes to grow to their genetic potential. In addition, the growth performance of G1 and G2 pigs were better than the post 2000 studies. If G1 and/or G2 had better growth performance traits compared to Australian genotypes for grower-finisher pigs, it may be of interest for Australia to open up their borders to permit new genetic material to be imported from New Zealand.

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APPENDIX 1: CALCULATION OF TARGET L/P AND PDMAX

According to de Lange et al. (2008) Target L/P is a linear function of daily digestible energy intake (DEI):

Target L/P = α x DEI

Where: the slope α is specific to a genotype

Between 20 kg LW and 50 kg LW the pigs were restricted fed so that energy was the limiting factor and growth was driven by Target L/P. Then between 50 kg LW and 95 kg LW the pigs were fed to appetite a diet which was not limiting in either energy of amino acids, and growth was driven by Pdmax.

In each period the total digestible energy intake (TDEI) and the change in empty body weight (δEBW = EBWe - EBWs) were measured. The growth model equations were used to derive two equations with two unknown variables, namely increased in whole body protein mass (δP) and the increase in whole body lipid mass (δL).

1) TDEi (MJ) = DEM + DEPM + DEG

Where: Digestible energy for maintenance:

DEM (MJ) = $\int_{lws}^{Lwe} 0.5\ x$ LW$^{0.75}$ / average daily gain (ADG (kg))

Digestible energy content of maintenance protein:

DEPM = (Basal + integument losses) x 24 /1000

Basal (g) = 11.8 x total dry matter intake

Integument losses (g) = $\int_{lws}^{Lwe} 0.093\ x$ LW$^{0.75}$ / ADG

Digestible energy for growth:

DEG = δP x 43.9 + δL x 52.8

2) TDEI (MJ) = DEM + DEPM + δP x 43.9 + δL x 52.8

3) δEBW (kg) = EBWe - EBWs

Where:

Empty body weight (EBW) = Live weight – gutfill = LW - 0.277*LW$^{0.612}$

EBW = Protein + Lipid + Water + Ash

$\delta EBW\ (kg) = P_e + L_e + W_e + A_e - P_s - L_s - W_s - A_s = \delta P + \delta L + \delta A + \delta W$

Water $W = 5.202 \times P^{0.855}$ => $\delta W = a \times \delta P$; the factor a is estimated by the slope of the first derivative of the water function at an average P over each experimental phase.

Ash = 0.189 x P => $\delta A = 0.189 \times \delta P$

4) $\delta EBW\ (kg) = \delta P \times (1 + 0.189 + a) + \delta L$

Equations 2 and 4 were solved for **δP and δL.**

Daily protein deposition (Pd) is δP divided by number of day in the period and lipid deposition (Ld) is δL divided by number of day in the period.

The target LP slope α: is δL / δP per unit of daily digestible energy intake in the first phase of the experiment and Pdmax is Pd in the second phase of the experiment