UNIVERSIDAD POLITÉCNICA DE MADRID

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA

AGRONÓMICA, ALIMENTARIA Y DE BIOSISTEMAS

MANAGEMENT AND NUTRITIONAL STRATEGIES TO

IMPROVE GROWTH PERFORMANCE AND CARCASS

MERIT IN WHITE PIGS

TESIS DOCTORAL

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Ingeniero Agrónomo

2017

DEPARTAMENTO DE PRODUCCIÓN AGRARIA
ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA AGRONÓMICA,
ALIMENTARIA Y DE BIOSISTEMAS

**MANAGEMENT AND NUTRITIONAL STRATEGIES TO IMPROVE
GROWTH PERFORMANCE AND CARCASS MERIT IN WHITE PIGS**

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2017

AGRADECIMIENTOS

A Gonzalo y a Clemente, por brindarme la oportunidad de formar parte de sus equipos, por compartir su tiempo y sus conocimientos conmigo.

A todos los profesores de Departamento de Producción Animal que me han ayudado de una manera u otra a lo largo de todos estos años resolviéndome dudas, dándome ánimos y consejos.

A Carlos Rodríguez, creo que todos estamos de acuerdo en que sin él todos estaríamos perdidos. A Juanillo y Bea, por su gran ayuda y trabajo durante las pruebas y a Andrés por su ayuda en el laboratorio.

A Copese, Sat Vallehermoso, el Grupo Vall Companys e Incarlopsa por permitirme irrumpir en sus labores diarias y poder realizar las pruebas en sus instalaciones y ayudarme en todo lo necesario.

A todos y cada uno de los becarios que han pasado y están en el Departamento por su ayuda, amistad y buenos momentos vividos. En especial a Julio D. Berrocoso y Jose I. Morales por todas las horas que pasamos juntos en el coche, en las granjas y en el matadero, que a pesar de ser un trabajo duro siempre estaban de buen humor y hacían el trabajo mucho más fácil. Y a Martina, por sus consejos y ayuda en los comienzos.

Al Doctor Kim y al Doctor Dilger por aceptarme en sus respectivos equipos durante mis estancias en EEUU.

Por último, a los miembros del tribunal de Tesis por aceptar formar parte de el y ajustar sus agendas.

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ABBREVIATION KEYS

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°C	degree Celsius
%	percentage
AA	amino acid
ADF	acid detergent fiber
ADG	average daily gain
ADFI	average daily feed intake
BF	backfat
BW	body weight
C18:2	linoleic acid
CF	castrate female
cm ²	square centimeter
CM	castrated male
CMD	consumo medio diario
CP	crude protein
d	day
DE	digestible energy
DS	desviación estándar
EE	ether extract
EM	entire male
EN	energía neta
et al.	and collaborators
Exp.	experiment
FCR	feed conversion ratio
G:F	gain to feed ratio
GE	gross energy

GIT	gastrointestinal tract
GMD	ganancia media diaria
h	hour
HC	hembra castrada
HCl	chloride acid
HE	hembra entera
IMC	immunocastrated male
kg	kilogram
km	kilometer
L	linear
m ²	square meter
Mcal	megacalorie
MC	macho castrado
ME	metabolizable energy
mg	miligram
min	minute
MJ	megajoule
ml	mililiter
<i>N</i>	normal
NDF	neutral detergent fiber
NE	net energy
NIR	reflectance by near-infrared spectroscopy
Nn	heterozygous halothane negative
NN	homozygous halothane negative
P	probability
PV	peso vivo

Q	quadratic
<i>r</i>	Pearson correlation coefficient
rsd.	residual standard deviation
s	second
SD	standard deviation
SEM	standard error mean
TSAA	total sulfur amino acids
vs.	versus
W	watt
wk	week

RESUMEN

RESUMEN

El objetivo principal de esta Tesis Doctoral ha sido estudiar el efecto de la uniformidad del peso vivo al destete, el contenido en energía neta del pienso durante el cebo, el sexo y la línea genética paterna sobre los parámetros productivos, la calidad de la canal y la calidad de la carne en cerdos. Para ello, se han realizado tres ensayos.

En el ensayo 1 se estudió la influencia de la uniformidad del peso vivo (PV) al destete [$7,5 \pm 0,6$ kg vs. $7,5 \pm 1,2$ kg (PV $\pm$ desviación estándar; SD)] y el sexo [machos castrados (MC) vs. hembras castradas (HC)] sobre los parámetros productivos durante las fases de crecimiento (7,5 a 27,3 kg PV) y engorde (27,1 a 130,5 kg PV), así como la calidad de la canal y de la carne al sacrificio. En la fase de crecimiento, los cerdos alojados en las cuadras más uniformes tuvieron peor eficiencia alimenticia ($P \leq 0,05$) que los alojados en las menos uniformes. Además, los MC consumieron más pienso (CMD; $P < 0,05$) y tuvieron mejores ganancias diarias (GMD; $P < 0,001$) y mejor eficiencia alimenticia ($P < 0,001$) que las HC. Durante la fase de engorde, la uniformidad inicial de la cuadra no afectó a ninguno de los parámetros productivos estudiados pero los MC tendieron ($P = 0,08$) a comer más y fueron menos eficientes que las HC. El porcentaje de partes nobles perfiladas tendió a ser superior en los grupos más uniformes en el momento del destete y en los MC. Se concluye que el reagrupamiento de los cerdos en base a la uniformidad de los pesos al destete no afectó ni a los parámetros productivos ni a la calidad de la canal. Las HC podrían ser una alternativa lógica a los MC cuando el destino de las canales es la obtención de productos curados.

En el ensayo 2 se utilizaron 540 cerdos con un PV inicial de 28,5 kg y se estudió el efecto del contenido de energía neta (EN) del pienso (2,29, 2,33, 2,37, 2,41 y 2,45 Mcal/kg) sobre los parámetros productivos y la calidad de la canal y de la carne de hembras enteras (HE), machos enteros y machos inmunocastrados (MI). Al aumentar la EN de los piensos aumentó el consumo energético ($P < 0,05$) y mejoró la eficiencia alimenticia ($P < 0,001$) de forma lineal. Los MI tuvieron un mayor CMD y mejor GMD que las HE o los machos enteros ($P \leq 0,001$). El espesor de la grasa dorsal aumentó ($P < 0,05$) y el rendimiento de los jamones perfilados se redujo de forma lineal ($P < 0,01$) según aumentaba la concentración energética del pienso. El espesor de grasa dorsal fue mayor en HE y MI que en machos enteros ($P < 0,05$). El rendimiento de la canal y de lomo fue superior en HE que en machos enteros o MI ($P < 0,001$). Se concluye que dietas con mayor contenido en EN fueron más apropiadas para la producción de cerdos pesados que las dietas bajas en energía. Sin embargo, se necesitan estudios más detallados para evaluar en función del coste de las materias primas según región y el año considerado de estudio.

En el ensayo 3 se estudió el efecto del contenido en EN de piensos isoproteicos y de la línea paterna (PIC L62 vs. Pietrain Alemán) sobre los parámetros productivos y la calidad de la canal y de la canal en cerdos cuya genética materna fue Landrace x Large White. El CMD disminuyó ($P < 0,001$) y la eficiencia alimenticia mejoró ($P < 0,001$) linealmente al aumentar la concentración de EN de los piensos. Los cerdos procedentes de la línea paterna PIC L62 consumieron más pienso ($P < 0,001$) y tuvieron mejores GMD pero peores índices de conversión ($P < 0,01$) que los cerdos procedentes de la línea paterna Pietrain

Alemán. Las canales de los híbridos de Pietrain Alemán fueron más magras ($P < 0,001$) y tuvieron mayor rendimiento de paleta que los híbridos de PIC L62. Se concluye que al aumentar la concentración en EN del pienso mejoró la eficiencia alimenticia sin afectar a las GMD. Los cerdos híbridos procedentes de PIC L62 crecieron más rápido y presentaron canales con más grasa que los cerdos híbridos resultados del cruce con Pietrain Alemán.

SUMMARY

SUMMARY

The main objective of this PhD Thesis was to study the influence of the body weight (BW) and uniformity at weaning, and the net energy (NE) content of the diet, gender, and sire line on growth performance during the fattening phase and carcass and meat quality in heavy pigs. Three experiments (Exp.) were conducted.

In Exp. 1, the influence of pen uniformity at weaning [7.5 ± 0.6 kg vs. 7.5 ± 1.2 kg (BW $\pm$ standard deviation; SD)] and sex [castrated male (CM) vs. castrated female (CF)] on growth performance during the nursery (7.5 to 27.3 kg BW) and the fattening (27.1 to 130.5 kg BW) phases, and on carcass and meat quality slaughter at 130.5 kg was studied. During the nursery phase, pigs from the more uniform pens were less efficient than pigs from the less uniform pens ($P = 0.05$). Also, CM had greater feed intake (ADFI; $P < 0.05$), and average daily gain (ADG; $P < 0.001$) and were more efficient ($P < 0.001$) than CF. During the fattening phase, initial pen uniformity did not affect pig performance but CM tended ($P = 0.08$) to have higher ADFI and worse feed efficiency than CF. Trimmed primal cut yield tended to be higher for pigs of the more uniform groups and for CM than for CF ($P = 0.09$). It is concluded that regrouping of pigs at weaning, according to uniformity of BW, had no effects on growth performance or carcass quality at slaughter. Castrated females might be an alternative to barrows for the production of carcasses destined to the dry-cured industry.

In Exp. 2, 540 crossbred pigs with an initial BW of 28.5 kg were used to investigate the effects of NE content of the diet (2.29, 2.33, 2.37, 2.41, and 2.45 Mcal/kg) on growth performance and carcass and meat quality traits of gilts, boars, and immunocastrated males (IMC). An increase in dietary energy increased NE

intake ($P < 0.05$) and improved feed conversion ratio (FCR) linearly ($P < 0.001$). The IMC pigs showed greater ADFI and ADG than gilts and boars ($P \leq 0.001$). Backfat (BF) depth increased ($P < 0.05$) and chilled and trimmed ham yield decreased ($P < 0.01$), as the dietary NE increased. Backfat depth was greater for gilts and IMC than for boars ($P < 0.05$). Also, gilts had greater carcass and loin yields than boars and IMC ($P < 0.001$). Diets with the higher NE contents were more appropriate for the production of heavy pigs than diets with lower the NE content. However, the economic interest of this practice needs further assessment, because it will depend on the relative cost among ingredient that vary with the region and year considered.

In Exp. 3, the effects of NE content of isoproteic diets on growth performance and carcass and meat quality traits were studied in crossbreds from Landrace x Large White females and two Pietrain sire lines (PIC L62 vs. German Pietrain). Feed intake decreased ($P < 0.001$) and feed efficiency improved linearly ($P < 0.001$) as the NE content of the diet increased. Crossbreds from PIC L62 had greater ADFI and ADG ($P < 0.001$) but were less efficient ($P < 0.01$) than crossbreds from German Pietrain. German Pietrain crossbreds were leaner ($P < 0.001$) and had more shoulder yield ($P < 0.01$) and less fat at *Gluteus medius* muscle ($P < 0.001$) than carcasses from PIC L62 crossbreds. In summary, an increase in the NE concentration of the diet improved feed efficiency but did not affect ADG. Crossbreeds from PIC L62 sires grew faster and had fatter carcasses than crossbreds from German Pietrain.

CHAPTER 1:

LITERATURE REVIEW AND OBJECTIVES

1. INTRODUCTION

Pig production is a relevant economic sector for meat production worldwide (Figure 1). Spain, with 29.2 million heads in 2016, is after China and EEUU the largest pig producer in the world (Eurostat, 2017).

Figure 1 Pig census worldwide by country (2016)

Statista Portal, 2017

Within the EU-28, Spain is the first producer followed by Germany, France, Denmark, and The Netherlands (Figure 2). The relevant position of the pig sector is a consequence of the 10% increase in head numbers in the last 2 years. In contrast, in the same period of time Germany, the second largest producer within the EU-28 decreased the number of heads by 3.5%.

Figure 2 Pig census in the EU-28 (2016) **Eurostat, 2017**

In 2016, Germany with 5.6 million tons of meat was the main producer in UE-28, followed by Spain with 4.1, France with 1.99, and Poland with 1.96 million tons (Eurostat, 2017). From 2010 to 2016, Spain increased meat production by 20.5%, whereas the growth was 2.3% in Germany and 12.8% in Poland (Figure 3). In this period, France decreased pork meat production by 1.1%. The increase in pig meat observed in Spain, compared with Germany, France, and Poland, resulted from an increase in slaughtered pigs (Figure 4) due primarily to an improvement in the number of piglets born alive per sow. Pork meat production accounts for 12.4% of the Final Agriculture Production and 34.2% of the Final Livestock Production of Spain (MAPAMA, 2017).

Figure 3 Pork meat production by the five main producers from 2010 to 2016 (EU-28)

Eurostat, 2017

Figure 4 Pigs slaughtered pigs in Spain. Historical

Eurostat, 2017

Spain, with 703,585 tons of fresh meat was the third exporter of fresh meat in EU-28 in 2016 after Germany with 1,193,323 tons and Denmark with 738,474 tons. In the last two years, pork meat export of Spain increased by 26% (Figure 5) while Germany exports decreased 3.4%. In 2017, the exports of pig meat of Spain is expected to be close to 45% of total production.

Figure 5 Fresh pork export, Spain. Historical

Statista Portal, 2017

Pork consumption per capita across the EU-28 declined between 2011 and 2013 but has grown in the last two years by around a kilogram. The average consumption per person in the EU-28 was 40.9 kg of meat in 2015. In any case, supplies of pork have continued to outstrip demand. Europe's growing export sales are strong with a self-sufficiency rate that increased from 110% to 112% in the last two years (Global meat, 2017).

2. FACTORS THAT INFLUENCE GROWTH PERFORMANCE AND CARCASS AND MEAT QUALITY OF PIGS

The objectives of pig production vary with the country considered. In all cases, cost of production per kg of carcass is of paramount importance, independent on the final objective. Also, an important variable to be taken into account is the destiny of the pork meat: fresh meat vs. dry-cured products. In this respect, Spain leads in the production of dry-cured products, a type of meat with its own characteristics and peculiarities that affect pig production and pork consumption.

Management, health status, gender, nutrition, BW and age at slaughter, logistics and transport to the slaughterhouse, and management during slaughter are main factors affecting growth of the pigs and the subsequent value of the carcasses.

2.1. Pen uniformity

Under commercial conditions, pigs are housed in the nursery barn by batches, with all animals within the batch and barn having similar age. In addition, pigs are regrouped in pens within the barn according to BW. Same procedure is practiced for regrouping the pigs at the start of the fattening phase (18 to 21 kg BW in Spain). Regrouping pigs by initial BW alters social interactions (Pluske and Williams, 1996; Mahan et al., 1998) and might affect carcasses uniformity at slaughter (O'Connell et al., 2005).

To minimize stress and disease risks associated with regrouping, some producers keep the pigs in the same group from weaning to slaughter (Hessing and Tielen, 1994). However, when pigs are not regrouped at the start of the finishing period (18 to 30 kg BW depending on the country) large within-group variations in

BW at slaughter are often reported. Lack of uniformity at slaughter leads to inefficient use of the finishing barn and to an increase in variability of carcass and meat characteristics (Wolter, 2002). Due to these problems, pigs are chosen by BW to be sent to the slaughterhouse. Because of this practice, pigs selected at the first option are those that grew faster during the fattening period and thus, with the greater growth potential. Consequently, the pigs remaining in the pens are those with the poorer performance traits, resulting in reduced feed efficiency and increased permanence time in the barn. Consequently, when pigs are sent to the slaughterhouse at different times, cost of production and labor needs increase and pig output per year decreases because less pigs are kept in the barn. Moreover, even when pigs are sent to the slaughterhouse with the same final BW, the carcass characteristics and quality of pigs are not uniform because the pigs are slaughtered at different age, which results in reduced farm benefits.

A practice used to reduce slaughter weight variability within group consists in allocating pigs by size to form the new groups. Small pigs might in particular benefit by this system in terms of acquiring an improved ability to gain access to resources. In any case, factors such as social status may result in some pigs growing faster than others (de Jonge et al., 1996), negating the potential benefits of classifying pigs in groups based on uniform initial BW. In addition, uniform weight groups might show incidence of aggressions associated with difficulties in resolving dominance relationships within the pigs, which may have a negative effect on growth performance and animal welfare (Stookey and Gonyou, 1994; Andersen et al., 2000; O'Connell et al., 2005).

2.2. Gender and castration

Sex of the pigs has a great influence on pig performance and carcass and meat quality traits. Consequently, pig uniformity and pork meat production might benefit if the animals are fattened in different barn or pens according to sex. Moreover, meat quality and especially fat content, varied with sex, characteristics that are of paramount importance Spain, in which a high percentage of the carcasses are destined to the production of dry-cured products (Peinado et al., 2008, 2011). Two strategies used by the pig industry to modify fat content and other characteristics of pork meat are: 1) to introduce a male line with more infiltrated fat such as Duroc and 2) to increase final BW at slaughter to at least 110 kg BW (Beattie et al., 1999). An increase to 110 kg BW requires the castration of the males at early ages to avoid boar taint and reduce aggressions and problems related with poor meat quality (Diestre et al., 1990). At present, males castration fits EU-28 legislation (European Food Safety Authority, 2004) on Animal Welfare but this practice, based on animal welfare concerns is not acceptable for many customers. In this respect, the EU-28 is considering the ban of surgical castration by 2018, a legislative approach that might affect market and traditional consumer preferences (Kallas et al., 2013).

Surgical castration of males has numerous drawbacks, such as an increase in cost of production, a reduction of animal welfare, and often, incidence of health problems. On the other hand, castration, besides avoiding boar taint, increases energy anabolism, with castrated pigs showing a tendency to accumulate fat in primal cuts, because they mature faster than entire pigs. Consequently, castration reduced meat hardness, which favors the chewing quality of dry-cured products,

and facilitates pigs management (Latorre et al., 2003a). Immunological castration reduces part of these problems, especially those related to animal welfare, but creates new concerns at the slaughterhouse and at the consumer level. Castration of males and females increases carcass fat and decreases lean yield (Nold et al., 1997; Weatherup et al., 1998; Peinado et al., 2008, 2011, 2012). Most of the data reported in the scientific literature agrees that CM 2 to 5 mm more BF thickness than gilts (Hamilton et al., 2000; Latorre et al., 2003b; Peinado et al., 2008). Also, most of the available information indicates that moisture content of the meat is similar between CM and gilts (Cisneros et al., 1996; Unruh et al., 1996; Hamilton et al., 2000).

At present time, females from traditional white strains are not castrated because they do not develop sexual odors. However, when both genders CM and gilts are fattened at the same farm and slaughtered at the same age, carcasses and primal cuts are heavier from CM, resulting in meat that is accepted better by the consumers. Moreover, carcasses from CM contain more intramuscular and subcutaneous fat, and have lower proportion of C18:2 than primal cuts from gilts (Peinado et al., 2015). Oestrous in gilts increases aggressions and mounting behavior, reducing feed intake, feed efficiency, and growth, and increasing skin lesions in the carcass and labor needs in gilts. When castration is performed before puberty, the secondary sex characters do not develop (Odo, 2002) which might results in a reduction in aggression behavior.

Uniformity is an important factor affecting profitability of the pig industry, and the production of gilts and CM in the same batch decreases carcass uniformity (Alfonso et al., 2010). Female castration uniforms growth and carcass

characteristics of a given batch of pigs, facilitating farm management and logistics of transport to the slaughterhouse. Consequently, female castration might improve farm profitability and carcass uniformity at slaughter (Peinado et al., 2015). However, surgical castration of females is not allowed in the EU-28, although its practice is permitted in numerous countries.

Immunocastration, a methodology that has been proved effective to reduce boar taint is a sound alternative to surgical castration (Gispert et al., 2010; Aluwé et al., 2012; Morales et al., 2013), and the use of IMC is increasing all over the world. Immunocastration (Improvac, Pfizer, Animal Health, Madrid, Spain) involves the use of active immunization against the GnRF hormone releasing factor. Immunocastration has been practiced commercially in Australia and New Zealand since 1998 through the use of Improvac. The system allows boars to be used during part of their productive life but convert them into CM at an age close to slaughter (Pauly et al., 2009; Lealiifano et al., 2011; Dunshea et al., 2013). Two subcutaneous injections of 2 ml are required for correct immunocastration. The first injection is given at approximately 8 wk of age and the second at least 4 wk after, ideally between 4 and 6 wk before the slaughter. The first injection has a limited effect and consequently the physiology of the immunocastrated males is similar to that of boars until the second injection (Quiniou et al., 2012). In this first period benefits in relation to animal welfare (avoids castration) and production (lower feed consumption and better feed efficiency) are similar to those of boars. After the second dose, the levels of anabolic hormones are reduced and the animal behave similarly to that of CM (Brewster and Nevel, 2013). In females, immunocastration is seldom applied, except

in the case of the Iberian pigs. In this case, a third injection of the vaccine is often required, reducing its economic benefits.

2.3. Net energy content

Energy systems used to express pig requirements have developed from the use of total digestible nutrients (NRC, 1971) to digestible energy (DE), metabolizable energy (ME), and more recently, NE systems. Energy represents a major cost of feed formulas. Improving the existing knowledge on energy utilization by the animal will result in better fit of the diet to pig requirements (Ajinomoto, 2017). Figure 6 illustrates the classical partitioning of the gross energy (GE) of feeds and ingredients. Energy partitioning divides energy intake into three general categories: heat production, products formed, and waste products. The energy values assigned to ingredients and diets and to energy requirements of the pig are affected by the physical-chemical characteristics of the ingredients and by the physiological state of the pig (growth vs. gestation vs. lactation; NRC, 2012).

Figure 6 Energy systems in pigs fed a standard diet based on cereals and soybean meal.

Ajinomoto, 2017

Not all the GE of a feed is available for meeting the requirements of the pig since variable proportions of GE are lost in faeces and urine, and as fermentation gases and heat. The DE content of a feed correspond to its GE content minus the faecal energy losses after digestion in the digestive tract. The ME content of a feed corresponds to the difference between the DE content and the energy losses in urine and gases. Net energy is defined as the ME content minus the heat increment associated with feed utilization (Noblet et al., 2010). The closest estimate of the “true” energy value of a feed for the animal should be its NE content, which takes into account differences in the metabolic utilization of the ME content in the nutrients

for maintenance and production. In addition, NE is the only system in which energy requirements and diet energy values are expressed on the same basis which, at least theoretically, should be independent of the characteristics of the feed.

An increase in the energy content of the diet, results usually in improved FCR (Smith et al., 1999; Quiniou and Noblet, 2012), increased BF depth, and often in an increase in the IMF content of pork meat (King et al., 2004; Liu et al., 2007). However, the beneficial effects of increasing the NE content of the diet on ADG are less consistent (Matthews et al., 2003; Quiniou and Noblet, 2012; Coca et al., 2012). An important aspect of the energy concentration of the diet is that energy content influences voluntary feed intake because pigs have a tendency to consume feed until their energy requirements are fulfilled (Nyachoti et al., 2004).

The information available on the influence of NE concentration of the diet on carcass and meat quality traits of pigs is unclear. Paiano et al. (2008) reported that an increase in NE concentration of the diet increased carcass fat deposition in pigs slaughtered at 120 kg BW. In contrast, Kerr et al. (2003) and Apple et al. (2004) reported no effects of NE concentration of the diet on carcass or meat quality traits in pigs slaughtered at 110 kg BW and 106 kg BW, respectively.

2.4. Sire line

During the last decades, the industry focused on methods and strategies to increase lean deposition and improve FCR (Dunshea et al., 2013). In fact, the continuous genetic improvement of pig lines has resulted in important increases in growth, feed efficiency, and quality of the final products. Currently, hybrid fattening pigs are obtained from numerous specialized genetic lines. Hence, it is difficult to

compare the effect of a particular genetic line, without knowing its origin and the purpose of the genetic program involved.

Traditionally, industrial crosses for pig production in Spain were based on crossbreds of Landrace, Large White, or Landrace × Large White hybrid females with Pietrain sire male lines, with animals slaughtered at 105 kg BW (Peinado et al. 2012). Currently, the most commonly used sire line in Spain is Pietrain, usually from German or Austrian origin (approximately, 70-80% of the fattening pigs; Agostini et al., 2013). These lean strain pigs are intended for the production of meat and carcasses with a high percentage of primal parts, often on detriment of growth rates and meat quality. These genotypes are most preferred when the main objective is to obtain carcasses with low FCR and thinner BF which reduces the cost of production. These carcasses are mainly intended eventually for industrial processing and sale of fresh meat.

The objectives of this Thesis were to study the effect of pen uniformity at weaning during the breeding, and sex, sire line, and energy content of the diet during the fattening period as key factors that could influence growth performance and carcass and meat quality in white pigs

CHAPTER 2:

**REGROUPING OF PIGS BY BODY WEIGHT AT
WEANING DOES NOT AFFECT GROWTH
PERFORMANCE, CARCASS QUALITY OR
UNIFORMITY AT SLAUGHTER OF HEAVY
WEIGHT PIGS**

1. INTRODUCTION

Under commercial conditions pigs are housed in the nursery barn by batches, with all animals within the barn and batch having similar age. In addition, pigs are regrouped in pens within the barn according to BW. Same procedure is practiced for regrouping the pigs at the start of the fattening phase. Regrouping pigs by initial BW alters social interactions (Pluske and Williams, 1996; Mahan et al., 1998) and might affect uniformity of carcasses at slaughter (O'Connell et al., 2005). In addition, differences in individual growth rates result in pigs, within a pen and within a given batch, reaching target final weights at different ages, which reduces farm benefits (Peinado et al., 2008).

Surgical castration of gilts is a common management practice in Iberian pig production, a system in which pigs are slaughtered with at least 145 kg BW (Serrano et al., 2009a). When fed under ad libitum conditions, BW gain, BF depth and *Gluteus medius* fat are similar for CM and CF and higher for both than for gilts (Peinado et al., 2008). Consequently, castration of males and females facilitates farm management, reduces the length of the fattening period and improves the logistics of transport, the uniformity of the pigs at slaughter and the commercialization of pork meat (Latorre et al., 2003a; Peinado et al., 2008, 2012). In addition, castration increases the amount of fat in the carcass which facilitates the drying and ripening process of primal cuts (Candek-Potokar et al., 2002) improving the aroma and flavor of the meat and the acceptance of dry-cured products by the consumer (Ruíz-Carrascal et al., 2000; Peinado et al., 2011). However, the information available on the effects of surgical castration of conventional white gilts on growth performance and carcass quality is very limited. The objective of this research was to study the

influence of BW uniformity at weaning on growth performance and carcass quality of CM and castrated females at the end of the nursery (27.3 kg BW) and fattening (130.5 kg BW) phases.

2. MATERIAL AND METHODS

2.1. Husbandry, diets, and experimental design

The experimental procedures used in this study were approved by the Animal Ethics Committee of the Universidad Politécnica de Madrid (Madrid, Spain) and were in compliance with the Spanish guidelines for the care and use of animals in research (Boletín Oficial del Estado, 2007). In total, 480 crossbred pigs from Landrace * Large White x Duroc dams mated to Duroc sires were used. The experiment was divided into two phases; nursery from weaning at 7.5 kg to 27.3 kg BW and fattening from this weight to slaughter at 130.5 kg BW. Diets fed to pigs during the different periods of the experiment were formulated to meet or exceed pig requirements according to Fundación Española Desarrollo Nutrición Animal (2006). The ingredient composition and the calculated (Fundación Española Desarrollo Nutrición Animal, 2010) and analyzed (Association of Official Analytical Chemists 2000 International) nutrient content of the diets are shown in Table 1. The design of the experiment was completely randomized with four treatments forming a 2 × 2 factorial with pen uniformity and sex as main effects. Each treatment was replicated four times and the experimental unit was a pen with 30 pigs in the nursery phase and 14 pigs chosen at random from their corresponding nursery pens in the fattening phase.

Table 1 Ingredient composition and nutrient content (% as fed basis, unless indicated otherwise) of the experimental diets

	28 to 49 d of age	49 to 77 d of age	77 to 160 d of age	160 to 201 d of age
Ingredient				
Cooked maize	49.24	-	-	-
Barley	6.00	34.25	40.73	58.00
Wheat	-	31.53	28.21	20.88
Fish meal, 67% CP	8.00	-	-	-
Animal plasma, 78%	6.80	-	-	-
Dried whey	20.00	-	-	-
Soybean meal, 44%	6.00	24.64	22.53	13.72
Lard	2.50	5.72	5.70	4.90
L-Lys, 78%	0.25	0.75	0.40	0.26
DL-Met, 99%	0.20	0.27	0.10	-
L-Thr, 99%	0.12	0.25	0.10	0.04
L-Trp, 99%	0.04	0.05	-	-
Calcium carbonate	0.20	0.68	1.04	1.04
Dicalcium	0.15	1.16	0.48	0.45
Sodium chloride	0.20	0.40	0.40	0.40
Premix ^a	0.30	0.30	0.31	0.31
Calculated				
NE, Mcal/kg	2.65	2.52	2.52	2.52
SID ^c Lys	1.36	1.14	0.93	0.69
SID Met + Cys	0.86	0.76	0.58	0.42
SID Thr	0.91	0.78	0.62	0.46
SID Trp	0.26	0.24	0.18	0.15
Calcium	0.83	0.75	0.72	0.69
Total phosphorus	0.70	0.69	0.57	0.55
Digestible	0.48	0.35	0.26	0.25
Analyzed				
Ash	6.1	4.8	4.5	4.2
Dry matter	91.8	90.3	89.9	90.1
Ether extract	5.0	6.4	5.4	6.0
Crude protein	20.1	17.5	16.6	14.4
Crude fiber	2.3	4.9	4.4	3.6

^a Provided the following (per kilogram of complete diet): Vitamin A (trans-retinyl acetate): 6,000 IU; vitamin D₃ (cholecalciferol): 1,200 I.U.; vitamin E (all-rac-tocopherol-acetate): 41 I.U.; vitamin k₃ (bisulphate menadione complex): 0.5 mg; riboflavin: 2.5 mg; pantothenic acid (D-Ca pantothenate): 8 mg; niacin: 8 mg; pyridoxine (pyridoxine HCL): 2.5 mg; vitamin B₁₂: 0.015 mg; Fe (FeSO₄·7H₂O): 80 mg; Mn (MnO₂): 50 mg; Zn (ZnO): 110 mg; Co (CoSO₄): 0.10 mg; Se (Na₂SeO₃): 0.2 mg; I (Ca (IO₃)₂): 0.5 mg; and Natuphos 5000, 300 FTU [6-phytase (EC 3.1.3.26) BASF Espanola S.A, Tarragona, Spain]. ^b According to Fundación Española Desarrollo Nutrición Animal (2010). ^c Standardized ileal digestible. ^d In duplicate.

2.2. Nursery phase

Upon arrival to the experimental farm, pigs were housed in an environmentally controlled room with slatted floor pens that were provided with individual feeders and two nipple drinkers. Pen dimensions were 3 m × 3 m, giving a space allowance of 0.3 m² per pig. Pigs were allotted in group of 30 to 16 pens within sex and uniformity, with all pens having similar average BW. Pigs belonging to the more uniform group were chosen to have a SD of BW of ± 0.6 kg within the pen and pigs belonging to the less uniform group were chosen to have a SD of ± 1.2 kg. All animals were managed and vaccinated against major diseases according to standard commercial practices. The temperature of the barn was maintained at $30 \pm 1.5^{\circ}\text{C}$ for the first week after weaning and then, it was reduced 2°C per wk until reaching 26°C . Males were castrated at 5 ± 2.0 d of age (2.5 ± 0.57 kg BW), 23 d before the beginning of the trial, and females at 69 ± 2.6 d of age (22.3 ± 0.83 kg BW), 41 d after the beginning of the trial and 8 d before the end of the nursery period. Castration of females at this late age is a common practice because of the difficulties to castrate gilts at younger ages. The methodology used for castration has been described in detail by Serrano et al. (2008). Briefly, gilts were immobilized, analgesized and anesthetized, and the ovaries were removed through a dorsolateral incision made at the left side flank by an experienced veterinarian. Pigs had free access to water and to a common pelleted commercial diet based on cereals and soybean meal. Individual BW and feed consumption per pen were recorded at 28, 49, 68 and 77 d of age. The growth performance controls conducted at 28 and 49 d of age coincided with a feed change. Pigs that died or were withdrawn from the experiment were weighed and the data used to calculate ADFI, ADG and feed

efficiency (G:F) per pen by period and for the entire nursery phase. In addition, BW variability was studied by determining the SD of the BW of the pigs at same ages. The experimental unit was the pen for all traits.

2.3. Fattening phase

At the end of the nursery phase (27.3 kg BW as an average), 14 pigs per pen chosen at random, were moved to the fattening unit and used in the second part of the experiment. Pigs were not commingled and therefore, all animals belonging to a given pen during the nursery phase were kept in the same pen during the fattening phase. The average BW of the pigs at the start of this phase was 27.1 kg. Pigs were housed in a natural environmental controlled barn in pens with slatted floors provided with an individual feeder and two nipple drinkers. Pen dimensions were 3.8 m × 3.8 m, giving a space allowance of 1 m² per pig. The average temperature during this phase varied from 28 ± 2.8°C (July, beginning of the fattening period) to 8 ± 3.0°C (November, end of the experiment). Pigs had free access to water and to common pelleted commercial diets based on cereals and soybean meal (Table 1). Pigs were weighed individually at 77, 135, 160 and 201 d of age and pigs that were withdrawn from the trial and mortality were recorded and weighed as produced. These data were used to calculate ADG, ADFI and G:F. The uniformity of BW of pigs was measured by period and cumulatively as indicated for the nursery phase. All pigs were slaughter the same day and the average BW was 130.5 kg.

2.4. Carcass traits

At the end of the experiment, pigs were fasted for 12 h, weighed individually and transported 30 km to a commercial abattoir (Copese S.A., Segovia, Spain)

where they were allowed a 12 h rest period with full access to water but not to feed. Pigs were stunned in an 80% carbon dioxide atmosphere for 50 s, exsanguinated, scalded, skinned and eviscerated, and the carcasses were split down the center of the vertebral column according to standard commercial practices. The hot carcass weights of 10 pigs chosen at random from each pen were recorded individually and the dressing percentage was calculated from these data. Then, the head was removed at the atlanto-occipital junction and the carcasses were blast chilled at 2°C (1 m/s) for 2 h. At 45 min *post-mortem*, fat thickness over the thinnest point at *Gluteus medius* muscle and BF depth between the 3rd and 4th last ribs on the midline of the left side of the carcass (skin not included) were measured using a flexible ruler with a precision of 0.5 mm. At 45 min and at 24 h *post-mortem*, the pH value and the temperature of the semimembranosus muscle were measured using a Crison 507 portable pH meter equipped with a glass electrode (model no. 52-00, Crison Instruments S.A., Barcelona, Spain).

Carcasses were fabricated according to the simplified European Community reference method (Branscheid et al., 1990). The weights of hams, shoulders and loins were measured 2 h *post-mortem* (fresh weight). Then, hams, shoulders and loins were suspended in the air and chilled for 24 h at 4°C. At 24 h *post-mortem*, untrimmed hams and shoulders but not loins, were weighed again. The difference between the weights of hams and shoulders measured at 2 and 24 h *post-mortem* was divided by the weight obtained at 2 h to estimate shrink loss. At 48 h *post-mortem*, hams and shoulders were trimmed of external fat by experienced slaughterhouse personnel and weighed again to calculate trimmed ham and shoulder yields.

2.5. Statistical analyses

Data on growth performance and carcass quality traits were analyzed as a completely randomized design using the MIXED procedure of Statistical Analysis Systems Institute (1990). The model included pen BW uniformity at weaning and sex as main factors, as well as the interaction. Also, the effects of growing period and its interaction with treatment for ADG, ADFI and G:F ratio were tested using the repeated measures analyses. Data on mortality showed no normal distribution and therefore, the Catmod procedure of Statistical Analysis Systems Institute (1990) was used for analyses. The Levene test was used to check for SD homogeneity of BW during nursery and fattening phases and for carcass quality traits. A P -value < 0.05 was considered a significant difference and P -value between 0.05 and 0.10 was considered a tendency. No significant interactions between pen BW uniformity at weaning and sex were detected for any of the traits studied and therefore, only main effects are presented.

3. RESULTS

3.1. Growth performance: nursery phase

Mortality was 1.04% and was not related to treatment (data not shown). No interactions between period and uniformity of the pigs were detected. However, the interaction between period and sex was significant for ADG and ADFI ($P < 0.001$) and tended to be significant for G:F ratio ($P = 0.080$). In this respect CF had lower ADG and ADFI and feed efficiency than CM from 68 to 77 d of age but not in the other periods considered (Figure 7). Cumulatively (28 to 77 d of age), pen uniformity at weaning did not affect ADFI or ADG of the pigs but pigs from the more uniform

pens had lower feed efficiency ($P = 0.05$) than pigs from the less uniform pens (Table 2).

Figure 7 Interaction between sex (CM = castrated males; CF = castrated females) and period on a) ADG, b) ADFI and c) G:F ratio during nursery (weaning at 28 d to 77 d of age) phase

a)

b)

c)

Table 2 Effect of body weight (BW) uniformity at weaning (UNIF) and sex on growth performance of the pigs during the nursery phase (7.5 to 27.3 kg BW)

Item	UNIF ^a		Sex		Pooled SEM ^d	Probability	
	± 1 SD	± 2 SD	CF ^b	CM ^c		UNIF	Sex
Initial BW, kg	7.5	7.5	7.5	7.5	0.018	0.538	0.489
Final BW, kg	27.2	27.3	26.3	28.2	0.38	0.823	< 0.001
From 7.5 to 13.1 kg BW (28 to 49 d of age)							
ADFI, kg/d	0.340	0.337	0.344	0.333	0.0077	0.776	0.190
ADG, kg/d	0.268	0.268	0.272	0.264	0.0050	1.000	0.148
G:F	0.790	0.797	0.792	0.795	0.013	0.614	0.846
From 13.1 to 22.3 kg BW (49 to 68 d of age)							
ADFI, kg/d	0.723	0.698	0.707	0.713	0.0091	0.019	0.530
ADG, kg/d	0.487	0.481	0.471	0.497	0.021	0.806	0.237
G:F	0.674	0.689	0.665	0.697	0.026	0.580	0.245
From 22.3 to 27.3 kg BW (68 to 77 d of age)							
ADFI, kg/d	1.062	1.055	0.977	1.141	0.044	0.883	0.003
ADG, kg/d	0.534	0.561	0.458	0.637	0.033	0.416	< 0.001
G:F	0.498	0.531	0.468	0.561	0.029	0.294	0.008
From 7.5 to 27.3 kg BW (28 to 77 d of age)							
ADFI, kg/d	0.621	0.609	0.601	0.629	0.0096	0.245	0.014
ADG, kg/d	0.402	0.404	0.383	0.423	0.0070	0.699	< 0.001
G:F	0.647	0.664	0.638	0.674	0.0082	0.052	< 0.001

^a The SD of BW at weaning was ± 0.6 and ± 1.2 kg for the more and less uniform groups, respectively. ^b CF = castrated females (ovariectomized at 22.3 ± 0.83 kg BW and 69 ± 2.6 d of age). ^c CM = castrated males (surgery was performed at 2.5 kg ± 0.57 kg BW and 5 ± 2.0 d of age). ^d Four pens of 30 pigs each per treatment. The interaction between sex and UNI was not significant ($P > 0.10$).

Also, from 49 to 68 d of age pigs from the more uniform pens had higher ADFI than pigs from the less uniform pens (0.723 vs. 0.698 kg/d; $P < 0.05$). At the end of this phase, the SD of BW was higher in pigs from the less uniform pens than in pigs from the more uniform pens (4.31 vs. 3.27 kg; $P < 0.001$) (Figure 8). Cumulatively (28 to 77 d of age), CF had lower ADFI (0.601 vs. 0.629 kg/d; $P < 0.05$) and ADG (0.383 vs. 0.423 kg/d; $P < 0.001$) and poorer G:F ratio (0.638 vs. 0.674; $P < 0.001$) than CM. From 68 to 77 d of age, immediately after castration, CF ate less feed ($P < 0.01$), had lower ADG ($P < 0.001$) and were less efficient ($P < 0.01$) than CM. At the end of this phase (77 d of age) the SD of the BW tended to be higher for CM than for CF (3.98 vs. 3.60 kg; $P = 0.094$) (Figure 9).

Figure 8 Effect of body weight (BW) uniformity at weaning (7.5 kg BW) on the SD of BW during the nursery (weaning at 28 d to 77 d of age) and the fattening (77 to 201 d of age) phases (n = 8)

Figure 9 Effect of sex (CM = castrated males; CF = castrated females) on the SD of body weight (BW) during the nursery (weaning at 28 d to 77 d of age) and the fattening (77 to 201 d of age) phases (n = 8)

3.2. Growth performance: fattening phase

Mortality was 3.6% and was not related to treatment (data not shown). No interactions between period and treatment were detected. Cumulatively, growth performance was not affected by pen uniformity, although from 160 to 201 d of age pigs from the more uniform pens tended to have lower feed efficiency ($P = 0.06$) than pigs from the less uniform pens (Table 3). At the beginning of this phase, the SD of the BW was lower in pigs from the more uniform pens than in pigs from the less uniform pens (3.21 vs. 4.34 kg; $P < 0.001$). However, by the time pigs reached the slaughter weight (130.5 kg BW and 201 d of age as an average) no differences were detected (11.9 vs. 12.2 kg).

At the start of this phase, CM were heavier than CF (28.3 vs. 25.9 kg; $P < 0.001$). From 77 to 135 d of age, CF had lower ADFI (1.511 vs. 1.636 kg/d; $P < 0.05$) than CM but ADG and G:F were not affected. For the entire fattening phase (77 to 201 d of age and 27.1 to 130.5 kg BW), CF tended to have lower ADFI (2.228 vs. 2.322 kg/d; $P = 0.09$) and better G:F ratio (0.370 vs. 0.363; $P = 0.08$) than CM but no differences were observed for ADG. Sex did not affect the SD of the BW during this phase.

Table 3 Effect of body weight (BW) uniformity at weaning (UNIF) and sex on growth performance of pigs during the fattening phase (27.1 to 130.5 kg BW)

Item	UNIF ^a		Sex		Pooled SEM ^d	Probability	
	± 1 SD	± 2 SD	CF ^b	CM ^c		UNIF	Sex
Initial BW, kg	27.1	27.1	25.9	28.3	0.46	0.979	< 0.001
Final BW, kg	129.3	131.6	128.2	132.7	2.59	0.388	0.103
From 27.1 to 71.3 kg BW (77 to 135 d of age)							
ADFI, kg/d	1.567	1.579	1.511	1.636	0.057	0.838	0.048
ADG, kg/d	0.782	0.769	0.753	0.797	0.026	0.618	0.107
G:F	0.499	0.487	0.499	0.488	0.0067	0.101	0.107
From 71.3 to 95.0 kg BW (135 to 160 d of age)							
ADFI, kg/d	2.543	2.645	2.549	2.639	0.052	0.074	0.111
ADG, kg/d	0.938	0.960	0.940	0.958	0.028	0.461	0.525
G:F	0.369	0.363	0.369	0.363	0.0084	0.507	0.507
From 95.0 to 130.5 kg BW (160 to 201 d of age)							
ADFI, kg/d	3.022	3.053	3.011	3.065	0.078	0.703	0.503
ADG, kg/d	0.815	0.874	0.854	0.835	0.036	0.123	0.603
G:F	0.270	0.286	0.284	0.272	0.0080	0.060	0.181
From 27.1 to 130.5 kg BW (77 to 201 d of age)							
ADFI, kg/d	2.257	2.293	2.228	2.322	0.050	0.481	0.086
ADG, kg/d	0.824	0.843	0.825	0.842	0.019	0.342	0.368
G:F	0.365	0.368	0.370	0.363	0.0039	0.599	0.076

^a The SD of BW at weaning was ± 0.6 and ± 1.2 kg for the more and less uniform groups, respectively. ^b CF = castrated females (ovariectomized at 22.3 ± 0.83 kg BW and 69 ± 2.6 d of age). ^c CM = castrated males (surgery was performed at $2.5 \text{ kg} \pm 0.57 \text{ kg BW}$ and 5 ± 2.0 d of age). ^d Four pens of 14 pigs each per treatment. The interaction between sex and UNI was not significant ($P > 0.10$).

3.3. Carcass quality traits

Pen uniformity had little effect on carcass quality traits. In fact, the only differences detected were for the temperature (41.2 vs. 40.0°C; $P = 0.06$) and pH (6.28 vs. 6.23; $P < 0.05$) of the *Semimembranosus* muscle at 45 min and for trimmed primal cut yield that were higher in pigs from the more uniform pens ($P = 0.09$). Carcass yield, BF depth and *Gluteus medius* fat were not affected by sex (Table 4). However, CM had higher fresh (31.0 vs. 30.0 kg; $P < 0.05$), untrimmed (30.7 vs. 29.7 kg; $P < 0.05$) and trimmed (27.4 vs. 26.5 kg; $P < 0.05$) ham weight than CF. Moreover, CM tended to have higher percentage (% carcass weight) of fresh (52.7 vs. 52.1%; $P = 0.08$) and trimmed (40.8 vs. 40.4%; $P = 0.09$) primal cuts than CF with most of the differences explained by the higher shoulder yield of CM ($P < 0.001$).

Table 4a Effect of body weight (BW) uniformity at weaning (UNIF) and sex at weaning on carcass and meat quality traits

Item	UNIF ^a		Sex		Pooled SEM ^d	Probability	
	± 1 SD	± 2 SD	CF ^b	CM ^c		UNIF	Sex
Slaughter weight, kg	129.9	130.7	127.8	132.7	2.35	0.747	0.057
Carcass weight, kg	104.7	104.6	102.8	106.5	1.59	0.988	0.041
Carcass yield, %	80.5	80.0	80.4	80.1	0.36	0.222	0.439
Fat thickness, mm							
Back fat P ₂	32.4	33.1	33.3	32.2	0.74	0.399	0.183
m. <i>Gluteus medius</i>	23.3	23.3	23.7	22.9	0.95	0.969	0.411
pH ^e							
45 min	6.28	6.23	6.19	6.31	0.023	0.048	0.002
24 h	5.60	5.63	5.61	5.61	0.042	0.405	0.749
Temperature, °C ^e							
45 min	41.2	40.4	41.0	40.6	0.39	0.059	0.402
24 h	3.43	3.20	3.39	3.24	0.29	0.459	0.619
Ham weight, kg							
Fresh	30.6	30.4	30.0	31.0	0.41	0.594	0.027
Untrimmed	30.3	30.1	29.7	30.7	0.41	0.684	0.030
Trimmed	27.1	26.7	26.5	27.4	0.38	0.377	0.031
Ham yield, %							
Fresh	29.3	29.0	29.2	29.1	0.17	0.194	0.832
Untrimmed	28.9	28.8	28.9	28.8	0.20	0.464	0.805
Trimmed	25.9	25.6	25.7	25.7	0.19	0.105	0.895

^a The SD of BW at weaning was ± 0.6 and ± 1.2 kg for the more and less uniform groups, respectively. ^b CF = castrated females (ovariectomized at 22.3 ± 0.83 kg BW and 69 ± 2.6 d of age). ^c CM = castrated males (surgery was performed at 2.5 ± 0.57 kg BW and 5 ± 2.0 d of age). ^d Four pens of 10 pigs each per treatment. ^e Measured at the *Semimembranosus* muscle.

Table 4b Effect of body weight (BW) uniformity at weaning (UNIF) and sex at weaning on carcass and meat quality traits

Item	UNIF ^a		Sex		Pooled SEM ^d	Probability	
	± 1 SD	± 2 SD	CF ^b	CM ^c		UNIF	Sex
Shoulder weight, kg							
Fresh	17.7	17.7	17.1	18.3	0.14	0.869	< 0.001
Untrimmed	17.5	17.3	16.8	17.4	0.23	0.409	< 0.001
Trimmed	15.6	15.5	15.0	16.1	0.18	0.629	< 0.001
Shoulder yield, %							
Fresh	16.9	16.9	16.6	17.2	0.10	0.495	< 0.001
Untrimmed	16.7	16.5	16.3	16.9	0.11	0.121	< 0.001
Trimmed	14.9	14.8	14.6	15.1	0.086	0.400	< 0.001
Loin weight, kg	6.71	6.60	6.54	6.77	0.14	0.251	0.124
Loin yield, %	6.41	6.23	6.27	6.36	0.17	0.288	0.717
Primal cut yield, %							
Fresh ^e	52.6	52.1	52.1	52.7	0.33	0.196	0.082
Untrimmed ^f	45.6	45.3	45.2	45.7	0.20	0.216	0.102
Trimmed ^f	40.8	40.4	40.4	40.8	0.24	0.091	0.091
Shrink loss, %	1.25	1.41	1.29	1.38	0.095	0.128	0.385

^a The SD of BW at weaning was ± 0.6 and ± 1.2 kg for the more and less uniform groups, respectively. ^b CF = castrated females (ovariectomized at 22.3 ± 0.83 kg BW and 69 ± 2.6 d of age). ^c CM = castrated males (surgery was performed at 2.5 ± 0.57 kg BW and 5 ± 2.0 d of age). ^d Four pens of 10 pigs each per treatment. ^e Determined in hams, shoulders and loins. ^f Determined in hams and shoulders exclusively. The interaction between sex and UNI at weaning was not significant ($P > 0.10$).

4. DISCUSSION

4.1. Growth performance

It is a common commercial practice to regroup pigs in pens within a barn by BW, both at weaning and at the start of the fattening period, to equalize sizes and reduce social competition. The objective of this practice is to improve growth performance and carcass uniformity at slaughter. In the current study, however, growth performance of the pigs was not affected by pen uniformity in any of the two phases (nursery and fattening) considered. These results agree with data of O'Connell et al. (2005) who did not detect any effect of pen uniformity at weaning on growth performance of the pigs during the nursery (9.8 to 30.2 kg BW) or the fattening (30.2 to 98.8 kg BW) phase. Similarly, Bruininx et al. (2001) reported that the distribution of pigs at weaning into pens according to BW, had limited benefits on ADG from 8.0 to 24.7 kg BW, although the more homogeneous groups had 3% better FCR than the less homogeneous groups. During the nursery phase, an interaction between period and sex on growth performance was detected. From 68 to 77 d of age, CF had reduced ADG, ADFI and feed efficiency than CM but no differences were detected from 28 to 68 d of age. Females were castrated at 69 d of age and consequently, a reduction in growth performance was expected, immediately after surgery.

The variability in BW at the end of the nursery phase was lower for pigs from the more uniform pens than for pigs from the less uniform pens, but no differences between groups were observed at slaughter. Magowan et al. (2011) reported also that the BW variability at 10 wk of age was reduced when pigs were regrouped by BW at weaning, consistent with these results reported herein. On the other hand,

O'Quinn et al. (2001) concluded that sorting pigs by BW at 14 wk of age (34.2 kg BW) did not improve BW uniformity at the end of the experiment (119 kg BW). Moreover, O'Connell et al. (2005) did not detect any improvement in BW variability at slaughter in pigs regrouped by BW at weaning (4 wk of age). In contrast, in a second experiment, these same authors reported that regrouping the pigs at 10 wk of age reduced within group variability at slaughter (97.5 kg BW). The reason for the discrepancies among authors is not known but might depend on the genetic background, sex and group size as well as on the age at which pigs were regrouped. For example, in the current experiment, in which no differences in BW uniformity were reported, pigs were not commingled at any stage of the growth period whereas in the second experiment of O'Connell et al. (2005) pigs were regrouped at 10 wk of age, resulting in pigs from the more uniform groups having less variability in slaughter weight than pigs from the less uniform groups.

Most published research on growth performance of pigs have compared entire males, CM and intact females (Augspurger et al., 2002; Latorre et al., 2003a,b) but little information is available comparing any of these 3 sexes with CF. In the current research, growth performance from 7.5 to 22.3 kg BW (weaning at 28 d to 68 d of age) was similar for CF and CM. However, for the last period of the nursery phase (68 to 77 d of age) ADG and G:F were better for CM than for CF, a finding that was expected because gilts were castrated at the beginning of this period whereas the males were castrated at 5 d of age, 23 d before the start of the experiment. Consequently, a negative impact of castration on growth performance of the females was expected. In fact, for the first 8 d following castration (69 to 77 d of age), CF had 39% lower ADG and 20% worse G:F than CM. As a result, CF grew

10.4% less and were 5.6% less efficient than CM for the entire nursery phase (28 to 77 d of age). The data available that quantify the detrimental effects of surgical castration on growth performance of gilts is very limited. In this respect, Peinado et al. (2011) did not find any effect of castration of conventional white females at 58 d of age on growth performance. However in the production of Iberian pigs, a system in which castration of females is a common practice, Serrano et al. (2009a) reported that gilts castrated at 92 d of age, tended to have 10.2% lower ADG and were 8.9% less efficient than intact females for the first 30 d after surgery. The discrepancies on the effects of castration on growth performance of gilts among authors are related to the methodology used for the surgery procedure as well as with the length of the period considered after surgery. In the experiment of Peinado et al. (2011), the period studied from surgery to the next control was longer (46 d after the surgery) than in the present experiment (9 d after the surgery). Consequently, castrated females had more time to recover from surgery in the experiment of Peinado et al. (2011) than in the current experiment.

During the fattening phase (77 to 201 d of age), CM tended to eat more feed and to be less efficient than CF. Ramírez and Cava (2007) reported similar ADG for CM and CF of crossbreds from Iberian dams and Duroc sires slaughtered at 159 kg BW, in agreement with the results of the current experiment. Peinado et al. (2012) compared growth performance of CM and CF crossbreds from Landrace x Large White dams and Duroc sires from 28.4 to 119.2 kg BW and reported 3.7% higher ADFI and 1.7% lower feed efficiency for CM, but the differences observed were not significant.

4.2. Carcass traits

Pen uniformity did not affect any of the carcass quality traits studied, except for trimmed primal cut yield that tended to be higher in pigs of the more uniform pens than in pigs of the less uniform pens. The information available on the effects of BW uniformity at weaning on carcass traits is very limited. In fact, the only data available is that of O'Connell et al. (2005) who did not detect any effect of BW uniformity at weaning on carcass weight and BF thickness of crossbreeds of Large White x Landrace dams mated to Landrace sires pigs at slaughter at 98 kg BW.

Sex did not affect carcass yield of the pigs, in agreement with data of Peinado et al. (2008) comparing CM, CF and intact females from Pietrain x Large White sires mated to Landrace x Large White dams and Peinado et al. (2012) comparing crossbreeds from Landrace x Large White dams mated to Duroc sires. Similar results have been reported by Ramírez and Cava (2007) comparing CM and CF Iberian pigs. Shoulder and primal cut yields were higher for CM than for CF, in agreement with data of Peinado et al. (2012). Carcass fat and shrink loss were similar for CM and CF, consistent with data of Peinado et al. (2012) comparing CM, CF and intact females slaughtered at 132 kg BW. Latorre et al. (2004) indicated that shrink loss of the carcass is inversely related to the amount of cover fat and therefore, no difference in shrink loss because of sex was expected in this experiment.

5. CONCLUSIONS

Regrouping of pigs at weaning according to initial body weight, did not provide any advantage on growth performance of the pigs during the nursery and fattening phases or on body weight uniformity or carcass quality traits at slaughter.

Consequently, the practice of commingling pigs at weaning to improve growth performance and carcass uniformity might not be recommended under all circumstances. Also, growth performance, backfat depth and fat content at *Gluteus medius* were similar for castrated females and castrated males. Consequently, castration of the pigs, irrespective of sex, might be a good commercial strategy to improve carcass quality and profitability of the production of pigs destined to the dry-cured industry in countries in which this practice is allowed.

6. ACKNOWLEDGMENTS

Financial support was provided in part by Copese, (40300, Segovia, Spain) and Ministerio de Economía y Competitividad (Project IDI-20070011, Madrid, Spain). Additional support for L. Cámara was provided by a PICATA fellowship (Moncloa Campus of International Excellence, UCM-UPM, 28040 Madrid, Spain) and by the Comunidad de Madrid (Project S2009/AGR-1704, 28040 Madrid, Spain).

CHAPTER 3:

**INFLUENCE OF NET ENERGY CONTENT OF
THE DIETS ON PRODUCTIVE PERFORMANCE
AND CARCASS MERIT OF GILTS, BOARS,
AND IMMUNOCASTRATED MALES
SLAUGHTERED AT 120 KG BW**

1. INTRODUCTION

An increase in energy content of the diet results usually in improved feed efficiency (Smith et al., 1999; Quiniou and Noblet, 2012) and increased BF depth and IMF content of pork meat (King et al., 2004; Liu et al., 2007). However, the beneficial effects of increasing the NE content of the diet on ADG are less consistent (Matthews et al., 2003; Quiniou and Noblet, 2012; Coca et al., 2012). Factors such as sex and genetic background of the pigs, balance between NE and indispensable amino acid (AA) of the diets, range of dietary energy levels studied and energy system used for feed evaluation, may affect the response of pigs to increases dietary energy density.

In Spain carcasses destined to the production of dry cured products require a minimal amount of BF between the 3rd and 4th last ribs on the midline of the carcass, *Gluteus medius* muscle fat and IMF to insure optimal quality of the final products (Peinado et al., 2008). Consequently, pigs destined to the dry cured industry are usually slaughtered at heavier weights than pigs destined to fresh pork meat production (Latorre et al., 2003b, 2004). However, an increase of BW at slaughter to approximately 120 kg reduces feed efficiency and increases the incidence of boar taint in meat (Font i Furnols et al., 2003).

Active immunization against GnRF is a recommended welfare option to surgical castration to avoid boar taint in pork meat (Thun et al., 2006; Borell et al., 2009). The authors have not found any report comparing the effects of increasing dietary NE concentration on growth performance and carcass and meat quality traits of gilts, boars and IMC. We hypothesized that an increase in energy content of diets with similar AA to NE ratio could result in an increase in energy intake and on the

amount of fat deposited in the carcasses, and that such an effect could be more noticeable in IMC than in boars, with gilts showing intermediate results. The objective of this research was to study the effect of NE content of the diet on growth performance and carcass and meat quality traits of gilts, boars and IMC pigs slaughtered at 120 kg BW.

2. MATERIAL AND METHODS

2.1. Husbandry, diets, and experimental design

All the experimental procedures used in this research were approved by the Animal Ethics Committee of Universidad Politécnica de Madrid and were in compliance with the Spanish guidelines for the care and use of animals in research (Boletín Oficial del Estado, 2007). A total, 540 crossbred pigs (72 ± 2 d of age and 28.5 ± 4.1 kg BW) obtained from a commercial farm were used. The female line (Syra, Gene+, Erin, France) included blood from Large White, Landrace and Duroc and the sire line was PIC 410 (PIC, Barcelona, Spain). From birth to the start of the experiment, pigs were managed according to standard commercial practices. Upon arrival at the experimental farm (start of the experiment), pigs were ear-tagged and housed in a naturally ventilated finishing barn. Pigs were individually weighed and allotted in groups of 12 to 45 pen replicates (4 m × 3 m) provided with total slatted concrete floors at a space allowance of 1 m²/pig according to sex (gilts, boars and IMC) and initial BW, with all pens having similar initial average BW. Active immunization against GnRF (Improvac, Pfizer Animal Health, Madrid, Spain) was performed by an experienced veterinarian with the first injection given at 90 d of age (18 d of experiment) and the second at 143 d of age (71 d of experiment; 45 d before slaughter) as recommended by the vaccine manufacturer. Health status of the pigs

was examined daily by experienced staff and weekly by the veterinarian in charge of the farm. The feeding program consisted of five periods in which pigs had free access to diets based on barley and soybean meal in mash form. Within each of the five feeding periods, the NE content of the experimental diets varied (2.29, 2.33, 2.37, 2.41, and 2.45 Mcal NE/kg) but the Lys:NE ratio was maintained constant (4.15, 3.67, 3.14, 2.93, and 2.62, respectively). Other indispensable AA (Met, Thr and Trp) and Cys were formulated according to the ideal protein concept, as indicated by Fundación Española Desarrollo Nutrición Animal (2006). The two summit diets within each feeding period were formulated and the intermediate diets were manufactured by judicious mixing of the two extreme diets in adequate proportions. The ingredient composition and the calculated (Fundación Española Desarrollo Nutrición Animal, 2010) nutrient content of the diets are shown in Table 5.

Table 5a Ingredient composition and calculated nutrient content of the summit diets used in each of the five feeding phases of the experiment^a

Item	72 to 90 d of age		90 to 126 d of age		126 to 143 d of age		143 to 168 d of age		168 to 188 d of age	
	Low	High	Low	High	Low	High	Low	High	Low	High
Ingredient										
Barley	65.75	58.40	70.08	61.50	70.19	62.65	74.91	67.30	74.60	72.94
Soybean meal, 47% CP	18.80	21.70	16.50	19.50	15.75	18.60	14.80	16.60	13.15	14.00
Corn	10.68	12.05	9.62	12.00	11.00	12.50	7.60	10.30	10.00	7.40
Animal fat	1.10	3.98	0.80	3.82	0.60	3.67	0.60	3.50	0.20	3.44
Calcium carbonate	1.17	1.18	1.08	1.08	1.07	1.06	0.90	0.92	0.90	0.92
Monocalcium phosphate	0.94	1.05	0.55	0.68	0.41	0.52	0.28	0.40	0.29	0.37
Salt	0.40	0.42	0.42	0.43	0.39	0.40	0.39	0.40	0.39	0.40
L-Lysine, 50%	0.53	0.54	0.40	0.41	0.19	0.18	0.12	0.16	0.07	0.13
DL-Methionine, 99%	0.11	0.14	0.08	0.09	-	0.01	-	0.01	-	-
L-Threonine, 98%	0.12	0.14	0.07	0.09	-	0.01	-	0.01	-	-
Vitamin and mineral premix ^b	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40

^a The three intermediate diets of each of the five feeding periods considered were prepared by mixing the two extreme diets in adequate proportions (75:25, 50:50 and 25:75, respectively). ^b Provided the following (per kilogram of diet): 6,000 IU vitamin A (trans retinyl acetate); 1,200 IU vitamin D₃ (cholecalciferol); 0.5 mg vitamin E (all-rac tocopherol acetate); 0.5 mg vitamin K₃ (bisulphate menadione complex); 2.5 mg riboflavin; 2.5 mg pyridoxine (pyridoxine HCl); 0.015 mg vitamin B₁₂ (cyanocobalamin); 8 mg d-pantothenic acid (d-Ca pantothenate); 8 mg niacin; 80 mg iron (FeSO₄·7H₂O); 50 mg manganese (MnSO₄·H₂O); 110 mg zinc (ZnO); 0.10 mg cobalt (CoSO₄ 7H₂O); 0.20 mg selenium (Na₂SeO₃); and 0.50 mg iodine (calcium iodate).

Table 5b Ingredient composition and calculated nutrient content of the summit diets used in each of the five feeding phases of the experiment^a

Item	72 to 90 d of age		90 to 126 d of age		126 to 143 d of age		143 to 168 d of age		168 to 188 d of age	
	Low	High	Low	High	Low	High	Low	High	Low	High
Calculated nutrient content ^a , %										
Net energy, Mcal/kg	2.29	2.45	2.29	2.45	2.29	2.45	2.29	2.45	2.29	2.45
Ether extract	3.03	5.88	2.72	5.73	2.56	5.60	2.50	5.41	2.15	5.29
NDF	13.73	12.87	14.18	13.18	14.23	13.33	14.68	13.77	14.67	14.26
SID ^b Lysine	0.95	1.02	0.84	0.90	0.72	0.77	0.67	0.72	0.60	0.64
SID total sulfur amino acids	0.57	0.61	0.52	0.55	0.43	0.46	0.43	0.44	0.41	0.41
SID Threonine	0.61	0.66	0.53	0.58	0.45	0.49	0.44	0.47	0.42	0.42
SID Tryptophan	0.17	0.18	0.16	0.17	0.16	0.17	0.15	0.16	0.15	0.15
Ca	0.72	0.74	0.61	0.63	0.58	0.60	0.49	0.52	0.48	0.51
Total phosphorus	0.57	0.59	0.48	0.51	0.45	0.47	0.42	0.44	0.41	0.43
Digestible phosphorus	0.30	0.32	0.23	0.25	0.20	0.22	0.18	0.20	0.17	0.19
SID Lys/NE ratio, g/Mcal	4.15	4.15	3.67	3.67	3.14	3.14	2.93	2.93	2.62	2.62

^a Fundación Española Desarrollo Nutrición Animal (2010). ^b Standardized ileal digestible.

2.2. Laboratory analyses

All diets were analyzed for moisture by the oven-drying method (930.15), nitrogen by combustion (method 990.03) using a Leco analyzer (model FP-528, Leco Corporation, St. Joseph, MI) and total ash using a muffle furnace (method 942.05) as described by AOAC International (2000). The GE content of the diets was determined using an isoperibol bomb calorimeter (model 356, Parr Instrument Company, Moline IL) (Table 6). To further test that the experimental diets were mixed correctly, the two extreme diets and the intermediate diet (50:50 ratio of the two extreme diets) of the five feeding periods were analyzed for neutral detergent fiber (NDF) and acid detergent fiber as described by Van Soest et al. (1991), ether extract (EE) by Soxhlet fat analyses after 3 *N* HCl acid hydrolysis (method 4.b) as described by Boletín Oficial del Estado (1995) and the AA as indicated by De Coca-Sinova et al. (2008). All the analyses were performed in duplicate (Table 7).

Table 6 Determined nutrient content of the experimental diets^a (% as-fed basis, unless otherwise indicated)

Item	Net energy, Mcal/kg				
	2.29	2.33	2.37	2.41	2.45
From 72 to 90 d of age					
Dry matter	91.4	90.8	91.1	90.7	91.4
Crude protein	15.9	16.0	16.5	16.7	17.5
Total ash	5.7	5.7	4.9	5.4	5.9
Gross energy, Mcal/kg	4.00	4.02	4.12	4.13	4.22
From 90 to 126 d of age					
Dry matter	90.1	90.5	90.5	91.0	90.4
Crude protein	14.8	14.8	15.0	15.4	15.7
Total ash	5.2	4.9	4.3	5.1	5.1
Gross energy, Mcal/kg	3.95	4.00	4.05	4.06	4.10
From 126 to 143 d of age					
Dry matter	90.6	90.7	90.0	90.0	90.7
Crude protein	14.8	15.0	15.2	14.8	15.8
Total ash	5.0	4.7	4.9	4.4	5.5
Gross energy, Mcal/kg	3.96	4.00	4.02	4.08	4.13
From 143 to 168 d of age					
Dry matter	90.6	91.0	90.5	90.9	91.1
Crude protein	14.9	14.9	15.5	15.0	15.3
Total ash	5.2	4.6	4.9	4.3	5.1
Gross energy, Mcal/kg	3.95	4.05	4.09	4.10	4.14
From 168 to 188 d of age					
Dry matter	91.3	90.8	91.4	91.0	91.9
Crude protein	13.8	14.0	13.8	13.7	14.1
Total ash	5.1	4.3	4.1	4.3	4.8
Gross energy, Mcal/kg	3.98	4.04	4.10	4.10	4.19

^a In duplicate.

Table 7 Determined nutrient and amino acid content of the two summit diets and the intermediate diet (50:50) used in each of the five feeding periods^a

Feeding period	NDF ^b	ADF ^c	Ether Extract	Total indispensable amino acids			
				Lys	TSAA ^d	Thr	Trp
Low energy ^e diets							
72 to 90 d of age	13.7	4.7	3.2	1.07	0.64	0.70	0.21
90 to 126 d of age	14.0	4.9	2.9	0.93	0.60	0.60	0.19
126 to 143 d of age	14.5	5.2	2.8	0.82	0.51	0.55	0.19
143 to 168 d of age	14.7	4.9	2.6	0.80	0.50	0.52	0.20
168 to 188 d of age	14.7	5.0	2.3	0.68	0.46	0.46	0.17
Intermediate energy ^f diets							
72 to 90 d of age	13.4	4.6	5.0	1.13	0.68	0.74	0.23
90 to 126 d of age	13.7	4.5	4.4	0.97	0.61	0.62	0.19
126 to 143 d of age	14.0	5.0	4.2	0.84	0.51	0.56	0.19
143 to 168 d of age	14.1	4.9	4.1	0.80	0.53	0.55	0.23
168 to 188 d of age	14.5	5.2	4.0	0.70	0.48	0.46	0.17
High energy ^g diets							
72 to 90 d of age	13.3	4.6	6.5	1.16	0.70	0.76	0.23
90 to 126 d of age	13.0	4.0	5.7	1.01	0.63	0.66	0.20
126 to 143 d of age	13.9	4.6	5.5	0.88	0.54	0.59	0.20
143 to 168 d of age	14.2	4.9	5.4	0.84	0.52	0.54	0.21
168 to 188 d of age	14.5	5.1	5.0	0.74	0.47	0.48	0.18

^a In duplicate. ^b Neutral detergent fiber. ^c Acid detergent fiber. ^d Total sulfur amino acids. ^e 2.29 Mcal/kg. ^f 2.37 Mcal/kg. ^g 2.45 Mcal/kg.

2.3. Growth performance

Individual BW and feed consumption per pen were recorded at 72, 90, 126, 143, 168, and 188 d of age (0, 18, 54, 71, 96, and 116 d of experiment). All controls were performed at the time of feed change. The growth performance controls conducted at 90 and 143 d of age coincided also with the injection of the 1st or 2nd dose of the vaccine. Pigs that died or were withdrawn from the experiment were weighed. From these data, ADFI, ADG, FCR, NE intake (g feed intake per day x Mcal NE/kg diet) and NE efficiency (Mcal NE intake per day/kg ADG) were calculated per replicate by period and cumulatively. All pigs were slaughtered at the same age (117 d of experiment and 189 d of age as an average).

2.4. Carcass and meat quality traits

The day before slaughter, pigs were weighed, fasted for 15 h and transported 300 km to a commercial abattoir (Incarlopsa, Cuenca, Spain) where they were allowed to rest for 4 h with full access to water but not to feed. Pigs were stunned in a 90% CO₂ atmosphere and then slaughtered, exsanguinated and scalded at 65°C according to standard commercial procedures. Lean percentage, BF depth and the weight and yield of fresh hams of four carcasses per pen chosen at random, were measured using the Autofom classification system (Carometec Spain, SL., Barcelona, Spain) as described by Busk et al. (1999). Then, carcasses were eviscerated and split down the center of the vertebral column. Hot carcasses weights were individually recorded and used to calculate carcass yield. Carcasses were suspended in the air and refrigerated at 2°C (1 m/s; 90% relative humidity) for 2 h. At 2 h *post-mortem*, the subcutaneous BF depth between the 3rd and 4th last ribs, including the skin, was measured at the thinnest point in the left side of each

carcass using a flexible ruler with a precision of 0.5 mm. In addition, pH values of the *Longissimus lumborum* muscle (LL) were measured at 24 h *post-mortem* using a pH meter (Model K21, NWK-Thien, Landsberg, Germany) equipped with a glass electrode. Before measurements, the instrument was calibrated with pH 7.00 ± 0.02 and 4.00 ± 0.02 buffers. Incisions were made through the skin and the subcutaneous fat and the pH probe was inserted into the selected points as described by Stalder et al. (1998). Carcasses were fabricated according to the simplified European Community reference method (Branscheid et al., 1990). Hams were kept in the chilled room at 4°C for 24 h and the weights of the untrimmed hams and loins were recorded (chilled weight). Then, hams were trimmed of external fat and weighed again (trimmed weight). The trimming consisted of eliminating part of the external fat and skin to fit commercial requirements and was performed by qualified personnel as described by Serrano et al. (2009b). Data on ham and loin weights were used to calculate chilled and trimmed ham yield and chilled loin yield. Because of the design of the processing line of the slaughterhouse and the method of carcass dissection, shoulder weights could not be recorded.

After collection of carcass data, a 300 g sample of LL was excised at the 3rd last lumbar vertebra from two pigs randomly chosen from the four pigs from each pen used for carcasses quality measurements. The meat samples were stored in individual plastic bags and vacuum packaged at -20°C for two d until subsequent meat analyses. Samples of LL were thawed inside the vacuum-packaged bags for 24 h at 4°C. Prior to analyses, the samples were removed from the packages and blotted dry for 20 min. The IMF, protein and moisture contents of the LL were determined with a near-infrared reflectance meat analyzer (Foss 6500

Spectrophotometer; Foss Analytical, Barcelona, Spain) between 400 and 2,200 nm and with the fiber-optic probe measuring these variables over an area of 0.50 cm². The samples were trimmed free of subcutaneous fat and connective tissue, minced and distributed into cup rings equipped with a plate (140 mm diameter and 15 mm deep). The monochromator contained a 50 W tungsten lamp and a diffraction grating that created monochromatic light.

2.5. Statistical analyses

All data were analyzed as a completely randomized design with NE content of the diet and sex and its interaction as main effects, by using the General Linear Model procedure of SAS (1990). Treatment sums of squares for NE content of the diets were partitioned into linear (L) and quadratic (Q) effects. When the effect of sex was significant, the Tukey test was used to separate treatment means. In addition, the Pearson correlation coefficient (*r*) of BF depth of the carcasses as measured directly with a ruler or estimated by Autofom was calculated. The experimental unit was the pen for growth performance traits and the individual pig for carcass and meat quality traits. Therefore, there were three experimental units for growth performance traits (12 pigs per pen replicate), 12 experimental units for carcass quality traits (four pigs chosen at random from each pen) and six experimental units for meat quality traits (two pigs chosen at random from each pen).

3. RESULTS

3.1. Growth performance

The determined nutrient content of all diets of the five experimental periods was close to expected values, indicating that the feeds were mixed correctly (Tables 6 and 7). Mortality and pigs withdrawn from the experiment was 2.2% and was not related to treatment (data not shown). From 143 to 168 d of age, pigs consumed less feed and had lower ADG than in the previous feeding period. This experimental period coincided with hot weather conditions with ambient temperatures inside the barn that occasionally reached 36°C.

NE content of the diet. For the entire experimental period, NE intake (L, $P < 0.05$) and ADG (L, $P < 0.05$) increased and FCR (L, $P < 0.001$) decreased as the NE content of the diet increased but no differences were observed for ADFI and NE efficiency (Table 8). From 72 to 143 d of age, a period between the start of the experiment and the second Improvac injection, ADFI decreased (L, $P < 0.05$) and FCR improved (L, $P < 0.001$) as the NE content of the diet increased but ADG, NE intake and NE efficiency were not affected. From 143 to 168 d of age (after second Improvac injection), ADG increased and FCR improved (L, $P < 0.05$) as the NE content of the diet increased but NE intake and NE efficiency were not affected. From 168 to 188 d of age, ADFI (L, $P < 0.05$) and ADG (L, $P < 0.001$; Q, $P = 0.061$) and FCR were improved (L, $P < 0.05$; Q, $P < 0.05$) as the NE content of the diet increased.

Table 8a Effect of net energy (NE) content of the diet and sex on productive performance from 72 to 188 d of age

Item	NE, Mcal/kg					Sex			r.s.d. ^b	Probability		
	2.29	2.33	2.37	2.41	2.45	Gilt	Boar	IMC ^a		Net energy		Sex
										L ^c	Q ^d	
Initial BW, kg ^e	28.5	28.4	28.5	28.5	28.4	29.9 ^x	27.7 ^y	27.8 ^y	0.1	0.230	0.694	< 0.001
Final BW, kg ^f	116.1	115.9	117.4	118.3	118.7	115.8 ^y	116.3 ^y	119.8 ^x	3.6	0.052	0.868	0.009
From 72 to 90 d of age (28.5 to 43.9 kg BW)												
ADFI, kg ^g	1.67	1.62	1.59	1.55	1.54	1.61	1.57	1.60	0.055	< 0.001	0.320	0.148
ADG, kg ^h	0.869	0.874	0.846	0.852	0.854	0.857	0.852	0.868	0.033	0.132	0.519	0.358
FCR ⁱ	1.92	1.85	1.88	1.82	1.81	1.89	1.85	1.84	0.07	< 0.001	0.786	0.103
NE intake, Mcal/d	3.83	3.77	3.78	3.74	3.78	3.82	3.73	3.78	0.13	0.383	0.371	0.144
NE efficiency, Mcal/kg ^j	4.40	4.31	4.47	4.39	4.43	4.47	4.38	4.35	0.15	0.418	0.873	0.119
From 90 to 126 d of age (43.9 to 72.3 kg BW)												
ADFI, kg	1.90	1.84	1.86	1.80	1.81	1.89	1.80	1.84	0.10	0.030	0.699	0.083
ADG, kg	0.805	0.785	0.790	0.787	0.794	0.785	0.787	0.805	0.051	0.718	0.461	0.473
FCR	2.36	2.35	2.36	2.29	2.28	2.40 ^x	2.30 ^y	2.28 ^y	0.09	0.014	0.382	< 0.001
NE intake, Mcal/d	4.35	4.30	4.41	4.34	4.42	4.46	4.27	4.35	0.23	0.451	0.731	0.089
NE efficiency, Mcal/kg	5.40	5.48	5.59	5.52	5.58	5.69 ^x	5.45 ^y	5.40 ^y	0.20	0.076	0.383	< 0.001
From 126 to 143 d of age (72.3 to 85.5 kg BW)												
ADFI, kg	2.10	2.08	2.05	2.01	2.01	2.05	2.04	2.06	0.10	0.014	0.762	0.862
ADG, kg	0.778	0.769	0.778	0.772	0.800	0.733 ^y	0.800 ^x	0.805 ^x	0.047	0.364	0.318	< 0.001
FCR	2.71	2.71	2.64	2.61	2.52	2.79 ^x	2.56 ^y	2.56 ^y	0.13	0.001	0.438	< 0.001
NE intake, Mcal/d	4.81	4.85	4.85	4.84	4.92	4.85	4.83	4.88	0.23	0.446	0.792	0.860
NE efficiency, Mcal/kg	6.21	6.31	6.25	6.29	6.18	6.62 ^x	6.05 ^y	6.07 ^y	0.31	0.814	0.401	< 0.001

^a Imunocastrated males. Pigs received the Improvac injections at 90 and 143 d of age. ^b Residual standard deviation. Nine replicates of 12 pigs each for the main effect of NE content of the diet and 15 replicates of 12 pigs each for the main effect of sex. ^c L = linear effect of NE content of the diet. ^d Q = quadratic effect of NE content of the diet. ^e 72 d of age. ^f 188 d of age. ^g Average daily feed intake. ^h Average daily gain. ⁱ Feed conversion ratio. ^j NE efficiency: Mcal NE intake/kg ADG. ^{x-y} Within a row, means without a common superscript differ ($P < 0.05$). The interactions between NE content of the diet and sex were not significant ($P > 0.10$) except for ADG and FCR from 168 to 188 d of age (see Figure 8).

Table 8b Effect of net energy (NE) content of the diet and sex on productive performance from 72 to 188 d of age

Item	NE, Mcal/kg					Sex			r.s.d. ^b	Probability		
	2.29	2.33	2.37	2.41	2.45	Gilt	Boar	IMC ^a		Net energy		Sex
										L ^c	Q ^d	
From 143 to 168 d of age (85.5 to 101.9 kg BW)												
ADFI, kg ^g	2.01	2.02	1.95	1.99	1.99	1.96	1.93	2.09	0.19	0.785	0.740	0.050
ADG, kg ^h	0.626	0.650	0.662	0.687	0.674	0.632 ^y	0.665 ^{xy}	0.682 ^x	0.053	0.023	0.360	0.042
FCR ⁱ	3.23	3.12	2.97	2.91	2.96	3.12	2.91	3.08	0.29	0.020	0.268	0.129
NE intake, Mcal/d	4.60	4.71	4.63	4.81	4.88	4.65 ^{xy}	4.57 ^y	4.96 ^x	0.44	0.152	0.741	0.048
NE efficiency, Mcal/kg ^j	7.39	7.26	7.04	7.01	7.25	7.38	6.90	7.29	0.68	0.468	0.280	0.130
From 168 to 188 d of age (101.9 to 117.3 kg BW)												
ADFI, kg	2.49	2.47	2.62	2.57	2.65	2.36 ^y	2.40 ^y	2.90 ^x	0.17	0.029	0.964	< 0.001
ADG, kg	0.712	0.729	0.811	0.803	0.795	0.701 ^y	0.749 ^y	0.860 ^x	0.057	< 0.001	0.061	< 0.001
FCR	3.50	3.40	3.23	3.21	3.34	3.38 ^{xy}	3.21 ^y	3.41 ^x	0.20	0.022	0.021	0.024
NE intake, Mcal/d	5.70	5.76	6.21	6.18	6.48	5.60 ^y	5.70 ^y	6.90 ^x	0.41	< 0.001	0.998	< 0.001
NE efficiency, Mcal/kg	8.02	7.92	7.66	7.73	8.18	8.02 ^{xy}	7.62 ^y	8.07 ^x	0.48	0.782	0.023	0.028
From 72 to 188 d of age (28.5 to 117.3 kg BW)												
ADFI, kg	2.02	1.99	2.00	1.96	1.98	1.97 ^y	1.93 ^y	2.08 ^x	0.10	0.316	0.717	0.001
ADG, kg	0.756	0.758	0.773	0.776	0.779	0.741 ^y	0.766 ^y	0.798 ^x	0.029	0.046	0.791	< 0.001
FCR	2.67	2.63	2.58	2.53	2.54	2.65 ^x	2.52 ^y	2.60 ^x	0.08	< 0.001	0.332	< 0.001
NE intake, Mcal/d	4.62	4.64	4.74	4.74	4.85	4.66 ^y	4.58 ^y	4.91 ^x	0.23	0.027	0.718	< 0.001
NE efficiency, Mcal/kg	6.12	6.12	6.12	6.11	6.23	6.29 ^x	5.98 ^y	6.15 ^{xy}	0.19	0.284	0.359	< 0.001

^a Inmunocastrated males. Pigs received the Improvac injections at 90 and 143 d of age. ^b Residual standard deviation. Nine replicates of 12 pigs each for the main effect of NE content of the diet and 15 replicates of 12 pigs each for the main effect of sex. ^c L = linear effect of NE content of the diet. ^d Q = quadratic effect of NE content of the diet. ^e 72 d of age. ^f 188 d of age. ^g Average daily feed intake. ^h Average daily gain. ⁱ Feed conversion ratio. ^j NE efficiency: Mcal NE intake/kg ADG. ^{x-y} Within a row, means without a common superscript differ ($P < 0.05$). The interactions between NE content of the diet and sex were not significant ($P > 0.10$) except for ADG and FCR from 168 to 188 d of age (see Figure 8).

An interaction between NE content of the diet and sex for ADG ($P < 0.01$) and FCR ($P < 0.05$) was found in this experimental period; ADG were similar for the three sexes when pigs were fed the 2.29 Mcal/kg containing diet, but IMC had greater ADG than gilts and boars when pigs were fed diets containing 2.33 or more Mcal EN/kg (Figure 10).

Consequently, IMC fed the 2.29 Mcal NE/kg diet had poorer FCR than boars and gilts whereas no difference among sexes were detected when fed the other diets.

Figure 10 Interaction between net energy (NE) content of the diet and sex (IMC: immunocastrated male) on (A) average daily gain (ADG) and (B) on feed conversion ratio (FCR) from 168 to 188 d of age (101.9 to 117.3 kg of BW).

A)

B)

Values with different superscripts (a, b, c and d) are significantly different ($P < 0.05$). Nine replicates of 12 pigs each for the main effect of NE content of the diet and 15 replicates of 12 pigs each for the main effect of sex (residual standard deviation: 0.0573 and 0.203 for ADG and FCR, respectively)

Sex. For the entire experimental period (72 to 188 d of age), IMC had greater ADFI (2.08 vs. 1.97 and 1.93 kg; $P < 0.01$) and ADG (0.798 vs. 0.741 and 0.766 kg; $P < 0.001$) than gilts and boars, and boars had better FCR (2.52 vs. 2.65 and 2.60; $P < 0.001$) than gilts and IMC. Also, NE efficiency values were greater for boars than for gilts with IMC being intermediate (5.98, 6.29 and 6.15 Mcal NE intake/kg ADG; $P < 0.001$). From 72 to 90 d of age (before the first Improvac injection), sex did not affect any of the growth performance traits studied. From 90 to 143 d of age (between the two Improvac injections), no differences in growth performance between boars and IMC were observed, but both sexes had better FCR and NE efficiency than gilts (data not shown). For the first 25 d after second Improvac

injection (143 to 168 d of age), IMC had greater ADFI ($P = 0.050$) and ADG ($P < 0.05$) than gilts with boars being intermediate. Also, IMC had greater NE intake ($P < 0.05$) than boars with gilts being intermediate. From 168 d to slaughter at 188 d age, IMC had greater ADFI ($P < 0.001$) and ADG ($P < 0.001$) than gilts and boars. Also in this period, boars had better FCR ($P < 0.05$) and NE efficiency ($P < 0.05$) than IMC with gilts being intermediate.

3.2. Carcass and meat quality traits

No interactions between NE content of the diet and sex were detected for any of the traits studied and therefore, only main effects are presented.

NE content of the diet. Carcass yield was not affected by dietary treatment (Table 9).

Table 9a Effect of net energy (NE) content of the diet and sex on carcass quality measured indirectly by Autofom and directly, and meat quality traits on chemical composition of longissimus thoracis

Item	NE, Mcal/kg					Sex			r.s.d. ^b	Probability		
	2.29	2.33	2.37	2.41	2.45	Gilt	Boar	IMC ^a		Net energy		Sex
										L ^c	Q ^d	
Final BW, kg	119.2	118.9	120.6	118.9	120.7	118.9 ^y	118.6 ^y	121.4 ^x	4.9	0.260	0.813	0.004
Carcass												
Weight, kg	91.3	90.8	92.1	90.8	92.4	92.2 ^x	90.0 ^y	92.2 ^x	4.1	0.305	0.527	0.004
Yield, %	76.6	76.3	76.4	76.4	76.6	77.5 ^x	75.9 ^y	75.9 ^y	1.4	0.996	0.287	< 0.001
Measured by Autofom												
Carcass lean, %	57.4	56.8	57.0	55.7	56.2	57.0	56.7	56.2	2.7	0.018	0.735	0.280
Backfat depth, mm	18.2	18.6	19.2	20.2	20.3	19.7 ^x	18.4 ^y	19.7 ^x	2.9	< 0.001	0.841	0.022
Chilled ham												
Weight, kg	13.9	13.9	14.0	13.8	14.0	14.0 ^x	13.7 ^y	13.9 ^x	0.5	0.612	0.656	< 0.001
Yield, %	15.2	15.3	15.2	15.2	15.1	15.2	15.2	15.1	0.7	0.530	0.777	0.648
Measured directly												
Backfat depth, mm	21.2	22.2	22.5	22.9	22.9	22.7 ^{xy}	21.2 ^y	23.3 ^x	3.6	0.050	0.443	0.008
pH at 24 h ^e	5.54	5.51	5.51	5.48	5.55	5.44 ^y	5.51 ^{xy}	5.60 ^x	0.16	0.796	0.239	0.002

^a Inmunocastrated males. Pigs received the Improvac injections at 90 and 143 d of age. ^b Residual standard deviation. The experimental unit was the pig. Thirty six replicates for carcass quality and 18 replicates for chemical composition of *longissimus lumborum* for the main effects of NE content of the diet and 60 replicates for carcass quality and 30 replicates for chemical composition of *longissimus lumborum* for the main effect of sex. ^c L = linear effect of NE content of the diet. ^d Q = quadratic effect of NE content of the diet. ^e Measured at *longissimus lumborum*. ^{x-z} Within a row, means without a common superscript differ (P < 0.05). All the interactions between NE content of the diet and sex were not significant (P > 0.10).

Table 9b Effect of net energy (NE) content of the diet and sex on carcass quality measured indirectly by Autofom and directly, and meat quality traits on chemical composition of longissimus thoracis

Item	NE, Mcal/kg					Sex			r.s.d. ^b	Probability		
	2.29	2.33	2.37	2.41	2.45	Gilt	Boar	IMC ^a		Net energy		Sex
										L ^c	Q ^d	
Chilled ham												
Weight, kg	13.4	13.4	13.5	13.2	13.2	13.6 ^x	13.1 ^y	13.4 ^{xy}	0.7	0.105	0.518	0.002
Yield, %	14.7	14.7	14.7	14.5	14.3	14.7	14.6	14.5	0.3	< 0.001	0.054	0.075
Trimmed ham												
Weight, kg	12.6	12.7	12.7	12.4	12.5	12.7 ^x	12.4 ^y	12.6 ^{xy}	0.6	0.238	0.681	0.008
Yield, %	13.8	13.9	13.8	13.7	13.6	13.8	13.8	13.7	0.4	0.004	0.129	0.383
Loin												
Weight, kg	5.77	5.68	5.81	5.66	5.78	5.95 ^x	5.53 ^z	5.73 ^y	0.43	0.971	0.603	< 0.001
Yield, %	6.32	6.25	6.31	6.20	6.27	6.45 ^x	6.13 ^y	6.22 ^y	0.38	0.494	0.654	< 0.001
Meat composition ^f , %												
IMF ^g	3.14	3.43	3.60	3.23	3.44	3.26	3.28	3.55	0.55	0.372	0.157	0.090
Protein	21.35	21.42	21.11	21.35	21.14	21.72 ^x	21.12 ^y	20.98 ^y	0.51	0.231	0.983	< 0.001
Moisture	73.78	73.49	73.65	73.64	73.76	73.37 ^y	73.55 ^x	73.67 ^{xy}	0.66	0.833	0.283	0.020

^a Inmunocastrated males. Pigs received the Improvac injections at 90 and 143 d of age. ^b Residual standard deviation. The experimental unit was the pig. Thirty six replicates for carcass quality and 18 replicates for chemical composition of *longissimus lumborum* for the main effects of NE content of the diet and 60 replicates for carcass quality and 30 replicates for chemical composition of *longissimus lumborum* for the main effect of sex. ^c L = linear effect of NE content of the diet. ^d Q = quadratic effect of NE content of the diet. ^e Measured at *longissimus lumborum*. ^f Measured by NIR. ^g Intramuscular fat. ^{x-z} Within a row, means without a common superscript differ (P < 0.05). All the interactions between NE content of the diet and sex were not significant (P > 0.10).

Percentage of lean in the carcass decreased (L, $P < 0.05$) and BF depth increased (L, $P < 0.001$), as measured indirectly by Autofom, with increases in NE content of the diet. However, no differences were observed for fresh ham yield. Backfat depth measured with a ruler, increased as the NE content of the diet increased (L, $P = 0.05$). The correlation between BF depth measured with Autofom and with a flexible ruler was significant ($r = 0.58$; $P < 0.001$; data not shown). Also, chilled ham yield (L, $P < 0.001$; Q, $P = 0.054$) and trimmed ham yields (L, $P < 0.01$) decreased with increases in NE content of the diet, but loin yield was not affected. Intramuscular fat and protein content of LL were not affected by NE content of the diet.

Sex. Carcass yield was greater for gilts than for boars and IMC ($P < 0.001$). As measured with Autofom, carcasses from gilts and IMC had more BF depth than carcasses from boars ($P < 0.05$). Fresh ham estimated by Autofom, was heavier for gilts and IMC than for boars ($P < 0.001$). Backfat depth measured with a ruler was greater from IMC than from boars with gilts being intermediate ($P < 0.01$). Also, pH values of LL at 24 h *post-mortem* were greater for IMC than for gilts with boars being intermediate ($P < 0.01$). Chilled and trimmed hams were heavier for gilts than for boars, with IMC being intermediate ($P < 0.01$). Loin yield was greater for gilts than for boars or IMC ($P < 0.001$). Protein content of LL was greater for gilts than for boars and IMC ($P < 0.001$) and IMF tended to be greater for IMC than for gilts and boars ($P = 0.091$).

4. DISCUSSION

4.1. Growth performance

NE content of the diet. For the entire experimental period, ADFI was not affected by energy content of the diet and consequently, energy intake increased as the energy density of the diet increased. Beaulieu et al. (2009) reported that ADFI decreased but energy intake increased as the DE content of the diet increased from 3.09 to 3.57 Mcal/kg. In contrast, Smith et al. (1999) did not observe any difference in energy intake in pigs from 29 to 107 kg BW fed diets varying in ME from 3.31 to 3.57 Mcal/kg. The reasons for the discrepancies among authors are not evident. Pigs consume feed primarily to satisfy their energy requirements and therefore, energy content of the diet is the main factor determining voluntary feed intake. Consequently, when the energy content of the diet increases, feed intake should be reduced proportionally (Chiba et al., 1991; Quiniou and Noblet, 2012). In the current experiment, feed intake was reduced as the NE content of the diet increased during the first stages of growth (72 to 143 d of age), resulting in similar energy intakes. However, during the last part of the fattening period (143 to 188 d of age), an increase in NE content of the diet resulted in an increase in energy intake. The reasons for the differences in voluntary feed intake of the pigs observed in these two periods are not known. Because of limited capacity of the gastrointestinal tract (GIT), young pigs from lean lines, such as those used in the current experiment, might not be able to consume enough feed when fed low energy diets. The capacity of the GIT however, increases with age and therefore, lean pigs might be able to over consume feed at older ages. Consequently, leaner pigs might eat less when fed low energy diets (that are also high in crude fiber content), a situation which

could have been accentuated in the current research because of the high temperatures that occurred during summer. The data suggest that under hot weather conditions fattening pigs might consume more energy and grow faster when fed high NE diets than when fed low NE diets a difference that could be more accentuated when lean pigs are used.

For the entire experimental period, ADG increased as the energy content of the diet increased, which was consistent with the greater energy intake of the pigs and in agreement with data of De la Llata et al. (2001). In contrast, Coca et al. (2012) observed that an increase in NE content of the diet did not affect ADG. The experiment of Coca et al. (2012) was conducted under moderate weather conditions with average monthly temperatures below 20°C whereas in the current research most of the fattening took place under hot weather conditions. Also, the NE content of the diets varied from 2.29 to 2.45 Mcal/kg whereas in the experiment of Coca et al. (2012) ranged from 2.35 to 2.50 Mcal/kg. It should be noticed that the improvement in ADG observed with increases in energy content of the diet in the current experiment was more pronounced when the NE was increased from 2.29 to 2.37 Mcal/kg than when it was increased from 2.37 to 2.45 Mcal/kg. This observation suggests that the response of pigs to increases in NE content of the diet might be greater when fed low than when fed high energy diets.

For the entire experimental period, FCR ratio was improved as the NE content of the diet increased, but NE efficiency was not affected. In contrast, Beaulieu et al. (2009) with diets varying from 3.09 to 3.57 Mcal DE/kg and Smith et al. (1999) with diets varying from 3.31 to 3.57 Mcal ME/kg reported that FCR and NE efficiency improved as the energy content of the diet increased. The reasons for

the discrepancies among authors are not apparent but might be related to the system used to express the energy content of the diets. An increase in energy content is generally attained by increasing the amount of supplemental fat and therefore, when diets are formulated on DE or ME bases rather than on NE bases, the real contribution of fat to the energy content of the diets is underestimated (Noblet and Van Milgen, 2004). Consequently, an increase in energy content of the diet should have less effect on feed efficiency when the NE system is used than when the DE or ME systems are used.

Sex. The information available comparing the response of gilts, boars and IMC to diets varying in NE content is very limited. From the beginning of the experiment to the second Improvac injection (72 to 143 d of age), no differences in growth performance between boars and IMC were detected, a finding that was expected because IMC behave as boars during this period (Fàbrega et al., 2010; Morales et al., 2010). From 143 to 188 d of age, when testes function was efficiently inhibited by the second Improvac injection, IMC had greater ADFI and ADG than boars, in agreement with most published research (Pauly et al., 2009; Morales et al., 2010). For the entire experimental period, IMC had greater ADFI and ADG than gilts and boars, in agreement with data of Fàbrega et al. (2010) in pigs slaughtered at 120 kg BW.

4.2. Carcass and meat quality traits

NE content of the diet. Energy content of the diet did not affect carcass yield, in agreement with data of Smith et al. (1999) and Hinson et al. (2011). In contrast, Beaulieu et al. (2009) reported greater carcass yield in pigs fed a diet with 3.57 Mcal DE/kg than in pigs fed a diet with 3.09 Mcal DE/kg. Dietary fiber increases as the

NE content of the diet is reduced. An increase in fiber intake increases the weight of the GIT which in turn might result in lower carcass yield. In the current research, the NDF of the diets varied from 14.7 to 13.3%, a difference that was probably too small to affect the development and weight of the GIT. The proportion of carcass lean content decreased as the energy content of the diet increased, in agreement with most published research (Bee et al., 2002; Beaulieu et al., 2009) and consistent with the increase in energy intake and BF depth observed. However, Matthews et al. (2003) did not detect any effect on this trait when the ME content of the diet increased from 3.22 to 3.42 Mcal/kg. The authors do not have any explanation for the differences reported in these researches. An increase in NE content of the diet increased BF depth of the carcass, in agreement with most published research (Bee et al., 2002; Beaulieu et al., 2009; Hinson et al., 2011). However, Apple et al. (2004) reported no effects on BF depth of pigs fed diets varying in ME content from 3.30 to 3.48 Mcal/kg. In the research of Apple et al. (2004) diets were supplemented with ractopamine, an additive that alters fat deposition pattern by reducing lipogenesis in adipose tissue and increase protein retention in muscle tissue, which in turn might result in a reduction in carcass fat in pigs fed the high energy diets.

The information available on the effects of energy content of the diet on the proportion of primal cuts of the carcass is scarce. In the current study, an increase in dietary energy reduced chilled and trimmed ham yields, an observation that was consistent with the greater fat and lower lean content of the carcasses. Suárez-Belloch et al. (2013) compared diets varying in NE content from 2.28 to 2.42 Mcal/kg during the finishing period and observed that the percentage of ham and loin decreased as the NE of the diet increased, in agreement with the results reported

herein. In contrast, Apple et al. (2004) reported that ham weight increased as the ME content of the diet increased from 3.30 to 3.48 Mcal/kg. The reasons for the discrepancies are not known but in the study of Apple et al. (2004) ractopamine was included in the fattening diets whereas no additives that could affect lean to fat ratio were used in the current experiment.

Sex. Carcass yield was similar for boars and IMC and lower for both than for gilts, in agreement with data of Pauly et al. (2009) and Morales et al. (2010). Gispert et al. (2010), however, reported that carcass yield was greater for gilts than for boars and greater for both than for IMC. The reasons for the discrepancies in respect to carcass yield of boars and IMC between the two experiments are unknown but may be due to differences in management as well as feed intake and final BW of the pigs. Gispert et al. (2010) reported that from the second Improvac injection to slaughter IMC ate more feed than boars resulting in heavier final weight. These authors suggested that the increase in voluntary feed intake observed in the IMC might have resulted in an increase in gut content and consequently, in lower carcass yield. Moreover, Boler et al. (2014) reported that intact males had less gut fill and less transport shrinkage than IMC, an observation which might help to explain the difference in carcass yield reported. Backfat depth was lower for boars than for gilts and IMC, in agreement with data of Morales et al. (2010). Ham yields were not affected by sex, in agreement with data of Gispert et al. (2010).

5. CONCLUSIONS

In summary, gilts, boars and immunocastrated males responded similarly, with respect to growth performance and carcass and meat quality traits, to increases in NE density of the diet. An increase in energy concentration improved ADG, feed

efficiency, and energy intake, and increased BF. Most of the benefits on ADG with an increase in the energy content of the diet were observed when the NE was increased from 2.33 to 2.37 Mcal/kg and in fact, no differences were reported between the 2.41 and 2.45 Mcal NE/kg diets. Active immunization against GnRF provides an alternative to surgical castration of boars when cumulative growth performance and carcass and meat quality traits are considered.

6. ACKNOWLEDGMENTS

The authors wish to acknowledge financial support from the Ministerio de Ciencia e Innovación (CDTI-Prodeco Project No. IDI-20090376, 28027 Madrid, Spain). Additional support for L. Cámara was provided by a PICATA fellowship (Moncloa Campus of International Excellence, UCM-UPM, 28040 Madrid, Spain). The authors thank E. Alcázar (SAT Vallehermoso S.A, 13248 Ciudad Real, Spain) for his help in the controls of the animals and J. Redondo, L. Calvo, and A. Rodríguez (Incarlopsa, 16400 Cuenca, Spain) for the help in the evaluation of carcasses and meat quality traits.

CHAPTER 4:

**GROWTH PERFORMANCE AND CARCASS
QUALITY OF CROSSBREDS PIGS FROM TWO
PIETRAIN SIRE LINES FED ISOPROTEIC
DIETS VARYING IN ENERGY
CONCENTRATION**

1. INTRODUCTION

One of the main objectives of the pork industry in Spain is to increase lean gain of the pigs while maintaining adequate levels of BF and IMF in the carcass. Factors such as the genetic background of the pigs, dietary NE, and NE to crude protein (CP) ratio of the diet, affect growth performance and carcass and meat quality (Quiniou et al., 1999; Latorre et al., 2003a). However, an increase in the NE content of the diet often results in greater energy intake and fatter carcasses (Cámara et al., 2014). On the other hand, high CP diets are often used to increase the safety margins of indispensable AA resulting in increases in N excretion and the emission of gas to the environment (Møller et al., 2004; Dinuccio et al., 2008) which reduces the interest of this practice (Cerisuelo et al., 2012). The use of crystalline AA allows to reduce the CP content of the diets while maintaining growth performance (Kerr et al., 2003). However, fatter carcasses are often observed in pigs fed low protein diets, in spite of the supplementation with extra amounts of supplemental AA (Kerr et al., 1995).

Because of the low susceptibility to stress, heterozygous halothane negative (Nn) fattening pigs are preferred to homozygous stress susceptible pigs in most European countries. The presence of one n-allele at the HAL locus in these pigs increases lean meat content and improves carcass conformation. However, the presence of the n-allele at the HAL locus often reduces lean tissue quality (Van Oeckel et al., 2001).

Most published reports observed a decrease in ADFI and an improvement in feed efficiency with increases in the energy content of the diet (Quiniou and Noblet, 2012; Serrano et al., 2013). However, the potential benefits of this practice on ADG

of growing-fattening pigs, is a subject of debate. In this respect, Cámara et al. (2014) reported a linear increase in ADG of the pigs as the energy content of the diet increased. In contrast, Cerisuelo et al. (2012) reported similar ADFI and ADG with an increase in the DE content of the diet from 14.0 to 14.4 MJ DE/kg.

The information available on the influence of NE concentration of the diet on carcass and meat quality traits of pigs is unclear. Paiano et al. (2008) and Cámara et al. (2014) reported that an increase in NE concentration of the diet increased carcass fat deposition in pigs slaughtered at 120.0 kg BW. In contrast, Kerr et al. (2003) and Apple et al. (2004) reported no effects on carcass or meat quality traits in pigs slaughtered at 110 kg BW and 106 kg BW, respectively. The purpose of this research was to investigate the influence of NE concentration of diets with similar CP content and indispensable AA to NE ratio, on growth performance and carcass and meat quality traits of crossbred pigs from two Pietrain terminal sire lines slaughtered at 160 d of age.

2. MATERIAL AND METHODS

2.1. Pig husbandry and diets

All the experimental procedures used in this study were approved by the Animal Ethics Committee of the Universidad Politécnica de Madrid and were in compliance with the Spanish guidelines for the care and use of animals in research (Boletín Oficial del Estado, 2007). In total, 480 crossbred pigs (67 ± 2.8 d of age and 25.6 ± 2.9 kg BW), resulting from the mating of Landrace x Large White females with PIC L62 (NN, homozygous halothane negative Pietrain; PIC España, Barcelona, Spain) or German Pietrain (Nn, heterozygous negative halothane;

UPB España S. A., Barcelona, Spain) sires were used. At 67 d of age, pigs were tagged and placed in groups of 10, according to genetic background, in 48 pens (2.48 m x 4.13 m) provided with 80% slatted floors in a naturally ventilated finishing barn. The average temperature inside the barn varied from $21 \pm 1.4^{\circ}\text{C}$ at the start of the experiment (November) to $18 \pm 1.8^{\circ}\text{C}$ in the last month (January). Each pen was provided with a hopper feeder and two bowl drinkers. Pigs had free access to feed in pellet form and clean water throughout the experiment. From 67 to 95 d of age (25.6 to 48.0 kg BW as an average), pigs were managed according to standard commercial practices and fed a common diet based on barley, wheat and soybean meal that contained 10.3 MJ NE/kg and 1.07% digestible lysine. At 95 d of age, pigs were weighed individually and allotted at random, within each genetic background, to their corresponding experimental diet. Treatments consisted in four diets that differed in the NE content. Because of differences in growth rate between the two sire lines, the average BW of the pigs at the start of the experiment (95 d of age) was higher (49.7 vs. 46.3 kg BW) for the PIC L62 crossbreds than for the German Pietrain crossbreds. The feeding program consisted of two periods with a growing diet supplied from 95 to 133 d of age and a fattening diet supplied from 133 d to the end of the experiment (160 d of age). All diets were based on cereals, rapeseed meal, and soybean meal. Within each of the two feeding periods, the NE content of the diets varied according to treatment (9.8, 10.0, 10.3, and 10.5 MJ/kg). As the NE concentration of the diets increased, the level of fat inclusion increased at the expense of wheat, primarily. In order to maintain a similar level of N excretion, diets within each period had similar CP content (16% from 95 to 133 d of age and 15.4% from 133 to 160 d of age) and consequently, the inclusion level of all the indispensable crystalline AA

varied among diets. However, the AA:NE ratio (g/MJ) of all diets was maintained constant. In fact, the lysine to NE ratio was 1.04 in the diets fed from 95 to 133 d of age (48 to 81.3 kg BW) and 0.97 in those fed from 133 to 160 d of age (81.3 to 103.8 kg BW). All the other indispensable AA were formulated according to the ideal protein concept (Fundación Española Desarrollo Nutrición Animal, 2013). The CP to NE ratio (g/MJ) of the diets fed from 95 to 133 d and from 133 to 160 d of age decreased from 16.3 to 15.7 for the diets with the lowest NE content and from 15.2 and 14.7 for the diets with the highest NE content, respectively. All diets met or exceeded the nutrient requirements of the pigs as recommended by Fundación Española Desarrollo Nutrición Animal (2013).

2.2. Chemical analyses of the diets

Diets were analyzed for moisture (method 930.15), CP (method 990.03), total ash (method 942.05), and starch (method 996.11) according to the procedures of the AOAC International (2000). Ether extract was analyzed after 3 *N* HCl acid hydrolysis (method Am 5-04) as described by AOCS (2004), using an Ankom XT10 Extraction system (Ankom Technology Corp., Macedon, NY). All the analyses were performed in duplicate. The ingredient composition, the estimated (Fundación Española Desarrollo Nutrición Animal, 2010) and determined nutrient content of the diets are shown in Table 10.

Table 10 Ingredient composition and calculated and determined chemical analyses of the diets (% as-fed basis, unless otherwise indicated).

Net energy, MJ/kg	48 to 81 kg BW				81 to 104 kg BW			
	9.8	10.0	10.3	10.5	9.8	10.0	10.3	10.5
Ingredient								
Barley	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Rye	12.0	12.0	12.0	12.0	15.0	15.0	15.0	15.0
Wheat	33.5	32.2	31.0	29.7	31.7	30.4	29.0	27.7
Rapeseed meal, 34% CP	6.0	6.0	6.0	6.0	8.0	8.0	8.0	8.0
Soybean meal, 47% CP	13.2	13.4	13.6	13.8	10.5	10.7	11.0	11.3
Animal fat	2.2	3.2	4.2	5.2	2.2	3.2	4.2	5.2
L-lysine, 50%	0.5	0.6	0.6	0.6	0.5	0.5	0.5	0.6
DL-Methionine, 99%	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
L-Threonine, 99%	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1
Sodium chloride	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Calcium carbonate	1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.0
Monocalcium phosphate	0.1	0.1	0.1	0.1	-	-	-	-
Formic acid, 75%	0.2	0.2	0.2	0.2	-	-	-	-
Vitamin and mineral premix ^a	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Calculated chemical								
Net energy, MJ/kg	9.8	10.0	10.3	10.5	9.8	10.0	10.3	10.5
Lysine	1.0	1.0	1.0	1.0	0.9	0.9	0.9	1.0
Lysine:NE, g/MJ	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9
Threonine	0.6	0.6	0.6	0.7	0.6	0.6	0.6	0.6
Neutral detergent fiber	13.4	13.2	13.1	13.0	13.9	13.8	13.6	13.5
Calcium	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Digestible phosphorus	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
Determined analyses								
Moisture	9.9	9.7	9.7	9.4	10.2	9.6	9.9	9.9
Starch	45.1	42.6	43.4	41.2	42.6	41.5	40.5	39.5
Ether extract	3.9	4.9	5.8	7.1	4.1	5.0	5.8	6.9
Crude protein	15.9	16.0	15.9	16.2	15.6	15.5	15.5	15.2
Ash	4.6	4.2	4.3	4.4	4.3	4.3	4.3	4.3

^a Supplied per kilogram of diet: 7,000 IU vitamin A (trans-retinyl acetate); 1,600 IU vitamin D₃ (cholecalciferol); 20 IU vitamin E (all-rac-tocopherol-acetate); 1.0 mg vitamin K₃ (bisulphate menadione complex); 0.7 mg thiamine (thiamine-mononitrate); 3.0 mg riboflavin; 9 mg of pantothenic acid (D-Ca pantothenate); 15 mg vitamin B₃ (niacin); 150 mg choline (choline chloride); 1 mg pyridoxine (pyridoxine HCl); 0.016 mg vitamin B₁₂ (cobalamin); 16.5 copper (CuSO₄·5H₂O); 75 mg iron (FeSO₄·7H₂O); 40 mg manganese (MnO₂); 110 mg zinc (ZnO); 0.3 mg selenium Se (Na₂SeO₃); 0.8 mg iodine [Ca(IO₃)₂], Natuphos 5,000, 500 FTU [6-phytase (EC 3.1.3.26) BASF Espanola S.A, Tarragona, Spain] and 125 mg ethoxiquin. ^b According to FEDNA (2010).

2.3. Growth performance

Individual BW of the pigs and feed disappearance per pen were recorded by phase and for the entire experimental period. All pigs that died or were withdrawn from the experiment were weighed and the data used to calculate ADG, ADFI and FCR per pen by period and cumulative. In addition, NE intake per day, estimated by multiplying the ADFI by the calculated NE content of the diets, and NE efficiency, expressed as MJ NE/kg ADG, were also calculated.

2.4. Carcass and meat quality traits

All pigs were slaughtered at the same age (160 d) and therefore, the final BW of the animals varied among treatments. The day before slaughter, pigs were individually weighed (average of 103.8 kg BW), fasted for 10 h and transported to a commercial slaughterhouse (Frivall, Cuenca, Spain) located 330 km away from the experimental farm. At arrival to the slaughterhouse, pigs were allowed a 9 h rest period with free access to water but not to feed. Then, the pigs were stunned in an 80% CO₂ atmosphere for 60 s, slaughtered, exsanguinated and eviscerated. As an average, pigs were slaughtered 23 h after being weighed at the farm. Fat depth of hams and loins, lean content of the carcasses, hams, bacon, shoulders, and loins, were measured using the Autofom Classification System (Carometec Spain, S.L., Barcelona, Spain) as described by Busk et al. (1999). Hot carcass weights were individually recorded and the data used to calculate carcass yield. Carcasses were split down the midline according to standard commercial procedures and the head was removed at the atlanto-occipital junction. Then, the carcasses were suspended in the air and refrigerated at 2°C for 17 h. At 2 h *post-mortem*, subcutaneous BF depth (between the 3rd and 4th last rib level, including

the skin) and fat thickness (at the thinnest point of the *Gluteus medius* muscle) were measured in the left side of each carcass using a flexible ruler with a precision of 0.5 mm.

Carcasses were jointed to yield fresh hams and shoulders weights according to the simplified European Community-reference method (Branscheid et al., 1990). The weights of the untrimmed ham and shoulder were recorded after chilling at 17 h *post-mortem* (chilled weight). Because of the method of carcass dissection and the design of the processing line of the slaughterhouse, loin weights could not be recorded. After collection of carcass data, 150 g samples of the LL were taken at the 3rd last lumbar vertebra from the left side of the carcasses from two pigs per pen chosen at random. The samples were placed in plastic bags and vacuum packaged at -20°C until subsequent meat analyses. The day before the analyses, the samples were thawed inside vacuum-package bags for 24 h at 4°C, removed from packages and blotted dry. Then, the IMF, CP and moisture contents of the samples were determined using a near-infrared reflectance meat analyzer (Foss 6500 Spectrophotometer; Foss Analytical, Barcelona, Spain) between 400 and 2,200 nm and with the fiber-optic probe measuring these variables over an area of 0.50 cm². The samples were trimmed free of subcutaneous fat and connective tissue, minced and distributed into cup rings equipped with a plate (140 mm diameter and 15 mm deep). The monochromator contained a 50 W tungsten lamp and diffraction grating that created monochromatic light.

2.5. Statistical analyses

All data were analyzed as a completely randomized design with eight treatments arranged as a 4 x 2 factorial. Main effects of NE content of the diet and sire line and their interactions were studied using the GLM procedure of Statistical Analysis Systems Institute (1990). For NE content of the diets, treatment sums of squares were partitioned into L and Q effects. Each treatment was replicated six times and the experimental unit was the pen with a number of pigs that depended on the trait studied: 10 animals for growth performance traits, four animals for carcass traits and two animals for all meat quality traits. Data in tables are presented as means. All differences were considered significant at $P < 0.05$ and P-values between 0.05 and 0.10 were considered a tendency.

3. RESULTS

3.1. Growth performance

No interactions between main factors were detected for any of the traits studied and therefore, only main effects are presented. Mortality and percentage of pigs withdrawn from the trial were 1.3 and 0.8%, respectively and were not related to treatment (data not presented). From 48.0 to 81.3 kg BW, ADFI decreased (L, $P < 0.001$) and FCR improved (L, $P < 0.001$) as the energy content of the diet increased, but neither ADG nor NE intake were affected. Similar results were obtained from 81.3 to 103.8 kg BW. For the entire experimental period (48.0 to 103.8 kg BW as an average), an increase in NE concentration of the diet reduced ADFI and improved FCR (L, $P < 0.001$) but ADG was not affected (Table 11).

Table 11 Effects of net energy (NE) content of the diet and sire line (SL) on growth performance of pigs from 48.0 to 103.8 kg body weight (BW).

Item	Net energy (MJ/kg)				Sire line		r.s.d. ^a	Probability		
	9.8	10.0	10.3	10.5	PIC L62	German Pietrain		Net energy		SL
								L	Q	
BW at 95 d of age, kg	47.9	48.1	48.2	47.9	49.7	46.3	1.211	0.916	0.436	< 0.001
BW at 133 d of age, kg	81.3	81.0	82.1	81.0	83.9	78.8	2.048	0.836	0.534	< 0.001
BW at 160 d of age, kg	103.4	103.2	104.3	104.1	106.7	100.7	2.807	0.340	0.984	< 0.001
From 48.0 to 81.3 kg BW (95 to 133 d of age)										
ADFI ^b , kg	2.02	1.96	1.98	1.88	2.05	1.87	0.0831	0.001	0.425	< 0.001
ADG ^c ,kg	0.881	0.865	0.893	0.873	0.901	0.855	0.0437	0.828	0.849	< 0.001
FCR ^d	2.29	2.27	2.22	2.16	2.28	2.19	0.0908	< 0.001	0.508	0.001
NE intake, MJ NE/day	19.8	19.6	20.4	19.8	20.8	19.0	0.851	0.398	0.376	< 0.001
NE efficiency ^e , MJ/kg ADG	22.5	22.7	22.8	22.7	23.1	22.2	0.926	0.480	0.468	0.001
From 81.3 to 103.8 kg BW (133 to 160 d of age)										
ADFI, kg	2.27	2.17	2.17	2.06	2.23	2.10	0.104	< 0.001	0.964	< 0.001
ADG, kg	0.816	0.823	0.819	0.854	0.845	0.811	0.0497	0.103	0.341	0.021
FCR	2.80	2.65	2.65	2.42	2.65	2.61	0.161	< 0.001	0.388	0.324
NE intake, MJ NE/day	22.2	21.7	22.3	21.7	22.6	21.3	1.054	0.607	0.872	< 0.001
NE efficiency, MJ/kg ADG	27.4	26.5	27.3	25.5	26.9	26.4	1.611	0.030	0.321	0.321
From 48.0 to 103.8 kg BW (95 to 160 d of age)										
ADFI, kg	2.12	2.05	2.06	1.96	2.13	1.97	0.0758	< 0.001	0.590	< 0.001
ADG, kg	0.854	0.847	0.863	0.865	0.878	0.837	0.0380	0.299	0.692	< 0.001
FCR	2.49	2.42	2.39	2.27	2.43	2.36	0.0914	< 0.001	0.349	0.009
NE intake, MJ NE/day	20.8	20.5	21.2	20.6	21.6	19.9	0.778	0.797	0.509	< 0.001
NE efficiency, MJ/kg ADG	24.4	24.2	24.6	23.8	24.6	23.9	0.924	0.320	0.261	0.009

^a Residual standard deviation. There were 12 and 24 replicates of 10 pigs each for the main effect of NE content and sire line, respectively. ^b Average daily feed intake. ^c Average daily gain. ^d Feed conversion ratio. ^e NE efficiency: MJ NE intake/kg ADG. The interaction between NE content and sire line was not significant ($P > 0.10$).

From 48.0 to 81.3 kg BW, crossbreds from PIC L62 sires had greater ADFI ($P < 0.001$) and ADG ($P < 0.001$) but lower FCR ($P < 0.01$) than crossbreds from German Pietrain sires. Consequently, energy efficiency in this period was poorer for PIC L62 crossbreds than for German Pietrain crossbreds ($P < 0.01$). Similar results were observed from 81.3 to 103.8 kg BW, with crossbreds from PIC L62 sires showing greater feed intake ($P < 0.001$) and ADG ($P < 0.05$) than crossbreds from German Pietrain sires. However, FCR and NE efficiency were similar for both sire lines. For the entire experimental period (48.0 to 103.8 kg BW as an average), crossbreds from PIC L62 had greater ADFI ($P < 0.001$) and ADG ($P < 0.001$) than crossbreds from German Pietrain sires. However, FCR ($P < 0.01$) and NE efficiency ($P < 0.01$) were poorer for PIC L62 than for German Pietrain crossbreeds.

3.2. Carcass and meat quality traits

Net energy content of the diet had little effect on carcass and meat quality traits (Table 12). In fact, the only effect observed was for fresh shoulder yield that increased as the NE content of the diet increased (Q, $P < 0.01$).

Table 12 Effects of net energy (NE) content of the diet and sire line (SL) on carcass quality.

Item	NE (MJ/kg)				Sire line		r.s.d. ^a	Probability		
	9.8	10.0	10.3	10.5	PIC L62	German Pietrain		Net energy		SL
								L	Q	
Slaughter weight, kg	109.5	108.3	110.4	110.3	113.1	106.1	3.509	0.351	0.604	< 0.001
Carcass										
Weight, kg	81.9	81.4	83.1	82.8	84.8	79.9	2.921	0.264	0.914	< 0.001
Yield, %	74.9	75.2	75.3	75.1	75.0	75.3	0.785	0.464	0.363	0.181
Backfat, mm	23.4	23.5	23.3	24.0	23.7	23.3	1.743	0.599	0.612	0.520
<i>Gluteus medius</i> muscle, mm	21.3	21.2	21.5	22.5	23.1	20.1	2.130	0.137	0.220	< 0.001
Fresh ham										
Weight, kg	12.9	13.0	13.0	13.0	13.1	12.8	0.522	0.729	0.580	0.048
Yield, %	17.2	17.4	17.3	17.3	17.5	17.1	0.716	0.815	0.449	0.024
Fresh shoulder										
Weight, kg	7.15	7.19	7.30	7.13	7.35	7.04	0.328	0.891	0.278	0.003
Yield, %	8.68	8.80	8.87	8.65	8.66	8.83	0.202	0.902	0.007	0.005

^a Residual standard deviation. There were 12 and 24 replicates of four pigs each for the main effect of NE content of the diet and sire line, respectively. The interaction between NE content and sire line was not significant ($P > 0.10$).

Crossbreds from PIC L62 sires had greater carcass weight ($P < 0.001$) but similar carcass yield ($P > 0.10$) than crossbreds from German Pietrain sires. Fat measured at *Gluteus medius* muscle ($P < 0.001$) was greater for PIC L62 sired pigs than for German Pietrain sired pigs. Also, PIC L62 crossbreds had higher ham yield ($P < 0.05$) and lower shoulder yield ($P < 0.01$) than crossbreds from German Pietrain sires. As measured with the Autofom, German Pietrain crossbreds had greater ($P < 0.001$) lean content in the carcass and in hams, bacon, shoulders and loin than PIC L62 crossbreds. However, the cover fat in hams and loins was greater ($P < 0.001$) in PIC L62 than in German Pietrain crossbreds (Table 13). Moreover, the intramuscular fat content of the LL muscle was greater ($P < 0.05$) in PIC L62 than in German Pietrain crossbreds.

Table 13 Effects of net energy (NE) content of the diet and sire line (SL) on carcass and meat quality of the pigs.

Item	Net energy (MJ/kg)				Sire line		r.s.d. ^b	Probability		
	9.8	10.0	10.3	10.5	PIC	German		Net energy		SL
					L62	Pietrain		L	Q	
Lean, %										
Carcass ^a	59.5	59.3	59.1	59.4	57.7	60.7	1.036	0.596	0.746	< 0.001
Ham ^a	46.2	45.9	45.7	45.9	44.2	47.3	1.094	0.402	0.741	< 0.001
Bacon ^a	58.6	58.6	58.0	58.4	56.1	60.4	1.454	0.449	0.693	< 0.001
Shoulder ^a	66.4	66.3	66.0	66.2	64.7	67.5	0.899	0.531	0.680	< 0.001
Loin ^a	61.5	61.4	60.9	61.3	59.2	63.1	1.317	0.470	0.734	< 0.001
Fat, mm ^a										
Ham ^{a,c}	10.7	10.8	11.3	11.0	12.1	10.0	0.730	0.162	0.955	< 0.001
Loin ^{a,c}	14.7	14.8	15.5	15.1	16.6	13.7	1.018	0.159	0.960	< 0.001
Meat composition, % ^d										
Moisture	74.7	74.4	75.0	74.8	74.5	75.0	0.883	0.564	0.845	0.092
Intramuscular fat	2.86	2.77	2.80	3.01	3.01	2.69	0.402	0.235	0.277	0.014
Protein	20.2	20.7	20.1	20.4	20.4	20.3	0.735	0.951	0.592	0.460

^a Measured with Autofom (Carometec Spain, S.L., Barcelona, Spain). ^b Residual standard deviation. There were 12 and 24 replicates of four pigs (carcass quality traits) or two pigs (meat quality traits) each for the main effect of NE content of the diet and sire line, respectively. ^c Measured between the third and fourth ribs. ^d Measured at *longissimus lumborum muscle*. The interaction between NE content and sire line was not significant ($P > 0.10$).

4. DISCUSSION

4.1. Growth performance

The benefits of an increase in the energy concentration of the diet on reducing ADFI and improving FCR are well documented (Quiniou and Noblet, 2012; Suárez-Belloch et al., 2013), and in agreement with the results of the current research. Pigs eat primarily to satisfy their energy requirements and therefore, energy concentration of the diet is the main factor determining voluntary feed intake (Noblet and van Milgen, 2004). Consequently, when diets with similar indispensable AA to NE ratio are fed to fattening pigs, an increase in NE concentration of the diet should result in a reduction in ADFI and an improvement in feed efficiency. In this respect, Quiniou and Noblet (2012) compared diets varying in NE concentration from 8.1 to 11.1 MJ NE (an increase of 37.0%) in pigs slaughtered at 109 kg BW and reported a reduction of 16.5% in ADFI, and an improvement of 31.2% in FCR and of 10.1% in ADG. Similarly, Serrano et al. (2013) reported in Iberian pigs, a 2.1% decrease in ADFI and an improvement of 3.6% in FCR when the NE content of the diet increased from 8.6 to 9.7 MJ/kg from 30 to 81 kg BW, 9.1 to 10.2 MJ/kg from 81 to 112 kg BW, with a common diet with 10.5 MJ/kg fed from 112 kg to 148 kg BW. In the current research, the increase in the NE content of the diet was of only 7.1% and the energy intake was not affected by the energy concentration of the diet, in agreement with data of Quiniou and Noble (2012) and Saraiva et al. (2014). However, Hinson et al. (2011) reported an increase in energy intake and an improvement in FCR as the ME content of the diet increased from 13.9 to 14.8 MJ/kg in pigs from 99.8 to 123.2 kg BW. The reason for the discrepancies among authors is not known. The NE system

estimates better than the ME or DE systems the real contribution of a diet to satisfy the energy requirements of the pigs. When diets are formulated on DE or ME values, an increase in energy concentration of the diet is generally attained by increasing the amount of fat and thus, the real energy contribution (NE vs. ME or DE) of the high energy diets is underestimated (Noblet and van Milgen, 2004). As a result, differences in energy intake and pig performance, with increases in energy concentration of the diet, can be ascribed, at least in part, to the system used to express the energy content of the diets. Consequently, fewer benefits of increases in dietary energy are expected when the diets are evaluated on NE as compared with DE or ME bases. In addition, many of the studies evaluating the effects of energy concentration of the diet on pig performance do not maintain constant the energy to indispensable AA ratio (Suárez-Belloch et al., 2013; Kerr et al., 2003). When the indispensable AA to energy content ratio of diets are not balanced, the beneficial effects of the high energy diets might disappear, because pig growth is penalized by a potential deficiency in the most limiting AA.

The beneficial effects of an increase in the energy content of the diet on ADG of the pigs are a subject of debate, with research showing benefits (Quiniou and Noblet, 2012) or no effects (Serrano et al., 2013) on this variable. In the current research, ADG was not affected by the energy concentration of the diet, in agreement with data of Permentier et al. (2013). Pigs eat to satisfy their energy requirements and consequently, energy content of the diet should not affect ADG. However, when low energy diets are used, pigs from lines selected for lean meat, characterized by a reduced feed intake capacity, might not be able to compensate with an increase in feed intake when fed low energy diets, resulting in a reduction

in energy intake both in young (Kyriazakis and Emmans, 1995) and fattening (Ferguson and Gous, 1997) pigs. Consequently, energy intake might not satisfy the energy requirement of these pigs (Beaulieu et al., 2009) resulting in lower ADG. In addition, differences in health status, age of the experimental pigs, management practices, ingredient composition and the range of dietary energy concentration used, might influence the response of pigs to increases in energy concentration of the diet (Nyachoti et al., 2004; Beaulieu et al., 2009; Cámara et al., 2014).

Crossbreds from PIC L62 sires had greater ADFI and ADG than crossbreds from German Pietrain sires. The authors have not found any report comparing growth performance of these two crossbreds, but the data reported herein are consistent with the different genetic background of the sire lines used. In this respect, Hamilton et al. (2003) showed that crossbreds from a lean Pietrain sire line had lower ADG and were less efficient than crossbreds from a less lean sire (a synthetic line comprised of Large White, Landrace, Duroc and Pietrain).

4.2. Carcass and meat quality traits

Net energy concentration of the diet did not affect carcass yield of the pigs, in agreement with data of Paiano et al. (2008) and Cámara et al. (2014). Moreover, De la Llata et al. (2001) and Matthews et al. (2003) reported similar carcass yield in 117 kg BW pigs fed diets varying in ME from 13.4 to 14.2 MJ/kg. In contrast, Smith et al. (1999) in 105 kg BW pigs fed diets varying in ME from 13.9 to 14.9 MJ/kg and Beaulieu et al. (2009) in 115 kg BW pigs fed diets varying in DE from 12.8 to 15.2 MJ/kg, reported an increase in carcass yield as the energy content of the diet increased.

Energy concentration of the diet did not affect the proportion of lean content or BF depth of the carcasses, in agreement with data of De la Llata et al. (2001) and Kerr et al. (2003) in pigs slaughtered at 120 kg BW. In contrast, Beaulieu et al. (2009) reported that BF depth increased in pigs slaughtered at 115 kg BW as the DE content of the diet increased from 12.8 to 15.1 MJ DE/kg. High energy diets contain more fat and less fiber and are more palatable than low energy diets, which may result in an increase in energy intake (Levasseur et al., 1998). Also, pigs would consume more energy than required when fed diets where the first limited resource is another nutrient, such as an indispensable amino acid. As a result, fat content of the carcass might increase with increases in energy concentration of the diet (Dunshea et al., 1998; Hinson et al., 2011). In the current experiment, however, energy concentration of the diet did not affect NE intake of the pigs and consequently, no effects of diet on BF depth or carcass lean was expected. Neither fresh ham nor fresh shoulder yields were affected by the NE concentration of the diet, consistent with data of Kerr et al. (2003) and Matthews et al. (2003) in pigs slaughtered at 117 kg BW.

The effects of energy and indispensable AA content of the diet on meat quality traits are a subject of debate. In the current study, the energy content of the diet did not affect the chemical composition of the m. LL. Cámara et al. (2014) reported also similar results for moisture, IMF, and protein content of this muscle when the NE concentration of balanced diets increased from 9.6 to 10.3 MJ/kg. Similarly, Matthews et al. (2003) reported that an increase of the energy concentration of the diet did not affect moisture or marbling score of the m. LL. Moreover, Hinson et al. (2011) did not observe any effect of the ME content of the

diet on the marbling score of this muscle. In the current experiment, pigs from all treatments had similar average NE intake and the AA to NE ratio was kept constant. Consequently, pigs consumed the same amount of energy and indispensable AA regardless of the type of diet and therefore, no differences in carcass quality traits were expected.

Crossbreds from PIC L62 had heavier and fatter carcasses but similar carcass yield than crossbreds of German Pietrain sires. Also, crossbreds from PIC L62 sires had higher proportion of fresh ham than crossbreds from German Pietrain sires. Permentier et al. (2013) reported higher proportion of lean content but similar dressing percentage in NN than in Nn halothane pigs, consistent with the results reported herein. In contrast, Van Oeckel et al. (2001) did not detect any difference in any carcass traits between NN and Nn Pietrain pigs. Also, Hamilton et al. (2003) reported that the proportion of fresh hams was higher in crossbreds from lean Pietrain sires as compared with that of a fatter (a synthetic line comprised of Large White, Landrace, Duroc and Pietrain) sire line.

5. CONCLUSIONS

A 7.1% increase in the NE concentration of the diet (from 9.8 to 10.5 MJ/kg) improved FCR by 9.1% but did not affect ADG or carcass and meat quality traits of the pigs. Consequently, increasing the NE content of the diet with the objective to improve growth performance and carcass quality of the pigs might not be justified under all circumstances. Crossbreds from PIC L62 sires have greater ADG and fatter carcasses than crossbreds from German Pietrain sires, but both crossbreds responded in similar way to increases in energy concentration of the feeds. In summary, PIC L62 sires could be a good alternative to German Pietrain sires to

produce carcasses destined to fresh pork production, a situation in which a certain amount of back fat and intramuscular fat is required. In contrast, when the objective is to increase lean meat proportion of the carcass, German Pietrain sires might be preferred.

6. ACKNOWLEDGMENTS

Financial support was provided by Ministerio de Ciencia e Innovación (CDTI-Procadeco; Project number IDI-20090376, Madrid, Spain). Additional support for L. Cámara was provided by a PICATA fellowship (Moncloa Campus of International Excellence, UCM-UPM, 28040 Madrid, Spain) and by Comunidad de Madrid (Project S2009/AGR-1704). We appreciate Alicia Álvarez of Cárnicas Frivall S. L. (Cuenca, Spain) for the help in the processing of the pigs, and to Yolanda Alegre of Universidad Politécnica de Madrid for the formal preparation of the manuscript.

CHAPTER 5:
GENERAL DISCUSSION

1. PEN UNIFORMITY

1.1. Growth performance

Pigs are commonly distributed within pens according to initial BW at weaning and at the start of the fattening period, with the objective of reducing social competition and increase growth performance and carcass uniformity at slaughter. In Exp. 1, however, pen uniformity did not affect growth performance of the pigs in any of the two periods considered, results that agree with data of O'Connell et al. (2005) who did not find any effect of pen uniformity on growth performance during the pre-fattening (9.8 to 30.2 kg BW) or the fattening (30.2 to 98.8 kg BW) periods. Similarly, Bruininx et al. (2001) reported that the distribution of pigs into pens at weaning according to BW, had limited benefits on ADG, although the more homogeneous groups had 3% better FCR than the less homogeneous groups.

1.2. Carcass traits

To our knowledge, little published work is available comparing carcass traits of pigs rearing in pens with different uniformity of BW from weaning to slaughter. In fact, the only data available in this respect, is that of O'Connell et al. (2005) who did not find any effect of BW uniformity of the pigs at four wk of age on BF of conventional white crossbreeds pigs slaughtered at 98 kg BW.

2. GENDER AND CASTRATION

2.1. Growth performance

Most published research on growth performance of pigs, compared entire males, IF, and CM (Augspurger et al., 2002; Latorre et al., 2003a,b) but little information is available comparing CF with any of these three genders. In Exp. 1, growth performance from 28 to 68 d of age was similar for CF and CM. However, in the last period of this phase (68 to 77 d of age), ADG and FCR were better for CM than for CF, a finding that was expected because gilts were castrated at 69 d of age. Consequently, the negative impact of castration on growth performance was expected to be greater for females than for males, which were castrated at 5 d of age. The data available on the effects of surgical castration of females on growth performance after surgery is very limited. Serrano et al. (2009a) reported in crossbreds of Iberian x Duroc pigs that CF tended to grow 10.2% less and to be 8.9% less efficient from 0 to 30 d after surgery than IF, a finding that is consistent with the results of the current experiment. Similar results were reported by Daza et al. (2016) comparing immunocastrated females and gilts. These authors reported that immunocastrated females grew slower and tended to have lower ADFI and higher FCR than gilts.

During the fattening period (77 to 201 d of age; 27.1 to 130.4 kg BW), CM tended to eat more but had worse FCR than CF. Ramírez and Cava (2007) reported similar ADG for CM and CF of crossbreds from Iberian dams and Duroc sires slaughtered at 159 kg BW, in agreement with the results of the current experiment. Peinado et al. (2012) compared growth performance of CM and CF crossbreds resulting from the progeny of Landrace x Large White dams and Duroc sires from

28.4 to 119.2 kg BW and reported that CM ate 3.7% more and had 1.4% poorer FCR than CF. however, the differences observed in this work did not reach significance.

Immunization allows the pig to grow as an entire male from birth to the second immunizing injection against GnRF. Following the second injection, pigs become similar to those of surgically castrated males. It is expected that any boar taint substances present in the carcass are metabolized progressively and thus, disappeared with time (Moore et al., 2017). In Exp. 2, no differences in growth performance were detected between boars and IMC from the beginning of the experiment to the second Improvac injection (72 to 143 d of age), a finding that was expected because IMC behave as boars during this period (Fàbrega et al., 2010; Morales et al., 2010; Moore et al., 2017). From 143 to 188 d of age, however, when testes function was efficiently inhibited by the second Improvac injection, IMC had higher ADFI and ADG than boars, in agreement with most published research (Pauly et al., 2009; Morales et al., 2010). For the entire experimental period, IMC had higher ADFI and ADG than gilts and boars, in agreement with data of Fàbrega et al. (2010) in pigs slaughtered at 120 kg BW. However, Daza et al. (2016) did not report any difference on growth performance between IMC and gilts slaughtered at 167 d of age with an average BW of 131.0 and 126.7 kg, respectively.

2.2. Carcass traits

In Exp. 1, carcass yield was similar for CM and CF, in agreement with data of Peinado et al. (2008) comparing CF, CM and gilts crossbreds from Pietrain x Large White sires mated to Landrace x Large White dams Peinado et al. (2012), comparing crossbreds from Landrace x Large White dams mated to Duroc sires, reported similar results. Also, similar data have been reported by Ramírez and Cava (2007) comparing CM and CF Iberian pigs. Carcass yield was similar for boars and IMC and lower for both than for gilts in Exp. 2, in agreement with data of Morales et al. (2010). Gispert et al. (2010), however, reported that carcass yield was higher for gilts than for boars and higher for both than for IMC. In contrast, Daza et al. (2016) reported no differences in carcass yield among IF and IMC. The reasons for the discrepancies in respect to carcass yield of boars and IMC between experiments are unknown but may be due to differences in ADFI and final BW of the pigs. Gispert et al. (2010) reported that from the second Improvac injection to slaughter, IMC ate more feed than boars, resulting in heavier final weight. These authors suggested that the increase in voluntary ADFI observed in the IMC might have resulted in an increase in gut content and consequently, in lower carcass yield. Backfat depth was lower for boars than for gilts and IMC, in agreement with data of Morales et al. (2010) and of Daza et al. (2016) comparing CM, IMC, IF, and immunocastrated females.

In Exp. 1, shoulder and primal cut yields were higher for CM than for CF, in agreement with data of Gispert et al. (2010) and Peinado et al. (2012). Gender did not affect shrink loss, consistent with data of Peinado et al. (2008, 2012) comparing CF, CM, and gilts in conventional white pigs slaughtered at 118.0 and 131.6 kg BW, respectively and Serrano et al. (2009b) comparing same genders in Iberian pigs

reared indoors and slaughtered at 152 kg BW. Shrink loss of carcass is inversely related to the amount of cover fat (Latorre et al., 2004). In the current research, however, carcass fat was similar for CM and CF and therefore, no differences in shrink loss were expected.

3. NET ENERGY CONTENT

3.1. Growth performance

Several studies have been conducted in recent years to investigate growth responses of pigs fed diets containing increased levels of energy. In Exp. 3, a linear decrease in ADFI and a lineal improve in FCR were observed as the NE content of the diet increased, in agreement with the results of Beaulieu et al. (2009). Pigs eat primarily to satisfy their energy requirements and therefore, energy concentration of the diet is the main factor determining voluntary feed intake (Noblet and van Milgen, 2004). Consequently, when diets with similar indispensable AA to NE ratio are fed to fattening pigs, an increase in NE concentration of the diet should result in a reduction in ADFI and an improvement in feed efficiency (Chiba et al., 1991). In this respect, Quiniou and Noblet (2012) reported a linear reduction in ADFI and a linear increases in ADG and G:F in pigs as NE concentration of the diet increased from 1.94 to 2.65 Mcal/kg. Similarly, Serrano et al. (2013) reported a decrease in ADFI and an improvement in FCR in Iberian pigs slaughter at 148 kg BW, as the NE content of the diet increased from 2.05 to 2.31 Mcal/kg from 30 to 81 kg BW, 2.18 to 2.45 Mcal/kg from 81 to 112 kg BW and then, using a common diet with 2.50 Mcal NE/kg from 112 kg BW to slaughter. However, Wu et al. (2016) did not observe any difference in ADFI, ADG, and G:F in pigs fed diets with a 94 kcal NE/kg difference in the diet. Similar results

were obtained in Exp. 2 of the current research. For the entire experimental period, ADFI was not affected by the energy content of the diet and consequently, energy intake increased as the energy density of the diet increased. Beaulieu et al. (2009) reported a decrease in ADFI, but an increase in energy intake as the DE content of the diet increased from 3.09 to 3.57 Mcal/kg. In contrast, Smith et al. (1999) did not observe any difference in energy intake in pigs from 29 to 107 kg BW fed diets varying in ME from 3.31 to 3.57 Mcal/kg. In Exp. 3, the difference in NE content of the diet was 6.4% but energy intake was not affected by the energy concentration of the diet, in agreement with data of Quiniou and Noble (2012). However, Hinson et al. (2011) reported increases in energy intake and improvements in FCR as the ME content of the diet increased from 3,317 to 3,537 kcal/kg in pigs from 99.8 to 123.2 kg BW. The reason for the discrepancies among authors is not known. The NE system estimates better than the ME or DE systems the real contribution of a diet to satisfy the energy requirements of the pigs (Noblet et al., 1994). When diets are formulated on DE or ME values, an increase in energy concentration is generally obtained by increasing the amount of fat and thus, the real energy contribution (NE vs. ME or DE) of the high energy diets is underestimated (Noblet and van Milgen, 2004). Consequently, differences in energy intake and pig performance with increases in energy concentration can be ascribed, at least in part, to the system used to express the energy content of the diets. Fewer benefits of increases in energy concentration are expected when the diets are evaluated on NE bases compared with DE or ME bases. In addition, many of the studies evaluating the effects of energy concentration of the diet on pig performance did not maintain constant the ratio between kcal of energy and indispensable AA (Kerr et al., 2003; Suárez-Belloch et al., 2013). When the diets are not balanced, the

beneficial effects of an increase in high energy might disappear, because pig growth is penalized by a potential deficiency in the most limiting indispensable AA. Also, the limited capacity of the GIT of young pigs from lean lines, such as those used in Exp. 3, might not be able to over-consume when fed low energy diets. The capacity of the GIT however, increases with age and therefore, lean pigs might be able to over-consume extra amounts of feed at older ages. Also, the genetic background of the experimental pigs might help to explain differences in the response of the animals in respect to energy intake with increases in energy content of the diet.

The beneficial effects of increasing in the energy content of the diet on BW gain of the pigs are a subject of debate, with research showing benefits (Quiniou and Noblet, 2012) or no effects (Serrano et al., 2013) on this variable. In Exp. 2 ADG increased as the energy content of the diet increased, results that are consistent with the increase in energy intake of the pigs, in agreement with data of De la Llata et al. (2001). In Exp. 3, however, ADG was not affected by the energy concentration of the diet, in agreement with data of Coca et al. (2012), Permentier et al. (2013), and Wu et al. (2016). Pigs eat to satisfy their energy requirements and consequently, energy content of the diet should not affect ADG. However, when low energy diets are used, pigs from lines selected for lean meat, characterized by a reduced capacity for feed intake, might not be able to compensate the low energy concentration of the diet and fail to maintain energy intake constant (Kyriazakis and Emmans, 1995). As a consequence, feed intake might not satisfy the energy requirement of the pigs (Beaulieu et al., 2009), resulting in a reduction in ADG. In addition, differences in health status, age of the experimental pigs, management

practices, ingredient composition, and the range of dietary energy concentration used, might influence the response of pigs to increases in energy concentration of the diet (Nyachoti et al., 2004; Beaulieu et al., 2009).

In Exp. 2 and 3, FCR ratio improved as the NE content of the diet increased, but NE efficiency was not affected. In contrast, Beaulieu et al. (2009) with diets varying from 3.09 to 3.57 Mcal DE/kg and Smith et al. (1999) with diets varying from 3.31 to 3.57 Mcal ME/kg reported that FCR and energy efficiency improved as the energy content of the diet increased. The reasons for the discrepancies among authors are not apparent but might be related to the system used to express the energy content of the diets.

3.2. Carcass traits

Energy content of the diet did not affect carcass yield in Exp. 2 or in Exp. 3, in agreement with data of Smith et al. (1999), Paiano et al. (2008), and Hinson et al. (2011). Moreover, De la Llata et al. (2001) and Matthews et al. (2003) reported similar carcass yield at 117 kg BW of pigs fed diets varying in ME from 3.20 to 3.40 Mcal/kg. In contrast, Smith et al. (1999) and Beaulieu et al. (2009) reported higher carcass yield in pigs fed a diet with 3.57 Mcal DE/kg than in pigs fed a diet with 3.09 Mcal DE/kg. Dietary fiber increases as the NE content of the diet is reduced. An increase in fiber intake improves the development and increased the size and weight of the GIT which in turn might result in lower carcass yield. In the current research, the NDF of the diets varied from 14.7% to 13.3% in Exp. 2 and from 13.4% to 13.0% in Exp. 3, a difference that was probably too small to affect the development and weight of the GIT. In Exp. 2, the lean content of the carcass decreased as the energy content of the diet increased, in agreement with most published research (Bee et

al., 2002; Beaulieu et al., 2009) and consistent with the increase in energy intake and BF depth observed. In Exp. 3, however, BF depth was not affected by energy concentration, in agreement with data of De la Llata et al. (2001) and Matthews et al. (2003) who did not detect any effect on this trait in pigs fed diets varying in ME content from 3.22 to 3.42 Mcal/kg. The authors did not give a clear explanation for the differences reported in these researches. An increase in NE content of the diet increases BF depth of the carcass, in agreement with most published research (Bee et al., 2002; Beaulieu et al., 2009; Hinson et al., 2011). High energy diets contain more fat and less fiber and are more palatable than low energy diets, which may result in an increase in energy intake (Levasseur et al., 1998). As a result, fat content of the carcass might increase with increases in energy concentration of the diet (Dunshea et al., 1998; Hinson et al., 2011). In Exp. 3, however, the energy concentration of the diet did not affect the energy intake of the pigs and consequently, no effects of diet on BF depth or carcass lean was expected. Apple et al. (2004) reported no effects on BF depth of pigs fed diets varying in ME content from 3.30 to 3.48 Mcal/kg. In the research of Apple et al. (2004), however, diets were supplemented with ractopamine, an additive that alters fat deposition pattern by reducing lipogenesis in adipose tissue and increase protein retention in muscle tissue, which in turn might result in a reduction in carcass fat in pigs fed the high energy diets.

In Exp 3. fresh ham and fresh shoulder yields were affected by the NE concentration of the diet, consistent with data of Kerr et al. (2003) and Matthews et al. (2003) in pigs slaughter at 117 kg BW. In Exp. 2, however, an increase in NE reduced chilled and trimmed ham yields, an observation that was consistent with

the higher fat and lower lean content of the carcasses. Suárez-Belloch et al. (2013) compared diets varying in NE content from 2.28 to 2.42 Mcal/kg during the finishing period and observed that the percentage of ham and loin decreased as the NE of the diet increased, in agreement with the results reported herein. In contrast, Apple et al. (2004) reported that ham weight increased as the ME content of the diet increased from 3.30 to 3.48 Mcal/kg.

The effects of the energy and indispensable AA content of the diet on meat quality traits are a subject of debate. In the current research, energy content of the diet did not affect the chemical composition of m. LT. Similarly, Matthews et al. (2003) reported no effects of the energy concentration of the diet on moisture content or marbling score of the m. LT. similarly, Hinson et al. (2011) did not observe any effect of the ME content of the diet on the marbling score of this muscle. In the experiments of this Thesis pigs had similar NE intake, and the AA to NE ratio was kept constant. Pigs consumed the same amount of energy and indispensable AA regardless of the type of diet and therefore, no differences in carcass quality traits were expected.

4. SIRE LINE

4.1. Growth performance

Crossbreds from PIC L62 sires had greater ADFI and ADG than crossbreds from German Pietrain sires. The authors have not found any report comparing growth performance of these two crossbreds but the data are consistent with differences in the genetic background of the sire lines used. In this respect, Hamilton et al. (2003) showed that crossbreds from a lean Pietrain sire line had

lower ADG and were less efficient than crossbreds from a less lean sire (a synthetic line comprised of Large White, Landrace, Duroc and Pietrain).

4.2. Carcass and meat quality traits

Crossbreds from PIC L62 had heavier and fatter carcasses but similar carcass yield than crossbreds from German Pietrain sires. Also, crossbreds from PIC L62 sires had a greater proportion of fresh ham than crossbreds from German Pietrain sires. Permentier et al. (2013) reported higher percentage of lean content but similar dressing percentage in NN and Nn halothane pigs, consistent with the results reported herein. In contrast, Van Oeckel et al. (2001) did not detect any difference in any carcass traits between NN and Nn Pietrain pigs. Also, Hamilton et al. (2003) reported that the proportion of fresh hams was higher in crossbreds from lean Pietrain sires as compared with that of fatter (a synthetic line comprised of Large White, Landrace, Duroc and Pietrain) sire lines. All this information indicate that at present time pig line might more important than “breed” in relation to growth and carcass quality of crossbred pigs.

CHAPTER 6

CONCLUSIONS

CONCLUSIONS

1. The distribution of pigs within pens, according to initial BW at weaning, did not provide any advantage on growth performance at the end of the pre-fattening period or on carcass quality traits at slaughter.
2. Surgical castration of the males and females did not affect growth performance during fattening phase.
3. Castrated females had more backfat and higher fat content at *Gluteus medius* muscle than castrated males.
4. Castration of the pigs, irrespective of gender, might be a good commercial strategy to improve carcass quality and profitability in the production of heavy pigs destined to the dry-cured industry in countries in which this practice is allowed.
5. An increase in the net energy concentration of the diet improved feed efficiency but the effect on average daily gain was not clear. More studies are needed.
6. An increase in net energy content of the diet did not affect growth performance or carcass quality in any of the genders considered.
7. Increasing the net energy content of the diet with the objective to improve growth performance and carcass quality of the pigs might not be justified under all circumstances.
8. Active immunization against GnRF provides an alternative to surgical castration of boars when cumulative data on growth performance and carcass merits and meat quality are considered.

9. Crossbreds from PIC L62 sires show greater ADG and fatter carcasses than crossbreds from German Pietrain sires, but both crossbreds types responded in similar way to increases in energy density of the diets.

CHAPTER 7:

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