Performance, Carcass and Meat Quality in Pigs

Influence of Rearing System, Breed and Feeding

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Abstract

Heyer, A. 2004. *Performance, Carcass and Meat Quality in Pigs - Influence of Rearing System, Breed and Feeding.* Doctoral dissertation.

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In this thesis, influences of conventional and organic rearing systems, breed crosses and feeding regimens on performance, carcass and technological and sensory meat quality traits in pigs were investigated.

In two studies, a seasonal outdoor rearing system was investigated. Maternal performance of once-bred gilts was studied and their carcass and meat quality was compared with maiden indoor reared gilts. In a third study, the outdoor-born progeny was raised indoors and outdoors; performance, carcass and meat quality of these growing/finishing pigs were compared. In a fourth study, indoor and outdoor rearing systems of growing/finishing pigs, born indoors, including different feeding regimens (strategic/*ad libitum*/restrictive), diets (diluted/undiluted; conventional/organic) and breed crosses (LW*L/LW*D) were investigated. In a fifth study, effects of extra maternal feed supply during early gestation on sow and progeny performance, carcass and meat quality were studied.

The studies showed that once-bred gilts were suitable for a seasonal outdoor rearing system and produced carcasses of adequate quality. LW*L once-bred gilts had more piglets at weaning, whereas LW*D progeny had higher growth rate. For the progeny, outdoor pigs had higher growth rate when fed *ad libitum* but grew slower during the second restricted phase. Technological quality was similar. In the fourth study, indoor pigs fed an organic diet grew faster than outdoor pigs. Strategic feeding increased daily weight gain, compared with an exclusively diluted diet. Extra maternal feeding increased litter size per sow, but not per gilt. A negative effect on progeny growth rate was found, whereas carcass and technological quality was unaffected. In this thesis, the results indicate that pig production parameters are not only affected by housing system (indoor/outdoor) but by the entire rearing system, including breed cross, feeding regimen, diet composition, final weight and age.

Keywords: growing/finishing pig performance, maternal nutrition, organic, piglet performance, production system, RN genotype, sow performance.

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Denn alles Fleisch es ist wie Gras und alle Herrlichkeit des Menschen wie des Grases Blume. Das Gras ist verdorret und die Blume abgefallen.

1. Petrus 1,24

Contents

Appendix

Papers I-V

The present thesis is a synthesis on the following papers, which will be referred to by their Roman numerals:

I. Heyer, A., Andersson H. K., Rydhmer, L. & Lundström, K. (2004). Carcass quality and technological and sensory meat quality of once-bred gilts in a seasonal outdoor rearing system. *Acta Agriculturae Scandinavica Section A*, 54, 103-111.

II. Heyer, A., Andersson, H. K., Leufvén, S., Rydhmer, L. & Lundström, K. The effect of breed cross on performance and meat quality of once-bred gilts in a seasonal outdoor rearing system. *Submitted for publication*.

III. Stern, S., Heyer, A., Andersson, H. K., Rydhmer, L. & Lundström, K. (2003). Production results and technological meat quality for pigs in indoor and outdoor rearing systems. *Acta Agriculturae Scandinavica Section A*, 53, 166-174.

IV. Heyer, A., Andersson, H. K. & Lundström, K. Performance, carcass and technological meat quality of growing/finishing pigs raised in organic and conventional systems. *Submitted for publication*.

V. Heyer, A., Andersson, H. K., Lindberg, J.E. & Lundström, K. (2004). Effect of extra maternal feed supply in early gestation on sow and piglet performance and production and meat quality of growing/finishing pigs. *Acta Agriculturae Scandinavica Section A*, 54, 44-55.

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List of abbreviation

AA	amino acid
ADG	average daily weight gain
BF	*m. biceps femoris*
C	control treatment
conv.	conventional
CP	crude protein
D	Duroc
DFD	dry, firm, dark
dil.	diluted
FOP	fibre optic probe
G-6-P	glucose-6-phosphate
GLM	general linear model
GLU	*m. gluteus*
H	Hampshire
HW	heavy weight group
IFOAM	International Federation of Organic Agricultural Movements
IMF	intramuscular fat
KRAV	Swedish incorporated association for developing of organic standards and promotion of organic labels
L	Landrace
l	litre
LD	*m. longissimus dorsi*
LH	luteinising hormone
LSM	least square means
LW	Large White
LW	light weight group
ME	metabolizable energy
MJ	mega joule
mmol	millimol
µmol	micromol
MW	middle weight group
org.	organic
pH_u	ultimate pH
pH_{BF}	ultimate pH value in *m. biceps femoris*
pH_{LD}	ultimate pH value in *m. longissimus dorsi*
PS	*m. psoas major*
PSE	pale, soft, exudative
RN	Rendement Napole
RN^-/rn^+	mutant of the PRKAG3 (RN) locus
rn^+/rn^+	wild type of the PRKAG3 (RN) locus
QUA	*m. quadriceps femoris*
SAS	statistical analyses system
S.D.	standard deviation

SE	standard error
SMA	*m. semimembranosus et aductor*
SLU	Sveriges Lantbruksuniversitet, Swedish University of Agricultural Sciences
ST	*m. semitendinosus*
strateg.	strategic
stdev	standard deviation
T35	treatment +35%
T70	treatment +70%
T100	treatment +100%
undil.	undiluted
WB	Warner-Bratzler shear force
WHC	Water-holding capacity

Introduction

Changes of the national and international pig market have brought new challenges for pig production. This is not only because new legislations are continuously established, but also because the consumers are becoming increasingly conscious. High expectations on production and product quality by the consumers are forwarded to the meat processing industry and thus to the pig producers. The high economic pressure of decreasing prices for pork and the expectation of maintained high product quality increase the interest for optimising the efficiency of pig production. The general objective of this thesis was to investigate productivity in different rearing systems and their influence on carcass quality and meat quality, namely technological and sensory meat quality.

Swedish pig production

In Sweden in 2003, 3.3 million pigs were slaughtered (including growing/finishing pigs, sows and others), giving 287,500 tons of pig meat, which corresponds to a self-sufficiency of 90 % (Jordbruksverket, Swedish Board of Agriculture, 2004). This was produced by about 3,000 herds, mostly situated in southern Sweden. Although the number of herds has decreased during the last decade, the number of growing/finishing pigs has been stable. Consequently, the average herd size has increased to 377 growing/finishing pigs. Most pork production occurs indoors but there are many rearing systems, differing in *e.g.* type of floor (partly slatted, plain concrete, deep litter), diet (composition), feeding system (dry/wet), feeding regimen (restrictive/*ad libitum*) and group size.

The yearly total meat consumption including processed products is about 77 kg/inhabitant (Jordbruksverket, Swedish Board of Agriculture, 2004) of which 36 kg is pork (Svensk Köttinformation, Swedish meat information, 2004). Consumption of unprocessed fresh and frozen meat in Sweden is 42.4 kg/inhabitant, of which 14.4 kg is pork (Jordbruksverket, Swedish Board of Agriculture, 2004). During the last decade, a clear trend of higher meat consumption could be noticed. This might be due to a decreased consumer price index for meat, while the total consumer price index increased continuously, but the price index for food was unchanged.

Organic pig production

In Sweden, organic pig production is only a small part of the total pork production. Compared to 204,000 sows and 3.2 million growing/finishing pigs conventionally raised in 2003, the number of organically raised sows was about 1,000 that produced 21,000 growing/finishing pigs (Jordbruksverket, Swedish Board of Agriculture, 2004). However, the promotion of higher proportion of organic production is a common EU-wide political goal. Organic production should comprise 10% of beef and lamb meat production and an undefined, but increased production of pork by 2005 (Jordbruksdepartementet, Ministry of Agriculture, Food and Consumer Affairs, 2004).

Nowadays, more consumers are concerned about animal welfare aspects and ask for organically produced meat and meat products. To meet this demand, organic labelling organisations guarantee organic production according to the international agreements by the International Federation of Organic Agricultural Movements (IFOAM) and the EU Council Regulation 2092/91. In Sweden, IFOAM has accredited KRAV as a certification organisation for organic production and products. Organic meat production in Sweden has to be in accordance with the KRAV regulations. Among other things the regulation covers generally the long-term sustainability of the production system, the non-use of synthetic pesticides and industrialised fertilisers. For pork production, specifically, the rules determine the possibility for the animals to access outdoor areas and roughage, the feeding of organically produced diets, the ban of synthetic amino acids and prophylactic antibiotics.

However, in contrast to the conventional production, organic pork production in Sweden has decreased during the last years (Jordbruksverket, Swedish Board of Agriculture, 2004), presumably because of the cold climate, uncomfortable working conditions for the producer and insufficient certitude about the final product quality. Due to increased production cost *i.e.* higher working and feed costs, organic pig meat is more expensive than conventionally produced pig meat. Thus for the consumer it might be assumed that the price of organic products is too high. Indeed, several authors reported that the higher price of organically produced meat induces the consumer to purchase conventional meat instead (Branscheid, 1998; Lücke, 1998).

In Sweden, outdoor rearing of sows is uncommon, mainly due to the climate. Therefore, a concept of seasonal outdoor rearing with slaughter of the once-bred gilt together with their progeny at the end of the season has been developed. However, the climate conditions still demand robust sows; the choice of a appropriate breed or breed cross is necessary to guarantee good maternal and piglet performance. The conventional indoor housing system for sows implies single keeping of the sows during lactation. This inhibits the natural behaviour performances, environmental stimuli and social contacts (Wülbers-Mindermann *et al.*, 2002). In general, outdoor housing is considered to be natural, environmental friendly and behaviourally appropriated, which lifts the image of these rearing systems at the consumers (Oldigs *et al.*, 1995).

Sow and piglet performance

In Swedish pig production, three breed crosses are commonly used to optimise fertility and growth ability. For this, the dam breed is often composed of breeds with high fertility characters (Large White and Swedish Landrace), whereas breeds with high growth performance and good carcass quality traits are used as terminal sire (Hampshire and Duroc). The value of a sow, used as the terminal dam breed is measured in number of live-born piglets, mortality and pre-weaning growth rate of the progeny. Production and carcass traits of the growing/finishing pigs are also important for the evaluation of the sow. On average in Sweden a cross-bred sow farrows 2.2 times per year and produces 21.8 piglets per year, and the piglet mortality from birth to weaning is 14.3% (QG, Quality Genetics, 2004).

The pre-weaning growth rate describes the milk producing ability of the sow. However, pre-weaning growth rate of the progeny not only depends on the sow, but on the genetic growth capacity of the piglet. In Sweden, piglets in conventional systems are weaned at an age of 4-5 weeks or in organic systems after at least an age of 7 weeks. Normally, the weaned piglets grow to 25-30 kg before moving to the growing/finishing stable.

Growing/finishing pig performance and carcass quality

The growing/finishing period lasts from a live weight of 25-30 kg until slaughter at a live weight of approximately 114 kg. The raising of growing/finishing pigs can vary in factors including housing system (indoor/outdoor), diet (composition) and feeding regimen (restrictive/*ad libitum*). In Sweden, raising of pigs usually occurs in indoor housing systems on a restrictive feeding regimen. Performance traits are evaluated as daily weight gain and feed conversion ratio. Carcass quality is included in the evaluation of performance; traits of interest are lean meat content, backfat thickness and dressing percentage. Cold carcass weight is on average 85.7 kg and lean meat content 57.5% (Jordbruksverket, Swedish Board of Agriculture, 2004).

Meat quality

Meat is the mammalian skeletal muscle, which has undergone a *post mortem* chain of metabolic changes. The muscle is a well organised structure based on contractile myofibrils (containing the myofilaments myosin and actin), organised in muscle fibres, each surrounded by a connective tissue, the so called endomysium. The muscle fibres are organised in larger units into muscle bundles, which are separated from each other by a connective tissue called perimysium. The muscle bundles are subunits of the entire muscle, surrounded by the epimysium. Lean muscle consists of about 75% water, 22% protein, 1.5-3% lipids, 0.5-1% carbohydrates and non-nitrogenous compounds, some non-protein nitrogenous substances and inorganic constituents (Hedrick *et al.*, 1994).

Quality (Latin for character, nature, property) is the measurable entirety of character traits, nature or quality grade of a product or service. Thus, quality traits distinguish products from other products either to their merits or deficiencies.

The term meat quality concerns both the meat as a product (product quality) and the way the meat was produced (production quality) (Hofmann, 1994). Further, product quality can be divided into technological, nutritional, hygienic and sensory quality. Measurement of each of these four meat quality traits and the production quality demand different assessments and are also of varying importance for the meat purchaser. The meat processing industry might be most concerned with technological meat quality, whereas the consumer is concerned with sensory meat quality and, increasingly, production quality (Hofmann, 1994). Meat has not a predetermined quality; many factors can affect meat quality during a pig's life – from the gene, to growth and slaughter and the final product (Figure 1).

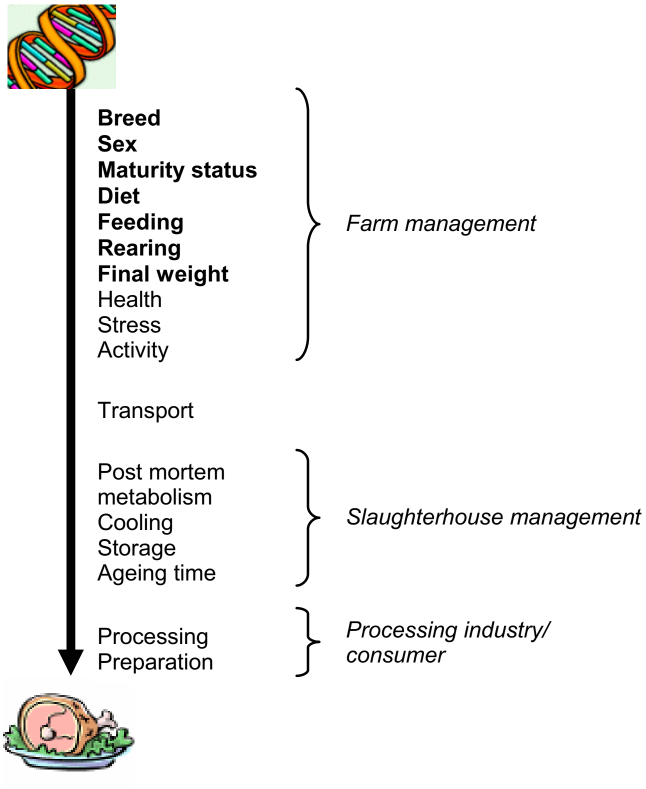

Figure 1. Factors influencing meat quality traits during the pig's life. Factors in bold were investigated in this thesis.

Technological meat quality

Technological meat quality includes the functional meat quality traits, such as pH, internal and surface reflectance, water-holding capacity, chemical composition and texture, measured as shear force.

The **pH-value** of pig meat is commonly influenced by several interacting factors, such as breed, gender, physical activity, and stress, all of which affect *post mortem* metabolism. In the *post mortem* muscle, supply of oxygen is stopped and consequently ATP must be regenerated by an anaerobic glycolytic breakdown of glycogen. The accumulation product lactic acid contributes to an acidification and thus to decreased pH in the muscle. A normal pH decrease from pH 7.2 in the living muscle to an ultimate pH (pH_u) of 5.5 can be observed in well-fed unstressed genetically unaffected pigs, depending on the muscle and muscle glycogen level (Lawrie, 1991). In short-term pre-slaughter stressed pigs, the pH decreases faster that leads to pale, soft and exudative (PSE) meat due to changed biochemical and physical processes (Briskey, 1964; Offer & Knight, 1988). A long-term pre-slaughter stress, on the other hand, results in a less extended pH decrease and a high pH_u. This meat is dark and firm and has a dry surface (DFD) (Warriss, Bevis & Ekins, 1989). In general, pH influences biochemically the enzymatic activity in the meat and physically the electrical charges of the muscle proteins, mainly the contracting myofibrils (Wismer-Pedersen, 1988).

Water-holding capacity (WHC) describes the ability of meat to hold water during storage or processing. The water content in the muscle amounts to 75%, some of which is bound to muscle proteins or is located as free water in extra-cellular space. Most water is, however, held in between the myofilaments actin and myosin of the myofibrils (Offer & Knight, 1988). Due to the *post mortem* pH decrease in the muscle, electrical charges of the myofilaments change that influences the WHC. WHC decreases with decreasing pH until the iso-electrical point of the myofilaments at pH 5.1. With further pH decrease, WHC increases and due to higher electric charge of the filaments, more water can again be held between the myofilaments (Wismer-Pedersen, 1988). WHC is an important economical meat quality trait for the meat processing industry, but also the consumer appreciates meat of good WHC.

Internal and surface reflectance are measured as the light scattering properties of meat proteins, which are related to the physical structure of the muscle fibres. Structural changes due to myofilament protein degradation are influenced by temperature and pH value and development, and they affect WHC and colour (MacDougall, 1982). The surface reflectance, or colour, can be defined as hue (colour itself), chroma (purity or saturation) and value (brightness). Besides the physical properties of the meat, concentration and properties of myoglobin (muscle pigment), and to a lesser extent, haemoglobin (blood pigment) contribute to meat colour (MacDougall, 1982). The physical properties and pigment content depend on several factors: genetics of the animal, nutrition, transport, and pre- and post-slaughter conditions. Meat colour was reported as an important technological meat quality characteristic that influences the purchase decision of consumers (Bryhni *et al.*, 2002; Ngapo *et al.*, 2004). Clearly, an attractive meat colour would positively affect sales.

Shear force estimates texture and toughness of meat samples. It is expressed as Warner-Bratzler (WB) maximal shear force and total work that is needed to cut through a standardised meat sample (Honikel, 1998). Meat tenderness depends on both the arrangement and physical properties of the structure proteins and the amount and the maturity of collagenous connective tissue (Harris & Shorthorse, 1988). Figure 2 shows a WB shear force curve. The height of initial yield force mostly depends on the myofibrillar structure due to its contraction and ageing. The second peak force values mostly depend on the amount and properties of collagenous connective tissue, varying with animal age, cooking time and temperature (Harris & Shorthorse, 1988).

The tenderisation of the muscles is an interaction between the pH and temperature decrease *post mortem* and its effect on proteolytic enzym activity and subsequent myofibrillar protein degradation (Ouali, 1992). In the living animal, the effect of growth rate (Enfält *et al.*, 1997b) and protein turnover (Kristensen *et al.*, 2002) on *post mortem* meat tenderness has been discussed. Many studies have determined production and processing factors affecting tenderness. Production factors such as breed, rearing system, carcass weight and feeding regimen were found to have less influence than meat processing factors (Wood *et al.*, 1996). Processing factors including pre-slaughter handling, stunning method, carcass chilling, ageing and cooking time are reported to influence shear force, *i.e.* tenderness (Tornberg, 1996).

Chemical composition of the meat in terms of water, protein, non-protein nitrogen, fat, carbohydrates and inorganic constituents may be affected along the way from farm to fork. Influence of water on meat quality in terms of WHC has already been discussed. Proteins operate in the living animal as structural or contractile proteins, as hormones, enzymes, antibodies and transport and osmotic proteins. In domestic vegetable feedstuff, the amino acid (AA) pattern of the protein is suboptimal and limited AA, such as lysine, metheonin/cystein, threonine and thryptophane should be added to optimise the diet (Menke & Huss, 1987).

Collagen is one of the most common proteins in the body forming the major component of connective tissue. Intermolecular cross-linking of single collagen molecules gives collagen its strength and more resistance to tensile stress. As the animal gets older, the collagen cross-links stabilise and the average diameter of the fibrils increases. The higher the number of heat-stable cross-links is, the tougher the meat. After cooking, the cross-links weaken, but do not break, contributing to the toughness of meat found in old animals. Cooking collagen from young animals produces gelatine, which is soft and soluble (Bailey & Light, 1989).

Fat in meat has a function as either structural or depot lipids and is quantified as intramuscular fat content. The measurements determine mainly phospholipids and triglycerides. The role of fat as taste and tenderness enhancer is widely discussed in literature (Bejerholm & Barton-Gade, 1986; Eikelenboom, Hoving-Bolink & van der Wal, 1996; Blanchard *et al.*, 1999a; Blanchard *et al.*, 2000; van Laack, Stevens & Stalder, 2001). Some studies indicated that IMF does not affect sensory meat quality traits, whereas Bejerholm & Barton-Gade (1986) reported that IMF levels between 2-3% enhance taste, flavour and tenderness. On the other hand, too high levels of IMF are reported to negatively affect consumer acceptability

(Fernandez *et al.*, 2000), because the consumer is more and more concerned about healthiness aspects. Thus, IMF has become a central issue of the purchase decision.

Generally, the carbohydrate glycogen comprises 0.5-1.3% of the muscle weight, whereas most of the body's glycogen is stored in the liver. Carbohydrates represent only a small proportion of body weight, but have extremely important functions in energy metabolism and structural tissues (Hedrick *et al.*, 1994).

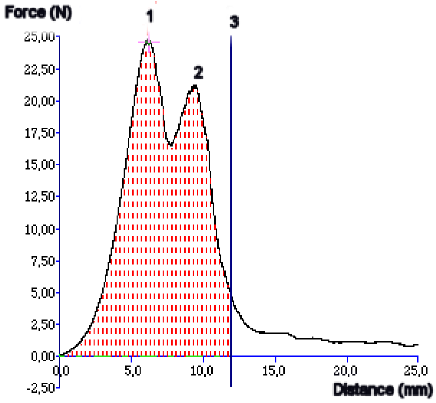

Figure 2. Warner-Bratzler shear force curve from own material. 1=maximal force value; 2=second peak force; 3=set anchor at 5 N for standardisation of all curves; spotted area = total work.

Sensory meat quality

The evaluation of meat quality through descriptive sensory analysis, as used in Study I and II, is a valuable tool, used both in industry and research. Due to a lack of adequate technology, a human taste panel is used as an objective and 'instrumental' tool to specify a great variety of sensory characters of food, *e.g.* juiciness, various flavours, stringiness, acidity and salinity in meat. Some technologies were developed to replace the time-consuming and expensive taste panel. Warner-Bratzler shear force is commonly accepted as a suitable measure of meat tenderness and pH is closely related to acidity (Study II) and flavour (Lütjens & Kalm, 1995). Other methods to evaluate sensory attributes, *e.g.* the electronic nose are still in a developing phase and cannot replace the skills of a trained taste panel. However, the reliability and repeatability of such panels has limitations (Hovenier, Kanis & Verhoeven, 1993).

RN genotype

In the late 1980s, Naveau *et al.* (1986) classified the *RN* gene as a porcine major gene in the Hampshire breed. Later, two alleles (the dominant RN^{-} and the recessive rn^{+}) on the PRKAG3 (RN) locus on chromosome 15 were identified by Milan *et al.* (2000). The dominant RN^{-} allele is known to increase lean meat content (Enfält *et al.*, 1997a), reduce technological meat quality (Lundström, Andersson & Hansson, 1996) and improve sensory meat quality (Jonsäll, Johansson & Lundström, 2000). Detrimental technological meat quality traits were shown to be related to a higher muscle glycogen content in RN^{-} carriers *post mortem* (Estrade, Vignon & Monin, 1993; Estrade *et al.*, 1993) and prolonged pH decrease to levels of about 5.4 (Le Roy *et al.*, 1990, Lundström, Andersson & Hansson, 1996; Lundström *et al.*, 1998; Gariépy *et al.*, 1999; Nilzén *et al.*, 2001). The lower pH_u in RN^{-} carriers was associated with higher reflectance values and inferior WHC (Lundström, Andersson & Hansson, 1996; Enfält *et al.*, 1997a; Le Roy *et al.*, 2000), especially determined as decreased technological yield (Le Roy *et al.*, 2000). Improved sensory meat quality in terms of lower shear force (Lundström, Andersson & Hansson, 1996; van Laack, Stevens & Stalder, 2001; Josell, Linda & Tornberg, 2003) and more tender meat (Jonsäll, Johansson & Lundström, 2000; Miller *et al.*, 2000; Josell, Linda & Tornberg, 2003) and juicier meat (Josell, von Seth & Tornberg, 2003) in sensory panel evaluation was found in meat from RN^{-} carriers.

Development of muscle (myogenesis)

Myogenesis is the development of muscle and muscle fibres during the embryonic development. Figure 3 shows the steps of the development from the mesodermal cell to the mature myofibre. Number and size of muscle fibres in the living animal are reported to be important factors in postnatal growth performance (Dwyer, Stickland & Fletcher, 1994; Nissen, Jorgensen & Oksbjerg, 2004). *Post mortem,* when muscle becomes meat, number and size of muscle fibres are relevant for meat quality characteristics (Stickland & Goldspink, 1975; Essén-Gustavsson, Karlström & Lundström, 1992).

Myogenesis starts in the embryo with the differentiation of mesodermal stem cells (for review see Dauncey & Gilmour, 1996). Hormonal signals, mainly initiated by the gene MyoD and Myf-5, start division and proliferation of the stem cells to myoblast. In a pig foetus this occurs at day 25 of gestation. Myoblasts are aligned by the influence of gene Myogenin and Myf-6, and are fused to undifferentiated myotubes. At this stage the nuclei are centred in the myotubes and the cell starts to express cell-specific muscle proteins. Through the influence of MRF4, the myotubes mature. The mature myotube, the myofibre, shows an equal distribution of the nuclei along the interior of the sarcolemma, the muscle cell wall. The nuclei are mitotically inactive, which means that myofibres are unable to divide. However, the nuclei express RNA by transcription and translation. During myogenesis, two kinds of myofibres are created. First, primary fibres build up from day 25 to day 50 (Ashmore, Addis & Doerr, 1973). They then act as a template for another generation of myofibres, the secondary muscle fibres. This second wave of differentiation occurs in pig foetus from day 50 to day 90 (Ashmore, Addis & Doerr, 1973; Wigmore & Stickland, 1983). The primary fibres mature to red fibres, whereas the secondary fibres mature to mostly white muscle fibres (Handel & Stickland, 1987a).

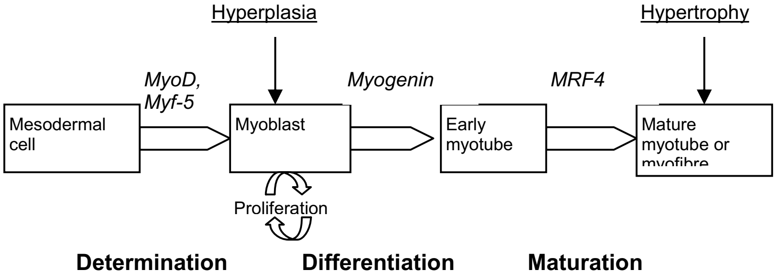

Figure 3. Skeletal muscle fibre development, showing the main events and regulatory genes involved in myogenesis.

Objectives

The increasing interest by the consumer and thus the industry in organically produced pork of good quality has raised many questions for the producers, such as how different rearing systems and different breed crosses can contribute to this demand. The improvement of growth performance and meat quality of growing/finishing pigs, which hypothetically might be a consequence of muscle development in the foetus, is of considerable interest for pig producers. The objectives of the five studies within this thesis were as follows:

- *Investigation of an outdoor rearing system with emphasis on the carcass and meat quality of once-bred gilts in comparison to maiden gilts.* A well-working seasonal outdoor rearing system of once-bred gilts with good carcass and meat quality could contribute to the extension of organically produced pig meat. The main objective of Study I was to investigate how this concept affects carcass and meat quality.
- *Comparison of two breed crosses of once-bred gilts in a seasonal outdoor rearing system regarding maternal performance, carcass and meat quality.* To establish outdoor pig rearing systems requires an applicable dam breed, which can endure the rough outdoor conditions. The main objective of Study II was to investigate the suitability of Large White x Landrace and Large White x Duroc once-bred gilts for this rearing system.
- *Determination of production results and technological meat quality of indoor vs. outdoor raised growing/finishing pigs.* The increasing interest of organic raising of pigs and the lack of ample literature was the basis for this study. The main objective of Study III was to compare growing/finishing pigs of different breed crosses and *RN* genotypes in a conventional indoor and a KRAV-regulated outdoor raising system.
- *Investigation of four different rearing systems of growing/finishing pigs, including different housing systems, diets and feeding regimens concerning performance, carcass and meat quality.* This study is a part of an EU project, where the whole chain of sustainability pork production, including welfare, meat quality, residues in meat, nutrition, and consumer attitudes were in focus. To this project we contributed with data from growing/finishing pigs, raised under conditions representative for Sweden. The main objectives of Study IV were to compare outdoor vs. indoor housing systems and organic vs. conventional diets.
- *Verification of the hypothesis of differentiated extra maternal feed supply during early gestation on maternal performance and the development of the progeny.* The most important traits for economic efficiency in pig production are number of live-born piglets per litter, piglet survival, and daily weight gain, feed conversion ratio and lean meat percentage. The main objective of Study V was to investigate if these traits might be influenced by extra feed supply in early gestation of the sow.

Material and Methods

Housing

This thesis is based on four different animal materials. All animals originated from Funbo-Lövsta Research Station, SLU. The outdoor housing of sows, until three weeks after farrowing, occurred in individual enclosures with farrowing huts and grazing possibilities. After, the suckling sows and their piglets and the growing/finishing pigs were kept on large enclosures with huts and grazing possibilities. Weaning occurred at 9 weeks of age. Indoor housing of sows occurred in single pens and the piglets had access to a separated area with an infra red light. The piglets were weaned at 5 weeks.

Animal material

An overview of the animal materials and assessed measurements for performance and meat quality traits is given in Table 1. All studies were carried out over two years.

In Study I, cross-bred maiden (n=14) and once-bred gilts (n=38) of Large White (LW) and Swedish Landrace (L) or Duroc (D) were used. Maiden gilts were kept indoors and were given a rearing diet restrictedly. Littermates to these maiden gilts (once-bred gilts) were raised in the same way as the maiden gilts until insemination with Hampshire (H) sperm at an average age of 251 days. Thereafter, they received a gestation diet and were housed outdoor from one week before farrowing. After farrowing the once-bred gilts received a lactation diet based on litter size. The piglets were weaned at an age of 9 weeks. After weaning, the once-bred gilts received a rearing diet, in year 1 twice per day according to their voluntary feed intake and in year 2 restrictedly (4 kg/day). The maiden gilts were slaughtered at an average live weight of 145 kg; the once-bred gilts, two to three weeks after weaning at an average live weight of 212 kg.

In Study II, the once-bred gilts (n=38) of both breed crosses from Study I were investigated.

In Study III, the progeny ([LW*L]xH or [LW*D]xH; n=279) of the once-bred gilts in Study I was divided by split litter technique into two groups of 2 x 33-38 pigs. One group was kept outdoors, the other group indoors. The same experimental design was applied the following year. Outdoor pigs were kept on pasture; indoor pigs were kept in an uninsulated building on deep litter. All pigs received a conventional diet *ad libitum* until a mean live weight of 60 kg. After, the daily feed allowance was restricted to 34.1 MJ ME per pig according to the Swedish standard (Andersson *et al.*, 1997); in year 2 only, the outdoor pigs received a maximum of 37.5 MJ ME per pig and day. The pigs were slaughtered at an average live weight of 108 kg.

Table 1. *Experimental design of the studies, included in this thesis*

Study	**Breed**	**N**	**Sex**	**Housing**	**Feeding regimen**	**Mat. perf.**	**Piglet perf.**	**Grow./fin. perf.**	**Carcass quality**	**Technol. quality**	**Chem. comp.**	**Sensory quality**
I	LW*L/ LW*D	14	gilts	indoor	restrictive							
	LW*L/ LW*D	38	once-bred gilts	indoor/outdoor	restrictive				X	X	X	X
II	LW*L											
		38	once-bred gilts	indoor/outdoor	restrictive	X	X		X	X	X	X
	LW*D											
III	[LW*L]xH			indoor	*ad lib*. (≤ 60 kg)/restr.							
		279	females/castrates					X	X	X		
	[LW*D]xH			outdoor	restrictive							
IV	LW*L			indoor	restrictive							
		280	females/castrates					X	X	X	X	
	LW*D			outdoor	*ad lib.*							
V	LW*L	38	sows (1^{st} and 2^{nd} parity)	indoor	restrictive (gestation)/ *ad lib*. (lactation)	X						
	[LW*L]xD	289	females/castrates	indoor	restrictive		X	X	X	X		

In Study IV, outdoor growing/finishing pigs of Large White x Swedish Landrace and Large White x Duroc were investigated. All piglets were born and reared indoors and weaned at five weeks of age. Using split litter technique, two groups of pigs were raised outdoor and one group indoors in year 1; a further indoor group was added in year 2. Outdoor pigs were kept on enclosures of 20 pigs of both breed crosses and sexes (female and castrated male pigs); indoor pigs were kept in pens with 10 pigs of the same breed cross and of both sexes. The two groups of outdoor pigs received an organic diet *ad libitum*, either diluted (with alfalfa meal) throughout the growing/finishing period or first the diluted diet and thereafter the undiluted diet with access to roughage (alfalfa pellets). The two groups of indoor pigs received either the undiluted organic diet or a conventional diet restrictively. The pigs were slaughtered at an average live weight of 107 kg.

In Study V during two parities, indoor kept Large White x Swedish Landrace gilts were inseminated with Duroc sperm. The gilts were randomly allocated to four different feed allowances of the same diet. The control group was fed according to the standard feeding regimen for gilts in Sweden (2.3 kg/day; Simonsson, 1994), the other treatments received 35, 70 and 100%, respectively, more feed than the control group during day 25 to 85 of gestation. During lactation, all sows received the same lactation diet *ad libitum*. The progeny was weaned at five weeks of age. The growing/finishing pigs were raised indoors in pens with nine pigs in each and were fed according to the standard feeding regimen for growing/ finishing pigs (Andersson *et al.*, 1997). The pigs were slaughtered at an average live weight of 110 kg.

Methods

Maternal and piglet performance

Maternal performance included the recording of body weight (Study II and V) and backfat thickness during gestation and lactation (Study II). Further, litter size, piglet mortality, and individual piglet weight at birth and at weaning were recorded.

Performance of growing/finishing pigs

Performance of growing/finishing pigs was measured as daily weight gain and feed conversion ratio in Study III, IV and V.

Sexual maturity

Sexual maturity of growing/finishing females was determined in Study III by measuring the diameter of the largest follicle with a ruler. The presence of corpora lutea was recorded. The females were then divided into three classes according to ovarian morphology:

Class 1 - sexually mature, follicle size >8 mm and/or presence of corpus luteum.
Class 2 - pre-pubertal, follicle size >5 mm but <8 mm; no corpus luteum.
Class 3 - immature, follicle size <5 mm; no corpus luteum.

Constitution

The constitution of the growing/finishing pigs was measured in Study III as the presence and severity of ostechondrosis in the knee joint and the scores ranged from 0 (best, undegenerated condyle) to 5 (worst, severe lesions) according to Reiland (1978) and as the weight of the femur bone.

Classification of RN phenotype/genotype

The classification of the animals as carriers (*RN*$^{-}$*/rn+*) and non-carriers (*rn+/rn+*) of the *RN*$^{-}$ allele in Study III was based on phenotypic trait measurements of the concentration of glucose + glucose-6-phosphate (G-6-P) in meat juice as described by Lundström & Enfält (1997) but in *m. semimembranosus et aductor* (SMA). The method gave a bimodal distribution and the *RN* classification was made on basis of the valley point. Pigs with a value ≥ 48 µmol/ml meat juice were classified as carriers of the *RN*$^{-}$ allele; pigs with a value ≤ 44 µmol/ml were classified as non-carriers. Fifteen samples with values close to this experimental dividing line (45-47 µmol/ml) underwent a final genotyping (*rn+/rn+* or *RN*$^{-}$*/rn+*) following the procedure reported in Milan *et al.* (2000). In total 106 animals were classified as carriers and 128 as non-carriers of the *RN*$^{-}$allele.

Carcass quality

For carcass quality, carcass weight (cold carcass weight in Study I, II, III and V; hot carcass weight in Study IV), dressing percentage as the quotient of live weight and cold carcass weight (Study III, IV and V), and backfat thickness as mm of the subcutaneous fat over the middle of *m. longissimus dorsi* (LD) just behind the last rib (Study I, II, IV and V) were measured. Ham (Study III) and loin (Study I, II, IV and V) of the right carcass half were weighed with skin and fat, then defatted and weighed again as meat and bone. Ham and loin were dissected into the muscles LD, SMA, *m. semitendinosus* (ST), *m. quadriceps femoris* (QUA), *m. gluteus* (GLU) and *m. biceps femoris* (BF) (Study I, II and V). In Study V, additionally *m. psoas major* (PS) was dissected. Calculation of lean meat percentage was performed with different equations according to gender and slaughter weight of the animal material (Hansson, 1997):

Study I and II
Lean meat percentage = -49.672 + (1.012* % ham in carcass) + (0.622* % meat and bone in ham) + (0.667* % loin in carcass) + (0.2* % meat and bone in loin)];
Study III and V
Lean meat percentage = -29.217 + (0.548* % ham in carcass) + (0.866* % meat and bone in the ham) and (+ 0.679 for females)];
Study IV
Lean meat percentage = -49.781 + (0.899* ham in carcass) + (0.612* meat and bone in ham) + (0.651*loin in carcass) + (0.252*meat and bone in loin) and (+0.249 for females)];

where the percentages of ham and loin in carcass are expressed as percentage of the right carcass side without head.

Technological meat quality

Technological meat quality measurements were applied in all studies on LD and additionally in Study III and IV on BF and in Study I and II on SMA. The muscles were dissected from the cooled carcass about 24 h (some after 48 h in Study V) after slaughter.

Ultimate pH (pH_u) was measured at cutting, using a portable pH-meter, calibrated to chilling room temperature (Knick, Berlin, Germany; equipped with a combination gel electrode SE104, Knick, Berlin, Germany. pH was measured on LD (all studies) and on BF (Study III and IV).

Internal reflectance (FOP) was measured using a fibre optic probe (FOP, 900 nm; TBL Fibre Optics Group Ltd., Leeds, UK) on LD (all studies) and on BF (Study III and IV).

Surface reflectance (colour) with the parameters L* (lightness), a* (redness) and b* (yellowness) was measured in all studies on LD after about one hour of blooming by using a Minolta colorimeter (Minolta Chroma Meter CR 300, DP-301, Osaka, Japan).

Water-holding capacity was measured as filter paper wetness on LD (Kaufmann *et al.*, 1986) (Study III and V) and as drip loss on a 2-cm thick slice of LD either after 3 days of horizontally storage at 4 ºC (Study I, II, III and V) (Barton-Gade *et al.*, 1994) or after 48 h storage in inflated bags at 4 ºC (Study IV) (Honikel, 1998). Thawing loss was determined on SMA (Study I and II) and on LD (Study IV) as the weight difference between fresh and defrosted meat. Cooking loss was determined on LD (Study IV) or BF (Study III) after cooking in a water bath of 70 ºC for 90 min.

Processing yield was measured as percentage of brine immersion in SMA, commercial processing yield (total yield; weight difference between the fresh and cured/smoked muscle) and laboratory processing yield (Napole yield) (Naveau, Pommeret & Lechaux, 1985) in Study I and II.

Shear force was measured as Warner-Bratzler (WB) maximal shear force and total work on LD in Study I, II and IV and on BF in Study III. The meat was vacuum-packed 24 h after slaughter, aged for 4 days and stored frozen at 20 °C. For WB measurements, the meat was thawed overnight at 4 ºC, vacuum packed and cooked in a water bath of 70 ºC for 90 min. The meat was cooled under running water and at least eight strings (10x10x50 mm; cross section 100 mm^2) were prepared. The strings were sheared across the fibre direction (Warner-Bratzler blade with a rectangular hole, 11 mm wide, 15 mm high, 1.2 mm thick; speed: 55 mm/min, TA-HDI texture Analyser; Stable Micro Systems, Surrey, UK) (Honikel, 1998).

Subjective **marbling score** (ranged from 0 = no marbling to 5 = high marbling) was assessed on a slice of LD in Study III.

Chemical composition

Chemical composition was determined as percentage of intramuscular fat (IMF), crude protein (CP) (Study I, II and IV), dry matter (DM) and ash (Study I and II) and as glycogen content (µmol/g; Study IV) of meat from LD.

IMF content was analysed after hydrolysis with HCl using petroleum ether for extraction (Soxtec System H+ equipment, Tecator AB, Höganäs, Sweden) (Study I and II). In Study IV, IMF content was analysed by the SBR-method after hydrolysis with HCl using ethanol, petroleum ether and diethyl ether for extraction (NMKL, Nordisk Metodikkomité for Næringsmidler, 1989) (Soxtec System H+ equipment, Tecator AB, Höganäs, Sweden).

Crude protein was analysed with the Kjeltec apparatus (Tecator AB, Höganäs, Sweden) using factor 6.25 for calculating the proportion of protein content.

Dry matter was determined after drying in 105°C for at least 16-18 h, and then the samples were heated in an ash oven at 550°C to determine **ash content**.

Glycogen was determined as the sum of glycogen, glucose and glucose-6-phosphate in homogenised muscle tissue (Dalrymple & Hamm, 1973) using the enzymatic kit Glucose HK 125 by ABX Diagnostics (Montpellier, France).

Sensory analyses

Sensory meat quality was determined on oven-baked LD and cured and smoked SMA by a trained taste panel in Study I and II. Oven-baked LD was prepared at 150°C oven temperature and 68°C internal meat temperature. SMA (frozen after cutting and thawed before processing) underwent a commercial processing of curing and warm smoking (10% sodium chloride brine, injected with needles and immersion in brine for 24 h, no tumbling; smoking temperature of 65°C for 12 h). Tenderness, juiciness and fat flavour were determined on both LD and SMA, acidity and meat flavour solely on LD and smoke flavour, stringiness and salinity solely on SMA. The scale for the taste characteristics scored from 1= very low intensity of the character to 100 = very high intensity.

Statistical analyses

Statistical data analyses of all studies were carried out with the SAS statistical programme (SAS Institute Inc., Cary, N.C., USA, version 8.02). The data analysed were performed with the GLM, MIXED and CORR procedures. Data given in the tables are least square means, standard errors and Pearson correlation coefficients. Interactions between fixed factors were included in the models, when significant. Relevant covariates were included in the models when significant. In the statistical analyses of sensory meat quality, taste panel member and individual pig were included in the model as random effects.

Summary of the presented papers

I. Carcass quality and technological and sensory meat quality of once-bred gilts in a seasonal outdoor rearing system

Seasonal application of once-bred gilts for piglet and meat production outdoors could be a worthwhile alternative rearing form to the commercial production. Compared to growing/finishing pigs, payment for sow carcasses is considerably reduced because of an assumed decrease in meat quality and processing properties. The purpose of this study was to compare maiden and once-bred gilts for carcass quality, and technological quality (pH, internal and surface reflectance, water holding capacity, commercial processing yield and laboratory processing yield, WB shear force), chemical composition and sensory meat quality. Sensory meat quality of oven-baked *m. longissimus dorsi* and cured and smoked *m. semimembranosus et adductor* was investigated (taste panel). Carcass quality traits such as higher lean meat content and lower backfat thickness were preferable for the once-bred gilts. In technological meat quality characteristics, once-bred gilts had lower thawing loss, Napole yield, dry matter and higher total work of WB shear force and intramuscular fat, compared with maiden gilts. Mostly, sensory meat quality was similar between the two groups. Solely in processed meat once-bred gilts had higher juiciness and salinity and unfavourable higher stringiness, compared with maiden gilts (Figure 4). Thus, once-bred gilts produce valuable carcasses and are suitable for an outdoor seasonal rearing system.

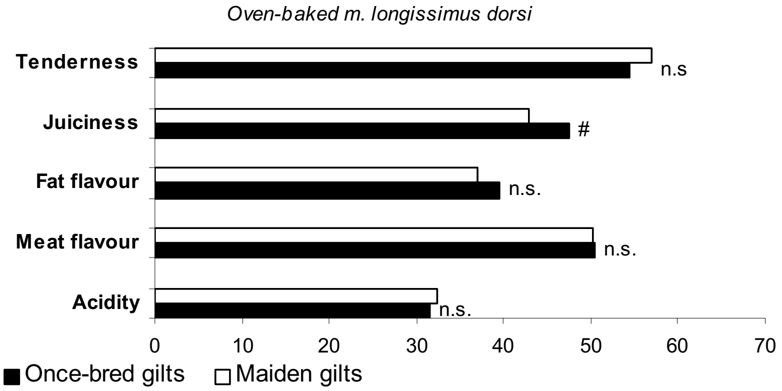

Figure 4. Sensory meat quality of oven-baked *m. longissimus dorsi* of once-bred and maiden gilts. Levels of significance: n.s.= p>0.10, #= p<0.10, **=p<0.01, *=p<0.05.

II. The effect of breed cross on performance and meat quality of once-bred gilts in a seasonal outdoor rearing system

This study investigated the suitability of once-bred gilts of two different breed crosses (Large White x Landrace (LW*L) and Large White x Duroc (LW*D) in an alternative seasonal outdoor rearing system, with slaughter of the once-bred gilts and their progeny at the end of the season. Body weight, backfat thickness and litter size of the once-bred gilts, and pre-weaning mortality and growth of the piglets were recorded. Carcass quality and technological meat quality (pH_u, internal and surface reflectance, water-holding capacity, processing yield and shear-force) of *m. longissimus dorsi* were measured. Sensory meat quality (taste panel) of oven-baked loin (*m. longissimus dorsi*) and cured and smoked ham (*m. semimembranosus et adductor*) was investigated. LW*L once-bred gilts had more piglets at weaning, whereas growth rate of LW*D progeny was higher; pre-weaning mortality and litter weight did not differ between the breeds. LW*L once-bred gilts had lower backfat thickness during the study (Figure 5) and higher lean meat content and lower backfat thickness at slaughter. Technological meat quality and chemical composition did not considerably differ between the two breed crosses. LW*D had higher quality concerning meat flavour and stringiness, but tended to have lower quality with regard to juiciness of cured and smoked ham, compared with LW*L.

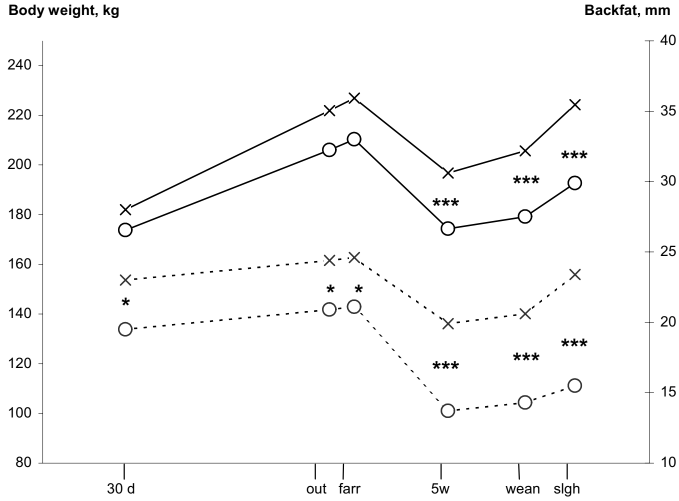

Figure 5. Body weight and backfat thickness of once-bred gilts from 30 days after service to slaughter. Measurements at time of: 30 d= 30 days after service; out= start of outdoor period, about one week before farrowing; farr = farrowing; 5w = five weeks after farrowing, wean = weaning; slgh = slaughter. X= LW*D cross; ○= LW*L cross; Straight line= body weight; Dashed line= backfat thickness; Levels of significance between breed cross: ***=p<0.001, *=p<0.05.

III. Production results and technological meat quality for pigs in indoor and outdoor rearing systems

The objective of the study was to compare production results and technological meat quality for pigs ([LW*L]xH or [LW*D]xH) born outdoors and reared indoors in a large pen on deep litter or outdoors during the summer. Daily weight gain and lean meat percentage were higher for pigs raised outdoors than raised indoors during year one (864 vs. 841g; 56.9 vs. 55.9%), but were similar for year two (859 vs. 844g; 55.9 vs. 55.6%). Outdoor pigs grew faster when fed *ad libitum*, but slower during the second phase when fed restrictively, with inferior feed conversion. Most technological meat quality traits (surface and internal reflectance, marbling, ultimate pH_{BF}, filter paper wetness, cooking loss and maximal Warner-Bratzler shear force) were similar between rearing systems, whereas ultimate pH_{LD} was higher indoors. Total work of Warner-Bratzler shear force was lower in outdoor reared pigs. Maternal sire breed (Duroc or Landrace) and sex (castrate or female) slightly affect meat quality traits. *RN* genotype affected meat quality more strongly than rearing system. It can be concluded by the resemblance in production results and meat quality in both systems that both indoor and outdoor rearing are good alternatives for summer rearing of pigs.

IV. Performance, carcass and technological meat quality of growing/finishing pigs raised in organic and conventional systems

Comparison of performance, carcass and technological quality traits of indoor and outdoor raised pigs of two breed crosses (LW*D and LW*L), fed organic or conventional diets *ad libitum* or restrictively, and investigation of effect of strategic feeding were the aims of this study. Four treatments were applied: I. Pigs kept outdoors, fed an organic diluted diet (20% alfalfa roughage); *ad libitum* (80 pigs). II. Pigs kept outdoors, strategically fed with first diluted and thereafter undiluted organic diet; *ad libitum* (80 pigs). III. Pigs kept indoors, fed undiluted organic diet restrictively (80 pigs). IV. Pigs kept indoors, fed a conventional diet restrictively (40 pigs). Indoor pigs fed the organic diet grew faster and had lower feed conversion ratio ($p \leq 0.01$) than outdoor reared pigs, possibly because outdoor pigs require more energy due to their higher agility. Strategic feeding increased daily weight gain compared with feeding a diluted diet throughout. Technological meat quality differed slightly between indoor and outdoor raised pigs. L* values in *m. longissimus dorsi* were higher in indoor raised pigs (year 1), possibly because of the lower pH and higher FOP values that year. Water-holding capacity was not affected by treatment. The diet (organic/conventional) for indoor pigs did not affect carcass and meat quality traits. Breed cross did not affect performance and carcass traits, whereas LW*D tended to have higher water-holding capacity and lower shear force compared with LW*L. However, an interaction between breed cross and treatment in total daily weight gain was found ($p = 0.001$; Figure 6).

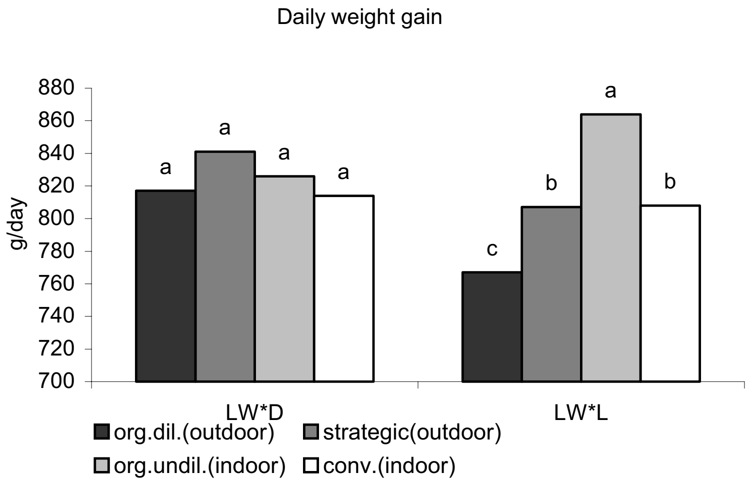

Figure 6. Daily weight gain from start to slaughter of growing/finishing pigs of two breed crosses in different rearing systems; bars with different superscripts (a,b,c) differ significantly, $p < 0.05$.

V. Effect of extra maternal feed supply in early gestation on sow and piglet performance and production and meat quality of growing/finishing pigs

The influence of differentiated extra maternal feed allowance during early gestation on maternal performance and postnatal development of the progeny from gilts and sows was investigated. Four different feed allowances of the same diet (Control [C], +35% [T35], +70% [T70], +100% [T100]) were assigned to cross-bred gilts (Swedish Landrace x Swedish Yorkshire), which continued as sows with the same feed allowance the following parity. The progeny was uniformly raised and slaughtered at a live weight of 110 kg. Additional maternal feed allowance resulted in significantly more weaned piglets per sow but not per gilt. The effect of more piglets was not increased from T35 to T70/T100. Piglet birth weight did not increase due to maternal feeding. The intra-litter variation in piglet birth weights was similar between the treatments. Independently of the additional feed allowance, all gilts/sows had similar weight after weaning and had good body condition. The growth rate of progeny from sows was negatively related to maternal feed supply; for progeny from gilts, no clear trend of nutritional influence could be observed. Carcass and technological meat quality was not affected by the maternal feeding treatment. Birth weight positively affected later growth performance (higher daily weight gain), carcass quality (lean meat content, backfat, proportion of muscles in ham/loin), whereas technological meat quality was unaffected.

General discussion

Effect of breed cross and maternal feeding on sow and piglet performance (Study II and V)

Breed

In Study II, larger litter size at birth and higher litter weight at weaning of the Landrace breed cross compared with the Duroc breed cross was observed. Litter size, *i.e.* number of live-born piglets and individual birth weight of the piglet are negatively correlated (Rydhmer, 1992; Tholen *et al.*, 1996). This relation should be considered, when measuring sow performance. Therefore, litter weight probably gives more comprehensive information about the maternal capacity. The good reproduction performance of pure-bred Landrace and its breed crosses is widely described (Gaugler *et al.*, 1984; Culbertson *et al.*, 1997; Tummaruk *et al.*, 2000; Cassady, Young & Leymaster, 2002). In Study II, mortality, mainly caused through crushing, did not differ between the two breed crosses. This might indicate similar maternal behaviour of the once-bred gilts. Crushing losses might also be related to the sow's body weight and consequently her agility (Wülbers-Mindermann *et al.*, 2002). However, in Study II the once-bred gilts had similar weight at farrowing.

Higher pre-weaning growth rate was observed in Duroc-sired piglets, and the difference in growth remained even after weaning (see Study III). However, higher growth rate of piglets was not significant when including litter size in the model. A similar model, including litter size, was used in a study of Rico *et al.* (2002), who found similar results. However, the litter weight at weaning, *i.e.* the produced piglet mass, was higher in LW*L compared with LW*D. This difference might be at the expense of the sows' weight and backfat thickness, which decreased more in LW*L than in LW*D sows. Body reserves are more depleted with more piglets (Neil, Ogle & Annér, 1996), because these reserves are used for milk production, which is the most important factor for post-natal growth of the piglets (Hardge *et al.*, 1999). It has to be considered that once-bred gilts were inseminated at an average age of 251 days and were still growing. Energy would therefore be used both for milk production and for own body development. Whittemore (1996) reported that first parity gilts have attained only 30-40% of the final lean tissue mass in the mature body and further less of final fat tissue mass.

The produced piglet mass and the sow's weight at weaning indicated that LW*L might be a better breed cross in the applied seasonal rearing system. However, LW*D once-bred gilts had higher backfat thickness. Therefore they might be more robust and tolerate weather conditions better than LW*L. Additionally, the piglets growth rate, which was higher for the LW*D progeny, has to be considered, when evaluating a cross breed in a rearing system.

Maternal feeding

Extra maternal feed supply during early gestation was reported to positively affect foetal fibre muscle development, *i.e.* to increase the amount of secondary and subsequently total fibre number (Dwyer, Stickland & Fletcher, 1994; Stickland, 1994). Higher total number of fibres is related to important traits for economic efficiency in pig production, such as weight per piglet at birth and at weaning, and daily weight gain from birth to slaughter (Handel & Stickland, 1987b; Dwyer, Fletcher & Stickland, 1993; Nissen, Jorgensen & Oksbjerg, 2004). However, in Study V, extra maternal feed supply during day 25 to day 80 of gestation did not affect maternal or piglet performance. Thereby, also fibre number of the progeny was supposed to be unaffected. This agrees with several other studies that refuted the hypothesis of increased amount of fibres and better performance traits due to extra maternal feeding (Gatel, Castaing & Lucbert, 1987; Einarsson & Rojkittikhun, 1993; Oksbjerg, Nissen & Danielsen, 2002; Nissen *et al.*, 2003; Bee, 2004).

In year two, the control sows had significantly fewer piglets at weaning, compared with the other treatments. A similar tendency of smaller litter size at birth could be found for the control sows. In this year, the control sows were not fed the standard feeding regimen for sows in Sweden (2.7 kg/day; Simonsson, 1994) but the regimen for gilts (2.3 kg/day). This indicated that low feed intake during gestation decreased litter size. The effect of undernutrition has been reported to negatively influence maternal performance in terms of litter size and growth rate of the progeny (Dwyer *et al.*, 1995; Robinson, Sinclair & McEvoy, 1999; Han *et al.*, 2000; Bee, 2004). Kirkwood, Baidoo & Aherne (1990) described that a low plane feeding during gestation after low plane feeding in lactation of second parity sows resulted in a lower embryo number and a higher embryo survival, compared with low plane/high plane feeding and high plane/high plane feeding during gestation and lactation, respectively. A positive effect of undernutrition during early gestation on ovulation rate and embryo survival was reviewed by Einarsson & Rojkittikhun (1993).

In Study V it was found that birth weight was positively related with piglet's performance traits *i.e.* daily weight gain. Powell & Aberle (1980) reported that runt piglets have less muscle fibres, which subsequently reduced growing performance compared with heavy-born piglets. Nissen *et al.* (2004) confirmed the findings of a positive relation between birth weight and fibre number. Kuhn *et al.* (2002) described the positive relation between birth weight, growing performance and carcass quality. Further, Dwyer *et al.* (1994) found that the feeding regimen decreased the variation in fibre number within the litter; light-born piglets developed more secondary muscle fibres, whereas fibre number of heavy-born piglets was unaffected. However, in our study variation in piglet birth weight within litter was unaffected.

Effect of rearing system, breed cross and maternal feeding on growing/finishing pig performance and carcass quality (Study III, IV and V)

Rearing system

Both in Study III and IV, different outdoor and indoor rearing systems were compared. However, the outdoor rearing systems in these studies applied are not suitable for comparison, because *e.g.* diet composition and feeding regimens differed and therefore general conclusions about 'outdoor rearing as such' could not be drawn. However, a tendency of higher daily weight gain of indoor raised growing/finishing pigs could be seen, which was also found in earlier studies (Enfält *et al.*, 1997b; Lebret *et al.*, 2002; Micklich *et al.*, 2002). This higher growth rate might depend on the lower agility of the indoor pigs and therefore their lower energy demand, as discussed by Enfält *et al.* (1997b). The higher initial growth rate of the outdoor pigs in Study III compared with the indoor pigs was unexpected. This might be because these pigs were born and raised outdoors and a growth check at weaning, partly due to environmental changes, did not occur as described by English *et al.* (1988). Also Gentry *et al.* (2002a) reported that environmental changes at the start of the growing/finishing period are disadvantageous for the growth. Millet *et al.* (2003) found higher final growth rate in organic raised growing/finishing pigs and explained that this was due to the higher feed intake of these pigs, compared with indoor pigs.

In our studies, backfat thickness was generally lower and lean meat content higher in outdoor raised pigs. Other studies have found similar results (Enfält *et al.*, 1997b; Sather *et al.*, 1997; Bondesan, Sartori & Danesi, 2004). Enfält *et al.* (1997b) explained differences in lean meat content were due to slower growth rate of the outdoor pigs, which might be a consequence of feeding regimen or management. However, in several studies, no differences were found in lean meat content between housing systems (Van der Wal *et al.*, 1993; Lebret *et al.*, 2002; Gentry *et al.*, 2004).

Breed

Performance of L and D three-bred crosses was compared in Study III and IV. No general differences in daily weight gain and lean meat content between the breed crosses could be found in our studies. However, D has commonly been known to have inferior performance and carcass quality traits, compared with white breeds. In a recent study, Pommier *et al.* (2004) compared carcass quality of pure-bred D, L and H pigs, but no significant differences between breeds could be found. The similar carcass quality for white breeds and D might be attributed to the breeding progress. During the last years, the phenotypic lean meat content was improved by 0.3 percentage points per year for D in the breeding company, from which our sires originated (Norsvin, 2004). Even if breed and breed crosses affect carcass quality, feeding regimen and diet composition also affect these traits, as discussed earlier and also described by Affentranger *et al.* (1996).

Maternal feeding

In Study V, the hypothesis of extended muscle cell development and a subsequent improvement of growth performance and carcass quality as postulated by an English group (Dwyer, Fletcher & Stickland, 1993; Dwyer, Stickland & Fletcher, 1994; Stickland, 1994) could not be verified. Similar investigations in Denmark (Nissen *et al.*, 2003) and Ireland (Lawlor, pers. comm.) support our findings. However, Study V did show that heavy-born piglets had improved growth performance and carcass quality compared with light-born piglets, which might be explained by the higher fibre number in heavy-born piglets. A positive relation was reported between birth weight, muscle fibre number and piglet performance traits *e.g.* daily weight gain (Nielsen & Kring, 2002; Nissen, Jorgensen & Oksbjerg, 2004). Nissen, Jørgensen & Oksbjerg (2004) found that fibre number of light and middle-weighted piglets was similar, but heavy piglets had more fibres. Further, they found a smaller muscle fibre area for light piglets, whereas area of middle-weighted and heavy piglets was similar. These muscle fibre characteristics, *i.e.* higher muscle fibre number and larger cross-sectional area, were associated with general better growing performance and higher lean meat content.

Effect of rearing system, breed cross and maternal feeding on technological meat quality and chemical composition (Study I, II, III, IV and V)

Rearing system

In Study I, III and IV, technological meat quality traits in different rearing systems were investigated (Table 2). Meat quality measurements were applied on LD. In Study III and IV, the investigation of certain quality parameters was additionally applied on BF. It has to be considered that these muscles differ in muscle fibre composition and metabolism (Karlsson *et al.*, 1993).

In the presented studies, pH and FOP values were not consistent. It should be considered that these values depend more on slaughter conditions (Casteels *et al.*, 1995; Lebret, Lefaucheur & Mourot, 1999; Fernandez *et al.*, 2002; Terlouw, Astruc & Monin, 2004), expression of the RN^{-} allele (Le Roy *et al.*, 1990) and breed (Edwards *et al.*, 1992) than on reproductive status (Ellis *et al.*, 1996), weight at slaughter (Candek-Potokar *et al.*, 1998), housing system (Van der Wal *et al.*, 1993; Gentry *et al.*, 2002a) and fibre type (Gentry *et al.*, 2004). Olsson (2004) tabled results of several investigations on the effect of alternative rearing systems with increased spontaneous activity on muscle pH_u (Table 3).

Table 2. *Technological meat quality traits and chemical composition, measured in Study I, III and IV*

	Study I[1]			Study III[2]			Study IV[1]					
	indoor	outdoor		indoor	outdoor		indoor		outdoor			
			p-value			p-value	org. undil	conv	org. dil.	strat.	SE, pool.	p-value
ultimate pH_{LD}	5.44±0.02	5.46±0.01	0.378	5.34±0.01	5.32±0.01	**0.039**	5.52	5.51	5.53	5.50	0.021	0.630
ultimate pH_{BF}				5.44±0.01	5.43±0.01	0.408	5.65	5.62	5.63	5.59	0.029	0.096
FOP_{LD}	35.0±1.82	36.6±1.12	0.459	37.1±0.80	38.4±0.80	0.147	27.9	27.9	29.0	29.4	1.10	0.499
FOP_{BF}				36.6	39.3	¤	27.7^a	29.3^a	32.2^b	35.6^c	0.79	**0.001**
L*	46.9±1.05	47.8±0.40	0.435	50.0±0.4	49.3±0.4	0.104	47.8	47.9	47.1	47.5	0.44	0.192
a*	8.0±0.61	8.4±0.23	0.535	7.1	7.3	¤	6.1	6.1	6.1	6.3	0.18	0.861
b*	4.0±0.59	3.6±0.22	0.480	2.8±0.1	3.1±0.1	0.068	1.5^a	1.7^{ac}	2.0^{bc}	2.1^b	0.12	**0.001**
Water-holding capacity, %												
Drip loss	5.7±0.52	5.3±0.32	0.501	8.1	8.6	¤	4.1	4.9	4.2	4.9	0.35	0.104
Cooking loss				27.8±0.7	27.5±0.7	0.618	18.4	19.2	18.8	17.8	0.44	0.136
Warner $Bratzler_{LD}$												
Max. shear force, N	36.3±2.21	39.6±1.37	0.209	48.4±1.6	45.1±1.6	0.104	33.8^a	31.7^{ab}	28.1^b	27.6^b	1.83	**0.006**
Total work, Nmm	181.1±7.90	203.4±4.88	**0.021**	281.4±7.3	263.9±6.7	**0.046**	163.1	155.8	150.8	144.6	6.01	0.143
Chemical $composition_{LD}$, %												
intramuscular fat	1.8±0.19	2.4±0.12	**0.011**				1.64	1.55	1.58	1.70	0.095	0.579
Crude protein	24.0±0.38	23.3±0.24	0.108				23.0	23.1	22.9	23.1	0.15	0.725

[1] WHC and WB were measured on LD.

[2] WHC and WB were measured on BF.

¤ Interaction between breed cross/*RN* genotype and rearing system.

In Study IV, means with different superscript within a row differ significantly ($p<0.05$).

Table 3. *Effect of alternative rearing systems on muscle pH_u (Olsson, 2004), modified*

Study	Muscle	No effect on pH_u	Lower pH_u	Higher pH_u
Warriss, *et al.*, 1983	LD	X		
Gandemer *et al.*, 1990	LD	X		
Stecchini *et al.*, 1990	SM	X		
Jones, 1993	LD	X		
van der Wal *et al.*, 1993	LD	X		
Dufey, 1995	LD	X		
Sather *et al.*, 1997	LD	X		
Bridi *et al.*, 1998	LD	X		
Hansen *et al.*, 2001	LD	X		
Gentry *et al.*, 2000	LD	X		
Lebret *et al.*, 2002	SM	X		
Study III, 2003	BF	X		
Study IV, submitted	LD, BF	X		
Barton-Gade & Blaabjerg, 1989	LD		X	
Gandemer *et al.*, 1990	AD		X	
Enfält *et al.*, 1997	LD		X	
Sather *et al.*, 1997	SM		X	
Nilzén *et al.*, 2001	BF		X	
Study III, 2003	LD		X	
Millet *et al.*, 2003	LD		X	
Olsson *et al.*, 2003	LD		X	
Lambooij *et al*, 2004	LD		X	
Lindahl & Karlsson, 2004	LD			X

The influence of rearing system on colour values in the presented studies was low. Ellis *et al.* (1996) hypothesised that colour is more related to pH than to rearing conditions, which supports our findings. Nonetheless, L* values are found to most depend on pigment content and myoglobin forms and only to a lesser extent on pH values (Lindahl, Lundström & Tornberg, 2001). Generally, outdoor rearing is related to darker/redder meat and higher pigment content (Warriss, Kestin & Robinson, 1983; Petersen *et al.*, 1997; Bridi, Müller & Ribeiro, 1998; Gentry *et al.*, 2002b; Millet *et al.*, 2003; Lindahl & Karlsson, 2004), even if pH values in these studies were sometimes unaffected. Higher pigment content in the meat might also be a consequence of increased capillarisation of the muscle due to higher activity of outdoor raised pigs (Essén-Gustavsson & Jensen-Waern, 1993).

In Study III, outdoor raised pigs, which were RN^{-} carriers, had a significantly higher a* value than indoor raised RN^{-} carriers and indoor and outdoor raised non-carriers. This is in accordance with a recent study by Olsson *et al.* (2003).

Outdoor pigs of [(LW*L)xH] breed cross (Study III) had higher drip loss values, compared with indoor pigs of the same breed cross. Otherwise, no differences in water-holding capacity between the rearing systems could be found. Some studies reported decreased WHC in meat from alternative rearing systems

(Enfält *et al.*, 1997b; Sather *et al.*, 1997; Gentry *et al.*, 2002a; Olsson *et al.*, 2003), whereas others found no effect of outdoor rearing on WHC (Warriss, Kestin & Robinson, 1983; Van der Wal *et al.*, 1993; Gentry *et al.*, 2002b; Millet *et al.*, 2003). These inconsistent results show that exclusively rearing system had no general effect, but more factors are probably involved in WHC *e.g.* slaughter conditions (temperature and pH development and final pH), chemical composition (protein/water/glycogen content), exercise of the pig and diet composition.

The effect of rearing conditions on Warner-Bratzler shear force values was not consistent in our studies. In other studies, shear force was reported to be higher in outdoor rearing systems (Enfält *et al.*, 1997; Olsson *et al.*, 2003), whereas no effect of the rearing system was found by Bridi, Müller & Ribeiro (1998). Gentry *et al.* (2002b) reported lower shear force values for outdoor raised pigs. Tornberg (1996) described WB shear force in relation to the contraction of muscle fibres. In raw meat shear force decrease significantly with increasing contraction, but is reverse when meat is cooked to 60°C. Therkildsen *et al.* (2002) reported improved tenderness in fast-growing pigs with a high protein turnover. A higher protein turnover might explain the lower shear force for initially faster growing outdoor pigs in Study III. However, in Study IV, indoor pigs grew faster, but had higher maximal shear force values the second year.

In Study I, significantly higher IMF for outdoor reared once-bred gilts compared with indoor reared maiden gilts was found which might be due to their higher age and weight at slaughter. With higher age, composition of meat changes towards higher IMF in the meat (Warkup & Kempster, 1991; Candek-Potokar *et al.*, 1998; Weatherup *et al.*, 1998). Chemical composition in outdoor reared pigs in comparison to indoor reared pigs is little discussed in literature. Generally, higher crude protein and lower water/protein ratio in extensively reared pigs have been reported (Dworschák *et al.*, 1995; Enfält *et al.*, 1997b). Enfält *et al.* (1993) measured lower IMF in BF in exercised pigs. Comparing rearing systems, Olsson *et al.* (2003) found lower IMF in LD in outdoor raised pigs than in indoor raised pigs.

Breed

Technological meat quality for different breed crosses was compared in Study II and IV. Generally, no apparent differences could be found between Duroc-sired and Landrace-sired once-bred gilts or growing/finishing pigs. However, WHC was better in meat from Duroc breed crosses, compared to Landrace breed crosses. This finding contradicts other studies, where no changes in WHC were observed (Martel, Minvielle & Poste, 1988; Oliver *et al.*, 1994). Blanchard *et al.* (1999b) found that an increased proportion of Duroc genes in the growing/finishing pig did not change WHC. Further, the authors reported that increasing proportion of D decreased shear force values. The Duroc breed is commonly known to have darker/redder meat (Cameron *et al.*, 1990; Oliver *et al.*, 1994), higher pH values, enhanced tenderness and higher IMF (MLC, 1992) compared with white breeds. In our studies, only small differences in technological meat quality except significantly better WHC of the Duroc breed cross could be found compared with the Landrace breed cross, which might be a consequence of the breeding progress during the last years. Meat quality traits are included in the breeding goal of the company from which our Duroc sires derived from (Norsvin, 2004). Decreasing IMF is one breeding goal, to increase consumer acceptance. An undesired increase in shear force and consequently increased toughness might be the consequence.

Maternal feeding

Differentiated extra maternal feeding during early gestation did not affect technological meat quality traits. This result was not unexpected, because only slight effects were found in piglet or growing /finishing pig performance. A similar Danish study, where sows during early gestation received a standard diet restrictively (control) or *ad libitum* corroborates our finding that maternal feeding did not affect technological quality traits (Nissen *et al.*, 2003).

Effect of rearing system and breed cross on sensory meat quality (Study I and II)

Rearing system

Sensory meat quality was comparable between indoor reared maiden gilts and outdoor reared once-bred gilts, except for a higher juiciness and a slightly increased stringiness and salinity for the once-bred gilts. Juiciness can be interpreted as a favourable trait, whereas stringiness and salinity is not considered to impair the sensory quality. The effects of rearing environment on juiciness, tenderness and flavour characteristics are widely discussed in literature (Enfält *et al.*, 1997b; Bridi, Müller & Ribeiro, 1998; Jonsäll, Johansson & Lundström, 2001). Enfält *et al.* (1997b) and Jonsäll, Johansson & Lundström (2001) reported a higher juiciness and a higher all-over acceptance of indoor reared pigs, whereas Bridi, Müller & Ribeiro (1998) found no differences between indoor and outdoor rearing systems.

Breed

In Study II, only slight differences between the breed crosses on sensory meat quality could be found. Cured and smoked SMA from LW*L, but not oven baked LD tended to be juicier, compared with LW*D. In the literature, Duroc and Duroc crosses are generally discussed to have more tender and juicier meat (Barton-Gade, 1988; Cameron, 1990; Blanchard *et al.*, 1999b). In both Study I and II, it has to be considered that not exclusively rearing system or breed cross, but several other factors *i.e.* different age and carcass weight, different feeding regimens, IMF, pH value and shear force might have contributed to the final sensory quality.

Concluding remarks

The results of this thesis show that rearing system influenced growing/finishing pig performance and carcass quality more than technological and sensory meat quality. Daily weight gain was higher for outdoor raised growing/finishing pigs when born and reared outdoors, but higher for indoor growing/finishing pigs when born and reared indoors. This indicates the environmental influence during early life on later growing performance. Technological meat quality of indoor and outdoor raised growing/finishing pigs was not consistent in the studies, not even between years within the same study. The effect of year, including different climate conditions and probable changes in management can have a great impact, especially, on the results for outdoor rearing systems. An important finding of this study was that dilution of the diet with roughage decreased daily weight gain for growing/finishing pigs. Therefore roughage supply in organic pig production, as recommended by the EU regulation, might be questioned. Inferior production performances are followed by a higher environmental loading regarding N and P (Fernández, 2004), whereas the assumed improvement of animal welfare traits might contribute to a higher consumer acceptance and purchase. To stimulate natural pig behaviour, less expensive roughage such as straw should be used.

Seasonal outdoor rearing of once-bred gilts resulted in good carcass, technological and sensory meat quality, which indicated that this system is a suitable alternative for pig production. However, it has to be considered that the price of the once-bred gilts' carcasses has to be appropriate if this system is to be profitable.

Breed cross only slightly influenced sow performance, growing/finishing pig performance, technological and sensory meat quality. Duroc-sired once-bred gilts were considered to be more robust, whereas Landrace-sired once-bred gilts showed better maternal performance. The Duroc-sired growing/finishing pigs had better growth performance. However, only small differences in technological meat quality except significantly better WHC in the Duroc breed cross could be found compared with the Landrace breed cross. This might be explained by the breeding progress for the Duroc breed, which has adapted the technological meat quality to a similar level as for the white breeds. Genotype/environment interactions should be considered when comparing outdoor and indoor rearing systems. Modern breeds are adapted to indoor requirements through breeding and selection over generations and might still not be optimal for outdoor conditions. New breeding goals towards an adapted organic pig could support organic pig production.

Extra maternal feeding during early gestation did not considerably affect either sow and piglet performance or technological meat quality of the progeny. However, undernutrition during early gestation resulted in smaller litter size but did not influence either piglet birth weight or variation of birth weight. A further finding was that piglet birth weight significantly affected later performance, but not technological meat quality.

When comparing rearing systems, it has to be considered that not only housing system (*i.e.* indoors vs. outdoors) is the decisive and exclusive factor affecting performance and quality results. Other factors such as different feeding regimens (*ad libitum* vs. restrictive), different diets (conventional vs. organic), roughage supply, status of maternal maturity and different weight and age at slaughter are involved in the rearing system. A change of one factor might significantly influence several others and the performance and quality results might change. Therefore, a general conclusion of an optimised rearing system cannot be drawn.

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German summary/Deutsche Zusammenfassung

Im Jahre 2003 stammten 204.000 Sauen und 3,2 Millionen Mastschweine aus konventioneller Aufzucht, jedoch lediglich 1.000 Sauen und 21.000 Mastschweine aus ökologischen Haltungssystemen. Damit macht die ökologische Schweinehaltung und Fleischerzeugung nur einen geringen Teil der gesamten Schweineproduktion Schwedens aus. Die Tendenz ist sinkend.

Dennoch gibt es ein steigendes Interesse an neuen ökologischen Produktionsformen. Dies kann auf mehrere Faktoren zurückgeführt werden:

- die staaliche Zielsetzung der schwedischen Regierung, ökologische Fleischproduktion zu steigern,
- kontinuierliche Veränderungen und Neuregelungen in der Schweineproduktion,
- ein steigendes Verbraucherinteresse an artgerechter Tierhaltung und ökologisch erzeugten Fleischprodukten.

Ein ökologisches Schweinehaltungssystem sollte den Anforderungen hoher Produktivität bei gleichzeitig hoher Schlachtkörper- und Fleischqualität entsprechen.

Ziel dieser aus fünf Studien bestehenden Arbeit war der Vergleich konventioneller und ökologischer Schweinehaltungssysteme bezüglich des Aufzucht- und Mastleistungsvermögens sowie der Schlachtkörper- und Fleischqualitätsmerkmale.

In zwei Studien wurde eine Haltungsform, bei der mit Hampshire (H) belegte Jungsauen ab dem Frühjahr im Freien gehalten und vor dem Winter mit ihren Nachkommen geschlachtet werden, untersucht. In der ersten Studie wurde die generelle Nutzungmöglichkeit dieses Produktionssystemes sowie die Schlachtkörper- und Fleischqualität der Jungsauen ermittelt. In der zweiten Studie wurden die in diesem Produktionssystem eingesetzten Rassenkreuzungen (Large White*Schwedische Landrasse (LW*L)) und (Large White*Duroc (LW*D)) hinsichtlich des mütterlichen Produktions- und Aufzuchtsleistungsvermögens sowie der mütterlichen Schlachtkörper- und Fleischqualität verglichen. Die Nachkommen der Jungsauen ([(LW*L)xH] und [(LW*D)xH]) wurden in einem Freiland- und einem Stallhaltungssystem gemästet. In dieser dritten Studie wurde das Wachstumsvermögen, sowie die Schlachtkörper- und Fleischqualität der Mastschweine untersucht. In einer vierten Studie wurden verschiedene Fütterungsstrategien (strategisch/*ad libitum*/restriktiv), Futtermittel (mit Rauhfutter gestreckt/ungestreckt; konventionell/ökologisch) und Rassen (LW*L/ LW*D) in einem Stall- und einem Freilandhaltungssystem verglichen. Das Anliegen einer fünften Studie waren die Untersuchungen über die Auswirkung von hohen Futtermengen für niedertragende Alt- und Jungsauen (25. bis 85. Tag der Trächtigkeit) auf das Aufzuchtsleistungsvermögen der Mütter und auf die Mastleistung, Schlachtkörper- und Fleischqualität der Nachkommen.

Die Ergebnisse der ersten beiden Studien wiesen auf eine gute Nutzungsmöglichkeit der Jungsauen für die auf den Sommer beschränkte Freilandhaltung hin. Es wurde eine gute Schlachtkörper- und Fleischqualität erzeugt. Die Sauen der Rassenkreuzung LW*L hatte mehr Absetzferkel und einen höheren Fleischanteil im Schlachtkörper, LW*D erzeugte jedoch Nachkommen mit höheren täglichen Zunahmen. Die sensorische Fleischqualität der Herkünfte unterschied sich unwesentlich. Die Ergebinsse konnten so interpretiert werden, daß keine der Rassenkreuzungen sich als besser einsetzbar oder vorteilhaft für dieses Produktionssystem erwies.

In der dritten Studie wurden bei Mastschweinen aus Freilandhaltung höhere tägliche Zunahmen und ein höherer Fleischanteil gemessen, als bei im Stall gehaltenen Mastschweinen. Die Rassenkreuzung sowie das Geschlecht hatten keinen Einfluß auf die untersuchten Fleischqualitätsparameter.

Im Gegensatz zu der dritten Studie, zeigten die Untersuchungen der vierten Studie, daß die im Stall gehaltenen, ökologisch gefütterten Mastschweine höhere täglische Zunahmen und bessere Futterverwertung aufwiesen als die im Freiland gehaltenen Mastschweine. Dieser Widerspruch bei den Zuwachsraten in Stall- und Freilandhaltung kann mit den unterschiedlichen Aufzuchtsystemen der Ferkel begründet werden. Die Ferkel der dritten Studie wuchsen in Freilandhaltung auf, die Ferkel der vierten Studie in Stallhaltung. Bei Mastbeginn verursachte der Wechsel aus dem gewohnten Milieu für die Ferkel eine kurzzeitige Zuwachsminderung. Die strategische Fütterung der vierten Studie, mit anfänglich gestrecktem Futter und in der Endmast konzentriertem Futter erhöhte die täglichen Zunahmen, im Vergleich zu der Mast mit ausschließlich gestrecktem Futter. Der im ersten Versuchsjahr gefundene niedrigere pH- und höhere FOP-Wert im Fleisch der im Stall gehaltenen Mastschweine konnte im darauffolgenden Jahr nicht wiederholt gemessen werden. Die Schlachtkörperqualität unterschied sich zwischen den Rassenkreuzungen nicht, jedoch hatte LW*D gegenüber LW*L eine leicht verbesserte technologische Fleischqualität.

Die fünfte Studie zeigte, daß die Verabreichung hoher Futtermengen in der Frühphase der Trächtigkeit positive Auswirkungen auf die Wurfgröße bei Altsauen hatte, jedoch nicht bei Jungsauen. Hohe Futtermengen während der Trächtigkeit hatten negativen Einfluß auf die tägliche Zunahme der Nachkommen. Schlachtkörper- und technologische Qualität der Mastschweine wurden nicht beeinflußt. Ein positiver Zusammenhang zwischen Ferkelgeburtsgewicht und Zuwachsrate sowie Schlachtkörperqualität wurde festgestellt. Die technologische Fleischqualität der Mastschweine blieb vom Geburtsgewicht unbeeinflußt.

Die Ergebnisse der Studien dieser Arbeit ergaben, daß das Aufstallungssystem (Stallhaltung/Freilandhaltung) isoliert betrachtet, nur geringfügig das Aufzucht- und Mastleistungsvermögen sowie Schlachtkörper- und Fleischqualitätsmerkmale beeinflußt. Dahingegen standen alle Produktionsfaktoren eines Haltungssystems (Aufstallungssystem, Rassenkreuzung, Fütterungsstrategie, Futtermittel, Schlachtgewicht, Schlachtalter) in Wechselwirkung und zeigten Auswirkungen auf die untersuchten Produktionsparameter.

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Carcass Quality and Technological and Sensory Meat Quality of Once-bred Gilts in a Seasonal Outdoor Rearing System

Heyer, A., Andersson, H. K., Rydhmer, L., Lundström, K. (Departments of Food Science, Animal Nutrition and Management, and Animal Breeding and Genetics, Swedish University of Agricultural Sciences, PO Box 7051, SE-750 07 Uppsala, Sweden). Carcass quality and technological and sensory meat quality of once-bred gilts in a seasonal outdoor rearing system. Accepted June 29, 2004. Acta Agric. Scand., Sect. A, Animal Sci. 54: 103–111, 2004. © 2004 Taylor & Francis.

Seasonal application of once-bred gilts for piglet and meat production outdoors could be a worthwhile alternative rearing form to normal commercial production. Compared with growing/finishing pigs, payment for sow carcasses is considerably reduced because of an assumed decrease in meat quality and processing properties. The purpose of this study was to compare maiden and once-bred gilts for carcass quality, and technological and sensory meat quality. The control group of 14 gilts (LW*L and LW*D) was reared indoors and slaughtered unmated at an average live weight of 145 kg. In contrast, 38 once-bred gilts of the same breeds were initially reared like the maiden control, inseminated and then housed outdoors from one month before farrowing until slaughter. Carcass traits, technological meat quality (pH, internal and surface reflectance, water holding capacity, commercial processing yield (total yield) and laboratory processing yield (Napole yield), WB shear force and chemical composition of *M. longissimus dorsi* were measured. Sensory meat quality (taste panel) of oven-baked *M. longissimus dorsi* and cured and smoked *M. semimembranosus et adductor* was investigated. Carcass quality traits such as higher lean meat content and lower backfat thickness were preferable with the once-bred gilts. For technological meat quality characteristics, once-bred gilts had lower thawing loss, Napole yield, dry matter and higher total work of WB shear force and intramuscular fat, compared to maiden gilts. In general, sensory meat quality was comparable between the two groups. In processed meat only, once-bred gilts had higher juiciness and salinity and unfavourable increased stringiness, compared to maiden gilts. Thus, once-bred gilts produce valuable carcasses and are suitable for an outdoor seasonal rearing system.

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Introduction

In Sweden, outdoor rearing of sows is an alternative to the common indoor piglet production, but is limited by the cold climate in winter. A new concept for piglet production proposes outdoor rearing of once-bred gilts and their litters during the summer period and slaughter of all pigs at the end of the season. The cost for this rearing concept differs from the conventional indoor rearing systems in savings in stable and feed costs during winter and higher costs for recruitment gilts in the following season. The assumed lower meat quality and yield in further processing of meat from sows which have farrowed once or more, often results in considerably reduced payments for sow carcasses by the slaughterhouse, compared to growing/finishing pigs. Sows after several parities have unfavourable carcass qualities such as low lean meat content and high weight due to their age (Lebret et al., 1999). Technological and sensory meat qualities are also impaired, e.g. changes in chemical composition towards a higher intramuscular fat content and tougher meat (Ellis et al., 1996a). Nevertheless, sows that have farrowed only once may still have an acceptable carcass quality, which differs only slightly from gilt carcasses (MacPherson et al., 1977). The differences between sensory and technological meat quality traits of once-bred and maiden gilts are rarely described in the literature. If once-bred gilts produce carcasses with high overall quality, seasonal outdoor production of pork might be a good alternative system for northern countries with cold winters. The production results, carcass and technological meat quality traits for the progeny of the once-bred gilts described in this study were published elsewhere (Stern et al., 2003).

The aim of this study was to investigate a concept of outdoor rearing system of once-bred gilts during summer with regard to carcass quality, technological and sensory meat quality.

Material and methods

Animals

This experiment was performed on 52 gilts (22 Large White × Swedish Landrace (LW*L) and 30 Large White × Duroc (LW*D)) during two years. All animals were reared indoors and given a rearing diet (Table 1) *ad libitum* up to a live weight of 90 kg and thereafter restrictedly according to standard feeding regimen for growing/finishing pigs in Sweden (Andersson et al., 1997). The control group, 7 LW*L and 7 LW*D gilts, remained indoors and unmated, and received the rearing diet until slaughter up to a live weight of 145 kg at an age of 234 days (SD 14). Littermates

Table 1. Composition and calculated nutrient content of the diets

	Maiden and once-bred gilts	Once-bred gilts			
	Rearing	Gestation	Lactation	After weaning 1st year	After weaning 2nd year
Ingredients, %					
Barley	67.00	9.24	23.45	17.72	23.45
Wheat	–	5.38	36.00	43.23	36.00
Oats	–	29.57	–	–	–
Wheat bran	–	10.00	–	–	–
Rye wheat	–	32.86	4.69	–	4.69
Rapeseed meal	7.05	8.89	15.00	13.73	15.00
Yellow peas	20.00	–	17.34	21.73	17.34
Feed fat	1.84	–	–	–	–
Limestone	0.51	1.45	0.89	0.92	0.89
NaCl	0.40	0.45	0.45	0.44	0.45
Dicalcium phosphate	1.95	1.16	1.18	1.23	1.18
L-lysine·HCl (78%)	0.16	–	–	–	–
DL-methionine (99%)	0.06	–	–	–	–
Vitamin and mineral premix	1.00	1.00	1.00	1.00	1.00
Calculated nutrient content					
ME, MJ/kg	12.4	11.3	12.0	12.0	12.0
CP, %	16.0	13.6	17.0	17.7	17.0
Lysine, digestible, %	0.72	0.44	0.70	0.72	0.70

(15 LW*L and 23 LW*D) to the maiden gilts received a rearing diet until insemination with Hampshire semen at an age of 251 days (SD 19). After insemination, all mated gilts received a gestation diet (30 MJ ME/day, Table 1) and were housed outdoors from one week before farrowing. The mated gilts farrowed in farrowing huts in individual enclosures in five batches (April, May and June 1999; April and May 2000). The once-bred gilts and piglets were moved to one large enclosure approximately three weeks after farrowing, where they remained until the piglets were weaned at an age of 9 weeks. A lactation diet (Table 1) was fed in a trough according to a norm based on litter size. The ratio was, however, increased, as the piglets started to consume large amounts of feed. After weaning, the once-bred gilts in the first year received a rearing diet (Table 1). During this period the sows were fed twice per day according to their voluntary feed intake. In the second year, they were fed the lactation diet restrictedly (4 kg/day). The once-bred gilts were slaughtered two to three weeks after weaning (slaughter age 446 days, SD 25).

Carcass traits, technological and sensory meat quality

All animals were slaughtered at a commercial slaughterhouse, after 10 km transport and at least 2 h of lairage in the abattoir. One day after slaughter, carcass weight was recorded. Backfat thickness was measured over the *M. longisimus dorsi* (LD), just behind the last rib. Ham and loin of the right carcass half were weighed with skin and fat, then defatted and weighed again as meat and bone. Five ham muscles (*M. semimembranosus et aductor* (SMA)*, M. semitendinosus* (ST)*, M. quadriceps* (QUA)*, M. gluteus* (GLU) and *M. biceps femoris* (BF)) were dissected and weighed separately. Lean meat percentage was estimated according to $[-49.672+(1.012^{*}\%$ ham in carcass$)+(0.622^{*}\%$ meat and bone in ham$)+(0.667^{*}\%$ loin in carcass$)+(0.2^{*}\%$ meat and bone in loin$)]$ (I. Hansson, pers. comm.).

Technological meat quality traits were measured on samples of LD taken at the last rib and backwards approximately 24 h after slaughter. Ultimate pH (portable pH-meter, Knick, Berlin, Germany; equipped with a combination gel electrode SE104, Knick, Berlin, Germany) and internal reflectance, using a fibre optic probe (FOP, 900 nm; TBL Fibre Optics Group Ltd., Leeds, UK) were measured. Surface reflectance with the parameters L* (lightness), a* (redness) and b* (yellowness) was measured, using a Minolta colorimeter (Minolta Chroma Meter CR 300, DP-301, Osaka, Japan). Water holding capacity was determined as drip loss on a 2-cm-thick slice of LD, stored horizontally for 3 days at 4°C (Barton-Gade et al., 1994) and thawing loss as weight difference of frozen and defrosted SMA. For the processing yield, brine absorption during immersion of SMA, the commercial processing yield (total yield; weight difference of unprocessed and cold cured warm-smoked SMA) and laboratory processing yield (Napole yield) on LD, according to Naveau et al. (1985) and modified as described by Lundström et al. (1996) were measured. Maximal shear force and total work of Warner-Bratzler (WB) were measured on 8 strings (10 × 10 × 50 mm), sheared across the fibre direction (speed: 55 mm/min) of cooked LD (internal temperature: 70°C, TA-HDI texture Analyser; Stable Micro Systems, Surrey, UK) (Honikel, 1998). Chemical composition of the LD was determined as intramuscular fat (IMF), crude protein, ash and dry matter. The fat content was analysed after hydrolysis, using petroleum ether for extraction (Soxtec System H^{+} equipment, Tecator AB, Höganäs, Sweden). Crude protein was analysed with the Kjeltec apparatus (Tecator AB, Höganäs), using factor 6.25 for calculating proportion of the protein content. Dry matter was determined after drying at 105°C for 16–18 h, and the samples were then heated in an ash oven at 550°C to determine ash content.

Sensory meat quality was determined on oven-baked LD of 6 maiden gilts and 20 once-bred gilts (all animals of the first year) and cured and smoked SMA of 8 maiden gilts and 18 once-bred gilts (all animals of the second year) by a trained taste panel. Oven-baked LD was prepared at 150°C oven temperature and 68°C internal meat temperature. SMA (frozen after cutting and thawed before processing) underwent a commercial processing of curing and warm smoking (10% sodium chloride brine, injected with needles and immersion in brine for 24 h, no tumbling; smoking temperature of 65°C for 12 h). Tenderness, juiciness and fat flavour were determined on both LD and SMA, acidity and meat flavour solely on LD and smoke flavour, stringiness and salinity solely on SMA. The scale for the taste characteristics scored from 1 = very low intensity of the character to 100 = very high intensity.

Statistics

Statistical analyses were performed with the GLM or MIXED procedure in SAS (SAS Institute Inc., Cary, N.C., USA, versions 8.2). Data given in the tables are least square means and standard errors. The model included reproductive status (maiden/once-bred gilts), breed cross (LW*D or LW*L) and year as fixed factors. Interactions were included, when significant ($P < 0.05$). For statistical analyses of sensory meat quality, taste panel member and individual pig were included in the model as random effects. Least square means were considered to be statistically significant when $P < 0.05$.

Results

Carcass quality traits

The maiden gilts were slaughtered at an age of 234 days and a carcass weight of 121 kg (Table 2). For the once-bred gilts, corresponding values were 446 days and 146 kg. For carcass weight an interaction ($P = 0.013$) between rearing system and breed was found. Once-bred gilts of LW*D had higher carcass weight than LW*L once-bred gilts (153.5 vs. 137.8 kg; $P = 0.001$), whereas there was no breed difference for maiden gilts (118.6 vs. 123.4 kg; $P = 0.481$). Lean meat content, proportion of ham in carcass and percentage meat and bone in ham and loin were significantly higher in once-bred than maiden gilts (Table 2). The proportion of SMA in the ham was lower in once-bred than in maiden gilts, whereas the proportion of QUA was higher in once-bred gilts. For BF in the ham, rearing system and breed showed an interaction ($P = 0.035$), where LW*L maiden gilts had a higher proportion than the once-bred gilts (28.9 vs. 27.8%; $P = 0.004$), whereas no differences between maiden and once-bred gilts of LW*D could be found (28.2 vs. 28.2%; $P = 0.924$). Further interactions between rearing system and breed for carcass, technological and sensory meat quality were found to be non-significant ($P > 0.05$).

Technological meat quality

pH, internal and surface reflectance, drip loss, total yield (commercial processing yield) and maximal shear force did not differ between once-bred and maiden gilts (Table 3). The total work of WB shear force measurement of meat from once-bred gilts was 22 Nmm higher, compared to the maiden gilts. Thawing loss and Napole yield (laboratory processing yield) were significantly lower in meat from once-bred than from maiden gilts. The intramuscular fat content in LD was 0.6 percentage points higher in once-bred than in maiden gilts, whereas dry matter was 1.1 percentage points lower.

Sensory meat quality

Oven-baked LD of once-bred and maiden gilts was equally scored in the sensory meat quality test (Fig. 1). Meat from once-bred gilts tended to be juicier than in maiden gilts according to the taste panel ($P = 0.07$). Cured and smoked SMA of once-bred gilts scored higher in juiciness, stringiness and salinity than SMA of maiden gilts.

Table 2. Carcass quality traits and ratio of different ham muscles of maiden and once-bred gilts, least square means (LSM) and standard errors (SE)

	Maiden gilts ($n = 14$)		Once-bred gilts ($n = 38$)		
	LSM	SE	LSM	SE	*P*-value
Carcass weight, kg	120.9	3.54	146.3	2.19	0.001 ϕ
Estimated meat percentage, %	51.5	0.63	55.0	0.39	0.001
Backfat thickness, mm	23.2	1.31	19.4	0.83	0.018
Ham in carcass, %	29.1	0.33	30.3	0.20	0.004
Meat and bone in ham, %	75.3	0.65	77.8	0.40	0.002
Loin in carcass, %	16.2	0.25	16.5	0.15	0.398
Meat and bone in loin, %	70.6	0.99	73.8	0.61	0.008
Proportion of muscles in ham[1]					
SMA[2], %	26.2	0.27	25.4	0.16	0.016
ST[3], %	8.2	0.15	8.5	0.09	0.088
QUA[4], %	20.1	0.24	21.0	0.15	0.006
GLU[5], %	17.0	0.29	17.1	0.18	0.604
BF[6], %	28.5	0.21	28.0	0.13	0.043 ϕ

ϕ: Interaction between rearing system and crossbreed was found; see text.

[1] Calculated without skin and bone.

[2] SMA: *M. semimembranosus et aductor.*

[3] ST: *M. semitendinosus.*

[4] QUA: *M. quadriceps.*

[5] GLU: *M. gluteus.*

[6] BF: *M. biceps femoris.*

Table 3. Technological meat quality and chemical composition of muscles from maiden and once-bred gilts, least square means (LSM) and standard errors (SE)

	Maiden gilts		Once-bred gilts		
	LSM	SE	LSM	SE	*P*-value
pH$_{LD}$	5.44	0.02	5.46	0.01	0.378
FOP$_{LD}$	35.0	1.82	36.6	1.12	0.459
Minolta value$_{LD}$	46.9	1.05	47.8	0.40	0.435
L*	46.9	1.05	47.8	0.40	0.435
a*	8.0	0.61	8.4	0.23	0.535
b*	4.0	0.59	3.6	0.22	0.480
Water holding capacity					
Drip loss$_{LD}$, %	5.7	0.52	5.3	0.32	0.501
Thawing loss$_{SMA}$, %	10.7	0.75	7.8	0.57	0.005
Processing yield					
Brine immersion$_{SMA}$, %	13.1	1.23	15.4	0.92	0.160
Total yield$^{1}_{SMA}$, %	98.2	0.99	98.6	0.74	0.699
Napole yield$^{2}_{LD}$, %	91.9	0.77	85.3	0.48	0.001
Warner-Bratzler					
Max. shear force, N$_{LD}$	36.3	2.21	39.6	1.37	0.209
total work, Nmm$_{LD}$	181.1	7.90	203.4	4.88	0.021
Chemical composition$_{LD}$					
Intramuscular fat, %	1.8	0.19	2.4	0.12	0.011
Crude protein, %	24.0	0.38	23.3	0.24	0.108
Dry matter, %	26.1	0.21	25.0	0.13	0.001
Ash, %	1.1	0.05	1.0	0.03	0.125

[1] Commercial yield during ham production.
[2] Laboratory processing yield.

Discussion

The purpose of this study was to compare maiden and once-bred gilts in carcass quality, technological and sensory meat quality traits. It has to be mentioned that not only the reproductive status (maiden/once-bred), but the whole rearing system might contribute to differences between these pigs. Thus, also the effects of housing system (indoor/outdoor), weight and age at slaughter are included in this discussion.

Carcass quality

In once-bred gilts, gestation, farrowing, lactation and post-weaning fattening period imply large changes in metabolism and consequently changes in body composition, because energy and protein supply are used for both reproduction and own growth. MacPherson et al. (1977) and Brooks & Cole (1973) reported leaner carcass for once-bred gilts than gilts. In a similar trial, comparing sows (live weight 150 kg; slaughtered 24 days after weaning) with gilts (live weight 130 kg), Kotarbinska & Kielanowski (1973) reported a lower backfat thickness, but also a slightly smaller area of loin for the sows. In another study, the finding of smaller area of loin for the sows was confirmed (Ellis et al., 1996a). Håkansson et al. (1982) stated that slaughter directly after weaning results in poor carcass quality and low-grade cutting characteristics. In the present study, the lower backfat thickness and leaner carcass of the once-bred gilts could be explained by the long lactation, when fat reserves were depleted. The short fattening period thereafter was insufficient to recover the fat reserves. It could not be determined how much the influence of reproductive status on carcass quality interacted with lactation intensity, lactation length and post-weaning period.

In the present study, the once-bred gilts were 212 days older and 26 kg heavier at slaughter than the maiden gilts. A negative influence of carcass weight on carcass quality traits was previously reported by Beattie et al. (1999), Candek-Potokar et al. (1998) and Weatherup et al. (1998). In these trials, a higher amount of fat and less lean meat in the heavier carcasses were observed, which was in contrast to our results. However, in the latter trials, the carcass weight ranged from 70 to 100 kg, which is not comparable to the carcass weights of 146 kg in the present study. The influence of such a high carcass

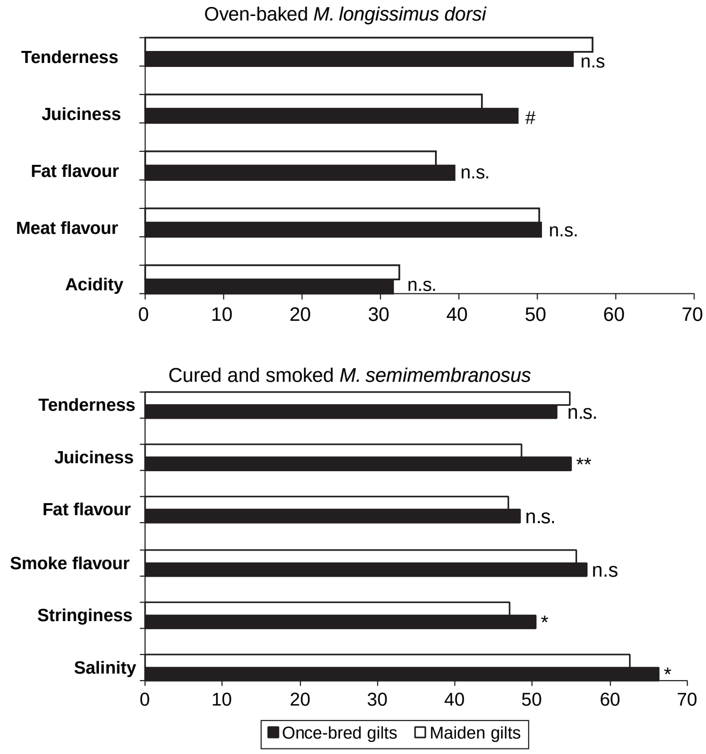

Fig. 1. Sensory meat quality of oven-baked *M. longissimus dorsi* and cured and smoked *M. semimembranosus*. Levels of significance: n.s. = $P > 0.10$, # $P < 0.10$, ** $P < 0.01$, * $P < 0.05$.

weight on carcass quality is not described in the literature. In the present study, the heavier once-bred gilts had, compared to the lighter maiden gilts, a decreased backfat thickness and a higher lean meat content. The leaner carcass might depend on, as earlier discussed, a long suckling period and a short post-weaning time for fat deposition.

The housing of pigs in indoor and outdoor conditions might have influence on carcass quality traits. Stern et al. (2003) reported that outdoor reared growing/finishing pigs with similar feed intake had higher lean meat content than the indoor reared pigs. This result of higher lean meat content in the outdoor reared growing/finishing pigs was confirmed in the present study with once-bred gilts. The feed was, however, restricted from a live weight of 90 kg and the full growth ability of the once-bred gilts could probably not be expressed. Thus, the outdoor environment of the once-bred gilts might have made them leaner than they would have been if kept indoors with the same feed intake. Whether the housing system (indoor/outdoor) strongly affected carcass quality or just assisted the general effects of the rearing system, including housing system, feeding regimen, maturity status and slaughter weight has to be questioned.

Technological meat quality

Measurements of pH, FOP value and colour indicated similar meat quality between maiden and once-bred gilts. This is in accordance with earlier studies, which consider that pH and FOP values depend more on slaughter conditions (Casteels et al., 1995; Lebret et al., 1999; Fernandez et al., 2002) and breed (Edwards et al., 1992), than on reproductive status (Ellis et al., 1996a), weight at slaughter (Candek-Potokar et al., 1998), or housing system (van der Wal & Mateman, 1993; Stern et al., 2003). Likewise, colour was not influenced by the reproductive status, which corroborates the findings of another study (Ellis et al., 1996a). The authors hypothesised that changes in colour are more closely related to the pH value than to rearing effects. Drip loss did not differ between once-bred and maiden gilts in the present study. The drip loss of 5–6% is comparable to values of indoor reared growing/ finishing pigs from the same site (Heyer et al., 2004), but is lower than the drip loss values from the progeny (Stern et al., 2003). Drip loss probably depends more on slaughter condition and subsequent changes in ultimate pH than on reproductive status. Støier et al. (2001) found significantly lower drip loss in low-stress stunned pigs than in traditionally stunned pigs, which might be the consequence of the significantly higher ultimate pH level. However, higher thawing loss and also higher Napole yield were found in the maiden than in once-bred gilts in the present study, though pH and FOP values were similar between the rearing systems. The higher thawing loss in SMA from maiden gilts could possibly be explained by the lower muscle weight and consequently greater surface, giving higher meat juice leakage. Higher Napole yield might be due to the higher protein and dry matter contents of those pigs. However, the higher Napole yield for maiden gilts measured on LD under laboratory conditions was not consistent with the total yield, measured on SMA under current processing conditions, which was similar between maiden and once-bred gilts. The similarity in total yield may be because of the use of thawed meat for processing, where higher previous water lost during thawing in maiden gilts might have led to a decrease in total yield.

Higher IMF, lower dry matter and a tendency of lower crude protein and ash content in once-bred gilts were found in the present study. This could be due to higher age of those pigs because composition of meat changes with higher age towards higher intramuscular fat (Warkup & Kempster, 1991; Candek-Potokar et al., 1998; Weatherup et al., 1998). On the other hand, Aziz & Ball (1995) reported that the chemical composition of sow meat is more related to carcass fatness than to carcass weight. With higher carcass fatness, water content decreases in the muscle, whereas the lipid content increases.

Ellis et al. (1996a) reported that tenderness is lower in once-bred gilts compared to maiden gilts, and that WB shear force increases with higher carcass weight (Ellis et al., 1996b). Beattie et al. (1999), in contrast, found a tendency of decreased shear force with increasing carcass weight from 70 to 100 kg. In the present study, the rearing system, including reproductive status, higher weight and age of once-bred gilts did not influence maximal WB shear force, but total work of WB shear force, which was higher in once-bred gilts, compared to maiden gilts. The similarity in maximal WB shear force values might refer to an adequate tenderness of once-bred gilts meat. Compared to the progeny of the once-bred gilts, both maiden and once-bred gilts had lower WB shear force values (Stern et al., 2003).

Generally, technological meat quality traits of once-bred gilts in the presented rearing system were comparable to maiden gilts.

Sensory meat quality

The rearing system did not seem to influence sensory meat quality traits of oven-baked LD, except for a tendency to higher juiciness for the once-bred gilts. Cured and smoked SMA of once-bred gilts on the other hand had higher juiciness and salinity, but also unfavourable higher stringiness.

In an earlier study, once-bred gilts, compared to maiden gilts, were generally judged to have tougher processed meat (LD), whereas no difference in fresh meat was found (Ellis et al., 1996a). Similar results were found by Elliot et al. (1982) for sensory meat quality analysis in cooked loin and ham. In their study, the mated gilts, slaughtered 72 h post-partum were significantly tougher than the maiden control gilts slaughtered at the same weight. In the present trial, tenderness was similar between the once-bred and maiden gilts, which could be explained by a longer post-weaning period, where the tissues could recover. Higher juiciness in meat of once-bred gilts found in the present study may be due to higher IMF content of these animals. The positive relation between IMF and higher juiciness in meat was earlier reported by other authors (Wood et al., 1986; Eikelenboom et al., 1996; Lebret et al., 1999). Also, lower thawing loss might have led to a juicier meat of the once-bred gilts. However, Ellis et al. (1996a) showed that the reproductive status did not affect sensory meat quality characters in cured LD, such as juiciness, pork flavour and saltiness. The higher saltiness of cured and smoked SMA in once-bred gilts of the present study might be due to the higher IMF of this meat because fat often intensifies taste characteristics (Lebret et al., 1999).

In many studies, differences in sensory meat quality due to indoor or outdoor housing of growing/finishing pigs are reported, concerning tenderness, juiciness and taste characteristics (Enfält et al., 1997; Bridi et al., 1998; Jonsäll et al., 2001). Comparing to an indoor reared control group, Jonsäll et al. (2001) and Enfält et al. (1997) reported an impaired juiciness for outdoor reared *ad libitum* fed growing/finishing pigs, whereas Bridi et al. (1998) found that an outdoor housing *ad libitum* feeding system did not influence sensory meat quality. Also the feeding regimen might be of importance for sensory meat quality. Restricted feeding, compared to *ad libitum* feeding was reported to produce less tender meat (Warkup et al., 1990). The tougher meat may be associated with the restricted feeding and the subsequently lower growth rate, possibly due to post-mortem proteolytic activity and/or collagen maturity (Warkup & Kempster, 1991). In the present study, it is impossible to distinguish effects of housing system on sensory meat quality from effects of reproductive status, weight, age, IMF content or feeding regimen.

Higher age and consequently higher weight of animals are considered to greatly affect sensory meat quality. Composition of collagen, structure of myofibrils and amount of fat storage change in the tissue according to the age of the animal. Consequently, this affects tenderness and stringiness of meat (for review see Lebret et al., 1999). The heavier once-bred gilts in the present study expressed higher unfavourable stringiness but no impaired tenderness of meat. Similar tenderness was unexpected because meat from heavier pigs is often reported to be tougher compared to low-weight pigs (Elliot et al., 1982; Warkup & Kempster, 1991). IMF was higher in once-bred gilts, probably due to increased age and weight. The higher IMF might have increased juiciness in those pigs, as discussed earlier. For flavour characteristics, the higher weight, including higher IMF did not influence the sensory quality in the present study, which is in accordance with other studies (Elliot et al., 1982; Blanchard et al., 2000).

Generally, the rearing system of once-bred gilts as performed in the present study can be seen to be favourable and not negative to sensory meat quality traits. The higher IMF of the once-bred gilts, which is an effect of higher age, weight and feeding regimen, might have contributed to the small differences in sensory meat quality in cured and smoked SMA.

Conclusions

Differences in carcass quality between maiden and once-bred gilts may not solely depend on the reproductive status, but may also depend on the accumulation of the different effects of the two rearing systems, including different housing systems, feeding regimes, weight and age at slaughter. Compared to the maiden gilts, carcass quality with regard to backfat thickness and lean meat content was favourable for the outdoor reared once-bred gilts. Technological and sensory meat quality measurements showed only small, negligible differences between the rearing systems. Thus, the valuable carcass of once-bred gilts and the benefit of one litter of piglets should support pork production in an outdoor rearing system.

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II

The effect of breed cross on performance and meat quality of once-bred gilts in a seasonal outdoor rearing system

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Abstract

This study investigated the suitability of once-bred gilts of two different breed crosses in an alternative seasonal outdoor rearing system, with slaughter of the once-bred gilts and their progeny at the end of the season. In total 38 once-bred gilts (Large White x Landrace (LW*L) and Large White x Duroc (LW*D) were housed outdoors one month before farrowing until slaughter, 2-3 weeks after weaning. Body weight, backfat thickness and litter size of the once-bred gilts, and pre-weaning mortality and growth of the piglets were recorded. Carcass quality and technological meat quality (pH_u, internal and surface reflectance, water-holding capacity, processing yield and shear-force) of *m. longissimus dorsi* were measured. Sensory meat quality (taste panel) of oven-baked loin (*m. longissimus dorsi*) and cured and smoked ham (*m. semimembranosus*) was investigated. LW*L once-bred gilts had more piglets at weaning, whereas growth rate of LW*D progeny was higher; pre-weaning mortality and litter weight did not differ between the breeds. LW*L had higher lean meat content and lower backfat thickness. Technological meat quality and chemical composition did not considerably differ between the two breed crosses. LW*D had higher quality with regard to meat flavour and stringiness, but tended to have lower quality with regard to juiciness of cured and smoked ham, compared with LW*L.

Keywords: carcass quality, Duroc, Landrace, litter size, maternal performance, piglet mortality, sensory meat quality, technological meat quality.

Introduction

In Sweden, the governmental goal for year 2005 includes 20% organic use of all agricultural area, 10% organic cattle and lamb production and a considerable increase of all organic animal production including pigs (Swedish Board of Agriculture, 2001). To contribute to that goal, seasonal outdoor rearing of once-bred gilts with their progeny and slaughter of all pigs at the end of the warm period might be a worthwhile, alternative rearing form for organic pork production. The advantages of such a rearing system are savings for stable and feeding costs during wintertime and a higher value of the carcass due to larger cutting details from once-bred gilts compared with female slaughter pigs (Håkansson *et al.*, 1982). The seasonal application of this rearing system benefits the natural cover of soil with grass because from late autumn until early spring the meadow has time to recover properly. An ample natural cover is important for nitrogen uptake by the plants and thus reduced nitrogen leak in the ground water. A year-long outdoor rearing of the pigs would require a larger area to dilute and disperse the porcine faeces. However, outdoor rearing of once-bred gilts is a rarely used system. This might be because of a low economic outcome, as the payment for the carcass is reduced due to an assumed decrease in meat quality and processing properties compared with the younger slaughter pigs.

To stimulate the seasonal production of pig meat and improve maternal performance, and carcass and meat quality characteristics of the once-bred gilts, an appropriate mother/dam breed has to be used. The Duroc breed and its crosses are common in outdoor production (Blanchard *et al.*, 1999) because of its robustness. This breed has advantages in growing performance (Ellis, McKeith & Miller, 1999) and meat quality (Barton-Gade, 1988; Oliver *et al.*, 1994). The generally stated higher intramuscular fat content of Duroc meat is often linked with better eating quality and favourable sensory meat quality characteristics (Bejerholm & Barton-Gade, 1986; Cameron *et al.*, 1990; MLC, 1992). The Landrace breed is known for good maternal performance (Gaugler *et al.*, 1984; Culbertson *et al.*, 1997; Tummaruk *et al.*, 2000) and high lean meat content with good processing abilities.

The objective of this study was to compare two types of breed crosses (Large White x Duroc and Large White x Swedish Landrace) in a seasonal outdoor piglet production with once-bred gilts regarding maternal performance, carcass quality, and technological and sensory meat quality.

Material and Methods

Animals

This study was performed on 38 once-bred gilts during two years. Of these, 15 were Large White (sow) x Swedish Landrace (boar) crosses, hereafter referred to as LW*L and 23 were Large White (sow) x Duroc (boar) crosses, referred to as LW*D. The gilts were reared indoors and given a rearing diet (Table 1) *ab libitum* up to a live weight of 90 kg and thereafter restrictedly according to the standard feeding regimen for growing/finishing pigs in Sweden (Andersson *et al.*, 1997). They were inseminated with Hampshire semen at an average age of 251 days (SD 19). After insemination, the gilts received a gestation diet (30 MJ ME/day) and were housed outdoors from approximately one week before farrowing. The gilts farrowed in farrowing huts in individual enclosures in five batches (April, May and June 1999; April and May 2000). They were moved to one large enclosure approximately 3 weeks after farrowing, where they remained until the piglets were weaned at an age of 9 weeks (76 days, SD 4). A lactation diet (Table 1) was given in a trough according to a norm based on litter size. The ratio was, however, increased, as the piglets started to consume large amounts of feed. No creep feed was used in this study. After weaning, the once-bred gilts in the first year received a rearing diet twice per day according to their voluntary feed intake. The second year, they were fed the lactation diet restrictedly (4 kg/day). The once-bred gilts were slaughtered two to three weeks after weaning (slaughter age 446 days, SD 25; period from weaning to slaughter 17 days, SD 3).

The gilts were weighed, and backfat was measured with ultrasound 30 days after insemination, at start of the outdoor season, 5 weeks after farrowing, at weaning and at slaughter. The once-bred gilts' individual weight and backfat thickness at farrowing were estimated by using linear regression from measurements at 30 days after insemination and from the day they were moved outdoors (9 days before farrowing, SD 5). Backfat was measured at the last rib of both sides, approximately 8 cm from the middle of the back. Litter size was recorded after farrowing by inspection through the hut window. The stable staff judged the causes when piglets were found dead. The piglets were weighed 4 days after birth and at weaning. The animals were monitored daily for health and all signs of disease or injury were recorded.

Table 1. *Composition and calculated nutrient content of the diet*

	Rearing	Gestation	Lactation	Post-weaning 1st year	Post-weaning 2nd year
Ingredients, %					
Barley	67.00	9.24	23.45	17.72	23.45
Wheat	-	5.38	36.00	43.23	36.00
Oats	-	29.57	-	-	-
Wheat bran	-	10.00	-	-	-
Rye wheat	-	32.86	4.69	-	4.69
Rapeseed meal	7.05	8.89	15.00	13.73	15.00
Yellow peas	20.00	-	17.34	21.73	17.34
Feed fat	1.84	-	-	-	-
Limestone	0.51	1.45	0.89	0.92	0.89
NaCl	0.40	0.45	0.45	0.44	0.45
Dicalcium phosphate	1.95	1.16	1.18	1.23	1.18
L-lysine•HCl (78%)	0.16	-	-	-	-
DL-methionine (99%)	0.06	-	-	-	-
Vitamin and mineral premix	1.00	1.00	1.00	1.00	1.00
Calculated nutrient content					
ME, MJ/kg	12.4	11.3	12.0	12.0	12.0
CP, %	16.0	13.6	17.0	17.7	17.0
Lysine, digestible, %	0.72	0.44	0.70	0.72	0.70

Carcass traits, technological and sensory meat quality

All animals were slaughtered at a commercial slaughterhouse, after 10 km transport and at least 2 h of lairage in the abattoir. Cold carcass weight was measured on the bled and eviscerated animal, with head but without tongue, front legs, hooves, genital organs, flare fat, kidney and diaphragm. Backfat thickness was measured over the *m. longissimus dorsi* (LD), just behind the last rib. Ham and loin of the right carcass half were weighed with skin and fat, then defatted and weighed again as meat and bone. Five ham muscles (*m. semimembranosus et aductor* (SMA), *m. semitendinosus* (ST), *m. quadriceps* (QUA), *m. gluteus* (GLU) and *m. biceps femoris* (BF)) were dissected and weighed separately. Lean meat percentage was estimated according to [-49.672 + (1.012* % ham in carcass) + (0.622* % meat and bone in ham) + (0.667* % loin in carcass) + (0.2* % meat and bone in loin)] (I. Hansson, pers. comm.).

Technological meat quality traits were measured on samples of LD taken at the last rib and backwards approximately 24 h after slaughter. All measurements followed the procedures as described in Heyer, Andersson & Lundström (2004). The technological meat quality measurements included ultimate pH (pH_u), internal reflectance (FOP), surface reflectance with the parameters L* (lightness), a* (redness) and b* (yellowness). Water-holding capacity was determined as drip loss on LD and thawing loss as weight difference of frozen and defrosted SMA. For processing yields, brine absorption during immersion of SMA, commercial processing yield (total yield) on SMA and laboratory processing yield (Napole yield) on LD were measured. Maximal shear force and total work of Warner-Bratzler (WB) was determined on cooked LD. Chemical composition of the LD was analysed as intramuscular fat (IMF), crude protein, ash and dry matter, according to the methods as described in Heyer, Andersson & Lundström (2004).

Sensory meat quality was determined on oven-baked LD of 20 once-bred gilts (all animals of the first year) and cured and smoked SMA of 18 once-bred gilts (all animals of the second year) by a trained taste panel. The meat (oven-baked LD and cured and smoked SMA) was prepared as described in Heyer, Andersson & Lundström (2004). Tenderness, juiciness and fat flavour were determined on both LD and SMA, acidity and meat flavour solely on LD and smoke flavour, stringiness and salinity solely on SMA. The scale for the taste characteristics scored from 1= very low intensity of the character to 100 = very high intensity.

Statistics

Statistical analyses of maternal performance, carcass quality and technological meat quality were performed with the GLM procedure in SAS (SAS Institute Inc., Cary, N.C., USA, versions 8.02). Data given in the tables are least square means and standard errors. The model included breed cross (LW*D or LW*L) and year as fixed factors. No interactions between the fixed effects were found. For litter weight and piglet growth, age of the piglets at weighing was included as a covariate. Pre-weaning mortality (no. weaned/no. live-born) and piglet growth were analysed with and without the fixed effect of litter size (class: ≤6; 7-9; 10-12; ≥13 live-born piglets). Statistical analyses of sensory meat quality were performed with the MIXED procedure in SAS. Taste panel member and individual pig were included in the model as random effects. Least square means were considered to be statistically significant when $p<0.05$.

Results

Maternal performance

All 38 once-bred gilts were healthy during the whole study; no sign of illness was observed. LW*L had significantly larger litters 4 days after birth (2.0 piglets; $p=0.021$) compared to LW*D (Table 2). These once-bred gilts also had more piglets at weaning (1.7 piglets) because pre-weaning mortality did not differ. The main reason for the mortality was crushing. For LW*L, 38.5% was registered as crushing losses, compared with 48.6 % for the LW*D. No effect of breed cross on litter weight 4 days after birth and at weaning was observed. Litters with LW*D mothers grew faster in the period from day 4 to weaning. When litter size was included in the model, a tendency of higher growth rate could still be seen.

From 30 days after service to slaughter, body weight of LW*D was considerably higher than of LW*L (Figure 1). At start of the outdoor period, the difference in weight was 16 kg ($p=0.069$). Five weeks after farrowing, LW*D was heavier than LW*L ($p=0.004$), even if the effect of litter size was included in the statistical model ($p=0.010$). During the first 5 weeks of lactation, LW*D had a lower weight loss, compared with the LW*L. Until weaning, both LW*D and LW*L increased in weight; the LW*D more than the LW*L (9 kg vs. 5 kg; $p=0.002$). At slaughter, LW*D was 32 kg heavier ($p=0.001$) and reached the similar weight as at the start of the outdoor period. Backfat of LW*D was initially significantly thicker than that of LW*L, and this difference remained during the whole rearing period. Compared with LW*L, LW*D had thicker backfat after farrowing ($p=0.028$), even if the effect of litter size was included in the statistical model ($p=0.032$). During the first 5 weeks of lactation, LW*D lost significantly less backfat than LW*L. At slaughter, these once-bred gilts were as fat as 30 days after service, whereas backfat of LW*L was 4 mm thinner.

Feed consumption during the first 10 days of lactation was 91 and 76% of the recommended amount based on litter size for LW*D and LW*L once-bred gilts, respectively. The total consumption of feed from farrowing until slaughter could not be compared between breed crosses because the animals were kept in mixed groups. On average, feed consumption was 681 kg per sow from farrowing to slaughter, including the feed consumed by the piglets (until weaning). The last weeks of lactation, the piglets were often observed to eat sows' feed. The piglets were weaned at a weight of 21.5 and 24.3 kg for LW*L and LW*D litters, respectively.

Carcass quality traits

The once-bred gilts were slaughtered at an approximate age of 450 days and a carcass weight of 146 kg. LW*D had higher carcass weight and thicker backfat than LW*L ($p<0.001$; Table 3). Lean meat content and percentage of meat and bone in ham and loin were significantly lower in LW*D than in LW*L. The proportion of loin in carcass was higher in LW*D. However, the proportion of QUA in the ham was lower in LW*D than in LW*L (p=0.007), whereas the proportion of ST was higher in the LW*D (p=0.001).

Technological and sensory meat quality and chemical composition

pH_u, internal and surface reflectance, thawing loss, total yield (commercial processing yield), shear forces and chemical composition did not differ between the two types of cross-bred gilts (Table 4). A tendency of a lower drip loss (p=0.063) and a 2.2 percentage points higher Napole yield (laboratory processing yield; p=0.023) were found in meat from LW*D than that from LW*L. No differences in chemical composition was found in meat of the two breed crosses. Oven-baked LD of LW*D and LW*L cross-bred gilts were equally scored in the sensory meat quality test, except meat flavour, where LD of LW*D scored higher (p=0.032) (Figure 2). Cured and smoked SMA of LW*L tended to have juicier meat (p=0.084) and higher stringiness (p=0.005) than of LW*D, according to the test panel.

Table 5 presents correlations between sensory meat quality in oven-baked loin and WB maximal shear force, IMF and pH_u in LD. Tenderness and WB maximal shear force correlated negatively (r=-0.67; p=0.001), as did acidity and pH_u (r=-0.56; p=0.009). A negative correlation between tenderness and stringiness in cured and smoked ham was registered (r=-0.84; p=0.001; not tabled).

Discussion

Maternal performance

In this study of once-bred gilts, LW*L had larger litters than LW*D. A higher number of live-born and weaned piglets of the Landrace breed and its crosses are widely described in the literature (Culbertson *et al.*, 1997; Tummaruk *et al.*, 2000). Gaugler *et al.* (1984) reported that Landrace females, compared to the breed of Duroc and Large White, are most productive in terms of litter size and litter weight, but the authors also emphasized that significant heterosis estimates were obtained for litter size, litter weight and piglet mortality. Also Cassady, Young and Leymaster (2002) highlighted the positive heterosis effects in LW*L and LW*D crosses on maternal performance.

Crushing is the main factor for pre-weaning mortality of piglets, caused by down-laying of the mother (McGlone & Hicks, 2000). In the present study, the main reason for pre-weaning mortality was crushing as well. It was 4 percentage units higher for LW*D than for LW*L once-bred gilts. The higher crushing rate might be because Duroc sows are larger and heavier and thus less agile in their movements at down-laying before suckling. However, no significant differences in total mortality could be found between the breed crosses. The LW*L once-bred gilts had the capacity to rear their larger litters and had consequently more piglets at weaning than the LW*D once-bred gilts. A mortality of 12 to 13%, as found in the present study, was on an acceptable level for an outdoor rearing system.

Spitschak (1997) found mortality of 12 to 24% for outdoor reared piglets, mainly caused by crushing. The author stated that mortality was higher during winter season, compared to the summer season, mainly because the sows preferred to stay inside the space-delimited farrowing huts. Wülbers-Mindermann *et al.* (2002) described that crushing losses increase with higher age/higher parity number due to the higher weight of the sow and her less agile movements. For this reason, once-bred gilts, compared to heavier multiparous sows, have advantageous lower piglet mortality. On the other hand, litter size in once-bred gilts is not fully exploited as it increases considerably in the following parities (Spitschak, 1997; Tummaruk *et al.*, 2000; Huang *et al.*, 2003). Primiparous sows compared to multiparous sows, are less experienced with their progeny as discussed by Wülbers-Mindermann (2002) and have a more aggressive behaviour towards them (Vieuille *et al.*, 2003), which leads to a higher piglet mortality. However, no aggressiveness towards piglets was observed in our study.

It has to be emphasized that despite the lack of access to creep feed for the piglets, they grew well and achieved a live weight of approximately 21 kg at an age of 9 weeks. Both the piglets and the once-bred gilts were in a good condition at weaning. Litter weight at weaning did not differ between the two breed crosses because the LW*D had smaller litters but higher growth rate. A higher growth rate for these LW*D pigs, compared to the LW*L pigs, was also observed during the growing/finishing period (Stern *et al.*, 2003).

In the present study LW*L had a higher weight loss during lactation, compared to the LW*D. This is in accordance with Cassady, Young & Leymaster (2002), who found that pure-bred Duroc sows have a lower weight loss during lactation, compared to Landrace and Large White pure-breeds. Weight loss during lactation is strongly related to litter size and piglet growth (Wülbers-Mindermann *et al.*, 2002) because sows mobilise more body reserves with greater number of piglets (Neil, Ogle & Annér, 1996). Also Hardge *et al.* (1999) considered that for pre-weaning growth, the most important factor is maternal milk yield. Thus, the higher weight loss of LW*L might be explained by their larger number of piglets in addition to a lower feed consumption. During the first 10 days of lactation, when individual feed intake was recorded, LW*L once-bred gilts consumed only 76% of the norm, which was based on litter size. However, pre-weaning growth rate tended to be higher for the LW*D progeny, even when corrected for the litter size, compared to the LW*L progeny. Less body reserves are probably mobilised during lactation in LW*D due to higher feed consumption. In several studies it was observed that greater backfat thickness prior to farrowing results in greater weight loss during lactation (Hultén *et al.*, 1993; Rojkittikhun *et al.*, 1993; Wülbers-Mindermann *et al.*, 2002). This could not be seen in our breed comparison, where LW*L had less backfat than LW*D, but lost more backfat during the first 5 weeks of lactation. Energy is used not only for milk production but also for own body development, which is not completed at the first parity (Solanes *et al.*, 2004). The high body weight and backfat thickness of the LW*D may indicate that these once-bred gilts are more suitable for outdoor production, especially in colder countries.

Carcass meat quality

Higher backfat thickness and lower lean meat content of LW*D compared to LW*L, as found in the present study was in accordance to earlier comparisons (Wood, Edwards & Bichard, 1988; Enfält *et al.*, 1997; Stern *et al.*, 2003) between Duroc crosses and other commercial breeds. Blanchard *et al.* (1999) reported that backfat thickness increased with increasing genetic portion of Duroc breed in the growing/finishing pig. Also the progeny of the once-bred gilts in the present study (25% Duroc or Landrace, 25% Large White, 50% Hampshire)) showed that Duroc cross breeds had lower lean meat content, compared to the Landrace cross breeds (Stern *et al.*, 2003). Nowadays Duroc has an improved carcass quality, in terms of higher lean meat content and thinner backfat thickness, because this was effectively included in the breeding goals for Duroc boars (Norsvin, 2004). However, differences in these carcass traits are still present. It has to be emphasized that the lower lean meat content in the LW*D carcass in the present study was found on once-bred gilts, which have a higher age, higher carcass weight and underwent a whole cycle of reproduction. In comparison with growing/finishing pigs, the once-bred gilts reach a lower price per kg meat because of their higher body weight and backfat thickness. This disadvantage of lower economic value per kg meat has to be taken into account if gilts are to be slaughtered after their first reproduction cycle. These once-bred gilts were compared with maiden gilts in another study (Heyer, Andersson & Lundström, 2004). It was shown that the once-bred gilts produced valuable carcasses of good quality with adequate technological and sensory meat quality.

Probably due to the higher backfat of the LW*D, the proportion of meat and bone in ham and loin was significantly lower, compared to the LW*L. Hansson *et al.* (1974) found no changes in proportion of ham muscles with increasing slaughter weight. In the present study, however, a one percentage point higher portion of ST and a one percentage point lower portion of QUA were found in LW*D carcasses, compared to the lighter LW*L carcasses.

Technological meat quality and chemical composition

The Duroc breed is widely known for its enhanced technological meat quality traits, *e.g.* decrease of WB shear force and cooking loss compared to white breeds (MLC, 1992) and is therefore often used as terminal sire breed (Oliver *et al.*, 1994). The breeding company, from which the Duroc sires in the present study originated, has technological meat quality included in the breeding goal (Norsvin, 2004). pH_u and FOP values did not differ between the two breed crosses. This is in accordance with other studies, reporting that breed did not influence these traits (Cameron *et al.*, 1990; Edwards *et al.*, 1992; Enfält *et al.*, 1997; Blanchard *et al.*, 1999). Enfält *et al.* (1997), who found no differences in pH_u between Duroc and Yorkshire breed crosses, suggested that differences in pH_u of pure breeds might be alleviated by the effect of breed cross. In literature, Duroc meat is often mentioned as darker (Oliver *et al.*, 1994) and also redder (Cameron *et al.*, 1990), compared to other breeds. Darker or redder colour is explained by the higher content of haem in the muscle fibres of Duroc pigs (MLC, 1992). However, in the present study, no differences in lightness or redness could be measured. This is perhaps because in once-bred gilts differences in surface reflectance between the breed crosses were decreased due to their higher age and weight, compared to the growing/finishing pigs of the cited studies.

The water-holding capacity in terms of drip and cooking losses in meat from pure breeds and breed crosses of Duroc are widely studied. Enfält *et al.* (1997) found no differences in drip and cooking losses between cross-bred Yorkshire and Duroc. Martel, Minvielle & Poste (1988) and Olivier *et al.* (1994) found no differences in drip loss in three breed crosses, using Landrace and Duroc as sires. Also Blanchard *et al.* (1999) concluded that with higher proportion of Duroc genes, drip loss did not change. However, in the present study, drip loss in LW*D tended to be lower, compared to LW*L. Also Napole yield differed between the two breed crosses with a higher yield for LW*D, whereas total yield after commercial ham processing was similar. The discrepancy between Napole and total yield might be due to the preparation of the meat (fresh/thawed) and/or the use of different muscles for yield determination.

Shear force values did not differ between breed crosses. Barton-Gade (1988) reported that shear force of meat from purebred Duroc pigs was significantly lower than that from white races. Blanchard *et al.* (1999) considered that with increasing portion of Duroc genes in the pig, shear forces decreased. Enfält *et al.* (1997) found similar results for breed crosses with Duroc or Large White as sires. In all named cases, the measurements were carried out on growing/finishing pigs and as possible explanation for differences in meat toughness, differences in IMF content and growth rate were discussed. However, in the present study once-bred gilts were used, and differences in WB shear forces between breeds might have been alleviated due to their high age and weight.

In contrast to the general perception of higher IMF in Duroc and its breed crosses (Barton-Gade, 1988; Wood, Edwards & Bichard, 1988; Oliver *et al.*, 1994), no differences between LW*D and LW*L once-bred gilts in IMF and other chemical components were found in the present study. This might be because the once-bred gilts underwent a whole reproduction cycle, including gestation and lactation. During lactation, fat reserves were depleted by the suckling progeny and could not be recovered during the short post-weaning fattening period. Even when the backfat thickness of the Duroc breed cross was higher post-weaning, the IMF content was similar.

Sensory meat quality

Sensory analysis of oven-baked LD and cured and smoked SMA showed that breed cross did not influence tenderness, and fat and smoke flavour. Cured and smoked SMA from LW*L , but not oven-baked LD tended to be juicier, compared with LW*D. The general consistency of sensory meat quality between breed crosses in the present study is contrary to findings from several authors (Barton-Gade, 1988; Cameron *et al.*, 1990; Blanchard *et al.*, 1999), who found higher tenderness and juiciness of Duroc and its crosses, compared to other breeds. Reportedly, sensory meat quality characteristics *i.e.* tenderness and juiciness are, between other carcass and meat quality characteristics, related to IMF, pH value and shear force (Wood *et al.*, 1986; Eikelenboom, Hoving-Bolink & van der Wal, 1996a,b; Enfält *et al.*, 1997; Ellis, McKeith & Miller, 1999; Olsson *et al.*, 2003). In the present study, pH_u, IMF and shear force did not differ between the breed crosses and therefore did not affect tenderness and juiciness (in LD) to a greater extent. The tendency of juicier SMA of LW*L pigs might be an effect of the lower water-holding capacity of this breed cross. Hullberg Johansson & Lundström (2004) described that a lower water-holding capacity, in that study determined as lower processing yield, resulted in higher juiciness. An explanation might be that meat with low water-holding capacity binds the water less strongly and releases water more easy during chewing.

Flavour of meat from Duroc breeds is often determined to be superior to other breeds (Martel, Minvielle & Poste, 1988; McGloughlin *et al.*, 1988). The flavour is partly determined by the IMF content (McGloughlin *et al.*, 1988), fatty acid composition and appearance of fatty acid oxidation products (Lebret, Lefaucheur & Mourot, 1999). Because fatty acid composition in meat is mostly determined by the diet, which was similar for both breeds in the present study, consistency in flavour was not unexpected. Acidity was negatively correlated to pH_u, and did not differ between the two breed crosses, as pHu did not differ. In pork meat, the appearance of stringiness is rarely described in literature, whereas stringiness of meat from other species, such as duck breast and lamb, is reported to be negatively related to tenderness (Baeza *et al.*, 1998; Carlucci *et al.*, 1999). This could be confirmed in the present study, where in cured and smoked ham stringiness correlated with tenderness ($r=-0.84$). The higher stringiness in cured and smoked SMA of LW*L pigs did not correspond to differences in either tenderness or other meat quality traits.

Conclusion

It can be concluded from this study that maternal performance of LW*L and LW*D once-bred gilts did not differ concerning litter weight, whereas LW*D once-bred gilts had smaller litters with higher daily weight gain and lost less body weight and backfat thickness during lactation. This might have contributed to leaner carcasses of LW*L once-bred gilts.

We found no data supporting the notion that one breed cross would be preferable to the other in terms of technological and sensory meat quality. No arguments could be strengthened for choosing one or the other breed cross for seasonal outdoor production. In general, over-all performance traits, such as piglet mortality and growth rate, were satisfactory and the once-bred gilts were in good condition at weaning. Therefore, the seasonal outdoor production of piglets by once-bred gilts seems to be a well-working system and could be established as an alternative system for organic production. With the present payment system, where the price of sow meat is low, irrespective of age of the sow, this will not be possible from an economic point of view. Thus, to make a seasonal rearing system with once-bred gilts economically viable, their carcasses must increase in value.

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Table 2. *Maternal and piglet performance traits for once-bred gilts of Landrace and Duroc breed crosses, least square means (LSM) and standard errors (SE)*

	LW*L (n=15)		LW*D (n=23)		
	LSM	SE	LSM	SE	p-value
Litter size					
no. born total	11.9	0.72	10.0	0.57	0.052
no. live-born	11.5	0.73	9.9	0.58	0.092
no. 4 day after birth	10.8	0.62	8.8	0.49	**0.021**
no. at weaning	10.2	0.60	8.5	0.48	**0.034**
Pre-weaning mortality, %	12.1	3.14	13.3	2.51	0.773
Pre-weaning mortality$_{corr}$[1], %	9.5	3.43	13.7	2.35	0.293
Litter weight 4 day after birth, kg	20.8	1.09	18.6	0.87	0.136
Litter weight at weaning, kg	206.9	10.81	193.2	8.65	0.334
Piglet daily weight gain, g					
day 4 to weaning	298	10.6	340	8.4	**0.004**
day 4 to weaning$_{corr}$[2]	323	9.8	344	6.7	0.071

[1] Values corrected for litter size; p=0.017 for effect of litter size.

[2] Values corrected for litter size; p=0.001 for effect of litter size.

Table 3. *Carcass quality traits and proportion of different ham muscles in once-bred gilts of Landrace and Duroc breed crosses, least square means (LSM) and standard errors (SE)*

	LW* L (n=15)		LW*D (n=23)		
	LSM	SE	LSM	SE	p-value
Carcass weight[1], kg	137.3	3.75	153.7	2.92	**0.002**
Lean meat content, %	56.0	0.62	54.0	0.49	**0.017**
Backfat, mm	16.7	1.18	22.1	0.89	**0.001**
Ham in carcass, %	30.0	0.35	30.5	0.27	0.252
Meat and bone in ham, %	79.6	0.65	75.8	0.51	**0.001**
Loin in carcass, %	16.2	0.26	16.8	0.20	**0.036**
Meat and bone in loin, %	75.4	0.97	72.0	0.76	**0.011**
SMA[2] in ham, %	25.5	0.27	25.3	0.21	0.554
ST[3] in ham, %	7.9	0.15	9.0	0.11	**0.001**
QUA[4] in ham, %	21.5	0.24	20.5	0.19	**0.007**
GLU[5] in ham, %	17.3	0.32	17.0	0.25	0.434
BF[6] in ham, %	27.8	0.20	28.2	0.16	0.118

[1] measured with head and without front legs; [2] SMA= *m. semimembranosus et aductor*; [3] ST= *m. semitendonosus*; [4] QUA= *m. quadriceps*; [5] GLU= *m. gluteus*; [6] BF= *m. biceps femoris*.

Table 4. *Technological meat quality and chemical composition of muscles in once-bred gilts of Landrace and Duroc breed crosses, least square means (LSM) and standard errors (SE)*

	LW*L (n=15)		LW*D (n=23)		p-value
	LSM	SE	LSM	SE	
ultimate pH$_{LD}$	5. 45	0.02	5. 48	0.01	0.143
FOP $_{LD}$	36. 0	1.74	37. 1	1.37	0.656
Minolta values$_{LD}$					
L* (lightness)	48. 1	0.63	47. 5	0.49	0.479
a* (redness)	8. 4	0.36	8. 4	0.28	0.921
b* (yellowness)	3. 5	0.29	3. 7	0.23	0.709
Water holding capacity					
Drip loss$_{LD}$, %	6. 0	0.52	4. 7	0.41	0.063
Thawing loss$_{SMA}$, %	8. 7	1.08	7. 6	0.58	0.352
Processing yield					
Brine immersion$_{SMA}$, %	15. 1	1.75	15. 4	0.93	0.879
Total yield$_{SMA}$[1], %	98. 1	1.36	99. 1	0.72	0.530
Napole yield$_{LD}$[2], %	84. 2	0.70	86. 4	0.55	**0.023**
WB shear force$_{LD}$					
max shear force, N	40. 7	2.19	38. 4	1.71	0.514
total work, Nmm	201. 6	7.77	202. 5	6.09	0.926
Chemical composition$_{LD}$					
Intra muscular fat, %	2. 2	0.21	2. 6	0.17	0.234
Crude protein, %	23. 4	0.42	23. 2	0.33	0.741
Dry matter, %	24. 8	0.21	25. 2	0.16	0.108
Ash, %	1. 0	0.05	1. 0	0.04	0.865

[1] Commercial yield during ham production; [2] Laboratory processing yield.

Table 5. *Correlations between sensory meat quality traits in oven-baked loin and WB shear force and intramuscular fat and pH$_u$ in m. longissimus dorsi (n=20)*

	Max. WB force	Intramuscular fat	pH$_u$
Tenderness	**-0.67** ***	0.13	0.20
Juiciness	-0.07	0.08	-0.18
Fat flavour	-0.22	0.16	0.01
Meat flavour	-0.26	0.05	0.11
Acidity	-0.26	-0.27	**-0.56** **

Levels of significance: ***=p<0.001, **=p<0.01.

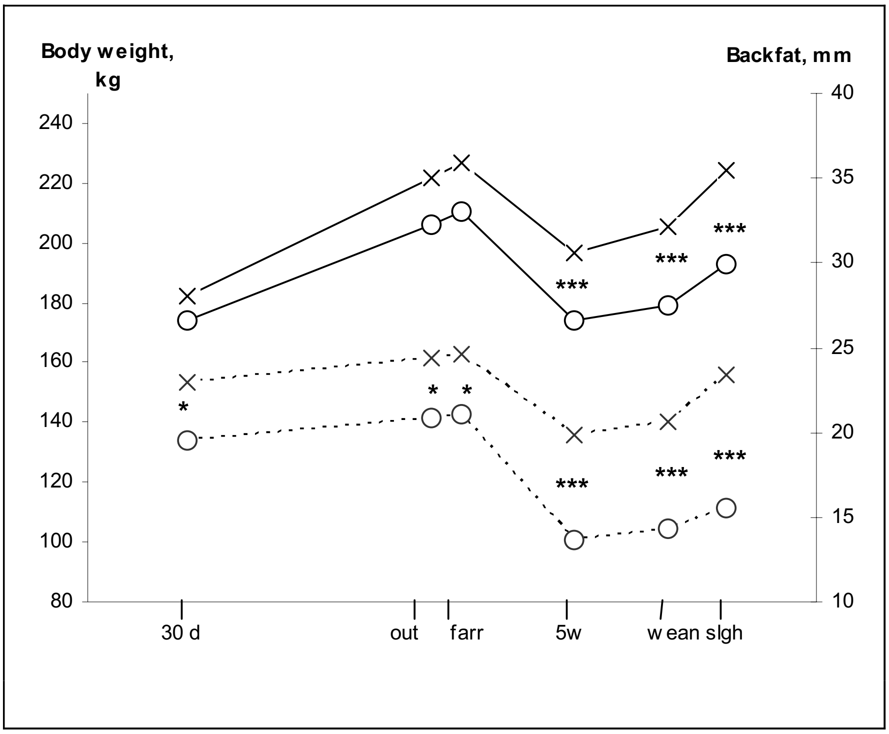
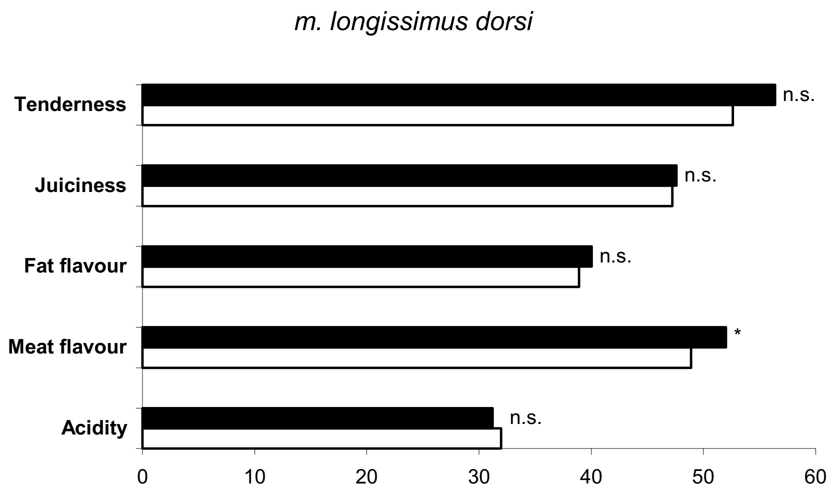


Figure 1. Body weight and backfat thickness of once-bred gilts from 30 days after service to slaughter. Measurements at time of: 30 d= 30 days after service; out= start of the outdoor period, approximately one week before farrowing; farr = farrowing; 5w = five weeks after farrowing, wean = weaning; slgh = slaughter.
X= LW*D cross; ○= LW*L cross; Straight line= body weight; Dashed line= backfat thickness; Levels of significance between breed cross: ***=$p<0.001$, *=$p<0.05$.


m. longissimus dorsi

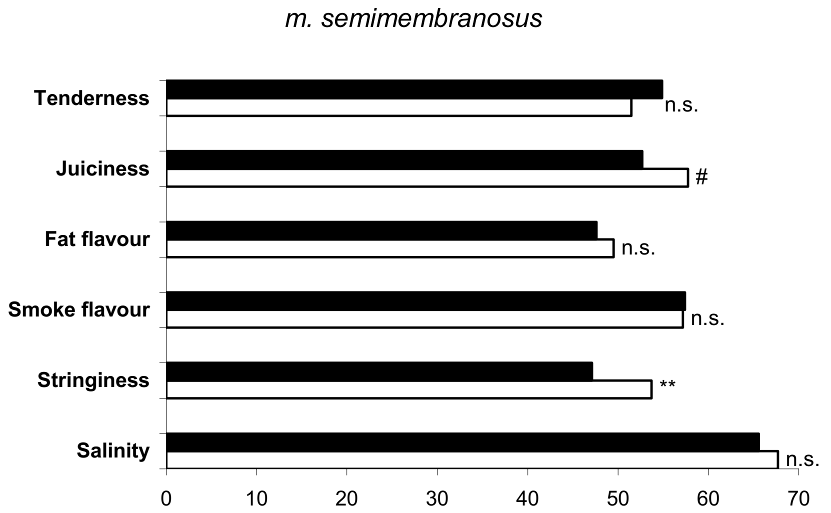

m. semimembranosus

Figure 2. Sensory meat quality of oven-baked *m. longissimus dorsi* (n=20) and cured and smoked *m. semimembranosus* (n=18) from once-bred gilts.
■ LW*D cross, □ LW*L cross; Levels of significance: n.s.= p>0.10, #=p<0.10, *=p<0.05, **=p<0.01.

III

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Production Results and Technological Meat Quality for Pigs in Indoor and Outdoor Rearing Systems

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The objective of the study was to compare production results and technological meat quality for pigs born outdoors and reared indoors or outdoors during the summer period. A total of 279 pigs was reared in a large pen on deep litter, or outdoors. Daily weight gain and lean meat percentage were higher for pigs outdoors than indoors during year one (864 vs. 841g; 56.9 vs. 55.9%), but were similar for year two (859 vs. 844g; 55.9 vs. 55.6%). Outdoor pigs grew faster when fed *ad libitum*, but slower during the second phase when restricted, with inferior feed conversion. Most technological meat quality traits (surface and internal reflectance, marbling, pH_{BF}, filter paper wetness, cooking loss and maximal Warner-Bratzler shear force) were similar between rearing systems, whereas pH_{LD} was higher indoors. Total work of Warner-Bratzler shear force was lower in outdoor reared pigs. Maternal sire breed (Duroc or Landrace) and sex (castrate or gilt) did not notably affect meat quality traits. RN genotype had a stronger impact on meat quality than rearing system. It can be concluded from the similarities in production results and meat quality in both systems, that both indoor and outdoor rearing are good alternatives for summer rearing of pigs.

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Key words: carcass traits, growth, organic production, pork, swine.

Introduction

In Sweden and in the other EU countries there is growing public and political pressure towards organically grown foods and animal production. In pig production, the move towards more organic production systems has been slow, and the goals set by politicians have not been satisfactorily attained (IFOAM, 2002). One reason for the slow change is that there are large differences between organic and conventional pig production. The regulations for organic production differ between countries, but generally it is prescribed that pigs should be reared outdoors. In Sweden the climate in winter is especially challenging for outdoor production. Therefore it can be of interest to use of once-bred gilts producing one litter in the spring. The piglets are reared through to slaughter during summer and early autumn and only gilts retained for breeding are kept over winter.

Many consumers prefer pork from organically reared pigs because they assume improved sensory

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meat quality (Branscheid, 1998). However, when comparing eating quality traits of indoor and outdoor reared pigs, Jonsäll et al. (2001) observed somewhat lower intensity for acidulous taste and juiciness of cooked ham (M. biceps femoris) in outdoor reared pigs, but no difference in tenderness. Gentry et al. (2002a) reported similar sensory characteristics (tenderness, juiciness and pork flavour) and shear force from pigs born and finished outdoors or indoors. In contrast, the authors found in another trial lower shear force values for outdoor reared pigs (Gentry et al., 2002b). These findings are contrary to the results of Enfält et al. (1997a) who observed impaired sensory and technological meat quality of meat from an outdoor rearing system. The aim of this study was to compare indoor and outdoor rearing systems with regard to production results and technological meat quality parameters of growing/finishing pigs.

Material and methods

Animals

This experiment was carried out as two replicates over two years and included 279 pigs (143 gilts and 136 castrated males). All piglets were born of first-parity gilts, 24 Large White × Duroc (LW*D) and 13 Large White × Swedish Landrace (LW*L). The gilts were randomly inseminated with semen of 14 Hampshire (H) sires. The gilts farrowed in insulated farrowing huts in individual enclosures in two batches each year (April and May). At the age of four days the piglets were individually marked and males were castrated.

The diet (11.3 MJ ME, 13.6% CP) was given *ad libitum* to the sows in a trough that also gave the piglets access to the diet. No creep feed was given to the piglets. The sows and piglets were moved to one large enclosure approximately three weeks after farrowing, where they remained until weaning.

Experimental design

At weaning each batch was divided by split litter technique into two groups with 33–38 pigs in each. One group was kept indoors in an uninsulated building on deep litter. The outdoor group was kept on an established pasture with huts and wallowing possibilities. Pigs had free access to water from water nipples. The pigs were fed twice a day in troughs with simultaneous access for all pigs. In addition, feeding dispensers were used. All pigs were fed the same diet (Table 1) *ad libitum* until the mean live weight of the group reached 60 kg. In the first year the daily feed allowance was restricted to 34.1 MJ per pig per day both indoors and outdoors in accordance with the standard feeding regime for growing pigs in Sweden (Andersson et al., 1997). In the second year the indoor pigs received a maximum of 34.1 MJ per pig per day, and the outdoor pigs 37.5 MJ per pig per day. Feed consumption was measured on a weekly basis. The pigs were weighed at the start of the experiment, after 4 and 8 weeks, thereafter every week indoors and every other week outdoors and the day before slaughter.

Table 1. Composition and calculated nutrient content of the diet

Ingredient	%
Wheat	43.23
Barley	17.72
Rapeseed meal	13.73
Yellow peas	21.73
Dicalcium phosphate	1.23
Limestone	0.92
Vitamin premix	1.00
Sodium chloride	0.44
ME, MJ	12.00
CP, digestible, g/kg	142.00
Lysine, g/kg	7.2
Methionine, g/kg	2.5
Theronine, g/kg	5.0
Ca, g/kg	8.2
P, g/kg	6.5
Dietary fibre	41.8
Crude fat	22.6

Slaughter registrations

The pigs were slaughtered at a live weight of about 108 kg. Carcass weight was recorded. The official meat inspectors recorded individual slaughter lesions. Lean meat percentage was calculated as [lean meat percentage = 29.217 + (0.548* % ham in carcass) + (0.866* % meat and bone in the ham) and (+0.679 was added for females)] (I. Hansson, pers. comm.). The subcutaneous fat and skin of the ham were removed. The femur bone was trimmed and weighed. The presence and severity of osteochondrosis was recorded in the knee joint at the same time and place as the jointing operation. These scores range from 0 (best, undegenerated condyle) to 5 (worst, severe lesions) according to Reiland (1978).

Sexual maturity

At slaughter, the ovaries from 135 females were collected and kept frozen at −20°, until simultaneous examination of all samples for each year. Follicle size was determined by measuring the diameter of the largest follicle with a ruler. The presence of corpora lutea was recorded. The females were divided into three classes according to ovarian morphology:

Class 1: sexually mature, follicle size >8 mm and/or presence of corpus luteum.
Class 2: prepubertal, follicle size >5 mm but <8 mm; no corpus luteum.
Class 3: immature, follicle size <5 mm; no corpus luteum.

Meat quality

Meat quality traits were measured in 133 pigs, born in the second year. Samples from M. longissimus dorsi (LD) taken at the last rib and the central part of M. biceps femoris (BF) were applied for technological meat quality measurements. On LD, the surface reflectance with the parameters L* (lightness), a* (redness) and b* (yellowness) was measured by using a Minolta-colorimeter (Minolta Chroma Meter CR 300, DP-301, Osaka, Japan). Further, ultimate pH (Mettler Delta 340 pH-meter equipped with a Xerolyte^{TM} electrode) and internal reflectance, using a fibre optic probe (FOP, 900 nm; TBL Fibre Optics Group Ltd., Leeds, UK) were measured in LD. Subjective marbling score (range from $0=$ no marbling to $5=$ high marbling) was assessed on a slice of LD. Drip loss was measured on a 2 cm thick slice of LD, stored horizontally for 3 days at 4°C (Barton-Gade et al., 1994), filter paper wetness was measured according to Kaufmann et al. (1986). Warner-Bratzler shear force and cooking loss were determined on an approximate 300 g piece of M. biceps femoris (BF), aged 4 days before freezing. The frozen meat was heated in a water-bath to an internal temperature of 70°C. On that sample, Warner-Bratzler shear forces were determined as maximal shear force and total work done (area under the curve) on a minimum of 8 strips ($10 \times 10 \times 50$ mm), sheared across the fibre direction (TA-HDI texture Analyser; Stable Micro Systems, Surrey, UK).

The classification of the animals as carriers (RN^-/rn^+) and non-carriers (rn^+/rn^+) of the RN^- allele was based on phenotypic trait measurements of the concentration of glucose+glucose-6-phosphate (G-6-P) in meat juice as described by Lundström & Enfält (1997) but in M. semimembranosus. The method gave rise to a bimodal distribution and the RN classification was made on basis of the valley point. Pigs with a value ≥ 0.53 mmol/l meat juice were classified as carriers of the RN^- allele; pigs with a value ≤ 0.48 mmol/l were classified as non-carriers. Fifteen samples with values close to this experimental dividing line (0.47–0.59) underwent a final genotyping (rn^+/rn^+ or RN^-/rn^+) following the procedure reported in Milan et al. (2000). In total 106 animals were classified as carriers and 128 as non-carriers of the RN^-allele.

Statistical analyses

Statistical analyses were performed with the MIXED procedure in SAS (SAS Institute Inc., Cary, N.C., USA, versions 8.02). The model included the fixed effects of treatment (indoors or outdoors), year (2 levels), batch (2 levels), breed of maternal grandsire (Duroc or Landrace), and sex (female or castrated male). The effect of RN genotype (carrier and non-carrier) was ignored when analysing production traits due to non-significant effects, but included in the analysis of meat quality traits. The dam was included in the model and treated as random. Comparison of production and carcass traits between indoor and outdoor rearing was made within each year, as feed allowances differed between the two years. Two-way interactions between the fixed effects breed, sex and RN genotype were included, when significant ($P \leq 0.05$). For calculation of daily weight gain, initial weight was included in the model as a covariate. The χ^2-test was used to analyse differences in sexual maturity between indoor and outdoor reared females.

Results

Production results

The piglets were weaned at a mean age of 61.5 days (range 51–70 days) and entered the experiment the same day. All weaned pigs in the litters were included in the experiment and the mean live weight was 22.9 kg with a range between 13 and 37 kg. The production results for indoor and outdoor reared pigs are presented in Table 2. When the pigs were fed *ad libitum* during the first period, the outdoor pigs had a higher daily weight gain than the indoor pigs. When the daily feed allowance was restricted according to indoor recommendations (first year), daily weight gain from 60 kg was lower outdoors than indoors. The second year, when a higher feed allowance was given to the outdoor pigs, less difference in daily weight gain between outdoor and indoor pigs was found. Feed conversion was inferior outdoors.

Lean meat percentage and percentage meat and bone in ham were higher for the outdoor than the indoor pigs during the first year, whereas no significant difference was found the second year. No difference in the percentage ham in carcass due to rearing system was found. Dressing percentage was higher for outdoor pigs. The femur bone was heavier for the outdoor pigs than for indoor pigs. The osteochondrosis score did not differ significantly between outdoor and indoor reared pigs. The most common slaughter lesions were white spots in the liver (2 and 9 outdoors vs. 9 and 6 indoors in the two years, respectively), whereas pleuritis was recorded on two

Table 2. Production and carcass traits (LS-means ± standard errors) for pigs reared indoors or outdoors

	Year 1			Year 2		
Variable	Indoor ($n = 72$)	Outdoor ($n = 71$)	*P*-value	Indoor ($n = 64$)	Outdoor ($n = 72$)	*P*-value
Initial weight, kg	25.2 ± 0.88	25.1 ± 0.88	0.753	20.1 ± 0.79	19.8 ± 0.79	0.512
Daily weight gain[1], g	841 ± 8.4	864 ± 8.5	0.050	844 ± 13.4	859 ± 13.1	0.166
Early gain (22–60 kg), g	746 ± 13.8	847 ± 14.0	0.001	658 ± 24.8	743 ± 24.2	0.001
Late gain (60–108 kg), g	973 ± 11.3	913 ± 11.1	0.001	976 ± 10.9	953 ± 10.4	0.091
Days in experiment	96.4 ± 1.27	92.2 ± 1.27	0.001	103.5 ± 1.58	104.2 ± 1.53	0.540
Final weight[2], kg	105.7 ± 0.84	104.4 ± 0.65	0.132	106.5 ± 0.84	108.6 ± 0.35	0.035
Kg feed/kg gain (22–108 kg)	2.73 ± 0.009	2.81 ± 0.009	0.076	2.74 ± 0.013	3.01 ± 0.013	0.043
Carcass weight, kg	79.9 ± 0.48	78.9 ± 0.49	0.132	80.5 ± 0.63	82.0 ± 0.60	0.035
Dressing percentage, %	75.1 ± 0.25	76.2 ± 0.25	0.001	74.7 ± 0.22	75.7 ± 0.21	0.001
Lean meat percentage	55.9 ± 0.31	56.9 ± 0.31	0.001	55.6 ± 0.45	55.9 ± 0.44	0.364
Meat and bone in ham, %	78.9 ± 0.28	80.1 ± 0.28	0.001	78.8 ± 0.45	79.3 ± 0.44	0.193
Weight of femur, g	366 ± 4.2	378 ± 4.3	0.004	391 ± 6.0	401 ± 5.9	0.019
Osteochondrosis score	2.1 ± 0.16	2.1 ± 0.16	0.990	1.7 ± 0.22	1.7 ± 0.22	0.828

[1] Daily weight gain was calculated from a final weight corrected for average dressing percentage within year.

[2] Indoor pigs were weighed every week, while outdoor pigs were weighed every other week due to technical reasons.

indoor pigs and one outdoor pig. Three indoor pigs had arthritis.

The pigs with LW*D mothers had a higher live weight when entering the experiment than the pigs with LW*L mothers (24.3 vs. 21.5 kg, respectively; Table 3). The LW*D pigs had a higher daily weight gain during the entire growing/finishing period and were younger at slaughter, but the lean meat percentage and percentage meat and bone in ham were lower. No significant effect of maternal grandsire was found for osteochondrosis score.

Sexual maturity

During the first year, females reared indoors were sexually more mature than females reared outdoors (27 vs. 0% classified as sexually mature, chi^2-test, $P = 0.004$), whereas there was no significant difference during the second year (6 vs. 0%, $P = 0.248$). No difference in age at slaughter, daily weight gain and lean meat percentage was found for different maturity classes.

Meat quality

Meat quality traits were determined solely from pigs born in the second year. In most cases no significant difference in meat quality traits between the two rearing systems was found (Table 4). However, pH_{LD} was higher in the indoor than in the outdoor reared pigs (5.34 vs. 5.32; $P = 0.039$). Less total work of shear force was needed for outdoor reared pigs compared to indoor reared pigs (263.9 vs. 281.4 Nmm; $P = 0.046$). The maternal grandsire influenced the FOP_{LD} value

Table 3. Production and carcass traits (LS-means ± standard errors) for crossbred pigs with different maternal grandsire

Variable	(LW*L) × H ($n = 114$)	(LW*D) × H ($n = 165$)	*P*-value
Initial weight, kg	21.5 ± 0.89	24.3 ± 0.68	0.018
Daily weight gain, g	841 ± 9.3	870 ± 7.4	0.020
Early gain (22–60 kg), g	720 ± 17.9	785 ± 14.1	0.089
Late gain (60–108 kg), g	946 ± 14.7	940 ± 11.7	0.759
Days in experiment	101.9 ± 1.43	95,4 ± 1.11	0.001
Final weight, kg	106.6 ± 0.50	106.9 ± 0.41	0.667
Carcass weight, kg	80.3 ± 0.47	80.9 ± 0.38	0.321
Dressing percentage, %	75.4 ± 0.22	75.7 ± 0.18	0.307
Lean meat percentage	56.5 ± 0.39	55.4 ± 0.29	0.037
Meat and bone in ham, %	79.8 ± 0.37	78.5 ± 0.28	0.009
Weight of femur, g	384 ± 5.30	388 ± 4.07	0.613
Osteochondrosis score	1.9 ± 0.18	1.9 ± 0.14	0.922

Table 4. Meat quality traits (LS-means ± standard errors) for pigs reared indoors and outdoors and for non-carriers and carriers for the RN−allele

Variable	Rearing Indoor ($n = 62$)	 Outdoor ($n = 71$)	 *P*- value	RN genotype rn^+/rn^+ ($n = 97$)	 RN^-/rn^+ ($n = 36$)	 *P*- value
L^*_{LD}	50.0 ± 0.4	49.3 ± 0.4	0.104	49.7 ± 0.4	49.6 ± 0.5	0.772
a^*_{LD}	7.1	7.3	†	7.1	7.4	†
b^*_{LD}	2.8 ± 0.1	3.1 ± 0.1	0.068	2.9 ± 0.1	3.0 ± 0.2	0.435
FOP_{LD}	37.1 ± 0.8	38.4 ± 0.8	0.147	38.4 ± 0.7	37.0 ± 1.0	0.231
FOP_{BF}	36.6	39.3	†	38.3 ± 0.7	37.6 ± 1.0	0.534
Marbling$^1_{LD}$	1.9 ± 0.1	2.0 ± 0.1	0.340	2.0 ± 0.1	1.9 ± 0.2	0.460
pH_{LD}	5.34 ± 0.01	5.32 ± 0.01	0.039	5.35 ± 0.01	5.31 ± 0.01	0.048
pH_{BF}	5.44 ± 0.01	5.43 ± 0.01	0.408	5.46 ± 0.01	5.41 ± 0.01	0.001
Filter paper$^2_{LD}$	2.3 ± 0.2	2.2 ± 0.2	0.843	2.0 ± 0.2	2.5 ± 0.3	0.153
Drip loss$_{LD}$, %	8.1	8.6	†	8.3 ± 0.4	8.4 ± 0.6	0.829
Cooking loss$_{LD}$, %	27.8 ± 0.7	27.5 ± 0.7	0.618	26.4 ± 0.7	28.9 ± 0.8	0.002
WB, max. shear force$_{LD}$, N	48.4 ± 1.6	45.1 ± 1.6	0.104	47.3 ± 1.5	46.2 ± 1.8	0.630
WB, total work$_{LD}$, Nmm	281.4 ± 7.3	263.9 ± 6.7	0.046	279.8 ± 6.7	303.8 ± 7.6	0.128

[1] Subjective scoring from 1 = no marbling to 5 = high marbling.
[2] Subjective scoring from 0 = dry filter paper to 5 = saturated filter paper.
†Interactions present, see Table 5 and Fig. 1.

and cooking loss in LD, whereas other meat quality characteristics were unaffected. FOP_{LD} was significantly higher with LW*L mothers than with LW*D mothers (39.1 vs. 36.3; $P = 0.036$). For internal reflectance in BF (FOP_{BF}) and drip loss, significant interactions between rearing systems and breed of the maternal grandsire were found (Table 5). FOP_{BF} scored significantly higher in outdoor reared pigs with LW*L mother, than in the other pigs. Drip loss differed between indoor and outdoor reared pigs with LW*L mother, but not between pigs with LW*D mother in the different rearing systems. For total work of shear force, a significant interaction between maternal grandsire and sex was found (not tabled). Females with LW*L mothers had higher total work of shear force than castrates of the same crossbreed and females from crossbreeds with LW*D mothers. Within (LW*D) × H crossbreeds, the castrates had higher values than the females.

The RN genotype had an influence on the meat quality traits pH and cooking loss. In RN^- carriers, pH in both muscles was significantly lower than in non-carriers. Cooking loss was higher for the carriers than for the non-carriers (28.9 vs. 26.4%; $P = 0.002$), whereas filter paper wetness and drip loss were not affected. Reflectance and shear force values were not significantly different between the genotypes, except that outdoor reared pigs with the RN^-/rn^+ genotype had higher a* value than the other pigs ($P = 0.02$ for interaction rearing × RN genotype; Fig. 1). An effect of sex (not listed in the table) was discovered for the L* and a* values, where castrates had slightly lighter and less reddish meat. However, sex had no influence on pH, filter paper wetness, drip and cooking loss or shear force values.

Discussion

Growth and production

The pigs in this study had high daily weight gain both indoors and outdoors. The high growth rate was

Table 5. FOP_{BF} and drip loss (LS-means ± standard errors) from crossbred pigs with different maternal grandsire reared indoors or outdoors ($n = 133$)

Variable	(LW*L) × H Indoor ($n = 18$)	 Outdoor ($n = 21$)	(LW*D) × H Indoor ($n = 44$)	 Outdoor ($n = 50$)
FOP_{BF}	$36.3^a \pm 1.35$	$41.1^b \pm 1.30$	$37.0^a \pm 0.82$	$37.5^a \pm 0.82$
Drip loss, %	$7.6^a \pm 0.75$	$9.1^b \pm 0.73$	$8.6^{ab} \pm 0.45$	$8.1^{ab} \pm 0.45$

Different letters within the rows indicate significant differences ($P \leq 0.05$) between the values.

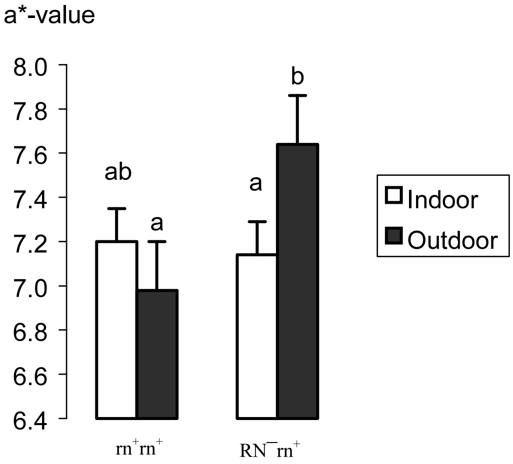

Fig. 1. LS-means ± standard errors of a*-value for pigs reared indoors or outdoors within different RN genotypes. Different letters between the bars indicate significant differences ($P \leq 0.05$) between the values.

observed even during the piglet period, although the piglets did not receive any creep feed. This could partly be explained by the long lactation period, which prevents the growth check at weaning that usually happens in conventional production with earlier weaning (English et al., 1988). It has been shown that piglets kept outdoors start to explore and eat dry food earlier than piglets kept indoors (Webster & Dawkins, 2000; Cox & Cooper, 2001). In addition, a lower infection load outdoors (Pig Management, 1995; Engblom, 1999) could be a contributing factor.

In the first part of the growing period when the pigs were fed *ad libitum*, outdoor pigs had an even higher growth rate than indoor pigs. This was unexpected and contrary to earlier investigations (Lundeheim et al., 1995; Sather et al., 1997; Engblom, 1999; Gustafson & Stern, 2003). In general, feed intake capacity is a limiting factor for growth (Smith et al., 1991) and outdoor pigs need to eat more than indoor reared to compensate for higher energy requirements. However, the design of this experiment was different from those cited, as indoor reared pigs had to adapt to a new environment after weaning. The change of environment at weaning from pasture outdoors to an indoor pen is probably a larger change than the move from one paddock to another.

The feeding regime in this study was *ad libitum* up to a live weight of 60 kg and thereafter restricted to reduce the fat deposition in the latter part of the growing/finishing period. Feed restriction increases weight variation within the groups, as rank and eating speed determine how much each pig eats (Stern & Lundeheim, 1998). During the second year, the feed allowance during the restrictive period was 10% higher outdoors in addition to access to the pasture. Pigs on pasture always graze (Gustafson & Stern, 2003) and root for food, however ME intakes from pasture are usually relatively low, around 5% of total ME intake (Gustafson & Stern, 2003; Stern & Andresen, 2003). In our study, pasture plus 10% extra feed was apparently too little supplement as the indoor pigs still tended to grow faster in this period. Berger et al. (2000), who investigated energy requirements during winter for sows outdoors and indoors in France, also had problems of estimating extra energy requirements for outdoor pigs. They estimated the supplementary need to be 17%. But as backfat at the end of the experiment still was too low in the outdoor sows they concluded that the allowances had needed to be an additional 10%. They explained the discrepancy with feed spillage, competition and short term climate variation outdoors. The extra amount of feed required for equal growth outdoors and indoors could not be estimated from our experiment. Nevertheless it can be concluded that the growing capacity of the outdoor pigs was not fully exploited, as they grew faster than indoor pigs during the first period but tended to grow slower during the second period when feed was restricted. In outdoor production, rearing time is, however, economically not as important as in conventional systems indoors with continuous production. Also, the feed efficiency would further decrease with an increased feed allowance, which needs to be compensated with lower initial investments for outdoor rearing pigs (Sather et al., 1997) and added value of the carcass (Branscheid, 1998).

Even though early growth rate was higher for outdoor pigs, the lean meat percentage was higher than for indoor pigs. This indicates that the high early growth rate in outdoor pigs was not unfavourable for carcass quality traits. A high leanness in outdoor pigs has also been found in earlier investigations (Lundeheim et al., 1995; Enfält et al., 1997a; Sather et al., 1997; Engblom, 1999). An effect of maternal grandsire was found on early growth rate, where the (LW*D) × H crossbreeds were younger and heavier at the start and also grew faster than the (LW*L) × H crossbreeds, but their lean meat percentage was lower in accordance with Enfält et al. (1997a). No interaction between rearing system and breed was found for growth rate in this study, or in the study by Enfält et al. (1997a). No positive effect of the RN^- allele on growth rate or lean content was found in our study, in contrast to the results obtained by Enfält et al. (1997b), who stated that RN^- carriers had a higher daily gain and leaner carcass than non-carriers.

Dressing percentage was higher for outdoor pigs, probably due to the fact that they had to walk approximately 800 meters from the pasture to the stable before the last weighing. Almost all animals defecated during this walk, resulting in a lower gut fill and thus higher dressing percentage. The higher weight of the femur bone for outdoor pigs was unexpected and needs to be confirmed in other studies. The prevalence of slaughter lesions (especially respiratory diseases and white spots) recorded in this study agrees with Kugelberg et al. (2001), who studied health status among pigs reared outdoors. They found low prevalence of respiratory disorders outdoors and similar levels of white spots in the liver indoors and outdoors.

Sexual maturity

The higher degree of sexual maturity for gilts reared indoors during the first year is an interesting observation. This might partly be due to the higher age at slaughter for these pigs (4 days), but this cannot explain the whole difference. In contrast to this study, Andersson et al. (1999) found a higher degree of maturity in outdoor reared females. However, in that study the females reared outdoors were substantially older at slaughter than the indoor pigs (192 and 182 days, respectively) and non-castrated male pigs were reared together with the gilts.

Meat quality

Consumers often associate meat from organically reared pigs with improved meat quality and better taste (Branscheid, 1998). In general, these expectations could not be verified by this study. Technological meat quality traits did not differ at all or only slightly between the outdoor and indoor rearing systems. These results are in accordance with results by several authors (Warriss et al., 1983; Van der Wal, 1993; Sather et al., 1997; Bridi et al., 1998). Van der Wal (1993) compared 'Scharrelschweine' in an outdoor system fed *ad libitum* with an indoor reared control group. Indoor pigs were not different in pH_{24}, drip loss, cooking loss, subjectively evaluated intramuscular fat content (marbling) and shear force, compared to outdoor reared pigs. A taste panel supported the similarity in sensory meat quality. The author concludes that rearing system has no influence on meat quality and proposes that emotional reasoning could lead to a preference and the imagination of a superior meat taste. Apparently some consumers are willing to spend more money on this meat, which compensates for higher feed costs for outdoor growing pigs.

In the study by Enfält et al. (1997a), outdoor reared pigs with Duroc or Yorkshire as terminal sire had impaired tenderness, juiciness and overall acceptance compared to indoor reared pigs. It should be noted that these outdoor pigs also had leaner carcass and lower growth rate compared to their indoor littermates. Technological meat quality was also less beneficial in the outdoor pigs, as these pigs had higher internal reflectance, lower ultimate pH, higher drip loss and higher shear force in the LD than in the indoor reared control group. The result of lower ultimate pH is in accordance with the present study, where lower pH_{LD} was measured in outdoor reared pigs, whereas no differences in FOP_{LD} and maximal shear force could be found between the two rearing systems. Drip loss was not different between the rearing systems for (LW*D) × H crossbreeds, but outdoor reared (LW*L) × H crossbreeds had significantly higher drip loss than indoor reared pigs. Micklich et al. (2002) stated that purebred Duroc pigs in outdoor rearing systems have lower drip loss than indoor reared pigs. On the other hand, Gentry et al. (2002b) found a tendency of higher drip loss in an indoor reared crossbreed, with Yorkshire, Landrace and Duroc. In accordance with the presented results from the (LW*L) × H crossbreeds, Sather et al. (1997) measured higher drip loss and significantly increased marbling of LD for outdoor reared pigs compared to an indoor control group. The authors noticed that pH_{LD} did not differ between the rearing systems, whereas pH in M. semimebranosus was significantly lower in outdoor reared pigs. The rearing system did not have the same influence on pH decrease in all muscles.

Measurements of shear force gave lower values of total work and a tendency to lower maximal shear force for outdoor pigs. These results indicated a slightly tougher meat for indoor pigs, however, total work of shear force is not as good a predictor for experienced bite resistance as maximum shear force (Hovenier et al., 1993). In any event, our results are in contrast to Lewis et al. (1989) who found that exercise comparable to outdoor rearing would produce tougher meat. In addition, Enfält et al. (1997a) observed significantly higher shear force for outdoor pigs. Maw et al. (2001) investigated the main factors influencing eating quality. The authors concluded that breed, followed by floor type (slatted floor vs. concrete floor vs. straw) and housing conditions (pigs/pen) were the main factors determining meat quality. However, an effect of breed on maximum shear force values could not be proved in our study.

Meat from carriers of the RN^- allele was significantly lower in pH (both muscles) and had higher cooking loss. These characteristics of meat quality were described also by other authors (Le Roy et al., 1990, Lundström et al., 1996; Enfält et al., 1997b). The a* value in the present study was significantly higher for outdoor reared RN^- carriers than for indoor reared carriers and outdoor reared non-carriers. The more reddish meat could be due to a higher myoglobin content in the muscle of pigs reared outdoors as found by Petersen et al. (1997). The intensity of red colour in pig meat might also be linked to an increased number of capillaries, and as a consequence a higher amount of haemoglobin in the muscle tissue after slaughter. In a recent trial, Gentry et al. (2002b) found a tendency to more reddish meat colour in outdoor reared pigs, and also Micklich et al. (2002) stated that outdoor rearing generally benefits meat colour. An effect of sex was discovered on the L* and a* values, where castrates had slightly lighter and less reddish meat. However, sex had no influence on pH, filter paper wetness, drip and cooking loss or shear force values.

It can be concluded that the RN genotype had a greater influence on technological meat quality characteristics than rearing system, sex and maternal grandsire. Differences in meat quality traits between the crossbreeds with different maternal grandsire within different rearing systems were detected. Outdoor rearing of (LW*L) × H crossbreeds was unfavourable compared to (LW*D) × H crossbreeds, regarding FOP_{BF} values. Drip loss was highest for (LW*L) × H crossbreeds outdoors whereas drip loss for (LW*D) × H crossbreeds was not affected by the rearing system. Maximal shear force did not differ significantly between the two crossbreeds.

Conclusions

Comparing production results and technological meat quality in pigs of indoor and outdoor rearing systems, it can be concluded that both rearing systems are suitable for pig rearing during summer. Outdoor pigs had higher daily weight gain when fed *ad libitum* but inferior feed conversion ratio. The experiment indicates that outdoor pigs need more than 10% extra feed to grow as fast as their indoor littermates. However, this will further decrease the feed efficiency. The pigs delivered a carcass of satisfying technological meat quality and lean meat percentage in both rearing systems. Other production results and technological meat quality traits were only marginally influenced by the rearing system. The effect of sex and maternal grandsire had low impact on meat quality traits whereas the RN genotype affected pH and cooking loss values significantly.

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IV

Performance, carcass and technological meat quality of growing/finishing pigs raised in organic and conventional systems

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Abstract

Comparison of performance, carcass and technological quality traits of indoor and outdoor raised pigs, fed organic or conventional diets *ad libitum* or restrictively, and investigation of effect of strategic feeding were the aims of this study. During two years, 280 pigs (females and castrates) of two breed crosses (LW*D and LW*L) were applied to four treatments: I. Pigs kept outdoors, fed an organic diluted diet (20% alfalfa roughage); *ad libitum* (80 pigs). II. Pigs kept outdoors, strategically fed with first diluted and thereafter undiluted organic diet; *ad libitum* (80 pigs). III. Pigs kept indoors, fed undiluted organic diet restrictively (80 pigs). IV. Pigs kept indoors, fed a conventional diet restrictively (40 pigs). Indoor pigs fed the organic diet grew faster and had lower feed conversion ratio ($p \leq 0.01$) than outdoor reared pigs, possibly because outdoor pigs require more energy due to their higher agility. Strategic feeding seems to increase daily weight gain compared with feeding a diluted diet throughout. Technological meat quality differed slightly between indoor and outdoor raised pigs. L* values in *m. longissimus dorsi* were higher in indoor raised pigs (year 1), possibly because of the lower pH_u and higher FOP values that year. Water-holding capacity was not affected by treatment. The diet (organic/conventional) for indoor pigs did not affect carcass and meat quality traits. Breed cross did not affect performance and carcass traits, whereas LW*D tended to have higher water-holding capacity and lower shear force compared with LW*L. However, an interaction between breed cross and treatment for total daily weight gain was found.

Keywords: carcass composition, meat quality, performance, pig, roughage, organic.

1. Introduction

The promotion of higher production of organic pork is an EU-wide political goal and the general regulation for this production was internationally assigned by the International Federation of Organic Agriculture Movements (IFOAM). Generally, in organic pig production, animals should be raised outdoors, fed organically produced diets and have access to roughage. Expansion of organic pig production is slower than that of other organic productions, *e.g.* milk and beef. This might be due to insufficient certitude about the production conditions and the final product quality. Outdoor raised pigs have been shown to need more than 10% extra feed to grow as fast as the indoor littermates (Stern *et al.*, 2003). Carcass quality, such as lean meat content, backfat thickness and area of loin has been reported to be less favourable for outdoor raised pigs (Van der Wal *et al.*, 1993; Bridi, Müller & Ribeiro, 1998; Olsson *et al.*, 2003). For technological meat quality, characteristics such as drip loss, colour and shear force were found less beneficial in outdoor produced meat (Enfält *et al.*, 1997; Olsson *et al.*, 2003; Stern *et al.*, 2003).

However, results for carcass and meat quality from outdoor raised pigs are not consistent. Effects of outdoor housing are also reported to enhance carcass and meat quality, such as higher lean meat content and lower shear force in outdoor pigs compared with indoor pigs (Stern *et al.*, 2003). Besides housing system (indoor/outdoor), other factors, such as feeding regimen, diet composition, carcass weight and slaughter procedure have to be considered when interpreting carcass and meat quality traits.

The aim of this study was to compare performance and carcass traits of indoor and outdoor raised pigs, fed organic or conventional diets *ad libitum* or restrictively. Also, the effect of strategic feeding with higher energy intensity the last period before slaughter was studied for the outdoor pigs. In addition, the suitability of two types of breed crosses for applied housing system was investigated.

2. Material and methods

2.1. Animals

This study was carried out over two years and included 280 growing/finishing pigs; 120 pigs in year 1 and 160 pigs in year 2, equally distributed across females and castrates and [Large White (sow) x Duroc (boar)] (LW*D) and [Large White (sow) x Swedish Landrace (boar)] (LW*L), using split litter technique. All piglets were born and reared indoors and weaned at 5 weeks of age. The experiment started when the pigs were 79 days in year 1 and 71 days in year 2 (S.D. 6 and 3 days, respectively), and had an average initial weight of 34.6 kg in year 1 and 26.4 kg in year 2 (S.D. 7 and 3 kg, respectively).

In year 1, two outdoor treatments and one indoor treatment were included in the study; in year 2, a further indoor treatment was added (Table 1). Outdoor pigs were housed in separated enclosures with grazing possibilities. Each enclosure consisted of 20 pigs of both breed crosses and sexes. One outdoor treatment received organic diet diluted with 20% roughage. To guarantee roughage consumption, the alfalfa meal was processed with the organic diet to pellets (Table 2). Pigs in the second outdoor treatment were strategically fed a diluted organic diet in early period and thereafter undiluted organic diet (higher energy density) with access to roughage (alfalfa; only produced into pellets). Early period lasted 58 days in year 1 and 70 days in year 2 and average live weight was 80.2 and 83.5 kg, respectively. Outdoor pigs were fed *ad libitum*. Both years, indoor pigs were fed the undiluted organic diet restrictively according to the standard feeding regimen for growing/finishing pigs in Sweden (Andersson *et al.*, 1997). In year 2, the pigs in the additional indoor treatment received a conventional diet, restrictively. All indoor pigs were kept in pens with 10 pigs of the same breed cross and of both sexes. Live weight of all pigs was recorded at start of the experiment, after four weeks, thereafter every second week and the day before slaughter. In year 2, the scale used to weigh indoor pigs developed a fault that was not detected, leading to higher carcass weights. Feed consumption was recorded on an enclosure/pen basis.

Table 1. *Experimental design*

Abbrev.	Housing system	Diet	Feeding regimen	Year
org.dil.	Outdoor	Organic diluted	*Ad libitum*	1+2
strategic	Outdoor	Organic diluted in early period and organic undiluted with access to roughage (alfalfa pellets) in late period	*Ad libitum*	1+2
org. undil.	Indoor	Organic undiluted	Restricted	1+2
conv.	Indoor	Conventional undiluted	Restricted	2

2.2. Carcass quality

The pigs were slaughtered at a live weight of approximately 107 kg (S.D. 3 kg in year 1 and 4 kg in year 2) at a commercial slaughterhouse, after 10 km of transport and approximately 2 h of lairage. The official meat inspector recorded individual slaughter lesions, such as joint lesions, pneumonia, and parasitic and other liver damage. Final weight was calculated on the basis of the recorded hot carcass weight and the average dressing percentage per year [final weight = hot carcass weight/(average dressing percentage)*100] and this weight was used to calculate daily weight gain and feed conversion ratio. Hot carcass weight was measured on the whole slaughtered animal, bled and eviscerated, without tongue, hooves and genital organs, without flare fat, kidney and diaphragm (Walstra & Merkus, 1995). Carcass lean meat was determined with the Hennessy Grading Probe at the slaughterhouse and was additionally estimated as [lean meat percentage = -49.781 + (0.899* ham in carcass) + (0.612* meat and bone in ham) + (0.651*loin in carcass) + (0.252*meat and bone in loin) + 0.249 (for females)] (Hansson, 1997). Measurements of the backfat thickness were carried out with a ruler on the cold carcass over the middle of *m. longissimus dorsi* (LD) at the cut behind the last rib.

2.3. Technological meat quality

Meat quality traits were measured on samples of LD taken at the last rib and backwards and of *m. biceps femoris* (BF) approximately 24 h after slaughter. Ultimate pH (pH_u) (portable pH-meter, Knick, Berlin, Germany; equipped with a combination gel electrode SE104, Knick, Berlin, Germany; calibrated to chilling room temperature) and internal reflectance, using a fibre optic probe (FOP, 900 nm; TBL Fibre Optics Group Ltd., Leeds, UK) were measured on LD and BF. Surface reflectance with the parameters L* (lightness), a* (redness) and b* (yellowness) was measured after one hour of blooming by using a Minolta colorimeter (Minolta Chroma Meter CR 300, DP-301, Osaka, Japan). Drip loss was determined on a gently dried 2-cm-thick slice, taken from LD directly in front of the last rib towards the forepart, stored in a plastic bag by a thread at 4°C for 48 h. Thawing loss was determined as the difference between the weight of fresh and thawed 300-g piece of LD after frozen storage at -20°C. On the same piece of meat, cooking loss was determined as the weight difference before and after cooking in a vacuum bag in a water bath at 70°C during 90 min. Maximal shear force and total work of Warner-Bratzler (WB) were measured on 8 strings (10x10x50 mm), sheared across the fibre direction of cooked LD (speed: 55 mm/min, TA-HDI texture Analyser; Stable Micro Systems, Surrey, UK) (Honikel, 1998).

2.4. Chemical composition

Analysis of glycogen, crude protein, intra muscular fat content (IMF), dry matter and ash was done on LD from approximately half of the animals, taken after the last rib towards the ham. Glycogen was determined as the sum of glycogen, glucose and glucose-6-phosphate in homogenised muscle tissue (Dalrymple & Hamm, 1973) using the enzymatic kit Glucose HK 125 by ABX Diagnostics

(Montpellier, France). Crude protein was analysed with the Kjeltec apparatus (Tecator AB, Höganäs, Sweden) using factor 6.25 for calculating the protein content. The fat content was analysed by the SBR-method after hydrolysis with HCl using diethyl ether and petroleum ether for extraction.

2.5. Statistics

Feed conversion and initial weight data were calculated with the GLM procedure in SAS. Statistical analyses of the other performance, carcass and technological meat quality traits, and chemical composition were performed with the MIXED procedure in SAS (SAS Institute Inc., Cary, N.C., USA, version 8.02). Each year was analysed separately. Data given in the tables are least square means with pooled standard errors. The models included treatment, breed cross (LW*D or LW*L) and gender (female or castrate) as fixed factors. Two-way interactions between the fixed factors were included in the model, when significant ($p<0.05$). Sire within breed cross and dam within breed cross and sire were treated as random. For the statistical analyses of average daily weight gain (total and early period) and days in experiment, initial weight was included in the model as a covariate. Three outdoor raised pigs fed organic diluted diet in year 2 were excluded from the calculation of late daily weight gain because they were in this period for less than 14 days.

3. Results

3.1. Treatment

3.1.1. Performance and carcass quality

Year 1

Indoor raised pigs had higher final weight compared to outdoor pigs fed diluted organic diet (Table 3). Generally, these indoor pigs grew faster from start to slaughter and had lower feed conversion ratio than both outdoor treatments. The difference in daily weight gain was on average 95 and 60 g, respectively, and was established in the early period, but could not be observed in the late period. However, there was an interaction between breed cross and treatment in total daily weight gain ($p= 0.001$; Figure 1); LW*D pigs strategically fed grew faster than LW*D pigs fed diluted organic diet throughout (881 g/day vs. 832 g/day; $p=0.015$), whereas there was no difference between these diets for LW*L pigs (847 g/day vs 827 g/day; $p=0.325$). During the late period, the total voluntary consumption of additional alfalfa pellets for outdoor pigs strategically fed was only 0.4-0.7 kg per pig.

Outdoor raised pigs with diluted organic diet had lower hot carcass weight compared to the indoor pigs fed undiluted organic diet ($p=0.003$; Table 3). Dressing percentage was highest for the indoor pigs, followed by the outdoor pigs strategically fed. Lowest dressing percentage was found for the outdoor pigs fed diluted organic diet. These pigs had also thinner backfat than the other pigs. However, treatment did not affect estimated lean meat content ($p=0.201$).

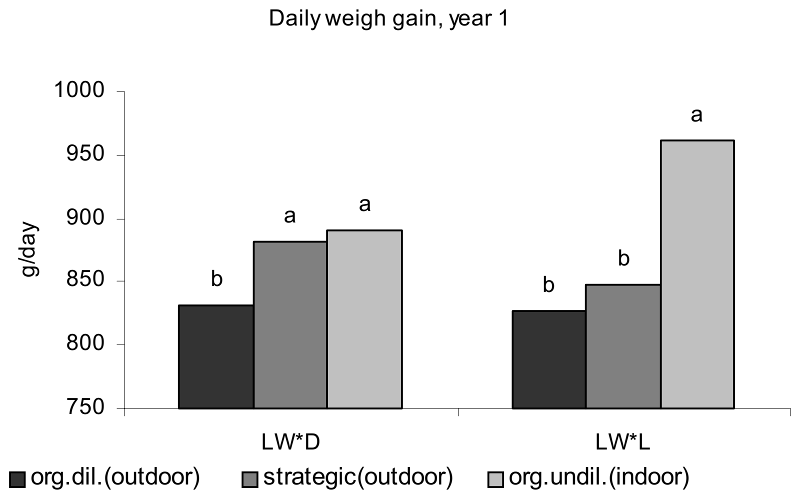

Figure 1. Daily weight gain from start to slaughter of growing/finishing pigs of two breed crosses in different rearing systems, year 1.

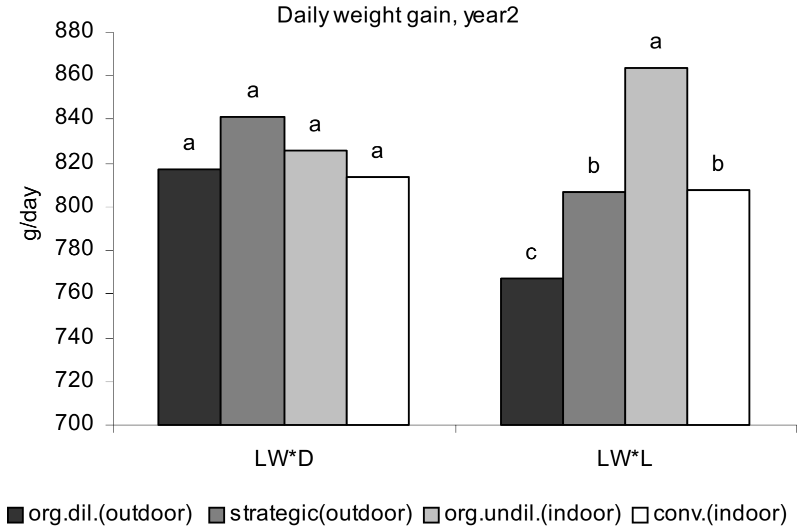

Figure 2. Daily weight gain from start to slaughter of growing/finishing pigs of two breed crosses in different rearing systems, year 2.

Year 2

Indoor pigs had higher final weight than outdoor pigs (Table 3). As in year 1, indoor pigs with organic diet grew faster and had a better feed efficiency than outdoor pigs. An interaction between treatment and breed cross for daily weight gain was found. In contrast to year 1, there was no difference in total daily weight between diets for LW*D pigs (Figure 2). However, LW*L indoor pigs fed the organic diet had higher daily weight gain (864 g/day; $p=0.001$) than the other pigs. LW*L outdoor pigs strategically fed grew faster than those pigs fed diluted organic diet throughout (807 g/day vs 767 g/day; $p= 0.029$).

Dressing percentage was lower in outdoor pigs, compared to indoor pigs ($p=0.001$). Backfat thickness was lower and lean meat content was higher in pigs with diluted diet compared to the other pigs raised outdoors and those indoor pigs given organic diet. In comparison with indoor pigs fed a conventional diet, no differences in carcass quality traits were observed ($p\geq0.05$).

In total, 48 of all 280 pigs got veterinary remarks for lesions found at slaughter; joint lesions (5 outdoor pigs), pneumonia (3 outdoor pigs), parasitic liver damage (2 indoor and 31 outdoor pigs) and other liver damage (1 indoor and 6 outdoor pigs).

3.1.2. Technological meat quality and chemical composition

Year 1

The pH_u value in LD was lower for indoor pigs given undiluted organic diet than for outdoor pigs strategically fed ($p= 0.013$; Table 4). Indoor raised pigs had higher FOP values and paler meat (higher L* value) than that from outdoor pigs. Treatment did not influence water-holding capacity, WB shear force values and chemical composition.

Year 2

pH_u did not differ between treatments ($p=0.630$; Table 4). The b* value (yellowness) in meat from outdoor pigs was higher, whereas maximal WB shear force was lower than from indoor pigs with organic diet. No differences were found for water-holding capacity ($p\geq0.05$). Glycogen content was higher for indoor pigs, compared to outdoor pigs fed diluted organic diet (Table 5). Outdoor pigs had lower maximal WB shear force compared to indoor pigs fed the organic diet. Outdoor pigs strategically fed had higher ash content in LD compared to the other outdoor pigs (1.28% vs. 1.23%; $p=0.001$). For water content in LD an interaction between treatment and breed cross was found ($p\leq0.05$). For LW*D pigs, diet influenced water content; meat from outdoor pigs given diluted organic diet and indoor pigs given conventional diet had higher values than the other pigs. Meat from LW*L pigs was not affected by the diet.

3.2. Breed cross

3.2.1. Performance and carcass quality

Both years, no differences in performance and carcass traits (not tabled), such as hot carcass weight, dressing percentage and lean meat content, could be found between the two breed crosses.

3.2.2. Technological meat quality and chemical composition

Results on technological meat quality are shown in Table 5. For a* (redness) in year 1, breed cross and gender showed an interaction (p=0.005), where meat from LW*L castrates was more red than that from females (5.82 vs. 5.28; p=0.012), whereas no difference between meat from castrates and females of LW*D could be found (5.92 vs. 6.23; p=0.138). Water-holding capacity was better or tended to be better in meat from LW*D pigs than that from LW*L pigs. In year 1, values of both WB total work and maximal shear force were lower in meat from LW*D pigs ($p \leq 0.05$). However, these traits did not differ in year 2.

Chemical composition of meat was comparable between the two breed crosses (Table 5). For glycogen content in year 1, an interaction (p=0.033) between breed cross and gender was found (not tabled); meat from LW*L castrates had a higher glycogen content than that from females (17.9 vs. 13.3 mmol/g; p=0.015), whereas no difference in meat from castrates and females of LW*D could be found (14.9 vs. 16.1; p=0.542). No further interactions between the fixed factors of treatment, breed cross and gender for performance, quality traits and chemical composition were found.

4. Discussion

4.1. Performance and carcass quality

4.1.1. Treatment

Both years, the final weight of indoor raised pigs was higher than of outdoor raised pigs. In year 2, this difference was increased due to minor problems with the indoor scale, where recorded body weight was lower than the real weight.

Daily weight gain of outdoor pigs was in general lower compared with indoor pigs. This might be because the outdoor pigs required more energy due to their higher agility. Furthermore, the diet was diluted with roughage, which lowered its energy content by approximately 10%. Even if outdoor pigs were fed *ad libitum*, the energy requirement for full growth ability could not be covered. Fischer (2001) reported a gradual decrease in growth rate with increasing replacement of concentrate by grass cobs. Stern *et al.* (2003) concluded that outdoor pigs need more than 10% extra feed to reach the same growth rate as indoor pigs. In other studies, where indoor and outdoor pigs were fed identical diets (Enfält *et al.*, 1997; Lebret *et al.*, 2002), indoor pigs had superior daily weight gain and needed fewer days to reach the same live weight at slaughter. Micklich *et al.* (2002) studied restrictively fed indoor and outdoor pigs, both additionally fed with forage. The authors found a higher daily weight gain for indoor pigs compared to outdoor pigs. Bridi, Müller & Ribeiro (1998) on the other hand, reported a similar growth rate for indoor and outdoor raised pigs fed *ad libitum*, in agreement with Gentry *et al.* (2002b), who concluded that rearing environment did not affect pig growth rate. The strategic feeding, including a diluted diet in early period and thereafter an undiluted diet with higher energy intensity until slaughter, increased the total daily weight gain significantly compared to pigs receiving a diluted diet throughout ($p \leq 0.01$). Feed efficiency is reported to be better for indoor reared pigs compared to outdoor pigs (Sather *et al.*, 1997). Accordingly, our results showed that indoor pigs had lower feed conversion ratio than outdoor pigs, which is probably because indoor pigs received an undiluted diet with high energy content and had highest daily weight gain.

The lower dressing percentage of outdoor raised pigs, especially for pigs given diluted organic diet throughout, might depend on the higher gut filling of these pigs. The diluted diet contained more indigestible fibre than the undiluted diet; moreover, outdoor pigs had access to pasture. A lower dressing percentage was also found by Fischer (2001), who reported a reduced dressing percentage with increased amount of roughage in the diet. The *ad libitum* feeding of outdoor pigs in our study would also contribute to a higher gut filling. This might also partly explain the difference in hot carcass weight between the treatments; outdoor pigs fed diluted diet throughout had the lowest, outdoor pigs strategically fed had the second lowest and indoor pigs had the highest hot carcass weight. Thus, to reach the same carcass weight, outdoor pigs receiving diluted diet have to be raised to a higher final weight. Comparing outdoor treatments, the strategically fed pigs had higher dressing percentage than those pigs receiving a diluted diet throughout. A reason for this might be that outdoor pigs strategically fed were given an undiluted diet (with higher energy density) in the late period. Even if they had access to alfalfa pellets during this period their alfalfa consumption was negligible (total amount 0.4-0.7 kg per pig). Additional roughage could therefore not have contributed much to gut filling, as the diluted diet did for the other outdoor pigs.

Lean meat content is often reported to be higher in outdoor raised pigs compared to indoor pigs, receiving identical diets (Enfält *et al.*, 1997; Sather *et al.*, 1997; Stern *et al.*, 2003). Enfält *et al.* (1997) explained the leaner carcasses from outdoor pigs with their lower daily weight gain, compared to indoor pigs. However, in these studies, the feeding regimen was identical between indoor and outdoor treatments, which was not the case in our study. Here all outdoor pigs received the diet *ad libitum*, compared to the restrictedly fed indoor pigs, which may explain the similarity in lean meat content between indoor and outdoor pigs in year 1. However, in year 2, the pigs with diluted organic diet had higher lean meat content. This could not be explained by their lower final weight because live weight at slaughter needs to be at least 15 kg higher to give one percentage point lower lean meat content (Andersson, Andersson & Hansson, 2002). Strategic feeding did not improve lean meat content. It has to be emphasised that the effect of housing system on carcass quality might interact with effects of feeding regimen, diet and carcass weight. The uniformity between indoor raised pigs in dressing percentage and lean meat content indicates that an organic diet can give carcass quality comparable with that from a conventional diet.

This study has confirmed earlier observations that voluntary consumption of additional roughage is low for growing/finishing pigs. Fernandez (2004) reported that pigs have a distinct preference for concentrate feed over roughage, regardless of its quality or palability. However, the directive for organic pig production requires roughage supply. Thus, to guarantee roughage consumption of pigs in our study, the alfalfa was processed into the ordinary diet. Feeding roughage to pigs can be questioned for several reasons. Firstly, pigs do not consume roughage voluntarily, secondly processing of diluted feed requires additional energy and thirdly performance, carcass and meat quality traits are not obviously better, compared to pigs not fed roughage. Thus, to meet the directives of roughage supply for pigs, access to pasture would probably be an adequate alternative in organic pig production.

The physical health status of the outdoor raised pigs was suboptimal, compared to the indoor raised pigs. Only 3 of the remarks given by meat inspectors in terms of lesions, pneumonia and liver damage were for indoor pigs, whereas 45 remarks were for outdoor pigs. Most remarks were parasitic liver damage, which pointed to a higher parasitic pressure in outdoor environments.

4.1.2. Breed cross

No difference in daily weight gain between the breed crosses could be found, which is in accordance with results by Blanchard *et al.* (1999). On the other hand, Stern *et al.* (2003) found that three-breed Duroc crosses had better daily weight gain than Landrace crosses. In earlier studies, carcass quality traits such as lean meat content and backfat thickness are often reported to be impaired in Duroc compared to white breeds (Barton-Gade, 1988; Edwards *et al.*, 1992). However, in our study, no differences in carcass quality could be observed between the two types of breed crosses. A reason for this might be that nowadays Duroc has an improved carcass quality, as higher lean meat content and thinner backfat thickness was effectively included in the breeding goals for Duroc boars. The phenotypic lean meat content of Duroc from the breeding company from which our sires originated increased with 0.3 percentage points per year during the last years (Norsvin, 2004). Affentranger *et al.*(1996) considered generally that lean meat content is mainly determined by genotype, but is also to a lesser extent influenced by feed consumption.

4.2. Technological meat quality and chemical composition

4.2.1. Treatment

Technological meat quality traits differed in some cases between the treatments. pH_u values in LD in year 1 were higher in outdoor pigs. It was earlier reported that housing system did not affect pH values in LD (Van der Wal *et al.*, 1993; Sather *et al.*, 1997; Gentry *et al.*, 2002a; Lebret *et al.*, 2002). In other studies, lower final pH from alternatively raised pigs, compared to conventional pigs was found (Enfält *et al.*, 1997; Olsson *et al.*, 2003; Stern *et al.*, 2003; Terlouw, Astruc & Monin, 2004). Other authors considered that pH and FOP values depend more on slaughter conditions (Casteels *et al.*, 1995; Lebret, Lefaucheur & Mourot, 1999) than housing system (Van der Wal *et al.*, 1993; Stern *et al.*, 2003). Exercise or type of diet might also influence the pH values. However, Rosenvold *et al.* (2001a) described that neither exercise nor diet (control vs diet with high amount of grass and rape seed meal) influenced the final pH in LD. Lower final pH in meat from outdoor raised pigs is described to depend partly on their greater glycogen stores in muscles (Enfält *et al.*, 1997; Terlou, Astruc, & Monin, 2004). Barton-Gade & Blaabjerg (1989) reported that also higher stress tolerance and consequently calmer behaviour at slaughter of outdoor raised pigs contribute to lower final pH values in meat. A significantly lower pH_u in pre-slaughter unstressed pigs, compared with stressed pigs was also found by Henckel *et al.*(2000). However, our result of higher pH_u in outdoor pigs in year 1, but not in year 2, contradicts other findings.

The less pale colour of the outdoor raised pigs in year 1 could be a consequence of not only the lower internal reflectance (lower FOP value) that year, but also more red fibres, containing more myoglobin in the muscle, due to exercise of the outdoor pigs (Essén-Gustavsson *et al.*, 1988). Lindahl, Lundström & Tornberg (2001) found that L* values in pig muscle without PSE or DFD quality mostly depended on pigment content and myoglobin forms and to a lesser not significant extent on pH and FOP values. In our study, water-holding capacity was not affected by rearing system. Again, it has to be mentioned, that besides housing system, slaughter conditions (pH development and final pH), chemical composition of meat (protein/water/glycogen content), exercise of pigs and diet composition (standard/diluted) could also have influenced water-holding capacity. Sather *et al.* (1997) and Labooij *et al.* (2004) found *e.g.* that a fast pH decline increased drip loss in meat. In our study, pH development could not be monitored, but the similarity in pH_u (year 2), drip and cooking losses indicated that pH development did not differ between treatments. Fernandez *et al.* (1991) considered that high glycogen content affected water-holding capacity in terms of higher water release during post mortem glycolysis. However, the authors described extreme differences in glycogen content comparing Hampshire breed crosses (carrier of the RN^{-} allele) with white breed crosses (non-carrier of the RN^{-} allele). The higher glycogen content in outdoor raised pigs in year 2 in our study did not affect water-holding capacity, which could be due to a smaller variation in glycogen content. Generally, an increased drip loss for outdoor raised pigs is reported by several authors (Nilzén *et al.*, 2001; Olsson *et al.*, 2003). In these studies, the increase could not be explained by differences in either pH or glycogen content of the meat. An explanation for lower water-holding capacity of outdoor raised pigs is given by Nilzén *et al.* (2001) namely that the lower crude protein and lower protein/water ratio might have contributed to the higher drip loss of those pigs. In our study, both protein content of the meat and water-holding capacity were similar between the treatments. Enfält *et al.* (1993) on the other hand, found lower drip loss for exercised indoor pigs and explained that as due to their increased physical activity. Rosenvold *et al.* (2001a) reported a significantly lower drip loss in LD in unexercised pigs, fed a diluted diet (grass and rape seed meal) compared to those fed a control diet, based on barley.

WB shear force in meat from indoor and outdoor raised pigs are widely investigated with various results. Comparing indoor and outdoor raised pigs, Olsson *et al.* (2003) found significantly higher WB shear forces for outdoor pigs. The authors related higher shear force values to lower IMF content in the meat. However, this could not be an explanation for our findings that outdoor raised pigs had lower maximal WB shear force but similar IMF content, compared with indoor raised pigs, given the organic diet. A higher growth rate including a high protein turn over and a subsequently improved tenderness of the meat was reported by Therkildsen *et al.* (2002). This relation between growth rate and shear force was found by Stern *et al.* (2003) who reported lower maximal WB shear force for outdoor pigs with higher daily weight gain compared with conventional indoor raised pigs. However, this relation between growth rate and shear force could not be found in our study, where the faster growing indoor pigs showed similar or even higher WB shear force values than the outdoor pigs.

Chemical composition did not differ between treatments in year 1, but in year 2 glycogen content was higher in indoor organically fed pigs, compared with the outdoor pigs, fed organic diluted diet throughout. However, other authors reported that physical exercise or outdoor raising improve glycogen stores in muscles (Essén-Gustavsson *et al.*, 1988; Enfält *et al.*, 1997). Rosenvold *et al.* (2001b) found that feeding regimen might influence glycogen stores in muscle. Pigs fed a diet low in digestible carbohydrates and high in protein had lower glycogen content in the muscles than the control group. Thus, in our study, the lower glycogen content of outdoor pigs might be because the diluted diet contained less digestible carbohydrates.

IMF is often reported to be lower in outdoor raised pigs (Nilzén *et al.*, 2001; Stern *et al.*, 2003). Affentranger *et al.* (1996) found that IMF content is mainly influenced by the feeding regimen, where *ad libitum* fed pigs had higher IMF values than restrictively fed pigs. These effects of outdoor raising and *ad libitum* feeding might counteract and therefore no differences of IMF in LD between outdoor pigs *ad libitum* fed and indoor pigs restrictively fed could be observed in our study.

The inconsistency in technological meat quality and chemical composition between the years, in spite of similar experimental design is difficult to explain, but stresses the importance of repeated trials.

4.2.2. Breed cross

The Duroc breed is widely known for its advantages in enhanced technological meat quality traits compared to white breeds and is therefore often used as terminal sire breed (Barton-Gade, 1988; Oliver *et al.*, 1994). Blanchard *et al.* (1999) and a report from Meat and Livestock Commission (MLC; 1992) indicated that with an increasing proportion of Duroc in the final breed cross, improvement of technological meat quality (decrease of WB shear force and cooking loss) and sensory meat quality (increase of tenderness, juiciness and palatable pork flavour) occurred. On the other hand, no effect of Duroc breed on final pH was found by these authors, which is consistent with our results. Higher a* values in year 1 are in accordance to the general consideration that meat from Duroc crosses is more red due to higher amount of myoglobin (MLC, 1992). In several studies, Duroc was found to have darker meat than other breeds (Cameron *et al.*, 1990; Oliver *et al.*, 1994). Maximal force and total work of WB shear forces in year 1 were lower for the Duroc breed cross in our study. It was earlier reported that Duroc breed and its crosses have less tough meat compared to white breeds (MLC, 1992; Enfält *et al.*, 1997) and that this could be connected to a higher IMF content of those pigs. Irrespective of this, Olsson *et al.*(2003) found only a correlation between IMF and tenderness measurement (taste panel) but not between IMF and WB shear force. In our data, including IMF as a covariate in the model, which was numerically higher in LD of LW*D pigs, the differences in WB shear force (year 1) between the breed crosses disappeared (p≥0.3). This might be an indication of a relation between IMF and WB shear force.

Although a higher IMF in Duroc and its crosses was found by several authors (Barton-Gade, 1988; Wood, Edwards & Bichard, 1988; Cameron *et al.*, 1990; Oliver *et al.*, 1994; Enfält *et al.*, 1997; Blanchard *et al.*, 1999), significant differences in IMF between the breed crosses were not found in our study. This might depend, as discussed earlier, on the breeding progress aimed at lower subcutaneous fat and subsequently lower IMF. However, Affentranger *et al.* (1996) related IMF to the feed consumption, rather than to genotype, which could also explain our results, because both breed crosses received the same diet and feeding regimen. Duroc had favourable technological meat quality characteristics, which could not be shown consequently both years; nonetheless, a tendency for better quality characteristics was clear.

4.3. Conclusions

Outdoor pigs strategically fed or receiving a diluted organic diet *ad libitum* had lower daily weight gain and higher feed conversion ratio compared to indoor pigs restrictively fed an organic diet. Dressing percentage was lower for the outdoor raised pigs, due to higher gut filling, compared to the indoor pigs. Physical health status in terms of parasitic liver damage was worse in outdoor raised pigs, compared to indoor raised pigs. Breed cross did not affect performance and carcass traits.

The comparison of outdoor pigs strategically fed and indoor pigs restrictively fed showed no clear difference in carcass and meat quality. Outdoor pigs receiving a diluted diet throughout had higher lean meat content and lower backfat thickness, compared to the other pigs. Breed cross did not affect carcass traits and most of the technological meat quality traits and chemical composition. However, higher water-holding capacity (including drip and cooking losses) and higher WB shear force and lower IMF content for LW*L pigs could be found, compared to LW*D pigs.

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Table 2. *Composition and nutrient content of the diets*

	Year 1		Year 2		
	org. dil.	org. undil.	org. dil.	org. undil.	conv.
Ingredients, %					
Wheat	18.4	23.0	18.4	23.0	48.47
Oats	16.0	20.0	16.0	20.0	-
Bran	16.0	20.0	16.0	20.0	8.00
Peas	16.0	20.0	16.0	20.0	7.00
Middlings	5.43	6.78	5.43	6.78	12.00
Potato protein	3.99	4.99	3.99	4.99	-
Rapeseed meal	2.14	2.68	2.14	2.68	10.00
Alfalfa meal	20.0	-	20.0	-	-
Barley	-	-	-	-	11.00
Soybean meal	-	-	-	-	1.00
Limestone	1.18	1.48	1.18	1.48	1.46
Monocalcium phosphate	0.46	0.57	0.46	0.57	0.20
Sodium Chloride	0.25	0.31	0.25	0.31	0.30
Vitamin premix	0.15	0.19	0.15	0.19	0.10
L-lysine HCL	-	-	-	-	0.41
Methionine	-	-	-	-	0.02
Threonine	-	-	-	-	0.04
Analysed nutrient content					
Metabolizable energy, MJ	11.3	12.1	11.9	12.6	12.7
Crude protein, %	18.0	18.5	16.8	16.7	17.4
Lysine, g/kg	9.1	9.9	8.5	9.2	9.9
Methionine, g/kg	2.8	2.9	2.5	2.8	2.8
Threonine, g/kg	7.0	7.1	6.4	6.3	6.0

Table 3. *Performance and carcass traits (LS-means and pooled standard error) of growing/finishing pigs raised oudoors- and indoors with different diets*

	Year 1					Year 2					
	Outdoor		Indoor			Outdoor		Indoor			
	org. dil.	strateg.	org. undil	SE	P-value	org. dil.	strateg.	org. undil.	conv.	SE	P-value
No. of animals	40	38	40			40	39	39	40		
Initial weight, kg	34.7	34.5	34.6	1.16	0.992	26.4	27.0	25.6	26.4	0.55	0.314
Final weight, kg	106.5^{b}	107.8^{ab}	108.9^{a}	0.57	**0.013**	103.9^{c}	105.0^{c}	110.9^{a}	109.2^{b}	0.60	**0.001**
Daily weight gain, g											
start - slaughter[1]	827^{b}	862^{c}	922^{a}	12.0	**0.001**¤	793^{b}	822^{c}	851^{a}	811^{bc}	14.2	**0.001**¤
initial period[1]	767^{b}	790^{b}	904^{a}	13.2	**0.001**¤	800	803	811	784	17.1	0.343¤
final period	922	968	927	51.2	0.345	753^{c}	854^{b}	949^{a}	876^{b}	23.4	**0.001**
Feed conversion, MJ/kg											
start - slaughter	38.7^{b}	39.4^{b}	32.3^{a}	0.93	**0.004**	39.4^{c}	38.9^{c}	33.1^{a}	35.0^{b}	0.72	**0.001**
initial period	36.1^{b}	36.7^{b}	30.2^{a}	0.79	**0.003**	36.3^{b}	34.9^{ab}	32.3^{a}	33.3^{a}	0.85	**0.050**
final period	43.0	44.2	39.4	1.74	0.059	52.7^{c}	49.5^{c}	34.7^{a}	38.3^{b}	1.35	**0.001**
Hot carcass weight, kg	80.0^{b}	80.1^{ab}	81.8^{a}	0.42	**0.013**	77.7^{b}	78.5^{b}	83.0^{a}	81.7^{c}	0.44	**0.001**
Dressing percentage	74.3^{b}	75.1^{c}	76.0^{a}	0.35	**0.001**	72.7^{b}	73.9^{c}	77.0^{a}	76.1^{a}	0.33	**0.001**
Backfat[2], mm	13.2^{b}	14.5^{a}	15.0^{a}	1.47	**0.006**	12.4^{b}	13.9^{a}	14.2^{a}	14.0^{a}	0.65	**0.007**
Estm. lean meat, %	58.3	57.5	57.6	1.19	0.201	60.3^{b}	58.6^{a}	58.8^{a}	59.5^{ab}	0.40	**0.004**

[1] Initial weight was included in the model as covariate; [2] Over the middle of *m. longissimus dorsi* at the cut behind the last rib.

¤ Interaction between the fixed factors breed cross and treatment; Means with different superscript within row and year differ significantly ($p<0.05$).

Table 4. *Technological meat quality traits and chemical composition (LS-means and pooled standard error) of growing/finishing pigs raised outdoors and indoors with different diets*

	Year 1					Year 2					
	Outdoor		Indoor			Outdoor		Indoor			
	org. dil.	strateg.	org. undil.	SE	P-value	org. dil.	strateg.	org. undil.	conv.	SE	P-value
No. of animals	40	37	40			40	39	39	40		
ultimate pH $_{LD}$	5.53^{ab}	5.56^{b}	5.50^{a}	0.020	**0.042**	5.53	5.50	5.52	5.51	0.021	0.630
ultimate pH $_{BF}$	5.65	5.68	5.67	0.032	0.520	5.63	5.59	5.65	5.62	0.029	0.096
FOP $_{LD}$	28.8^{a}	26.2^{b}	29.6^{a}	1.04	**0.004**	29.0	29.4	27.9	27.9	1.10	0.499
FOP $_{BF}$	34.4^{b}	33.2^{ab}	31.7^{a}	0.07	**0.019**	32.2^{b}	35.6^{c}	27.7^{a}	29.3^{a}	0.79	**0.001**
Minolta value$_{LD}$											
L*	47.8^{b}	46.9^{b}	49.1^{a}	0.60	**0.001**	47.1	47.5	47.8	47.9	0.44	0.192
a*	5.9	5.9	5.7	0.15	0.336	6.1	6.3	6.1	6.1	0.18	0.861
b*	2.2	1.8	1.8	0.16	0.074	2.0^{bc}	2.1^{b}	1.5^{a}	1.7^{ac}	0.12	**0.001**
WHC$_{LD}$											
Drip loss, %	4.6	4.0	3.9	0.03	0.113	4.2	4.9	4.1	4.9	0.35	0.104
Thawing loss^{1}, %	7.2	7.0	7.3	0.59	0.952	9.8	10.4	10.7	11.6	0.48	0.091
Cooking loss^{1}, %	21.4	21.1	22.1	0.57	0.558	18.8	17.8	18.4	19.2	0.44	0.136
WB shear force$^{1}{}_{LD}$											
total work, Nmm	175.2	161.9	167.8	5.58	0.243	150.8	144.6	163.1	155.8	6.01	0.143
max. shear force, N	30.5	28.9	30.6	1.39	0.506	28.1^{b}	27.6^{b}	33.8^{a}	31.7^{ab}	1.83	**0.006**
Chem. composition$_{LD}{}^{1}$											
Glycogen, µmol/g	15.0	14.3	17.4	1.48	0.152	12.4^{b}	14.3^{ab}	16.6^{a}	15.7^{a}	1.13	**0.044**
Crude protein, %	23.5	23.8	23.8	0.15	0.297	22.9	23.1	23.0	23.1	0.15	0.725
Intramusc. fat, %	1.86	1.92	1.86	0.22	0.897	1.58	1.70	1.64	1.55	0.095	0.579

[1] Values are determined on approx. half of the animal material; Means with different superscript within row and year differ significantly ($p<0.05$).

Table 5. *Technological meat quality traits and chem. composition (LS-means and pooled standard error) of LW*D and LW*L cross-bred pigs*

	Year 1				Year 2			
	LW*D	LW*L	SE	P-value	LW*D	LW*L	SE	P-value
No. of animals	57	60			79	79		
ultimate pH $_{\text{LD}}$	5.52	5.50	0.018	0.507	5.56	5.50	0.021	0.079
ultimate pH $_{\text{BF}}$	5.65	5.66	0.021	0.964	5.65	5.63	0.032	0.634
FOP $_{\text{LD}}$	28.7	27.7	0.20	0.565	27.9	29.0	0.10	0.244
FOP $_{\text{BF}}$	34.5	31.7	0.53	**0.007**	32.1	30.3	0.55	0.051
Minolta value$_{\text{LD}}$								
L*	47.4	48.5	0.78	0.398	46.9	48.2	0.50	0.099
a*	6.1	5.6	0.16	0.336¤	6.1	6.2	0.19	0.578
b*	2.0	1.8	0.20	0.467	1.8	1.9	0.11	0.601
Water-holding capacity$_{\text{LD}}$								
Drip loss, %	3.6	4.8	0.39	0.064	3.7	5.3	0.34	**0.009**
Thawing loss^1, %	6.7	7.6	0.47	0.232	10.0	11.2	0.33	**0.031**
Cooking loss^1, %	20.3	22.7	0.64	**0.045**	18.1	19.1	0.31	0.051
WB shear force$^1{}_{\text{LD}}$								
total work, Nmm	156.5	180.1	4.47	**0.014**	152.5	154.6	5.21	0.787
max. shear force, N	27.8	32.2	1.21	**0.048**	28.9	31.6	1.93	0.360
Chemical composition$_{\text{LD}}{}^1$								
Glycogen, µmol/g	15.5	15.6	1.63	0.967¤	14.0	15.5	0.93	0.292
Crude protein, %	23.5	23.8	0.15	0.198	23.0	23.1	0.11	0.446
Intramuscular fat, %	2.22	1.52	0.290	0.144	1.70	1.55	0.086	0.269

¤ Interaction between the fixed factors breed cross and gender;

[1] Values are determined on approx. half of the animal material; Means with different superscript within row and year differ significantly ($p<0.05$).

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Effect of Extra Maternal Feed Supply in Early Gestation on Sow and Piglet Performance and Production and Meat Quality of Growing/Finishing Pigs

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The influence of differentiated extra maternal feed allowance during early gestation on maternal performance and postnatal development of the progeny from gilts and sows was investigated. Four different feed allowances of the same diet (Control [C], +35% [T35], +70% [T70], +100% [T100]) were assigned to 20 crossbred gilts (Swedish Landrace × Swedish Yorkshire), which continued as sows with the same feed allowance the following parity. The progeny was uniformly raised and slaughtered at a live weight of 110 kg. Additional maternal feed allowance resulted in significantly more weaned piglets per sow but not per gilt. Piglet numbers did not increase from T35 to T70/T100. Piglet birth weight did not increase due to maternal feeding. The intra-litter variation in piglet birth weights was similar between the treatments. Independent of the additional feed allowance, all gilts and sows had similar weights after weaning and had good body condition. The growth rate of progeny from sows was negatively related to maternal feed supply; for progeny from gilts, no clear trend of nutritional influence could be observed. Carcass and technological meat quality was not affected by maternal feeding treatment. Birth weight positively affected later growth performance (daily weight gain), carcass quality (lean meat content, back fat, proportion of muscles in ham/loin), whereas technological meat quality was unaffected.

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Key words: birth weight, carcass quality, feed allowance, growth rate, litter size, maternal nutrition, postnatal development, technological meat quality.

Introduction

In pig production, number of live-born piglets per litter, piglet survival, daily weight gain, feed conversion ratio and lean meat percentage are the most important traits for economic efficiency (Palmø, 1999). Some of these traits might be influenced by early prenatal muscle development and be stimulated by maternal treatment, as extra feed supply or hormone supplementation (Rehfeldt et al., 1993; Dwyer et al., 1994;

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Brameld et al., 1998; Rehfeldt et al., 1999). In other studies it has been observed that high piglet birth weight, which might be a consequence of beneficial prenatal muscle fibre development, is positively correlated to daily weight gain, feed conversion ratio and lean meat percentage (Powell & Aberle, 1980; Wolter et al., 2002).

Prenatal development of muscle fibres has a biphasic nature. The primary fibres develop during day 20 to 50 of gestation (Stickland, 1994). These fibres serve as a template for genesis of the secondary fibres, which occurs during day 54 to 90 of gestation as a formation around single primary fibres (Wigmore & Stickland, 1983). In postnatal development, the primary fibres are transformed to slow-twitch oxidative fibres, and secondary fibres to fast-twitch glycolytic fibres (Ashmore et al., 1973). Genetically, the number of primary fibres is fixed, whereas it has been stated that secondary fibre formation is inter alia nutritionally influenced (Dauncey & Gilmour, 1996). Thus, supplementary feeding of sows during gestation should lead to a higher number of secondary fibres (Stickland, 1994). In total, this increase in fibres should result in faster postnatal growth rate and improved meat quantity and quality (Stickland & Goldspink, 1975; Dwyer et al., 1993). The increase in the total number of muscle fibres, which is the sum of primary and secondary fibres, could be of interest for the pig producer because the fibre number is positively related to piglet birth weight (Oksbjerg et al., 2002), muscle mass and lean meat percentage (Rehfeldt et al., 2000).

The aims of this project were to study the influence of additional feed supply to the sow during early gestation on sow performance and, for the progeny, the effects of maternal nutrition and piglet birth weight on performance, carcass traits and technological meat quality.

Material and methods

Gilts/sows

The experiment was conducted over two years. In the first year, 20 crossbred gilts (Swedish Landrace × Swedish Yorkshire) were inseminated with sperm from 4 Duroc boars. In the second year, 15 sows from the first year along with 3 new sows of the same crossbreed and in the same parity were inseminated with sperm from 3 of the 4 boars from the first year. The boars were used randomly and were almost equally distributed. Number of piglets at birth and weaning were recorded. The sows were weighed at farrowing and weaning.

Experimental design

The gilts were randomly allocated to four different feed allowances of the same diet (control [C], +35% [T35], +70% [T70], +100% [T100]; Table 1). Treatment C was the standard feeding regimen for gilts in Sweden (2.3 kg/day) over the whole gestation (Simonsson, 1994). During day 25 to 85 of gestation the animals in treatments T35, T70 and T100 received 35, 70 and 100%, respectively, more feed than the control treatment. In both parities, the gilts/sows were allocated the same feed allowance. Before and after day 25 to 85 of gestation the gilts/sows in treatment T35, T70 and T100 received the same amount of feed as treatment C. During lactation, all sows were fed the same lactation diet *ad libitum*.

Piglets and growing/ finishing pigs

All progeny, a total of 398 pigs (castrates and females), were raised indoors in a commercial production system. The piglets were offered a creep feed from two weeks of age and were weaned at approximately five weeks of age. The experimental period spanned the live weight range from approximately 30 to 110 kg. In this growing/finishing period, the pigs from the different sow treatments were randomly mixed with nine pigs per pen. The pigs received a diet (12.6 MJ ME, 16.0% CP; Table 1) consistent with the standard feeding regimen for growing/finishing pigs in Sweden (Andersson et al., 1997). The weight of the pigs was recorded every two weeks and average daily weight gain (ADG) was calculated. Pigs were slaughtered in a commercial abattoir at an average live weight of 110 kg, registered the day before slaughter. Carcass weight was recorded. Back fat thickness was measured over the *M. longisimus dorsi* (LD), just behind the last rib. The right carcass half was portioned in cuts, and ham and loin were weighed with and without skin and fat. The ham muscles (*M. semimembranosus et aductor* (SMA), *M. semitedinosus* (ST), *M. biceps femoris* (BF), *M. quadriceps* (QUA), *M. gluteus* (GLU)) and *M. psoas major* (PM) were dissected and weighed separately. Carcass lean meat percentage was estimated according to [lean meat percentage = –29.217 + (0.548*% ham in carcass) + (0.866*% meat and bone in ham) (+0.679 for females)] (I. Hansson, pers. comm.).

Meat quality

Meat quality traits were measured on samples of LD taken at the last rib and backwards approximately 24 h after slaughter. Surface reflectance with the parameters L* (lightness), a* (redness) and b* (yellowness) was measured by using a Minolta colorimeter (Minolta Chroma Meter CR 300, DP-301, Osaka, Japan).

Table 1. Composition and nutrient content of the diets

	Sows		
	1st parity	2nd parity	Growing/finishing pigs
Ingredients, %			
Barley	72.42	14.06	40.17
Wheat	–	42.25	30.00
Oats	4.20	20.00	–
Wheat middlings	5.00	5.00	–
Wheat bran	–	5.00	–
Rapeseed meal	4.36	–	10.00
Yellow peas	–		9.59
Soybean meal	8.27	10.00	4.68
Limestone	0.85	0.95	1.25
NaCl	0.37	0.40	0.44
Dicalcium phosphate	1.48	–	–
Monocalcium phosphate	–	1.02	0.75
L-lysine.HCl (78%)	0.01	0.08	0.32
DL-methionine (99%)	0.04	0.01	0.05
L-threonine (98%)	–	0.04	0.07
Vitamin and mineral premix	1.00	1.00	1.00
Feed fat (Akofeed)	2.00	0.19	1.74
Calculated and analysed nutrient content			
ME, MJ/kg			
calculated	12.4	12.3	12.6
analysed	12.6	12.2	12.4
CP, digestible, %			
calculated	15.5	15.3	16.0
analysed	14.9	15.6	16.2
Lysine, %			
calculated	0.69	0.70	0.97
analysed	0.69	0.71	0.96

Ultimate pH (Mettler Delta 340 pH-meter equipped with a Xerolyte™ electrode) and internal reflectance, using a fibreoptic probe (FOP, 900 nm; TBL Fibre Optics Group Ltd., Leeds, UK) were measured. Subjective marbling score (ranging from 0 = no marbling to 5 = high marbling) was assessed on a slice of LD. Water holding capacity was determined as drip loss on a 2-cm-thick slice of LD, stored horizontally for 3 days at 4°C (Barton-Gade et al., 1994) and as filter paper wetness (Kaufmann et al., 1986).

Statistical analyses

Statistical analyses were performed with the GLM and MIXED procedure in SAS (SAS Institute Inc., Cary, N.C., USA, versions 8.2). Data given in the tables are least square means ± standard errors. Maternal data were analysed by using a GLM model with feed allowance (C, T35, T70, T100) as a fixed factor. Piglet and growing/finishing pig data were analysed using a mixed model. Fixed factors were feed allowance, birth weight group, sex and two-way interaction between all factors, when statistically significant. Three birth weight groups were defined (light weight (LW), medium weight (MW) and heavy weight (HW)), using the 25% and 75% quartiles of birth weight of live-born piglets within litter. The effect of mother was treated as random. For back fat thickness, carcass weight was included in the model as a covariate.

Results

Influence of maternal nutrition

Sow performance. The effects of the different feed allowances of sows during early gestation on their performance traits are recorded in Table 2. For sows in first parity, no effect on number of born or weaned piglets per litter was observed. However, for sows in second parity extra feed supply (T35, T70, T100) indicated a tendency to approximately additional 3 piglets born per litter compared to treatment C ($P = 0.067$). These sows also had more piglets at weaning, irrespective of the amount of additional feed (C = 9.5; T35 = 11.4; T70 = 11.8; T100 = 12.4,

Table 2. Effect of feed allowance on maternal performance traits (LS-means ± standard errors)

	1st parity					2nd parity				
	Control	T35	T70	T100	P-value	Control	T35	T70	T100	*P*-value
No. of animals	4	6	5	5		4	5	4	5	
Litter size										
no. born	12.5 ± 1.72	11.8 ± 1.40	13.0 ± 1.54	12.6 ± 1.54	0.953	11.3 ± 0.86	14.0 ± 0.77	14.5 ± 0.86	14.0 ± 0.77	0.067
no. live-born	12.0 ± 1.74	11.2 ± 1.42	12.2 ± 1.56	11.8 ± 1.56	0.964	11.0 ± 1.08	13.0 ± 0.96	13.8 ± 1.08	13.0 ± 0.96	0.341
no. at weaning	10.0 ± 1.55	10.3 ± 1.26	10.8 ± 1.38	10.6 ± 1.38	0.982	9.5^{a} ± 0.68	11.4^{ab} ± 0.61	11.8^{b} ± 0.68	12.4^{b} ± 0.61	0.043
Mortality, %	16.9 ± 4.66	6.0 ± 3.81	12.0 ± 4.17	8.5 ± 4.17	0.338	12.0 ± 5.00	10.5 ± 4.47	13.9 ± 5.00	4.7 ± 4.47	0.549
Birth weight per piglet, kg										
live-born	1.50 ± 0.096	1.66 ± 0.078	1.45 ± 0.085	1.63 ± 0.085	0.257	1.58 ± 0.088	1.62 ± 0.079	1.50 ± 0.088	1.57 ± 0.079	0.788
coefficient of variation, %	20.4 ± 2.71	15.6 ± 4.25	18.8 ± 8.83	14.9 ± 4.37	0.410	13.7 ± 3.8	19.4 ± 5.09	14.5 ± 3.77	15.4 ± 3.7	0.213
Weight loss during lactation, %	19.6 ± 7.70	23.3 ± 5.44	29.1 ± 6.28	26.1 ± 4.87	0.787	7.6^{a} ± 2.96	13.1^{a} ± 2.65	13.9^{ab} ± 2.96	21.4^{b} ± 2.65	0.023
Sow's weight at weaning, kg	169.7 ± 12.35	179.5 ± 8.74	169.8 ± 10.70	175.8 ± 9.60	0.873	200.0 ± 10.25	214.4 ± 9.17	206.0 ± 10.25	200.8 ± 9.17	0.689

Means with different superscript within row and parity differ significantly ($P < 0.05$).

$P = 0.043$). Maternal nutrition had no effect on piglet mortality. Birth weight per live-born piglet and the intra-litter variation in birth weight was not significantly affected by maternal nutrition. Weight loss (%) of sows during the first lactation did not differ between treatments, whereas the weight loss during the second lactation was greater with increased feed supply (7.6% for C and 21.4% for T100, $P = 0.023$). At weaning, the weight of sows did not differ.

Piglet performance. ADG of the piglets during the suckling period was not significantly influenced by the maternal nutrition level (Table 3).

Growing/finishing pig performance. The performance and carcass traits of the growing/finishing pigs are recorded in Table 3. ADG during the growing/finishing period of the progeny of sows in first parity was significantly different between the treatments, although no consistent tendency could be observed. Extra feed supply to sows in second parity affected ADG of their progeny negatively. These pigs also had a lower ADG from birth to slaughter, 652, 631 and 619 g, respectively, compared to 672 g for the control pigs.

Carcass characteristics. Different feed allowances of the sows during gestation had no effect on carcass characteristics of the progeny as carcass weight, dressing percentage, lean meat content, back fat thickness, proportion of the valuable carcass components and proportion of the ham muscles (Table 4).

Meat quality traits. The technological meat quality traits as pH, FOP value, marbling, Minolta values, filter paper wetness and drip loss were not influenced by maternal nutrition (Table 5). A tendency to more red meat due to additional maternal supply was measured in the progeny of sows in first parity ($P = 0.057$).

Influence of birth weight

Piglet performance. Average birth weight for LW, MW and HW groups was 1.19 and 1.23 kg, 1.57 and 1.59 kg, 1.86 and 1.89 kg for sows in first and second parity, respectively. ADG during suckling increased significantly with higher birth weight (Table 6).

Growing/finishing pig performance. The performance of growing/finishing pigs, related to their birth weight, is presented in Table 6. Despite differences in birth weight, no significant differences in the initial weight at start of the experiment of progeny of sows in first parity could be recorded, whereas the initial weight was significantly higher for pigs of MW and HW groups compared to the LW group in progeny of sows in second parity. Birth weight affected ADG during the growing/finishing period positively. Pigs from the HW group had an approximately 50 g higher ADG than pigs from the LW group. Consequently, those pigs required less time to reach slaughter weight.

Carcass characteristics. Lean meat content was significantly higher in HW and MW pigs compared to LW pigs (Table 7). In progeny of sows in the first parity, back fat thickness was lower in the HW group compared to the MW group. An interaction between sex and birth weight for dressing percentage was observed in the progeny of sows in first parity. For castrates the dressing percentage decreased from 76.7 to 75.8% with higher birth weight ($P = 0.012$), whereas for females it was unaffected. The proportion of meat and bone in ham and loin was higher in carcasses from MW and HW pigs than in LW pigs. MW and HW pigs of sows in second parity had a higher proportion of PM in the carcass, compared to LW pigs. Significantly higher or a tendency to higher proportion of SMA, GLU and BF in the ham was observed for pigs from the HW group compared to pigs from the LW group. No differences in proportions of ST and QUA in ham between the weight groups could be found.

Meat quality traits. Birth weight of the piglets had no significant influence on the measured technological meat quality traits (data not tabled).

Discussion

Influence of maternal nutrition

The application of different feed allowances to sows in early gestation resulted in several changes in sow and progeny performance.

Sow performance. The litter size of first parity sows was not influenced by additional feed supply during early gestation. However, second parity sows with extra feed supply tended to have larger litters at birth than the sows of the control treatment (C). Increasing the feed allowance above T35 had no further effect. It must be stressed that the sows on treatment C did not receive the standard feeding regimen for sows in Sweden (Simonsson, 1994) (2.7 kg/day), but the regimen for gilts (2.3 kg/day). Thus, the sows in treatment T35, T70 and T100 were given 15, 45, and 70%, respectively, more feed than the recommended amount. The feed allowance for the sows in treatment C could have been insufficient and might have resulted in a negative development of foetus numbers and embryonic survival. The relationship between level of feed during early gestation and subsequent reproductive performance (litter size) has been established in several studies. According to Whittemore (1996) a reduction or increase of feed to gilts during gestation is unfavourable for maternal performance. On the other hand, Einarsson and Rojkittikhun (1993) and Gatel et al. (1987) reported that level of energy intake during gestation hardly affected litter size. This was verified in recent studies from Oksbjerg et al. (2002a) and Nissen et al. (2003a), where no effect in number of born or weaned piglets due to maternal feed allowance in early gestation was observed. In our study, the lower number of piglets of second parity sows from treatment C may be explained by maternal hormonal changes due to feeding regimen. In sows, insufficient feeding tended to affect LH concentration in plasma negatively and therefore foetus numbers, whereas adequate feeding benefited litter size (Whittemore, 1996).

In piglet pre-weaning mortality, no significant difference between treatments was observed. Thus, second parity sows with extra feed supply had the capacity to rear their larger litters and had subsequently more piglets at weaning than sows on treatment C. Even if the number of weaned piglets was significantly higher, piglet birth weight was unaffected. Generally, number of born piglets is negatively correlated to birth weight (Rydhmer, 1992; Tholen et al., 1996). The uniformity in piglet birth weight between the treatments could be explained by the utilisation of the extra feed for own body development (first parity sows) or larger litters (second parity sows), not for higher birth weight of the piglets. This corroborates the findings of several authors (Dwyer et al., 1994; Oksbjerg et al., 2002a; Nissen et al., 2004) that increased maternal feed allowance does not influence piglet birth weight. However, in these studies piglet number per sow was unaffected. Dwyer et al. (1994) stated that increased foetal fibre formation due to increased maternal feed allowance in early gestation was associated with a reduced distribution of muscle fibre number within the litter. As total fibre number correlates with birth weight (Handel & Stickland, 1987), the hypothesis of smaller intra-litter variation in birth weight due to extra maternal feed supply could not be verified in our study.

Although the lactation diet was given *ad libitum*, additional feed supply during early gestation resulted in more weight loss of the sow during lactation, whereas weight at weaning did not differ between treatments. This higher loss of body weight during lactation can be explained by the larger litters, which involves a higher utilisation of the body reserves for milk production. In addition, the negative relationship between gestation feed intake and voluntary lactation feed intake could have contributed to the loss of body weight (Whittemore, 1996).

Progeny performance. Dwyer et al. (1994) stated that progeny of sows in third parity with extra feed supply during early gestation had faster pre-weaning growth rate due to an increased secondary/primary fibre ratio. This hypothesis of higher ADG of the progeny of sows with extra maternal feed supply during early gestation could not be verified in our study. There was, on the contrary, a non-significant decrease in pre-weaning ADG with additional maternal feed supply for progeny of second parity sows. Miller et al. (2000) reported that a high feed allowance during late gestation did not influence the pre-weaning ADG of progeny of sows in first to third parity. However, in this study the extra maternal feed was given when the muscle fibre development was already finished. On the other hand, Schoknecht et al. (1997) found that a low energy/protein supply during gestation leads to insufficient later growth rate in piglets. The lower ADG in progeny of sows fed additional levels, found in our study, might be explained by the negative effect of high energy intake during gestation on the mammary development of the sow and the subsequent reduced milk production (Farmer & Sorensen, 2001). Reduced milk production might also be due to the lower feed intake during lactation as a consequence of high feed intake during gestation, as already mentioned above (Whittemore, 1996). The assumed deficiency in milk supply of sows fed higher levels could explain the lower ADG in the progeny in our study. Another explanation could be the larger litters of the sows fed higher levels and the higher milk demand from the piglets, which could not be completely satisfied.

During the growing/finishing period ADG differed significantly between progeny of first parity sows, but there was no consistent relationship between maternal nutrition and growth rate. This can partly be explained by the limited number of animals; five sows per treatment. For progeny of second parity sows, ADG decreased significantly with higher maternal nutrition. As mentioned, piglets of sows with extra feed supply had lower growth rate during suckling. This difference increased during the growing/finishing period, due to mixing pigs of all treatments in the same pen. Thus, lighter pigs were at a competitive disadvantage for feed compared to heavier ones.

Carcass characteristics. Carcass quality traits, as dressing percentage, lean meat content and back fat thickness, were not influenced by extra maternal feed supply. In the literature, no indications are given for influence of maternal feed allowance on progeny carcass traits. LD and the ham muscles SMA, GLU and BF contain proportionally more fast-twitch glycolytic fibres (white fibres, derived from secondary fibres) than slow-twitch oxidative fibres (red fibres, derived from primary fibres) (Monin et al., 1987; Brocks et al., 2000), whereas ST contains more red muscle fibres (Handel & Stickland, 1987). Dwyer et al. (1994) stated that extra maternal feed supply results in an over-expressed formation of secondary fibres during foetal development, which hypothetically leads to an increased size or proportion of the muscles, containing proportionally more fast-twitch fibres. However, none of the muscles, either slow- or fast-twitch, were affected by maternal nutrition in our study.

Meat quality traits. For progeny of second parity sows, ADG differed between treatments; therefore varying technological meat quality might have been expected. However, a possible influence of higher growth rate on meat quality traits was not observed. This is in accordance with Oksbjerg et al. (2002b) who reported that growth rate did not influence meat quality. There are no clear indications in the literature of direct influence of maternal nutrition on technological meat quality of the progeny. Fibre number is suggested to increase with high maternal feed intake during gestation (Dwyer et al., 1993). This increase might be followed by an improved meat quality, as assumed by Stickland & Goldspink (1975). However, this has not been verified in other studies. Nissen et al. (2003a) conducted a study where 39 sows in the fourth parity had restricted (control treatment) or *ad libitum* access to a standard diet (7.5 MJ net energy) during early gestation. In this study, neither fibre number/fibre composition, nor technological meat quality (pH, drip loss and Minolta values) of the progeny was affected by the extra maternal feed supply.

Influence of birth weight

Piglet and growing/finishing pig performance. A relationship between piglet birth weight and later performance was established in this study. Increased birth weight was closely connected to improvement in growth rate during the suckling period. This confirms the findings of Powell & Aberle (1980), who reported a lower weight gain but unaffected feed conversion for pigs with a birth weight below 1100 g compared to pigs with a birth weight above 1300 g. Because pigs from all treatments were randomly mixed in the pen, feed consumption per pig could not be calculated in our study. In a Danish study (Nielsen & Kring, 2002) over 12,400 growing/finishing pigs were analysed for ADG from birth to slaughter (25 weeks), where piglets with a

Table 3. Effect of maternal nutrition on performance of suckling and growing/finishing pigs (LS-means ± standard errors)

	1st parity					2nd parity				
	Control	T35	T70	T100	*P*-value	Control	T35	T70	T100	*P*-value
No. of animals	39	60	50	50		37	55	45	62	
Live weight of animals										
at weaning, kg	9.1 ± 0.99	10.2 ± 0.76	9.4 ± 0.84	9.6 ± 0.90	0.833	11.1 ± 0.64	11.3 ± 0.54	9.7 ± 0.60	9.8 ± 0.56	0.143
at start of expt., kg	31.5 ± 2.45	33.8 ± 2.01	28.0 ± 2.20	36.3 ± 2.21	0.088	$34.4^{a} \pm 1.32$	$30.7^{b} \pm 1.16$	$26.1^{c} \pm 1.30$	$26.5^{c} \pm 1.15$	0.001
at slaughter, kg	111.2 ± 0.53	111.0 ± 0.44	110.7 ± 0.47	111.9 ± 0.48	0.361	$112.0^{a} \pm 0.48$	$111.6^{a} \pm 0.39$	$110.3^{b} \pm 0.43$	$110.4^{b} \pm 0.37$	0.024
Daily weight gain, g										
birth to weaning	217 ± 26.5	244 ± 20.3	227 ± 22.4	228 ± 23.9	0.850	279 ± 17.4	280 ± 14.7	239 ± 16.5	239 ± 15.2	0.134
start of expt.–slaughter	$830^{a} \pm 15.0$	$872^{b} \pm 12.4$	$819^{a} \pm 13.4$	$874^{b} \pm 13.6$	0.017	$880^{a} \pm 17.3$	$848^{ab} \pm 14.9$	$814^{b} \pm 16.7$	$815^{b} \pm 14.8$	0.040
birth–slaughter	621 ± 11.7	650 ± 9.7	615 ± 10.5	635 ± 10.7	0.109	$672^{a} \pm 12.6$	$652^{ac} \pm 11.0$	$631^{bc} \pm 12.2$	$619^{b} \pm 10.9$	0.032
Days in experiment	$97^{ab} \pm 3.9$	$90^{a} \pm 3.2$	$101^{b} \pm 3.5$	$87^{a} \pm 3.6$	0.040	$90^{a} \pm 2.4$	$96^{a} \pm 2.1$	$105^{b} \pm 2.3$	$103^{b} \pm 2.1$	0.001
Age at slaughter, days	178 ± 3.4	169 ± 2.8	178 ± 3.1	175 ± 3.1	0.158	166 ± 2.8	169 ± 2.4	174 ± 2.7	176 ± 2.4	0.053

Means with different superscript within row and parity differ significantly ($P < 0.05$).

Table 4. Effect of maternal nutrition on carcass characteristics of growing/finishing pigs (LS-means ± standard errors)

	1st parity					2nd parity				
	Control	T35	T70	T100	*P*-value	Control	T35	T70	T100	*P*-value
Carcass weight, kg	85.1 ± 0.47	84.7 ± 0.39	84.3 ± 0.42	85.3 ± 0.43	0.389	85.8 ± 0.50	85.1 ± 0.42	84.4 ± 0.47	84.0 ± 0.40	0.064
Dressing percentage, %	76.5 ± 0.30	76.3 ± 0.25	76.2 ± 0.28	76.2 ± 0.28	0.786	76.6 ± 0.25	76.3 ± 0.21	76.6 ± 0.23	76.1 ± 0.20	0.341
Lean meat content, %	58.6 ± 0.62	59.1 ± 0.51	59.1 ± 0.55	58.2 ± 0.56	0.630	57.4 ± 0.56	58.4 ± 0.48	58.9 ± 0.54	58.4 ± 0.47	0.275
Back fat thickness[1], mm	16.6 ± 0.61	15.7 ± 0.51	15.5 ± 0.55	16.3 ± 0.57	0.542	18.3 ± 0.61	17.2 ± 0.51	16.3 ± 0.57	16.9 ± 0.51	0.155
Ham in carcass, %	31.8 ± 0.31	31.8 ± 0.25	32.1 ± 0.28	31.6 ± 0.28	0.669	31.4 ± 0.42	31.5 ± 0.37	31.8 ± 0.41	31.6 ± 0.37	0.915
Meat and bone in ham, %	77.3 ± 0.61	77.9 ± 0.51	77.8 ± 0.55	76.8 ± 0.57	0.527	76.4 ± 0.53	77.3 ± 0.46	77.8 ± 0.51	77.3 ± 0.45	0.338
Loin in carcass, %	17.6 ± 0.37	17.8 ± 0.30	17.5 ± 0.33	17.5 ± 0.34	0.920	17.5 ± 0.38	17.3 ± 0.33	17.6 ± 0.37	17.5 ± 0.33	0.947
Meat and bone in loin, %	73.5 ± 0.78	73.9 ± 0.64	74.2 ± 0.69	73.5 ± 0.72	0.867	71.7 ± 0.71	73.2 ± 0.61	73.9 ± 0.68	73.0 ± 0.60	0.220
PM[2] in carcass, %	1.2 ± 0.03	1.3 ± 0.02	1.2 ± 0.03	1.2 ± 0.03	0.812	1.3 ± 0.03	1.2 ± 0.02	1.3 ± 0.03	1.3 ± 0.03	0.976
SMA[3] in ham, %	12.6 ± 0.26	12.6 ± 0.22	12.4 ± 0.24	12.45 ± 0.24	0.832	11.8 ± 0.24	12.2 ± 0.21	11.9 ± 0.23	12.1 ± 0.21	0.660
ST[4] in ham, %	3.7 ± 0.09	3.8 ± 0.08	3.9 ± 0.09	3.8 ± 0.09	0.705	3.6 ± 0.06	3.8 ± 0.04	3.8 ± 0.05	3.8 ± 0.05	0.061
QUA[5] in ham, %	9.3 ± 0.18	9.2 ± 0.15	9.1 ± 0.16	9.3 ± 0.16	0.644	9.1 ± 0.15	9.1 ± 0.13	9.2 ± 0.15	9.2 ± 0.13	0.924
GLU[6] in ham, %	7.8 ± 0.17	7.7 ± 0.14	7.4 ± 0.15	7.6 ± 0.16	0.474	7.1 ± 0.15	7.2 ± .013	7.3 ± .014	7.4 ± .013	0.501
BF[7] in ham, %	12.5 ± 0.23	12.5 ± 0.19	12.2 ± 0.21	12.3 ± 0.21	0.662	11.6 ± 0.24	11.6 ± 0.21	11.7 ± 0.23	11.8 ± 0.20	0.842

[1] Carcass weight was included in the model as covariate.

[2] PM = *M. psoas major* [3] SMA = *M. semimembranosus et aductor*; [4] ST = *M. semitendonosus*; [5] QUA = *M. quadriceps*; [6] GLU = *M. gluteus*; [7] BF = *M. biceps femoris*.

Table 5. Effect of maternal nutrition on technological meat quality of growing/finishing pigs (LS-means ± standard errors)

	1st parity					2nd parity				
	Control	T35	T70	T100	*P*-value	Control	T35	T70	T100	*P*-value
pH	5.44 ± 0.036	5.42 ± 0.030	5.45 ± 0.032	5.45 ± 0.033	0.913	5.58 ± 0.032	5.55 ± 0.027	5.54 ± 0.030	5.53 ± 0.026	0.595
FOP	33.2 ± 1.34	32.9 ± 1.11	31.4 ± 1.20	31.0 ± 1.24	0.513	28.9 ± 0.83	30.3 ± 0.68	29.1 ± 0.75	29.7 ± 0.65	0.545
Marbling[1]	2.0 ± 0.15	2.0 ± 0.12	2.0 ± 0.13	1.8 ± 0.14	0.784	2.0 ± 0.20	1.8 ± 0.18	1.8 ± 0.20	1.7 ± 0.17	0.735
L* value (lightness)	48.0 ± 0.64	48.1 ± 0.52	47.5 ± 0.57	46.4 ± 0.59	0.159	47.3 ± 0.43	47.7 ± 0.37	47.2 ± 0.41	47.8 ± 0.36	0.653
a* value (redness)	6.4 ± 0.20	6.7 ± 0.16	6.8 ± 0.17	7.2 ± 0.18	0.057	6.0 ± 0.16	6.2 ± 0.14	6.5 ± 0.15	6.4 ± 0.13	0.115
b* value (yellowness)	2.2 ± 0.23	2.3 ± 0.19	2.1 ± 0.20	2.0 ± 0.20	0.669	1.9 ± 0.13	2.1 ± 0.10	2.0 ± 0.11	2.2 ± 0.10	0.298
Filter paper wetness[2]	1.5 ± 0.26	1.6 ± 0.22	1.4 ± 0.23	1.8 ± 0.24	0.659	1.4 ± 0.26	1.3 ± 0.22	1.2 ± 0.25	1.5 ± 0.22	0.761
Drip loss, %	5.5 ± 0.52	5.3 ± 0.43	5.9 ± 0.47	5.8 ± 0.48	0.724	4.8 ± 0.49	4.8 ± 0.42	4.7 ± 0.47	4.7 ± 0.42	0.998

[1] Subjective scoring from 1 = no marbling to 5 = high marbling.
[2] Subjective scoring from 0 = dry filter paper to 5 = saturated filter paper.

Table 6. Effect of birth weight of piglets on performance of suckling and growing/finishing pigs (LS-means ± standard errors)

	1st parity				2nd parity			
	LW	MW	HW	*P*-value	LW	MW	HW	*P*-value
No. of animal	36	106	57		39	99	61	
Live weight of animals								
at weaning, kg	$8.3^{a} \pm 0.47$	$9.8^{b} \pm 0.43$	$10.6^{c} \pm 0.45$	0.001	$8.9^{a} \pm 0.37$	$10.9^{b} \pm 0.31$	$11.6^{c} \pm 0.33$	0.001
at start of expt., kg	32.0 ± 1.38	31.6 ± 1.17	33.6 ± 1.26	0.085	$26.4^{a} \pm 0.80$	$30.6^{b} \pm 0.66$	$31.3^{b} \pm 0.72$	0.001
at slaughter, kg	111.1 ± 0.55	111.5 ± 0.32	111.0 ± 0.43	0.572	$109.8^{a} \pm 0.46$	$111.8^{b} \pm 0.29$	$111.6^{b} \pm 0.37$	0.001
Daily weight gain, g								
birth to weaning	$202^{a} \pm 12.6$	$235^{b} \pm 11.5$	$250^{c} \pm 12.0$	0.001	$223^{a} \pm 10.0$	$271^{b} \pm 8.4$	$284^{c} \pm 9.0$	0.001
start of expt.–slaughter	$813^{a} \pm 13.2$	$865^{b} \pm 8.4$	$869^{b} \pm 10.7$	0.001	$806^{a} \pm 11.4$	$851^{b} \pm 8.9$	$862^{b} \pm 10.0$	0.001
birth–slaughter	$602^{a} \pm 8.2$	$637^{b} \pm 6.0$	$651^{c} \pm 7.0$	0.001	$612^{a} \pm 7.7$	$653^{b} \pm 6.3$	$665^{c} \pm 6.9$	0.001
Days in experiment	$98^{a} \pm 2.4$	$93^{b} \pm 1.9$	$90^{c} \pm 2.1$	0.001	$104^{a} \pm 1.6$	$96^{b} \pm 1.2$	$94^{b} \pm 1.4$	0.001
Age at slaughter, days	$184^{a} \pm 2.2$	$174^{b} \pm 1.7$	$168^{c} \pm 1.9$	0.001	$178^{a} \pm 1.7$	$170^{b} \pm 1.4$	$166^{c} \pm 1.5$	0.001

Means with different superscript within row and parity differ significantly ($P < 0.05$).

Table 7. Effect of birth weight on carcass characteristics of growing/finishing pigs (LS-means ± standard errors)

	1st parity				2nd parity			
	LW	MW	HW	*P*-value	LW	MW	HW	*P*-value
Carcass weight, kg	85.0 ± 0.48	85.1 ± 0.28	84.5 ± 0.38	0.511	83.8^{a} ± 0.43	85.5^{b} ± 0.29	85.3^{b} ± 0.35	0.003
Dressing percentage, %	76.4 ± 0.23	76.3 ± 0.16	76.2 ± 0.20	0.796ϕ	76.3 ± 0.23	76.5 ± 0.15	76.4 ± 0.18	0.817
Lean meat content, %	57.9^{a} ± 0.43	58.8^{b} ± 0.31	59.5^{b} ± 0.36	0.003	57.7^{a} ± 0.38	58.4^{b} ± 0.29	58.7^{b} ± 0.33	0.037
Back fat thickness[1], mm	16.4^{ab} ± 0.48	16.3^{a} ± 0.33	15.4^{b} ± 0.40	0.048	17.7 ± 0.48	16.9 ± 0.33	16.9 ± 0.39	0.261
Ham in carcass, %	31.6^{a} ± 0.20	31.9^{ab} ± 0.15	32.1^{b} ± 0.17	0.037	31.7 ± 0.23	31.5 ± 0.20	31.7 ± 0.21	0.194
Meat and bone in ham, %	76.8^{a} ± 0.43	77.5^{b} ± 0.31	78.0^{c} ± 0.36	0.048	76.7^{a} ± 0.36	77.4^{b} ± 0.27	77.5^{b} ± 0.31	0.047
Loin in carcass, %	17.7 ± 0.22	17.6 ± 0.18	17.6 ± 0.20	0.753	17.6 ± 0.22	17.5 ± 0.19	17.3 ± 0.20	0.248
Meat and bone in loin, %	72.5^{a} ± 0.60	73.8^{b} ± 0.40	75.0^{c} ± 049	0.001	72.1^{a} ± 0.53	73.1^{ab} ± 0.38	73.6^{b} ± 0.45	0.039
PM[2] in carcass, %	1.2 ± 0.02	1.2 ± 0.01	1.2 ± 0.01	0.275	1.2^{a} ± 0.02	1.3^{b} ± 0.02	1.3^{b} ± 0.02	0.008
SMA[3] in ham, %	12.2^{a} ± 0.17	12.5^{a} ± 0.13	12.8^{b} ± 0.15	0.001	11.8 ± 0.14	12.1 ± 0.12	12.1 ± 0.12	0.051
ST[4] in ham, %	3.7 ± 0.06	3.8 ± 0.05	3.8 ± 0.05	0.472	3.7 ± 0.05	3.7 ± 0.03	3.7 ± 0.04	0.448
QUA[5] in ham, %	9.1 ± 0.11	9.2 ± 0.09	9.3 ± 0.10	0.125	9.0 ± 0.09	9.2 ± 0.08	9.2 ± 0.08	0.089
GLU[6] in ham, %	7.5^{a} ± 0.13	7.6^{a} ± 0.08	7.9^{b} ± 0.10	0.015	7.1 ± 0.10	7.3 ± 0.08	7.4 ± 0.09	0.055
BF[7] in ham, %	12.1^{a} ± 0.16	12.4^{b} ± 0.12	12.6^{b} ± 0.13	0.006	11.5^{a} ± 0.14	11.8^{b} ± 0.12	11.8^{b} ± 0.13	0.018

[1] Carcass weight was included in the model as covariate.

[2] PM = *M. psoas major* [3] SMA = *M. semimembranosus et aductor*; [4] ST = *M. semitendonosus*; [5] QUA = *M. quadriceps*; [6] GLU = *M. gluteus*; [7] BF = *M. biceps femoris*.

ϕ Significant interactions of fixed factors, see text.

Means with different superscript within row and parity differ significantly ($P < 0.05$).

high birth weight had significantly higher ADG than piglets with low birth weight. The authors showed that piglets with a birth weight of 1.5 kg had 2.5 kg extra weight gain from birth to slaughter (25 weeks), compared to piglets with a birth weight of 1.4 kg. This corresponds to the present findings, where heavy-born piglets were approximately 14 days younger at slaughter than piglets with low birth weight. A physiological explanation for the higher growth rate could be the increased total fibre number of heavy-born piglets, established by several authors (Handel & Stickland, 1988; Dwyer et al., 1993; Kuhn et al., 2002; Oksbjerg et al., 2002a; Nissen et al., 2004).

Carcass characteristics. The carcass quality was also improved with higher piglet birth weight. Lean meat content was 1 to 1.6% higher and back fat thickness 0.9 to 1 mm lower in the heavy-born piglets compared to the light-born ones, in accordance with findings by Kuhn et al. (2002). In contrast, Wolter et al. (2002) and Powell & Aberle (1980) reported that heavy- and light-born piglets were similar in lean meat content and back fat thickness. An explanation for impaired carcass quality traits of light-born pigs in our study could be the assumed reduced number of muscle fibres. Kuhn et al. (2002) explained that this reduction of fibre number is combined with limited hypertrophy during the growing/finishing period, which leads to lower muscle protein and higher fat deposition in light-born pigs. Birth weight clearly affected partial cutting details of the carcass. Higher content of meat and bone in ham and loin is in accordance with the higher lean meat content of the heavy-born piglets. The higher proportion of SMA, GLU and BF could support the theory of higher secondary fibre number in piglets with high birth weight (Handel & Stickland, 1987) and the subsequent higher portion of more white muscles, as previously discussed. On the other hand, no difference in proportion of ST could be measured. This is not in accordance with the theory of decreased total muscle fibre number due to reduction of secondary muscle fibres of runt piglets in ST (Handel & Stickland, 1987) and postponed growth ability (Dwyer et al., 1994).

Meat quality traits. Although birth weight is related to muscle fibre number (Kuhn et al., 2002; Oksbjerg et al., 2002a), fibre diameter (Nissen et al., 2004) and fibre density (Stickland & Goldspink, 1975), meat quality traits as FOP value, Minolta value, filter wetness and drip loss were not affected in our study. Oksbjerg et al. (2002a) also reported similar technological meat quality traits of light- and heavy-born pigs.

Conclusions

This study clearly showed that extra maternal feeding during early gestation increased number of weaned piglets per sow in second parity, but also decreased ADG of the progeny. The economic advantage of more piglets at weaning arising from additional feeding of sows must be balanced by the increased feed costs for the sows, and inferior growth rate and lack of improvement of carcass or meat quality of the progeny. The positive relationship between birth weight and growing/finishing pig performance and carcass quality was confirmed in this study.

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