# Effects of feeding and rearing systems on growth, carcass traits and meat quality in pigs

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# EFFECTS OF FEEDING AND REARING SYSTEMS ON GROWTH, CARCASS TRAITS AND MEAT QUALITY IN PIGS

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**SUMMARY** - Animal growth performance and quality of pork depend on the interactive effects of genotype, rearing conditions, pre-slaughter handling, and carcass and meat processing. This paper focuses on the effects of feeding and rearing systems on growth performance, carcass composition, and eating and technological qualities of pork. The feeding level and pattern (restriction / realimentation) and the composition of the diet (protein level, protein to energy ratio, fatty acids composition) can be used to manipulate growth rate and composition of weight gain at both carcass and muscle levels, and thereby modify carcass and meat quality.

The effects of indoor housing conditions (floor type, space allowance, ambient temperature), alternative rearing with outdoor area, or free-range (extensive) systems on animal performance, carcass and meat quality are presented, with a special focus on the Mediterranean production systems, in which interactions between genotype (local breeds) and extensive finishing conditions lead to high eating quality of pork and pork products.

**Key words** : Pigs, Feeding, Rearing conditions, Performance, Meat Quality

## INTRODUCTION

Growth performance of pigs, carcass composition and quality of pork and pork products depend on multiple interactive effects of genotype (genetic background, presence of major genes hal and $RN^-$), rearing conditions (feeding level, housing and environmental conditions, production system), pre-slaughter handling, and carcass and meat processing (reviews of Sellier, 1998; Monin, 2003; Rosenvold and Andersen, 2003; Terlouw, 2005). This paper focuses on the influences of feeding and rearing system on growth performance, carcass and muscle composition, and eating and technological qualities of pork.

The effects of feeding level, composition (protein:energy ratio) and pattern (restriction-realimentation) as tools to manipulate growth rate, composition of weight gain, intramuscular fat (IMF) deposition which is often associated with improved meat sensory traits (DeVol *et al.,* 1988; Fernandez *et al.,* 1999; Wood *et al.,* 2004) and thereby improved pork quality, are described. Variations in muscle lipid composition and nutritional value of meat through dietary supplementation (fatty acids, antioxidants) are also presented.

Considering pig rearing systems, the specific effects of housing conditions (ambient temperature, floor type, space allowance…), and outdoor and free range rearing systems on animal performance and carcass and meat quality are described. Finally, a special focus is given on specific production systems from the Mediterranean area, involving local breeds that are extensively pastured and slaughtered at advanced age for the production of high-value dry-cured products.

Except for the last paragraph on traditional Mediterranean production systems, the results presented in this paper concern “conventional” breed of pigs or crossbreeds, i.e. animals issued from lines that have been genetically improved for growth rate and carcass leanness.

## FEEDING

The feeding level (restriction), pattern (restriction-realimentation) and the protein:energy ratio of the diet, together with the genetic growth potential of pigs, determine the growth rate and the composition of weight gain at both whole body and muscle levels. These factors are therefore used to modify growth rate and/or carcass and muscle composition at slaughter.

## Feed restriction

Restricted feeding (up to 35% compared to *ad libitum* feed intake) can be applied to reduce growth rate and thereby increase age at slaughter at a given body weight (BW). A 25% restriction in feed allowance during the growing-finishing period decreases growth rate by about 27% (Lebret *et al.,* 2001). Since body fat deposition rate highly increases with age, in contrast to protein deposition rate which remains almost constant during the growing-finishing period (Reeds *et al.,* 1993), feed restriction affects more fat than lean tissue deposition when applied during the finishing period. Therefore, restricted feeding leads to leaner carcasses compared with *ad libitum* feeding (Ellis *et al.,* 1996; Wood *et al.,* 1996; Lebret *et al.,* 2001). IMF deposition is also reduced by up to 25% in the m. *Longissimus* of restricted compared with *ad libitum* fed pigs (Candek-Potokar *et al.,* 1998; Lebret *et al.,* 2001). Consequently, eating quality can be adversely affected with lower tenderness and juiciness (Ellis *et al.,* 1996) even though some studies do not report any significant effect of feeding level on loin sensory traits (Wood *et al.,* 1996; Candek-Potokar *et al.,* 1998). Muscle fibre type composition and glycolytic potential as well as technological meat quality traits (pH1, pHu, drip loss, colour) remain generally unaffected by feed restriction (Candek-Potokar *et al.,* 1998, 1999; Lebret *et al.,* 2001).

## Compensatory growth response

Compensatory growth response is a physiological phenomenon of accelerated final growth rate induced by a restricted food supply during the growing period, followed by *ad libitum* feeding thereafter. The level of animal response to this feeding strategy depends on the onset, duration and intensity of the feed restriction, and the onset and duration of realimentation (Campbell *et al.,* 1983). When restriction occurs during early growth (28-90 days), a full compensatory response can be observed at slaughter at 140 d (Therkildsen *et al.,* 2004). Besides, pigs exhibiting compensatory growth might have increased muscle protein turn-over and improved meat tenderness, compared with controls slaughtered at similar age and BW (Kristensen *et al.,* 2004; Therkildsen *et al.,* 2004).

At the whole body level, compensation in the rate - and often efficiency - of weight gain mainly results from an increase in adipose tissue and internal organ growth, but not from a higher carcass lean deposition, generally giving rise to similar carcass composition at slaughter in re-fed as in control pigs (Bikker *et al.,* 1996; Heyer and Lebret, 2007). In pigs, storage capacity for IMF (i.e. number of adipocytes) increases with age, whereas IMF deposition increases with energy intake (Gondret and Lebret, 2002). Therefore, we could hypothesize that increasing slaughter age and final energy intake through a restriction – re-alimentation feeding strategy could enhance final muscle lipid accretion and IMF content at slaughter. However, in a recent study, we could not demonstrate any positive effect of refeeding from 70 up to 110 kg BW after restriction from 30 to 70 kg BW, on muscle lipid deposition rate nor IMF content at final slaughter. Therefore, meat eating quality was not improved in compensatory pigs compared with controls (Heyer and Lebret, 2007). It was concluded that elevated IMF content and improved pork quality might be achieved by modifying the onset or duration of the restriction and realimentation periods.

It is worthy noting that in the traditional Mediterranean production system, local pig breeds are finished during autumn in forests of oaks or chestnuts. Due to their high consumption of acorns or chestnuts, which are rich in starch, pigs exhibit a compensatory growth characterized by a very high lipid accretion at both whole body and intramuscular levels (Lopez-Bote, 1998; Secondi *et al.,* 2007). In that case, the rearing conditions (advanced slaughter age, compensatory growth with acorns feeding during finishing) allow pigs to express their high genetic potential for IMF deposition, with subsequent positive consequences on the eating quality of pork and pork products.

## Dietary protein level and protein:energy ratio

Diet composition, particularly the protein to energy ratio can be used to modify the composition of growth and increase IMF deposition. Indeed, feeding pigs *ad libitum* with protein or lysine-deficient but adequate energy diets during the growing or finishing phases has been shown to increase IMF content and improve meat tenderness and juiciness. Growth rate is reduced as a consequence of limited protein or lysine intake. However, back fat thickness or percentage of dissectible fat is also increased, even though the effect is much lower on carcass than muscle lipid deposition (Essén-Gustavsson *et al.,* 1994; Wood *et al.,* 2004). For example, Castell *et al.* (1994) reported values of 15.3

*versus* 14.9 mm back fat thickness (P<0.10) and 3.4 *versus* 1.4 % IMF (P<0.001) for pigs fed *ad libitum* a diet containing 13.3 or 17.6% crude protein, respectively.
By contrast, a progressive decrease in lysine to energy ratio combined with limited energy allowance (80% of the *ad libitum* level) all over the growing-finishing phase leads to extended growing-finishing period and older pigs at slaughter, in order to fulfil the requirements of the french Label Rouge quality label (minimum 182 d at slaughter). This feeding strategy highly increases IMF deposition but does not modify back fat thickness and carcass lean meat content, compared with controls fed *ad libitum* (Fig. 1) (Lebret *et al.,* 2001). On the contrary, a global feed restriction (75% of *ad libitum* level) over the same period leads to similar overall growth rate, but leaner carcasses and lower IMF content. Therefore, a progressive reduction in lysine:energy ratio together with limited energy intake seems to be a more efficient strategy to modify rate and composition of growth at both carcass and muscle levels for improved pork quality, rather than *ad libitum* distribution of a protein-deficient diet or, worst, feed restriction alone. Unfortunately, despite its large influence on muscle composition, we could not demonstrate any positive effect of our feeding strategy on pork eating quality, suggesting that IMF would not markedly influence eating traits within the range of concentrations observed in this study. Other muscle traits, such as myofiber type composition, as well as technological meat quality are generally unaffected by the dietary protein or lysine:energy ratio (Castell *et al.,* 1994; Essén-Gustavsson *et al.,* 1994; Lebret *et al.,* 2001).

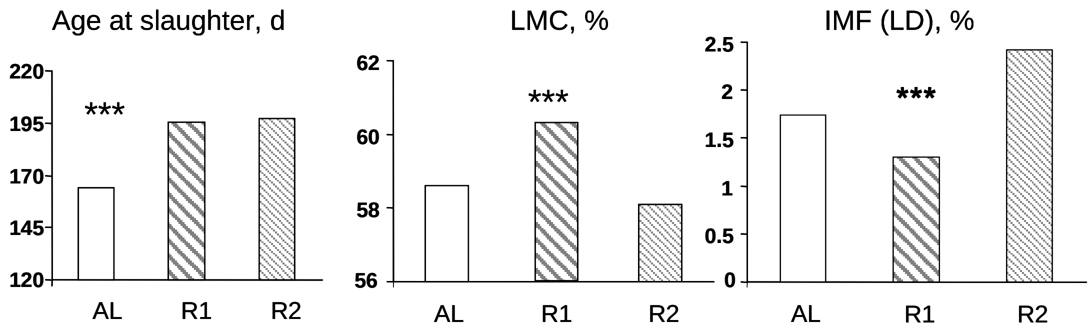


Figure 1. Influence of feed restriction (R1) or progressive decrease in dietary lysine:energy ratio (R2) compared to ad libitum feeding (AL) on age at slaughter, carcass lean meat content (LMC) and intramuscular fat (IMF) level in the m. *Longissiums* of Duroc crossbreeds (***: P<0.001) (Modified from Lebret *et al.,* 2001)

**Dietary fatty acids and antioxidants**

Fatty acid composition of pork can be easily manipulated through the feeding regime, as a consequence of the well known influence of the dietary fatty acids on fatty acid deposition in both subcutaneous and intramuscular lipids in pigs (Mourot *et al.,* 1991; Wood *et al.,* 2003). There has been an increased interest in recent years in manipulating lipid composition of pork to produce healthier meat, i.e. with increased n-3 PUFA (polyunsaturated fatty acids) level and decreased n-6:n-3 PUFA ratio (Legrand and Mourot, 2002; Wood *et al.,* 2003). Feeding sources rich in n-3 PUFA such as rapeseed oil and especially crushed linseed lead to increased n-3 PUFA level in meat, particularly for C18:3 and C20:5 (EPA), and C22:6 (DHA) to a lesser extent. The n-6:n-3 ratio is then reduced up to the target level of 4, compared to 10 in controls (Wilfart *et al.,* 2004). Even though these long chain n-3 PUFA are heat-sensitive, these authors demonstrated that the n-3 PUFA level and the n-6:n-3 ratio were not modified in cooked meat (loin roast) compared with raw muscle.
Increasing the n-3 PUFA concentration in pork must be accompanied with increased antioxidant concentration to prevent lipid oxidation and avoid unfavourable flavours in meat. Diet supplementation with vitamin E has been shown to prevent PUFA oxidation (Monahan *et al.,* 1990; Mourot *et al.,* 1991) and improve colour stability and water holding capacity during storage, through reduced cellular membrane damages (Monahan *et al.,* 1992; Cheah *et al.,* 1995). It is worthy noting that lipid composition and antioxidant levels in adipose and muscular tissues of pigs can be highly modified consequently to grazing during the rearing period (cf below).

## REARING SYSTEM

Influences of pig rearing system on animal performance, carcass and meat traits result from the interactive effects of (i) housing conditions : floor type, space allowance, ambient temperature, outdoor access or free range rearing … that influence physical activity and feed requirements, (ii) feeding level and composition, and (iii) genotype, especially in specific production systems with local pig breeds.

### Indoor housing conditions: ambient temperature, floor type and space allowance

The ambient temperature influences the energy requirements and the growth performance of pigs, the energy maintenance requirement increasing as temperature decreases. In pigs fed *ad libitum* to compensate for their higher energy requirement, Lefaucheur *et al.* (1991) reported that rearing at a low ambient temperature (12 vs 28°C) had no effect on carcass fat percentage, but strongly influenced its distribution with increased external fat at the expense of internal adipose tissues. Pigs raised at 12°C were also shorter and more 'squat', altogether indicating animal adaptation to the environmental conditions. The low temperature influenced fatty acid composition through higher monounsaturated and lower saturated and polyunsaturated FA proportions. Cold exposure enhanced the glycolytic capacity of the *Longissimus* muscle and led to lower initial and ultimate post-mortem pH, thus impairing technological meat quality, whereas IMF content was not affected (Lefaucheur *et al.,* 1991). By contrast, a smaller difference in ambient temperature (17°C vs 24°C) increased growth rate due to higher voluntary feed intake, but did not affect backfat and muscle thickness, or technological meat quality. Rearing at 17°C led to lighter and less homogeneous colour of dry-cured hams, but did not affect texture or flavour (Lebret *et al.,* 2002). On the opposite, warm exposure (31 vs 18.5°C) reduced growth rate as a consequence of the reduced feed intake of pigs, and decreased the monounsaturated FA level in back fat (Rinaldo and Le Dividich, 1991).

The floor type in pig buildings indeed modifies various other housing conditions, such as ambient temperature, space allowance, and the level of physical activity for animals, that all affect growth performance and carcass and meat traits. Compared to slatted floor (0.76 $m^2$/pig), pigs reared on straw bedding (3.5 $m^2$/pig) exhibited higher feed consumption, growth rate and carcass fatness (Beattie *et al.,* 2000; Gentry *et al.,* 2002a), the higher voluntary feed intake being likely explained by the lower ambient temperature and the easier access to the feeder provided in the "enriched" (straw-bedding) system (Lebret *et al.,* 2006a). The positive influence of enriched housing conditions on increased investigative activity of pigs is now clearly established (Petersen *et al.,* 1995; Beattie *et al.,* 2000) and may be interpreted as improved animal welfare. The possible effects of animal behavior during the rearing period on their physiological responses to stress at transport and slaughter, and consequently on pork quality, are of great interest (Terlouw, 2005). Several studies (Geverink *et al.,* 1999; de Jong *et al.,* 2000; Klont *et al.,* 2001) aimed to evaluate the effect of the enrichment of indoor environment (extra space and straw versus conventional) on pig behavior and physiology during preslaughter handling and subsequent meat quality. Although housing conditions have been shown to affect animal activity during transport and salivary cortisol levels both at the home pen and during transport, the differences were generally no longer significant at the end of the lairage period. This led to only small (Klont *et al.,* 2001) or non significant (Geverink *et al.,* 1999) effects on biochemical or technological meat quality traits.
Maw *et al.* (2001) assessed meat produced from different farms in Scotland, taken into account the effects of genotype and husbandry conditions (floor type, space allowance, air quality…). They demonstrated that bacon from pigs reared on straw bedding had higher greasiness and eating quality (flavor) scores to that from pigs reared on slatted or concrete floor without bedding. A possible explanation for the improved pork flavor could be a higher IMF content that would parallel the usually higher carcass fatness of pigs reared on straw bedding (Beattie *et al.,* 2000; Gentry *et al.,* 2002a), because of the positive genetic correlation between these two traits (Sellier, 1998).

### Alternative housing system with outdoor access

Alternative pig rearing system with indoor space and free outdoor access constitutes an interesting intermediate situation between indoor-enriched and free range systems, as it positively influences the perception of pork by the consumers (Rainelli, 2001; Dransfield *et al.,* 2005) but with reduced

drawbacks on labour conditions for the producer and production (feeding) costs, compared with free-range rearing. Moreover, it corresponds to regulations for improved quality pork, i.e. the 'Scharrel' pigs in the Netherlands and the Label Rouge Fermier in France, and to the European standards for housing of organic pigs.
An experimental evaluation of two production systems for growing-finishing pigs (synthetic line x (Large White x Landrace) crossbreeds, all free of the halothane-sensitive (n) and $RN^-$ alleles) was conducted to evaluate animal welfare and health, growth performance, carcass and meat quality, and environmental impact (Lebret *et al.,* 2004, 2006a). Sawdust-shave bedding (1.3 m²/pig) with free access to a sheltered outdoor area on concrete floor (1.1 m²/pig) (O) was compared with a conventional system (totally slatted floor, 0.65 m²/pig, controlled ambient temperature at 22°C) considered as control (C). Concerning animal behaviour, pigs reared in the O system spent less time resting (58 *versus* 73%, P<0.001) and more time in investigative behaviour (30 *versus* 19%, P<0.001) particularly towards the bedding, compared with the C pigs, in agreement with Lyons *et al.* (1995) and *Beattie et al.* (2000). Sensitivity to respiratory tract pathologies as well as plasma haptoglobine level, an indicator of the inflammatory response, were lower for the O than the C pigs. Altogether, this suggests that the O system would improve animal welfare. A comparison of air quality between the bedding (O system) and conventional rooms showed similar levels of dusts and ammonia, but a high decrease in the level of offensive odours determined by olfactometry in the indoor area of the O compared with the C system, that might lead to a better acceptability of this production system by citizens (Lebret *et al.,* 2004). Pigs reared in the O system exhibited higher growth rate due to their higher feed intake, higher back fat depth and lower lean meat content (Table 1). The O system did not influence the behavioural activities of pigs during lairage at the slaughterhouse, or plasma ACTH, cortisol and creatine kinase immediately after slaughter. This indicates that the rearing system (i.e., the prior experience of pigs) did not influence their behavioural or physiological response to pre- and slaughtering procedures, and the pattern of muscle peri- and post-mortem metabolism (Table 1) (Lebret *et al.,* 2004, 2006a). However, in a more stressful environment, the animal response to preslaughter handling could have differed according to their rearing conditions (Terlouw, 2005). In the *Longissimus*, ultimate pH was not affected, but the O pigs had higher drip loss and higher IMF content. By contrast, a higher glycolytic potential and a lower ultimate pH were observed in the *Semimembranosus* and *Biceps femoris* muscles of O compared with C pigs (Table 1). Therefore, the influence of pig rearing system on muscle glycogen store or use and consequently ultimate pH is muscle-dependent, the ham muscles being more affected than the loin, confirming the results of Gentry *et al.* (2002a) and Bee *et al.* (2004). The higher glycogen level in the ham muscles of the O pigs might have resulted from their higher spontaneous physical activity, which was shown to enhance muscle oxidative capacity and thereby spare intramuscular glycogen (Petersen *et al.,* 1998).

Table 1. Effects of rearing conditions on performance, indicators of physiological response of pigs to preslaughter handling, carcass composition and muscle traits. (Reproduced with permission from B. Lebret, "Comparaison expérimentale de deux conduites d'élevage de porcs en croissance", Journées de la Recherche Porcine, 36, 53-62, published by Institut Technique du Porc, Paris, France, 2004)

| | Rearing system | | |
|---|---|---|---|
| | Conventional | Outdoors | Sign.[a] |
| Average daily gain, g/d | 960 | 1045 | *** |
| Feed consumption, kg/d | 2.71 | 2.94 | ** |
| Feed conversion ratio, kg/kg | 2.83 | 2.82 | ns |
| Slaughter weight (155 d), kg | 109.6 | 116.6 | *** |
| Average backfat thickness, mm | 18.5 | 20.9 | ** |
| Lean meat content, % | 61.2 | 59.2 | *** |
| | | | |
| Plasma cortisol, ng/ml | 42.2 | 49.9 | ns |
| m. *Longissimus* | | | |
| pH 30 min | 6.42 | 6.37 | ns |
| pH 24 h | 5.49 | 5.50 | ns |
| Drip loss, 4 d post mortem | 4.6 | 5.7 | ** |
| IMF, % | 1.44 | 1.68 | ** |
| m. *Semimembranosus* | | | |
| pH 24 h | 5.57 | 5.50 | *** |

[a] ***: P<0.001; **: P<0.01; ns: P>0.05. [b] Winter replicate

Concerning eating quality, the O system increased meat juiciness (average score of 3.7 *versus* 3.4, for O and C meat, respectively, P<0.05), which may have resulted from its higher lipid content, whereas odour, flavour and tenderness remained unaffected (Lebret *et al.,* 2006a). Pig production system did not influence the overall appreciation of meat by consumers when no information on the pig production system was provided. But, awareness of the production system strongly influenced the perception of pork with 59% of the French consumers under study choosing the meat labeled 'outdoor' and 8% the meat labeled 'indoor' (34% inconsistent choices) (Dransfield *et al.,* 2005). These results highlight the differences between the "perceived" and "actual" quality of pork products issued from outdoor systems and conventional genotypes, as previously discussed by Edwards (2005).

**Free range rearing**

Several studies have been conducted to evaluate the effects free range rearing of "modern" pig genotypes on performance and meat quality. In these systems, pigs are submitted to various and changing climatic conditions; they are offered great space and environmental diversity, allowing physical activity and expression of investigative behaviour, and potential to forage for a range of different foodstuffs complementarily to the 'conventional' food provided. All these factors interact to determine the animal response in terms of growth and meat quality. Pigs raised outdoors are generally kept in large groups, thus avoiding or limiting the mixing of pigs from different pens during transport or lairage at the slaughterhouse, and its consequences on animal behaviour and meat quality. However, the occurrence of mixing during preslaughter handling depends on the group size and the management practices, and can vary between the systems – and the experiments – considered. It is therefore an important point to be considered when evaluating the influence of rearing system on pork quality, especially since the stress reactions of pigs to slaughter procedure can depend on their prior experience (Terlouw, 2005).

Many studies show that outdoor rearing in mild climate has only slight or even no significant effects on growth rate and carcass composition (Gentry *et al.,* 2002a,b), but reduced growth rate and back fat thickness have been observed for pigs reared outdoors in cold climates, particularly when average ambient temperature is below the thermoneutral zone (Enfält *et al.,* 1997; Sather *et al.,* 1997; Bee *et al.,* 2004). As for carcass traits, influence of extensive outdoor rearing on muscle composition, particularly lipid content varies with the actual rearing conditions of pigs (climate, feeding level). Both decreased (Enfält *et al.,* 1997; Sather *et al.,* 1997; Bee *et al.,* 2004) or similar (Nilzen *et al.,* 2001; Gentry *et al.,* 2002b) muscle lipid contents have thus been reported for outdoor compared with conventional reared pigs. However, it must be mentioned that grazing or the consumption of different feedstuffs by pigs reared outdoors strongly influences the fatty acid composition of animal tissues. For instance, the level of linolenic (18:3) and other n-3 PUFA is highly increased, and the n-6:n-3 ratio is decreased in meat from pigs reared on pasture compared with controls, as a consequence of the very high amount of C18:3 in the grass (Nilzen *et al.,* 2001; Bee *et al.,* 2004; Lebret and Guillard, 2005). The higher n-3 PUFA is accompanied by increased vitamin E deposition in both external fat and intramuscular lipids (Nilzen *et al.,* 2001), thus preventing further excessive lipid oxidation during meat storage (Andres *et al.,* 2001). Therefore, outdoor rearing beneficially modifies the nutritional quality of meat. In a similar manner, the consumption of grass or acorns during finishing of pigs in the traditional Mediterranean pig production systems highly influences the fatty acid profile of tissues and the subsequent quality of pork products (cf below) (Lopez-Bote, 1998).

Concerning the technological qualities of meat, Gentry *et al*. (2002b) and Bee *et al*. (2004) reported no differences in the rate and extent of *post-mortem* pH drop in the *Longissimus* of outdoor compared with indoor pigs, whereas Enfält *et al*. (1997) observed reduced ultimate pH and water holding capacity in the loin of outdoor reared pigs. Again, the consequences of outdoor rearing on muscle technological traits are likely muscle-dependent, with greater negative effects in ham than loin muscles (Gandemer *et al.,* 1990; Bee *et al.,* 2004). An important and often debated question is weather pigs reared in different environments cope differently with pre-slaughter stress, thereby leading to differences in meat quality. Terlouw et al. (2004) evaluated the behavioural and physiological responses of pigs to preslaughter mixing, depending on their rearing conditions (oudoor *versus* conventional). They showed that, when mixed, outdoor pigs exhibited lower fighting levels than indoor pigs, resulting in lower skin damage, higher pre and post-slaughter muscle glycogen level, and lower pH for the formers. Barton-Gade (2004) also reported less aggressive events and serum creatine kinase activity for outdoor than indoor reared pigs after mixing at loading, suggesting that mixing is more stressful for conventional than outdoor reared animals. Consequences on meat quality indicators remained low in the study of Barton-Gade (2004), but can be of greater extent when preslaughter handling conditions (high level of mixing of pigs from different farm pens) promote aggressive behaviour and physical activity (fights) during lairage in conventional reared pigs compared with a group of outdoor-non mixed pigs, a situation that can often be encountered in practical conditions (Lebret *et al.,* 2006b). Eating quality of loin meat issued from conventional genotypes reared outdoors in mild climate conditions and controlled (low stress) pre-slaughter handling is only slightly (improved tenderness, Gentry *et al.* (2002b) or even not modified (Gandemer *et al.,* 1990). In contrast, Enfält *et al.* (1997) reported decreased tenderness and juiciness of loin from outdoor reared animals, which could be explained by their lower lipid content and ultimate pH value.

**Traditional Mediterranean production systems: Genotype X rearing system interactions**

The traditional Mediterranean sylvopastoral system is based on local breeds that are extensively pastured in natural forests for the production of high value dry-cured products, in particular hams. These breeds exhibit slow growth rate, great fatness and mediocre conformation, and a greater predisposition to deposit oleic acid than conventional breeds (Edwards and Casabianca, 1997). In addition, in the 'traditional' systems, the finishing takes place during autumn in forests of oaks or chestnuts ('la dehesa'). The animals convert large quantities of acorns or chestnuts, which are rich in starch, into fat deposits at both whole body and intramuscular levels, resulting in very high eating quality (juiciness, flavour) of dry-cured products: 'montanera' finishing for Iberian pigs or 'montanheira' for the Portuguese Alentejano breed, and similar traditional finishing systems for Corsican, Basque or Gascon pigs in France; Cinta Senese and Nero Siciliano in Italy. Besides advantages of this extensive late fattening phase when considering the pork chain, in particular the quality of products, this traditional production system is also of major significance for the management of the forest heritage and the conservation of landscape: the 'dehesa' is a man-made ecosystem which becomes rapidly unproductive when abandoned. Therefore, in these traditional Mediterranean production systems, the pig production is deeply bound to the ecosystem and significantly collaborates in its preservation (Lopez-Bote, 1998; Edwards, 2005).

The use of local breeds together with the utilisation of the natural environment for the production of specific and high quality pork products is explicitly recognized through the "Protected Designation of Origin" (PDO) European label, even though all PDO terms and conditions for pork products do not necessarily involve local breeds. For example in Spain, 4 PDO labels ("Dehesa de Extremadura", "Guijuelo", "Huelva", "Pedroches") are based on pure Iberian pigs or their crossbreeds (see below). Other European pork PDO labels are based on pure local breeds: the Alantejano in Portugal ("Presunto de Barrancos") and projects that are underway in Italy with the Nero Siciliano and Cinta Senese, and in France with the Corsica, Basque and Gascon breeds. By contrast, white pigs are used for the production of PDO "Jamon de Teruel" in Spain, and many Italian PDO labels ("Prosciutto di San Daniele", "Prosciutto di Parma") are based on the tradition of heavy pigs from conventional genotypes raised in indoor systems.

The pig production systems for the production of dry-cured Iberian hams, which are indeed not unique but where different genotypes and rearing conditions can be encountered, are interesting examples of the positive consequences of genetic x environment interactions on pork quality. All these combinations are included in the PDO regulation ("Norma de Calidad"). Concerning genotype, pigs are issued from pure Iberian sows (including the various existing red and black lines) and pure Iberian, Duroc, Duroc-Jersey or their crossbreeds, as sire. Therefore, the "Iberian ham" denomination includes hams from purebred Iberian up to 50% Iberian-50% Duroc pigs. These crosses have been carried out (mainly with Duroc-Jersey) to increase prolificity and improve growth rate, feed efficiency and lean content, without serious damage to the quality characteristics of the meat products according to Lopez-Bote (1998), even though a recent study showed that differences in ham eating properties are noticeable by consumers (Ventanas *et al.,* 2007). Besides genotype, different feeding systems during finishing can be encountered (Lopez-Bote, 1998; Daza and Lopez-Bote, 2007):

- "Cerdo de bellota": the late fattening phase (90-120 up to 140-160 kg) takes place on oak woodland pasture ('montanera') in specified regions for 2 to 3 months between November to January, which corresponds to the maturation period of acorns. During this phase, pigs must gain a minimum of 46 kg BW, and they are fed only the natural resources present on the land, i.e. mostly acorns (7 to 10 kg/d) and variable quantity of grass. The average growth rate of pigs is generally comprised between 750 and 1000 g/d during the montanera finishing period, which can therefore be considered as compensatory growth. The very high contents of starch (50% of dry matter (DM)) and fat (6-9% of DM) of the acorns lead to a very high accumulation of body lipids during this period, whereas the grass supply is an important source of protein (14-17% of DM) and compensates for the low protein concentration of acorns (4-6% of the DM). Moreover, the high linoleic (C18:1 n-9) acid (more than 60% of the FA) and the limited concentrations of linolenic and saturated FA of acorns, together with the high concentration of n-3 FA of the grass, modifies the lipid profile of Iberian pigs towards increased proportions of C18:1n-9 and C18:3, C22:5 and C22:6 n-3, and decreased levels of C16:0, C18:0 and C18:2 n-6 (Rey *et al.,* 2006). As mentioned above, grass is also an important source of $\alpha$-tocopherol which prevents subsequent lipid oxidation during storage, together with other micronutrients present in the feeds ingested by the Iberian pigs (Rey *et al.,* 1997; Andres *et al.,* 2001).

- "Cerdo de recebo" (mixed system): pigs start the finishing period in the 'montanera' system where they gain at least 29 kg, and afterwards receive supplementary feed mainly based on cereals and leguminous plants. This production system is encountered in case of insufficient production capacity or too high stocking charge of the woodland.
- "Cerdo de pienso": pigs are finished indoors or outdoors in free range systems and receive formulated feeds based on cereals and leguminous plants. This system gives the ability to produce Iberian pigs throughout the year, and has therefore led to the expansion of the Iberian pork industry.

The classification between 'montanera' or 'recebo' depends on the fatty acid composition of the subcutaneous adipose tissue, the thresholds being determined every year by the Ministry of Agriculture and the Interprofessional Association for Iberian pig production. For example, in 2003-2004, pigs were considered as 'bellota' for maximum levels of 21% C16:0, 9.8% C18:0, 9.5% C18:2, and a minimum level of 54% C18:1 (Daza and Lopez-Bote, 2007).

As for the pig production system, the process of Iberian dry-cured hams is also well adapted to the natural environmental conditions of the mountainous regions in the South west of Spain, with very long process duration in comparison to other meat products of the Mediterranean area (18-24 months of processing for hams). This of course participates in the specific characteristics of the Iberian pork products that have been recognized and are valued through the PDO label.

Within genotypes, studies have been carried out to describe variations in fat and muscle tissues characteristics and eating traits during the finishing regime: for example, Cava *et al.* (2000) and Rey *et al*. (2006) for Iberian pigs, Gueblez *et al*. (2002) for Basque and Gascon pigs, Pugliese *et al*. (2004a) for Nero Siciliano and Pugliese *et al*. (2004b) for Cinta senese pigs. As for the 'bellota' Iberian system, Secondi *et al*. (1992) showed that finishing of Corsican pigs on chestnut plantation leads to a compensatory growth response with very high fat deposition. They indeed demonstrated that the succession of a moderate followed by a fast growing period in extensive finishing conditions would be necessary to express the high potential for muscle lipid accretion of the Corsican pigs (Secondi *et al.,* 2007). During extensive finishing with chestnuts feeding, intramuscular fat content is increased from 1.9 up to 5.8% in the *Longissimus,* mainly due to accumulation of triglycerides (storage lipids). This is accompanied by an increase in the proportion of MUFA in muscle triglycerides from 42.6% up to 55% of the FA, and a decrease of PUFA from 16.6 up to 5.3% (Secondi *et al*., 1992). The type of finishing system strongly influences the quality of pork products, as shown by Cava *et al*. (2000) when comparing the sensory characteristics of dry-cured hams from Iberian pigs reared either in a free range based on acorns an pasture, or in confinement on a concentrate feed (Fig. 2).

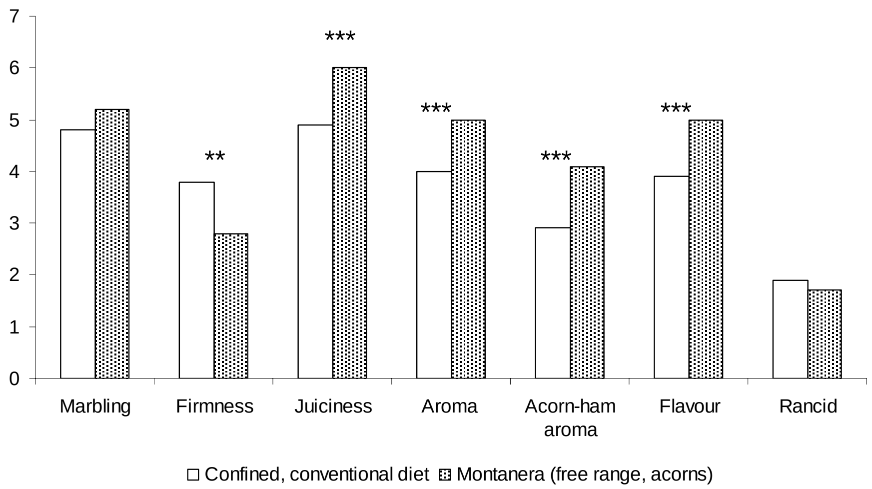


Figure 2. Influence of rearing system on the sensory traits of Iberian hams (**: P<0.01; ***: P<0.001) (modified from Cava *et al*., 2000)

Influence of the rearing system (and crossbreeding for Iberian ham production) is also noticeable by consumers: Ventanas *et al*. (2007) reported that dry-cured loin from pure Iberian pig finished outdoors on acorns and grass was preferred to those from animals reared indoors on concentrates, even though the mixed diet was enriched with MUFA and antioxidants, or to meat from Iberian X Duroc crossbreds, despite similar IMF contents. Altogether, these results demonstrate the occurrence of genotype x environment interactions on animal growth pattern, carcass and muscle properties, and their positive consequences for the sensory quality and the acceptability of pork products.

## CONCLUSION

This article shows that both feeding and rearing system influence growth performance and carcass composition in pigs, through the relative growth deposition of fat and muscular tissues. Muscle composition can also be affected, in particular lipid content, thereby influencing pork eating quality. Other muscle components can of course impact pork eating quality, especially glycogen stores at slaughter and post-mortem muscle metabolism, that largely depend on pre-slaughter handling procedure, but also on the rearing conditions of animals (space allowance, ambient temperature, physical activity…). Therefore, meat quality can be manipulated through feeding and rearing systems, but studies generally show limited effects on sensory quality when using conventional ("improved") pig genotypes. However, pigs from local breeds reared in extensive finishing conditions lead to high quality pork products, thereby demonstrating the positive genotype x environment interactions. These local breeds of pigs show a high potential for intramuscular fat deposition that can be expressed by their specific rearing conditions, but they exhibit very likely other differences in composition and ultrastructure of muscle that could impact pork quality, and are therefore interesting models for the studies on the relationships between muscle properties and subsequent pork quality. A better understanding of the relationships between muscle phenotypical traits at a "deep" level (muscle composition, metabolism, fibre typing, transcriptomics and proteomics approaches to characterize the expression of genes and proteins,…) and their relationships with eating quality traits should be achieved through the current European Q-Porkchain project, allowing further improvement of the quality or pork meat through rearing / genetic factors.

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