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# Review

# Welfare, performance and meat quality of fattening pigs in alternative housing and management systems: a review

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**Abstract: Conventional husbandry systems for pork production are scrutinized by members of the general public as well as the scientific community. As a response, alternative forms of pig production, such as outdoor housing, organic farming and environmental enrichment are gaining interest. The question arises whether these production systems are indeed able to improve the welfare and health status of the animals, and whether these production systems alter production characteristics and meat or carcass traits. Measures of poor welfare have been described, but evaluating overall welfare is difficult. Certain parameters of alternative housing will improve welfare in some ways but, simultaneously, other welfare problems are inflated, and the weighting of each of these problems is very subjective. Alternative housing systems allow pigs to display species-specific behaviour and decrease the occurrence of abnormal behaviours by acting on several parameters: indoor versus outdoor housing, floor space/density, floor type, and provision of bedding or other types of environmental enrichment. Evaluating alternative housing systems should be done by looking at all the welfare-improving factors and the cost of alleviating welfare-decreasing problems in a given production system. Data in the literature on growth, meat and carcass traits in alternative production systems, are inconsistent, indicating that other factors can play an important role. However, as equal, or in some cases even better, performance can be attained in certain production systems that meet concerns of animal welfare scientists and members of the general public, alternative production forms may be considered preferable.**


**Keywords:** alternative housing; pig; welfare; growth; carcass quality; meat quality

## INTRODUCTION

Intensive pig farming has moved away from the traditional methods of the past when pigs were allowed to roam freely during the day and sleep in a spacious sty at night (reviewed in Fraser[1]). Instead, in recent decades pigs are continuously confined to a limited, stimulus-poor space for economical, ergonomical and health reasons, resulting in the production of considerable quantities of high-quality meat.

Despite the good health status of the animals, both animal welfare scientists and many members of the general public are concerned with the welfare of production animals in conventional systems, even though their arguments are not based on the same scientific grounds. Pigs confined in stalls are no longer able to express their full range of species-specific behaviours or engage in voluntary social interaction. Therefore, while food safety and sensory quality have been very important to consumers of pork, the quality of life of production pigs has become a major point of concern as well.

Consumers nowadays are willing to pay extra for pork with certain assurances, including the welfare of pigs being respected.[2] Furthermore, the belief exists among consumers that pork from animals raised in extensive systems is of better quality.[3] As a result, over recent decades, alternative housing systems, such as outdoor housing, organic farming and application

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of environmental enrichment, have gained interest. Organic farming is the most regulated of alternative housing systems, thereby imposing minimally on the environment and the welfare of production animals, and avoiding the use of polluting agents, including antibiotics.[4] The issue is whether these new systems indeed improve welfare of farmed pigs and whether, given the fact that they replace systems which already produce high-quality meat, they affect production characteristics and meat or carcass traits. This review aims to evaluate the effects of alternative housing systems on behaviour and health of fattening pigs and the subsequent differences in growth performance, meat and carcass traits.

## INDICATORS OF ANIMAL WELFARE

An encompassing definition of welfare is difficult to find as it is a man-made and complex concept.[5] In the broadest sense 'the welfare of an animal is its state as regards its attempts to cope with its environment'.[6] If the animal is unable to cope, it is stressed.[7] It is beyond the scope of this paper to elaborate on the concept of stress and the problems associated with its use. Excellent overviews can be found elsewhere.[7–9] Briefly, stress is defined by Moberg[10] as 'the biological response elicited when an individual perceives a threat to its homeostasis'. Depending on the situation, stress can be short-term (acute) or long-term (chronic).

Housing is usually a long-term condition for farm animals[5] and thus results in a chronic state of an individual, be it stressed or not. Measures of poor animal welfare can be summarized as: (1) increased mortality, (2) impaired growth and breeding ability, (3) external/internal lesions and/or pain, (4) disease, (5) immunosuppression, (6) profound physiological changes, (7) expression of few or no species-specific behaviours, and (8) occurrence of behavioural abnormalities.[11] One type of behavioural abnormalities are the so-called stereotypies, which are repetitive invariant behaviours, apparently without function.[12] Stereotypies are often thought to develop as strategies to cope with the limited stimuli available in captivity.[13] In pigs, stereotypies consist of bar biting, head-weaving, vacuum chewing, tail biting, rooting bare floor, and maintaining dog sitting position in relation to apathy.[14–17]

Alternative housing systems generally improve welfare by providing the opportunity to express species-specific behaviour and engage in interaction with conspecifics. However, by doing so, these extensive systems might inflate other welfare problems, mainly related to health.[18] This trade-off makes it very difficult to evaluate overall welfare, especially because the value of each welfare problem is weighted differently by different scientists.[15] Instead, Rushen[5] advocates evaluation of specific problems within each type of housing system. These problems can be identified using various parameters of a husbandry system, which are discussed in the next Section, and evaluating their effect on pig welfare and health. A good housing system with regard to animal welfare is one with a small number of problems and/or with the possibility to improve upon the less positive conditions. In conventional housing it is sometimes impossible to make appropriate changes, such as providing opportunities for greater locomotion in indoor pens with limited space, while it is more straightforward to control parasites by a preventive deworming strategy in an alternative housing system where animals are housed on pasture or on a paddock.

## PARAMETERS OF ALTERNATIVE HOUSING AND THEIR EFFECT ON HEALTH AND WELFARE

Table 1 describes several housing systems that are discussed further on in this review. They differ from conventional housing, mainly in the parameters discussed below.

### Indoor versus outdoor

A major change from conventional to alternative housing systems is that pigs are kept outdoor on paddocks or pasture. This allows for the animals to engage in extended locomotion[19,20] and rooting,[19] the latter mainly on pasture or if the outdoor paddocks are bedded with soil, straw or wood shavings. When given the opportunity, pigs engage in a great amount of rooting behaviour, indicating this is a part of their normal ethogram.[21] The effects of the presence of bedding are presented in a subsequent Section. The main health problem associated with outdoor housing in organic farming is the occurrence of ecto- and endoparasites.[22] Hoffman *et al*[23] noted mosquito bites and fleas in outdoor-reared pigs. Also, housed outdoors, pigs are exposed to sun and often sunburn occurs in these conditions.[24] However, Guy *et al*[25] observed less adventitious bursitis, injuries, stomach ulceration, lung damage, mortality and morbidity of disease in outdoor paddocks and straw yards compared with pigs in fully slatted pens. Hansson *et al*[26] evaluated pig health by studying the carcasses for tumours, abscesses, joint lesions, tail biting, lung lesions, ascariosis and other liver diseases in a slaughterhouse survey. In the organic pigs, a significantly lower percentage of animals showed abscesses, tail biting, pleuritis and white spots, whilst more arthritis and arthrosis was surveyed than in conventional pigs. However, as with a slaughterhouse survey, the results have to be considered very cautiously. The lower percentage of white spots, for instance, can be explained by a lower incidence of ascariosis, but an earlier infection, with already recovered lesions at the moment of slaughter, is a possible explanation as well. Vaarst *et al*[27] observed a wide variation in prevalence of disease in Danish organic slaughter-pig herds.

Hence, although some authors describe health problems in certain production systems, others do not

**Table 1.** Different alternative housing conditions used for experiments

| Publication | Outdoor (O)/Indoor (I) | Number of pigs | Surface per pig | Bedding and enrichment |
|---|---|---|---|---|
| Beattie *et al*[36] | I | 6 | 2.3 $m^2$ (7–13 weeks)<br>4.7 $m^2$ (14–20 weeks) | Peat area and straw area |
| Beattie *et al*[92] | I | 8 | 1.75 $m^2$ (8–14 weeks)<br>3.5 $m^2$ (15–21 weeks) | Peat area and straw area |
| Beattie *et al*[19] | I | 6 | 0.5–2.3 $m^2$ | Peat area and straw area |
| Bridi *et al*[64] | O | 12 | 300 $m^2$ | — |
| Day *et al*[93] | I | 10 | 1.12 $m^2$ | 30 cm chain<br>Bucket chopped straw<br>Commercial destructible enrichment device |
| de Jong *et al*[94] | I | 4 | 1.16 $m^2$ | Half concrete area covered with straw |
| Ekkel *et al*[28a] | I | 10 | 0.7 $m^2$ | |
| Enfält *et al*[67] | O | 51 | 980 $m^2$ | Hut with straw bedding |
| Gandemer *et al*[62] | O | 8 | 50 $m^2$ | 3 kg beets $day^{-1}$ |
| Gentry *et al*[42] | O | 40 | 2 $m^2$ | Hut with straw bedding |
| Gentry *et al*[42] | O | 6 | 212 $m^2$ | Hut with straw bedding |
| Gentry *et al*[42] | I | 25<–>1500 | 7.5 $m^2$<–>12 $m^2$ | |
| Gentry *et al*[69] | I | 4 | 9.4 $m^2$ | |
| Geverinck *et al*[79] | I | 4 | 1.16 $m^2$ | Half concrete area covered with straw |
| Guy *et al*[25,68,95] | | 20 | 1.65 $m^2$ | Straw yards |
| Guy *et al*[25,68,95] | O | 20 | 20 $m^2$ | Bedded hut |
| Hansson *et al*[26b] | Slaughterhouse survey on organic pigs | | | |
| Hill *et al*[43] | I | 8 | | Two chains and two rubber devices |
| Hoffman *et al*[23] | O | 24 | 75 $m^2$ | |
| Klont *et al*[40] | I | 4 | 1.16 $m^2$ | Half concrete area covered with straw |
| Lambooij *et al*[77] | I | 10 | 0.7 $m^2$ | Straw bedding |
| Lambooij *et al*[77] | I | 30 | 1.25 $m^2$ | |
| Lebret *et al*[60] | I/O | 12 | 0.45/0.70 $m^2$ | |
| Lewis *et al*[53] | I | 2 | 20 $m^2$ | |
| Millet *et al*[54b] | I/O | 4 | 2 $m^2$ indoor/2 $m^2$ outdoor | Straw bedding |
| Olsson *et al*[63b] | O | 40 | 150 $m^2$ | |
| Pearce *et al*[96] | I | 8 | 0.72 $m^2$ | Chains, bar and rubber tyres |
| Petersen *et al*[46] | I | 40 | 0.9 $m^2$ | |
| van der Wal *et al*[61c] | I/O | 79 | | Straw bedding |
| Warriss *et al*[72] | O | 24 | 18.75 $m^2$ | Tree stumps, motor tyres |
| Wolter *et al*[97] | I | 25/50/100 | 0.68 $m^2$ | |

[a] Specific-stress-free housing system: pigs that were not mixed and were provided with straw.
[b] Organic farming.
[c] Scharrel pigs.

confirm this, indicating that with a good management it might be possible to counter such problems.

## Floor space/density

With decreasing space allowance, pigs made fewer and longer visits to an automated feeder with higher feed intake, but showed depressed growth rate.[28] They remained in the feeder longer because they could escape from the crowded situation and aggressive conspecifics. Ekkel *et al*[29] recorded lower coughing and sneezing frequencies in a 'specific-stress-free' (SSF) housing system, in which pigs were raised from birth and were never mixed, than in a conventional stable. Mixing of pigs after weaning and at different stages in the production process is the cause of severe aggression,[1,30] which results in lesions from scratches and bites. Fewer such lesions were observed in the SSF housing.[29] Space allowance did not seem to affect tail biting in commercial grower–finisher barns.[31] If mixing of pigs cannot be avoided, providing barriers in the pen will allow victims of aggression to escape.[32] It is also possible to reduce potential aggression by taking the individual aggressiveness into account and to mix only low-aggressive animals.[33]

## Floor type, bedding and enrichment objects

Pigs kept in substrate-impoverished conditions showed less diversity in behaviour in the home pen as well as when they were faced with a behavioural challenge such as a novel object test.[34] Providing bedding (mainly straw or soil) on solid or slatted concrete floors makes these surfaces more comfortable to lie and walk on. A number of studies showed that, when straw is provided as bedding, the activity of pigs increases and the occurrence of abnormal behaviours is reduced.[19,35–39] Moreover, the level of aggression between pigs in a straw-enriched pen has been shown to decrease in comparison with pigs kept in barren environments.[40]

This is not to say that adding straw is positive on all accounts, especially in relation to management and lameness. When pigs are kept on slatted floors, the mixing of straw with manure can complicate the effective removal of manure using automated systems.[41] Whether they are solid concrete, concrete and partially slatted, or either of these bedded with straw or soil, the type of floor will affect the prevalence of foot lesions and lameness (reviewed in Arey[36]). Pigs housed on slatted floors often show an increased prevalence of heel erosions.[42] In contrast, in the study of Gentry *et al*,[43] pigs finished on wheat straw bedding showed a smaller number of foot lesions, but the foot pad lesions were more severe than in the control group kept on concrete-slatted flooring.

Straw is the main type of enrichment given to pigs. Relatively few studies have been done to test other enrichment objects for pigs. Hill *et al*[44] found that, when providing pigs with two chains and two rubber hoses, age has an effect on the time spent manipulating each object. A clear preference developed for the hoses in the finishing stage, whereas after weaning, interaction time with hoses and chains was similar. Animals seem to prefer soft, pliable toys that are easy to manipulate. In a study by Apple and Craig,[45] four-week-old growing pigs played more with a rubber dog toy and a knotted rope than with a chain and a hose. In the same study, a greater pen size resulted in less overall playing time. Other enrichment objects used, mostly in combination with straw bedding, are pieces of forest bark, tree branches[34] and even car tyres.[46]

## EFFECTS OF ALTERNATIVE HOUSING AND MANAGEMENT ON GROWTH AND CARCASS QUALITY CHARACTERISTICS (TABLE 2)

Feed consumption, climate, space allowance, level of activity, live weight, genotype, health status and stress can affect growth and carcass composition.

**Table 2.** Influence of alternative housing on daily growth, backfat thickness and meat percentage

| Author | Type of housing | Daily gain | Backfat thickness | Meat percentage |
|---|---|---|---|---|
| Ekkel *et al*[28] | Specific-stress-free housing | ↑ | | |
| Gentry *et al*[42] | Pigs born and finished outdoors | ↑ | ↓ | ↑ |
| Gentry *et al*[42] | Deep bedding | ↑ | ↓ | |
| Lebret *et al*[60] | Lower temperature indoors | ↑ | = | = |
| Millet *et al*[54] | Organic housing | ↑ | ↑ | = |
| Olsson *et al*[63] | Organic pigs | ↑ | ↑ | ↓ |
| Beattie *et al*[92] | Enriched housing | ↑ from 55–100 kg | ↑ | |
| Guy *et al*[68] | Outdoor paddocks/straw yards | ↑/↑↑ | Straw yards higher than outdoor housed; fully slatted intermediate | |
| Beattie *et al*[19] | Enriched housing | = | | |
| Bridi *et al*[64] | Outdoor rearing | = | ↑ | = |
| Enfält *et al*[51] | Effect of training | = | = | = |
| Gentry *et al*[42] | Indoor-born pigs finished outdoors during winter | = | = | = |
| Gentry *et al*[69] | Expanded space allowance | = | = | = |
| Klont *et al*[40] | Enriched housing | = | = | = |
| Lewis *et al*[53] | Exercise | = | ↑ | |
| Wolter *et al*[97] | Groups of 50 and 100 pigs | = | = | = |
| Enfält *et al*[67] | Outdoor rearing | ↓ | ↓ | ↑ |
| Hale *et al*[52] | Effect of training | ↓ | = | = |
| Hoffman *et al*[23] | Free-range pigs | ↓ | ↓ | ↑ |
| Randolph *et al*[57] | Crowded pigs | ↓ | | |
| Hyun *et al*[55] | Pigs with multiple stressors | ↓ with crowding and mixing | | |
| Lebret *et al*[60] | Outdoor rearing during summer | ↓ | ↓ | = |
| Petersen *et al*[46] | Effect of training and group housing in large pens | Lower in group-housed | Lower total fat content in group-housed | ↓ |
| Hill *et al*[42] | Environmental enrichment/isolation | Treatment × genotype[a] | Lower in isolated animals | Higher in isolated animals |
| Gandemer *et al*[62] | Outdoor housing | | | ↓ |
| Hansson *et al*[26] | Slaughterhouse survey free-range and organic pigs | | | ↓ |
| Lambooij *et al*[77] | Straw bedding/free-range housing | | = / = | |
| van der Wal *et al*[61] | Free-range pigs | | Trend to higher values | ↓ |
| Warriss *et al*[72] | Pigs in an outdoor paddock | | ↓[b] | |

[a] Commercial genotype pigs showed no differences in ADG by different forms of environmental enrichment, while pigs of an experimental genotype line supplied with toys showed higher ADG.

[b] In the group showing numerically the largest differences, the intensively reared pigs reached a higher live weight at slaughter than the extensively reared animals.

↑, increase; ↓, decrease; =, remains the same.

In environmentally enriched or outdoor housing systems, the level of activity is likely to be increased, which suggests elevated energy requirements for maintenance.

Group-housed pigs in an experiment of Petersen *et al*[47] showed a slower daily gain and a lower total fat content than individually housed pigs. This can be due to a higher spontaneous activity, but a lower feed intake can also play a role since 40 pigs had to share four feeders compared with the individual feeding and housing of the control group. Similarly, de Haer and Devries[48] demonstrated a higher growth rate and backfat thickness in individually housed pigs than in pigs housed in pens of eight animals, which could partially be explained by a higher feed intake. In addition, several authors[49–51] have observed higher growth rates in individually housed than in conventionally housed pigs. Therefore, individual housing might not be suitable for comparing alternative and conventional housing. Training of pigs, housed individually[47] and in groups,[47,52] did not affect daily gain or carcass lean meat percentage. Hale *et al*,[53] on the contrary, observed a faster growth in exercised pigs, without changes in carcass conformation. Lewis *et al*[54] found no effect of exercise on daily gain of pigs, but the backfat thickness of exercised pigs was lower.

In outdoor-housing systems, maintenance energy requirements increase when the ambient temperature is below the thermal comfort zone. Furthermore, allowing for increased activity might also raise energy requirements. If outdoor-housed pigs spend more energy for activity and thermoregulation, it follows that, with an equal feed consumption, a higher proportion of the diet will be used for maintenance requirements. This results in a slower growth and a lower fat content in the pigs at similar age. This hypothesis can only be confirmed in an experiment based on restricted feeding, as feed intake is a major determinant in daily gain and carcass quality. If the pigs can compensate the extra energy demands by eating more feed, the growth rate can remain unaffected or rise.[55]

However, a potentially reduced incidence of several kinds of stressors in alternative housing systems will probably lower the energy requirements. In a study of Hyun *et al*,[28] space reduction of pigs resulted in a lower daily gain without affecting feed intake. This effect was attributed to increased energy expenditure as a result of increasing abnormal behaviour and higher levels of aggression.[56] Randolph *et al*[57] noted a reduction in daily gain and a higher feed to gain ratio in crowded pigs, whereas feed intake was not affected. There was evidence that crowding increases aggressive behaviour, but a correlation between aggressive behaviour and performance of the pigs was not demonstrated. Reducing stress positively affects performance.[29] Several stressors, such as high cycling temperature, stocking density and regrouping, depress the average daily feed intake and subsequent daily gain.[58] A positive linear relationship between, on the one hand, space allowance and, on the other hand, daily feed intake and daily gain of group-housed pigs was found by NRC-89.[59]

Lebret *et al*[60] showed the importance of temperature on daily feed intake and growth rate, both in indoor- and in outdoor-housed pigs. They compared indoor-housed pigs at either 17 °C or 24 °C with outdoor-housed pigs in both winter and summer circumstances. Average outdoor temperatures in summer and winter were respectively 18.3 °C and 26 °C, but with large day-to-day variations. In comparison with indoor-housed pigs at 24 °C, the indoor-housed pigs at 17 °C showed higher growth rates. Outdoor-housed pigs during winter and summer showed growth rates, respectively, similar to and lower than indoor-housed pigs at 24 °C. The indoor pigs at 17 °C and the outdoor pigs in winter showed significantly higher feed intakes, whilst the outdoor pigs during summer showed a trend to a lower feed intake. Cold-stressed pigs spent more time feeding in the experiments of Hicks *et al*,[56] but this was not accompanied by a higher feed intake.

The rate of fat accretion will depend on the amount of feed consumed and the maximal daily rate of protein accretion. van der Wal *et al*[61] and Hansson *et al*[26] found lower lean meat percentages in free range and organically grown pigs than in conventionally fattened pigs. Similarly, lower muscle percentages and higher fat thickness, were found for outdoor-housed pigs[62] and organically raised pigs.[63] This was accompanied by a faster growth. Therefore, the maximal capacity for protein deposition might be attained, with consequently extra fat deposition. Bridi *et al*[64] and Millet *et al*[55] detected a higher backfat thickness but equal meat percentage in outdoor-reared pigs and pigs in organic housing conditions respectively. In contrast, Warriss *et al*[65] found a lower backfat thickness in outdoor- versus indoor-raised animals. In the analysis of this experiment, however, live weight at slaughter and treatment group was confounded. The intensively reared pigs reached a higher live weight at slaughter than the extensively reared animals. Therefore, both the housing system and the higher live weight may explain the higher fat thickness. Subcutaneous fat thickness increases with carcass weight.[66] Enfält *et al*[67] and Gentry *et al*[43] noticed leaner carcasses in outdoor- versus indoor-reared pigs. Probably because the feeding was not entirely *ad libitum*, the outdoor-fattened pigs in the experiments of Enfält *et al*[67] could not compensate for additional energy demands, leading to a slower growth than the indoor-housed pigs, which can explain the leaner carcasses. In addition, in an experiment by Hoffman *et al*,[23] lower feed intakes of free-range pigs led to slower growth rates and lower backfat thickness. Gentry *et al*[43] found a higher average daily gain for outdoor pigs during warm months compared with indoor pigs, whereas in the winter months no differences were found between the groups. Guy *et al*[68] observed significantly higher backfat levels in pigs grown in straw yards compared with outdoor pigs; pigs housed in a conventional stable showed an intermediate backfat level. Klont *et al*[41] did not observe differences in meat percentage between pigs raised in barren and enriched housing systems, nor did Gentry *et al*[69] in pigs with increased space allowance.

In addition, Enfält *et al*[67] detected an interaction between sire breed and rearing form for the leanness in the ham. In the experiments of Hill *et al*,[44] genotype and forms of enrichments tended to interact, with similar average daily gain and feed to gain ratios in a commercial pig genotype and improved average daily gain and feed to gain ratios in an experimental line receiving toys in contrast to other types of enrichment. Thus, the choice of the genotype in relation to the housing system can be important in view of production traits.

In conclusion, alternative production leads, in a majority of studies, to an equal or even a faster growth. Several factors in alternative housing systems can lead to an increased appetite and consequently a higher feed intake. In this case, the additional energy needs related to these systems can be overcompensated, even resulting in a higher daily gain. In some studies this higher growth rate is causing extra fat deposition, leading to lower muscle percentages. It is clear that daily feed intake will be one of the determining factors for the daily gain obtained and ultimate carcass quality, in combination with the factor genotype.

## EFFECTS OF ALTERNATIVE HOUSING AND MANAGEMENT ON MEAT QUALITY CHARACTERISTICS

The literature gives two explanations for potential housing effects on meat quality: differences in preslaughter stress and physical training. Animals in alternative housing systems can engage in extended locomotion, since they often have more space allowance and more stimuli to move. For this reason, the physical activity during loading and transport of these animals might not be as demanding physically and might be less stressful. In the next sections several factors of meat quality in relation to alternative housing systems and management systems will be discussed: (1) muscle glycogen content, lactate and pH values, (2) meat colour and muscle fibre characteristics, (3) intramuscular fat content, and (4) meat tenderness, water-holding capacity and juiciness of the meat.

### Muscle glycogen content, lactate, and pH values (Table 3)

Dark, firm and dry (DFD) meat occurs in pigs that were exhausted at slaughter. The exhausted pigs have muscles with a very low glycogen content, and thus only minor amounts of lactic acid can be formed. The pH decrease is somewhat slower than for normal meat, resulting in an ultimate pH above 6.0. The incidence of DFD meat is rather limited in pig carcasses. It can be expected that alternatively housed pigs, with more opportunity for exercise than indoor-penned pigs, do not become as exhausted during loading, which could be a positive factor in relation to the incidence of DFD meat.

With increasing physical fitness, muscles generate relatively less ATP through anaerobic pyruvate catabolism,[70] which reduces muscle lactate formation. Lactate formation following physical stress was significantly lower in trained versus untrained pigs.[71]

Higher liver glycogen levels are correlated with a lower ultimate pH.[72] Glycogen content and ultimate pH are determined by many factors. Metabolic and contractile properties of muscle are important sources of variation in glycogen content.[73] All the events occurring during the handling of pigs before slaughter can lead to a depletion of muscle glycogen.[73] Muscle glycogen content was higher in *m biceps femoris* of moderately exercised than in non-exercised crossbred pigs.[74] Enfält *et al*[67] noted more glycogen in the muscles at slaughter and a significant lower ultimate pH in outdoor-reared pigs than in conventional ones. The higher glycogen level before slaughtering would implicate a lower risk for DFD meat, but a greater risk of meat being pale, soft and exudative (PSE). PSE meat occurs more frequently in pig carcasses than DFD meat. PSE mostly occurs in pig muscles with a high glycolytic potential. According to Enfält *et al*,[75] the development of muscles with PSE characteristics is initiated by a combination of a lower muscle pH at exsanguination, due to lactate accumulation before slaughter, and a faster pH decrease *post mortem*. As early as 45 min *post mortem* a pH of 5.6–5.8 is reached in PSE meat, but the ultimate pH is similar or slightly lower than in normal meat. PSE meat is caused by severe, short-term stress just prior to slaughter, which leads to a rapid breakdown of muscle glycogen. Alternatively housed pigs seem to cope better with stressful circumstances at slaughter.[76]

In contrast to free range pigs, Lambooij *et al*[77] observed higher lactate formation in conventional pigs, resulting in a lower initial pH. Even so, Petersen *et al*[78] observed lower pH values 45 min *post mortem* in female confined pigs than in trained pigs or group-housed pigs. In both studies, ultimate pH was not affected by the treatments, and neither did Lewis *et al*[54] find an effect of exercise on ultimate pH of *m longissimus dorsi* and *m quadriceps femoris*. Similarly, Enfält *et al*[52] observed no effect of animals walking 735 m a day on glycogen content and ultimate muscle pH in *m longissimus dorsi* and *m biceps femoris*.

Different forms of environmental enrichment, or outdoor housing did not alter muscle glycogen content[61,72] or pH values.[23,43,44,61,79]

Organic housing led to a lower ultimate pH in the experiments of Millet *et al*.[55] Guy *et al*[68] saw lower initial pH values for outdoor-housed pigs although not statistically significant. Klont *et al*[41] determined a higher ultimate muscle pH at 24 h *post mortem* in pigs on a straw bedding.

**Table 3.** Influence of different housing systems on meat pH at 45 min and 24 h after slaughtering

| Author | Type of housing | Initial pH | Ultimate pH |
|---|---|---|---|
| Ekkel *et al*[28] | Specific-stress-free housing | ↓ | ↑ |
| Klont *et al*[40] | Enriched housing | = | ↑ |
| Beattie *et al*[92] | Enriched housing | ↓ | = |
| Bridi *et al*[64] | Outdoor rearing | = | = |
| Enfält *et al*[51] | Effect of training | | = |
| Gentry *et al*[42] | Indoor-born pigs finished outdoors during winter | = | = |
| Gentry *et al*[42] | Pigs born and finished outdoors | | = |
| Gentry *et al*[69] | Expanded space allowance | ↑ | = |
| Geverinck *et al*[79] | Enriched housing | = | = |
| Guy *et al*[68] | Outdoor paddocks/straw yards | | = |
| Hoffman *et al*[23] | Free-range pigs | = | = |
| Lambooij *et al*[77] | Straw bedding | ↑ in *m biceps femoris* | = |
| Lebret *et al*[60] | Lower temperature indoors | = | = |
| Lewis *et al*[53] | Exercise | = | = |
| Petersen *et al*[78] | Effect of training and group housing in large pens | Lowest in trained; highest in group-housed; confined intermediate | = |
| Petersen *et al*[46] | Effect of training and group housing in large pens | Higher in *m biceps femoris* of sows; lower in trained versus group-housed | = |
| van der Wal *et al*[61] | Free-range pigs | = | = |
| Warriss *et al*[72] | Pigs in an outdoor paddock | = | = |
| Hale *et al*[52] | Effect of training | | ↓ |
| Lambooij *et al*[77] | Free-range housing | ↑ | ↓ |
| Millet *et al*[54] | Organic housing | = | ↓ |
| Olsson *et al*[63] | Organic pigs | | Interaction with genotype |
| Gandemer *et al*[62] | Outdoor housing | | Lower in *m adductor longus* |
| Beattie *et al*[36] | Enriched housing | Tended to be lower in outdoor paddocks | |

↑, increase; ↓, decrease; =, remains the same.

In general, experimental housing conditions did not alter initial or ultimate pH in a consistent manner, indicating that other factors have more influence on the glycolysis rate and the resulting meat quality.

Genetics will be of major importance for meat quality. Breed together with preslaughter handling are critical for the muscle glycogen content.[73] Warriss *et al*[65] detected an interaction between breed and rearing environment for haem pigment. In an experiment of Olsson *et al*,[63] type of production interacted with the presence of the $RN^-$ allele on ultimate pH, drip loss and shear force value. Nutrition might affect meat quality as well. Rosenvold *et al*[80] demonstrated that by feeding finishing pigs diets low in carbohydrates and high in protein three weeks prior to slaughtering, the muscle glycogen stores at slaughter can be reduced. Hence, both genotype and to a lesser extent nutrition will be important for meat quality.

## Meat colour and muscle fibre characteristics

Meat colour is influenced by different factors like post-mortem glycolysis rate, intramuscular fat content, pigment level and oxidative status of the pigment.[81,82]

Conventional myofibre typing, based on differences in sensitivity of the acto-myosine-ATP-ase activity to pH preincubation distinguished three fibre types in pig muscles: types I, IIa and IIb. Type I are slow-twitch (ST) and type II are fast-twitch (FT) fibres. Type I fibres are oxidative, whereas type IIa fibres are oxido-glycolytic, and type IIb fibres consist of oxido-glycolytic and glycolytic fibres. A more appropriate typing, taking into account the presence of four adult myosine heavy chains (MyHC) differentiates between four fibre types: I, IIa, IIx and IIb. Speed of contraction increases from type I to type IIa and IIx to IIb.[83] An increased proportion of glycolytic fibres is associated with a decreased myoglobin content, which can result in paler meat, while an enhanced oxidative metabolism leads to more red meat, but also to a reduced muscle colour stability.[83,84]

Physical training increases the oxidative capacity of skeletal muscles in different species.[71,85,86] However, Enfält *et al*[52] could not demonstrate an effect of exercise on haem pigment. In experiments of Petersen *et al*,[87] physical activity induced a change in muscle fibre characteristics. The results differed between muscles types, type of training and sex of the animals. A shift from IIb towards IIa fibres was seen in *m semitendinosus* and *m biceps femoris* of exercise trained male pigs or male pigs with allowance for spontaneous activity in comparison with confined pigs. Both training and activity increased the proportion of ST fibres in the *m trapezius thoracis*, whereas no effect was seen in the *m longissimus dorsi* of trained pigs. In pigs housed in large pens, the ratio of FTa to FTb fibres of *m longissimus dorsi* increased, but interactions between gender and physical activity were noted. Exercise thus affects muscle fibre type in that, in general, a shift occurs towards more oxidative fibres, but the function of the muscles as well as the type of activity seems to influence the distribution pattern.

Gentry *et al*[69] found no differences in colour or fibre type distribution between conventional pigs and pigs with increased space allowance, while Bridi *et al*[64] observed more red meat in outdoor-housed pigs and Millet *et al*[55] found more red and darker meat in organically housed pigs. Warriss *et al*[65] observed slightly paler meat in intensively reared pigs than in pigs reared in an outdoor paddock. This effect could not be attributed to a lower haem pigment or a lower $pH_{45}$ value as these parameters were not significantly affected. Gentry *et al*[43] and van der Wal *et al*[61] found no effects of housing on meat colour. Haem pigment was not different between confined, trained or group-housed pigs in the experiments by Petersen *et al*.[78] They observed slightly higher reflectance values in exercised than in control pigs. Enfält *et al*[67] also found a tendency towards higher internal reflectance values in outdoor-reared pigs.

In conclusion, housing type will predominantly affect meat colour by influencing the muscle fibre type as a result of a training effect, although other factors may be of importance as well. The type of housing and the space allowance may influence the level of activity and therefore meat colour.

### Intramuscular fat content

Several studies suggest a favourable relationship between intramuscular fat (IMF) content and juiciness and tenderness of pork.[88,89] According to Fernandez *et al*,[90] an increase in IMF level up to a level of 3.5% enhances the consumer's acceptability of pork.

Enfält *et al*[67] found a tendency towards lower IMF levels in outdoor-reared pigs compared with indoor-housed pigs (2.3% versus 2.6%). Likewise, in 1993, they detected a lower IMF level in exercised pigs.[52] Others[55,63] have found that organic housing led to a lower IMF level than conventionally housed pigs. No effect on IMF level was seen in free-range pigs,[61] or pigs reared outdoor.[60] However, other than housing and management, factors such as nutrition will also be important and might even overrule housing effects. For instance, in organic pig husbandry, the absence of synthetic amino acids can lead to a higher IMF content.[55,91]

### Water-holding capacity, juiciness and tenderness of meat

Enfält *et al*[67] and Olsson *et al*[63] found a lower water-holding capacity for outdoor or organically reared pigs compared with conventionally reared pigs, while water-holding capacity was unaffected by outdoor rearing in several studies.[55,61,72,77] In addition, Gentry *et al*[69] found no differences in water-holding capacity between conventional pigs and pigs with increased space allowance.

Juiciness of the *m biceps femoris* of male pigs was positively affected by training of the pigs in an experiment by Petersen *et al*.[78]

The indoor-reared pigs in a study by Enfält *et al*[67] showed lower shear force values and greater meat tenderness and juiciness than outdoor reared pigs. Likewise, van der Wal *et al*[61] found lower shear force values in the *m longissimus dorsi* of indoor-than outdoor-housed pigs.

In a study by Lewis *et al*,[54] exercise of the pigs had a negative effect on the tenderness scores by taste panel of the *m longissimus dorsi*, but shear force values were not statistically affected. Similarly, Petersen *et al*[78] and Essén-Gustavsson *et al*[74] noted no effect of training of pigs on shear force values of the *m longissimus dorsi*.

In conclusion, water-holding capacity remained unaffected or was lower in outdoor-reared pigs. Juiciness was positively affected by training in one experiment and outdoor housing led in a few number of studies to decreased tenderness of the meat.

## CONCLUSION

Several parameters can be changed in alternative housing systems compared with conventional husbandry of fattening pigs. Most allow animals to display their species-specific behaviour repertoire as well as engage in social contact. However, such changes might endanger the welfare of pigs in other aspects, mostly related to health. Nonetheless, it is easier for alternative housing systems to deal with such problems through good management than for conventional husbandry to change in such a way that behavioural needs of pigs are met.

Alternative housing systems also affect pigs' production characteristics. In several studies, pigs in an alternative production system show an equal or in some cases a better performance. This can lead in some, but not all, cases to lower meat percentages. Genetics will interfere with this, as the maximal capacity of protein accretion will be determining for the fatness of the animals. Meat quality characteristics will be influenced by housing and management parameters, although unambiguous conclusions on the effects of one housing type on these parameters cannot be drawn. Therefore, other factors such as nutrition and genetics have to be considered. These studies demonstrate that alternative production forms might lead to acceptable production performance or meat quality characteristics when compared with conventional systems. Taking into account that these production systems are developed to enhance animal welfare, and that the general public has less opposition to them, the absence of negative effects on production quality encourages favouring alternative housing systems.

 

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