

## **The effect of straw-based housing on selected quality attributes of pork – a meta-analysis**

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### **SUMMARY**

The aim of the research was to estimate the effect of straw-based housing on selected quality attributes of pork, using a meta-analytical approach. Meta-analysis is statistical procedure that combines the results of individual, independent studies into one common treatment effect, called the effect size. Data were extracted from 17 independent studies (20 experiments) and analysed using a random-effect model to estimate the effect of straw-based housing on the pH (initial pH at 45 min post mortem and ultimate pH), drip loss, colour (L\*, a\*, b\*) and Warner-Bratzler shear force of pork loins. The meta-analysis of the available results showed that pigs from straw-based systems may produce pork with a faster early post-mortem pH decline (pH<sub>45</sub>), higher drip loss, and greater lightness than those reared under barren conditions with concrete (slatted) floors. A subgroup analysis showed that greater space allowance for straw-housed pigs had a greater negative effect on initial pH (pH<sub>45</sub>), drip loss, and lightness than straw housing with normal/minimal floor space requirements.

**KEY WORDS:** straw housing system, concrete (slatted) floors, pork quality, meta-analysis

### **INTRODUCTION**

The pork market is an important part of the meat sector in Europe. Over the last decade, however, average pork consumption decreased from 34,4 to 33,4 kg per capita, although it remains the most frequently purchased meat (EC 2020). Consumers' attitudes and expectations towards meat are important determinants of meat consumption (Henchion et al. 2014). Today's consumers are interested in lean, safe pork of high quality. Other considerations, however, such as the production system and animal welfare, are becoming increasingly important in consumer decision-making (Krystallis et al. 2009, Verbeke et al. 2010, Trienekens and Wognum 2013). Animal welfare is perceived as an important attribute of overall food quality. Welfare-oriented consumers believe that products from systems with a high level of animal welfare will be of high quality (Verbeke 2009,

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Napolitano et al. 2010).

Animal welfare is a very complex problem, defined in many ways by various interested parties. Nevertheless, whatever the definition or overall perception of this problem, in general it includes such aspects as the ability of animals to cope with their environment, their mental/emotional state, and the ability to show normal patterns of behaviour (Hartung et al. 2009). The provision of straw in pig production systems is considered beneficial for the animals' welfare (Tuytens 2005) and one of the best ways of meeting the behavioural needs of pigs (Temple et al. 2012). Over the last two decades, the effect of straw-based housing on pork quality has been studied by many authors (Geverink et al. 1999, Klont et al. 2001, Day et al. 2002, Gentry et al. 2002, Lambooij et al. 2004, Millet et al. 2004, Lebret et al. 2006). The meat quality of pigs housed on straw and slatted floors has also been summarized by Millet et al. (2005), Ollson and Pickova (2005), and van de Weerd and Day (2009). However, the results of these individual studies are inconsistent and may be confusing and misleading as to the overall direction and magnitude of the effect of this factor on pork quality. An effective and powerful tool to predict the average response to and efficacy of a treatment, using all available research results, is meta-analysis. Meta-analysis is statistical procedure that combines the results of individual, independent studies into one common treatment effect, referred to as the effect size (Borenstein et al. 2009).

The objective of this study was to estimate the effect of straw-based housing on selected quality attributes of pork, using a meta-analytical approach.

## **MATERIAL AND METHODS**

The search for relevant publications was performed using the Scopus, Google Scholar, EBSCO, ProQuest and Science Direct digital databases, with the keywords 'straw', 'straw bedding', 'pigs', and 'pork' in combination with 'muscle and meat quality'. Additionally, a manual search of references from original papers and reviews was performed to capture studies not identified in the electronic search. Only studies comparing straw housing to concrete/slatted floor housing systems were included in the analysis. The following criteria were used to build the database: papers published in peer-reviewed journals and conference materials, the use of straw in housing, slatted floor housing as a control, species (pigs), muscle (longissimus), number of animals, mean and variance (standard deviation or standard error) for relevant outcomes, and meat quality measurement procedures. The meat quality outcomes of typical finishing pigs extracted from the studies included pH measured at 45 min post mortem, ultimate pH ( $pH_u$  – measured 24 or 48 h after slaughter), meat lightness determined with the Minolta Chroma Meter or Hunter Lab Miniscan in the CIE  $L^*a^*b^*$  system, drip loss expressed as weight loss after 24 h of storage at 4°C as a percentage of the initial weight of the muscle sample, and Warner-Bratzler shear force (WBSF, kg).

When a publication covered several independent experiments, these experiments with their relevant outcomes were considered as separate studies. The meta-analysis was based on procedures previously described by Zybert et al. (2019), using PQ-Stat 1.6.4.188 (PQStat Software, Poland). The effect size, which in meta-analysis reflects the direction and magnitude of the experimental treatment effect, was computed using weighted mean difference. The overall effect size was calculated by combining the effect sizes of the individual studies included in the meta-analysis. The effect size, with the corresponding 95% confidence intervals (95CI) and statistical significance of the effect, was computed using a random-effect model, assuming that the individual studies included in the meta-analysis may vary due to differences in treatment procedures or sampling errors (Borenstein et al.

2009). A positive estimate of the effect size indicates higher results in the control group (slatted floor housing), while a negative estimate indicates higher results in the experimental group (straw-based housing). The heterogeneity among studies, defined as the proportion of the total variance between them that is due to differences in effect sizes as opposed to chance, was tested using  $I^2$  statistics (Higgins and Thompson 2002). The existence of homogeneity between studies indicates that the treatment will have a similar effect when applied to a new subject. In the case of heterogeneity, when its source is not identified, the effect of the treatment will be more difficult to predict (von Hippel 2015). According to Higgins et al. (2003),  $I^2$  values on the order of 25%, 50% and 75% are considered low, medium and high, respectively. The use of a random-effect model can help to consider heterogeneity, but does not remove it. The data were split into two subgroups distinguished by space allowance (normal, in agreement with minimum legal requirements, and increased space, with extra indoor space in pens or access to outdoor space) and subjected to separate meta-analyses.

For a better understanding of the results, the effects of straw-based housing on pork quality traits were presented in forest plots. A forest plot is a graphic display of the estimated results of a meta-analysis, representing estimates of the effect size and corresponding 95CI of the effect size of individual experiments as well as the overall effect size.

## RESULTS AND DISCUSSION

Primary production, including housing conditions, alongside pre-slaughter handling, stunning method, and chilling, is an important element of a high-quality pork supply chain (Trienekens and Wogun 2013). Pork quality covers a variety of properties that determine its suitability for retail or further processing. The main quality attributes of pork, whether intended for culinary purposes or for further processing, are pH, drip loss, colour, and tenderness. A summary of the data from individual experiments included in the meta-analysis is presented in Table 1.

**Table 1**

Summary of parameters from individual experiments included in the meta-analysis

Parameter	Number of studies (experiments)	Housing system					
		Conventional (slatted)			Straw		
		n	mean	SE	n	mean	SE
pH <sub>45</sub>	13(16)	832	6,32	0,03	876	6,37	0,04
pH <sub>u</sub>	17(20)	1118	5,59	0,02	1130	5,59	0,03
DL	13(13)	699	3,57	0,07	752	3,35	0,07
L*	13(16)	789	53,69	0,2	842	53,09	0,2
a*	12(14)	600	5,84	0,03	600	5,96	0,04
b*	12(14)	600	8,51	0,04	600	8,35	0,03
WBSF (kg)	8(8)	608	4,17	0,14	630	4,12	0,14

pH<sub>45</sub> - pH at 45 min after slaughter; pH<sub>u</sub> - ultimate pH; DL - drip loss; L\* - lightness; a\* - redness; b\* - yellowness; WBSF – Warner-Bratzler shear force

The meta-analysis of all available data demonstrated that the use of straw in housing may result in a significant overall decrease in initial pH by 0,07 units (Table 2, Figure 1A). However, high, unexplained heterogeneity ( $I^2 = 78,26$ ) was detected across the combined studies, indicating that other factors may affect pH<sub>45</sub>. When the data were split for the subgroup analysis, a significant change in

pH<sub>45</sub>, greater than the overall change, was obtained for straw-housed pigs given extra space in pens or access to outdoor space (Table 2).

**Table 2**

Meta-analysis results of the effects of the housing system on pH<sub>45</sub>, pH<sub>u</sub>, DL, colour (L\*, a\*,b\*) and WBSF

Parameter (response variable)	n	Effect size	95% CI	P-value	I <sup>2</sup>	
pH <sub>45</sub>	Overall	1693	0,070	0,001, 0,141	≤0,05	78,26%
	Normal space	1086	0,016	-0,030, 0,064	>0,05	0%
	Increased space	607	0,140	0,012, 0,271	≤0,05	91,27%
pH <sub>u</sub>	Overall	2248	0,016	-0,004, 0,036	>0,05	47,98%
	Normal space	1246	0,006	-0,022, 0,035	>0,05	29,38%
	Increased space	1002	0,024	-0,001, 0,048	>0,05	46,41%
DL (%)	Overall	1451	-0,40	-0,702, -0,094	≤0,01	66,73%
	Normal space	684	-0,084	-0,546, 0,378	>0,05	44,06%
	Increased space	764	-0,654	-1,230, -0,076	≤0,05	80,25%
L*	Overall	163	-0,871	-1,230, -0,510	≤0,01	0%
	Normal space	864	-0,603	-1,072, -0,135	≤0,01	0%
	Increased space	767	-1,226	-1,886, -0,565	≤0,01	24,61%
a*	Overall	1200	-0,130	-0,314, 0,051	>0,05	28,73%
	Normal space	433	0,036	-0,082, 0,155	>0,05	0%
	Increased space	767	-0,420	-0,665, -0,178	≤0,01	0%
b*	Overall	1200	-0,210	-0,456, 0,032	>0,05	74,29%
	Normal space	433	0,042	-0,279, 0,364	>0,05	72,64%
	Increased space	767	-0,307	-0,505, -0,111	≤0,01	44,39%
WBSF (kg)	Overall	1238	-0,018	-0,191, 0,154	>0,05	71,90%
	Normal space	475	-0,365	-0,641, -0,089	≤0,01	0%
	Increased space	733	0,106	-0,034, 0,247	>0,05	60,56%

pH<sub>45</sub> - pH at 45 min after slaughter; pH<sub>u</sub> - ultimate pH; DL - drip loss; L\* - lightness; a\* - redness; b\* - yellowness; WBSF - Warner-Bratzler shear force; CI - confidence interval; I<sup>2</sup> - percentage of total variation due to heterogeneity

The rate and extent of post-mortem pH decline are the most important determinants of pork quality. In normal pork muscles, pH gradually declines from about 7,2 to an ultimate pH of about 5,4-5,5. In the case of a rapid early post-mortem pH decline, the muscles exhibit a pH of less than 5,8 during the first hour after slaughter. Rapid post-mortem glycolysis is associated with stress factors and the response of pigs to pre-slaughter stressors (Scheffler and Gerrard 2007). Gentry et al. (2002) and Millet et al. (2004) reported significantly lower pH<sub>45</sub> in pigs housed on straw litter, while others (Geverink et al. 1999, Klont et al. 2001, Day et al. 2002, Lambooij et al. 2004; Lebret et al. 2006, Peeters et al. 2006, Patton et al. 2008, Lebret et al. 2011, Lebret et al. 2015, Jordan et al. 2018) found no differences in pH<sub>45</sub> when pigs on straw litter were compared with those housed on slatted floors.

In contrast, muscles with normal rates of pH decline but extended post-mortem glycolysis may achieve an ultimate pH lower than 5,4 units. The glycogen concentration in the muscles before slaughter plays a key role in the development of ultimate pH (van Laack and Kauffman 1999, Zybert et al. 2015). Glycogen concentration is known to vary depending on the breed and muscle, but other factors, such as rearing conditions, may also affect glycolytic resources in the muscles (Scheffler and Gerrard 2007). Some of the difference in glycogen concentration in the longissimus muscles is attributed to the physical activity of pigs during their growth. Enfalt et al. (1997) and Bee et al. (2004) reported that pigs reared outdoors had more glycogen in the longissimus muscle than those from indoor systems. However, glycogen levels may also vary in the muscles of pigs housed in indoor systems. Geverink et al. (1999) found that pigs housed on straw litter had lower (but statistically non-significant) glycogen levels one day before slaughter and 1h after slaughter than those reared on concrete floors. Lambooij et al. (2004) reported that pigs housed on straw litter had significantly lower glycogen levels than pigs from slatted floor pens, but only at the moment of stunning. Later, at 1h, 4h and 24h after slaughter, the housing system had no effect on the glycogen concentration in the longissimus muscle. Klont et al. (2001) reported that lactate concentrations at 4h and 24h after the slaughter were higher in loins from pigs from enriched housing compared with barren housing.

The impact of straw-based housing on the ultimate pH of pork loins is also not consistent. Jordan et al. (2018), Millet et al. (2004), Morrison et al. (2007), Omana et al. (2014) found that loins from pigs reared on straw litter had significantly lower pH<sub>u</sub> than those from slatted floor housing. In contrast, Klont et al. (2001) reported that the loins of pigs finished on slatted floors had a lower pH<sub>u</sub> than pigs finished on straw, while Lambooij et al. (2004) and Peeters et al. (2006) found no effect of housing on ultimate pH.

The overall meta-analysis showed that straw-based housing had no effect on ultimate pH (Table 2, Figure 1B). In the subgroup analysis, no significant change in pH<sub>u</sub> was obtained for pigs kept on straw with either normal (minimum) space or extra space (in pens or with access to an outdoor area) (Table 2).

As mentioned above, housing-related differences in the rate and extent of pH decline are associated with the animals' response to pre-slaughter stress. Geverink et al. (1999) reported that pigs from an enriched treatment were less motivated to leave their pens than pigs from the conventional treatment. Additionally, these pigs had higher cortisol levels before and after slaughter than those finished on slatted floors. Klont et al. (2001) also found higher cortisol levels in pigs from enriched housing before transport compared to pigs from conventional housing. However, after transport and lairage, no differences were found between pigs from the two housing systems. According to Klont

et al. (2001) and Jordan et al. (2018), pigs from enriched housing systems cope better and react less adversely to pre-slaughter stress than pigs from barren housing systems.

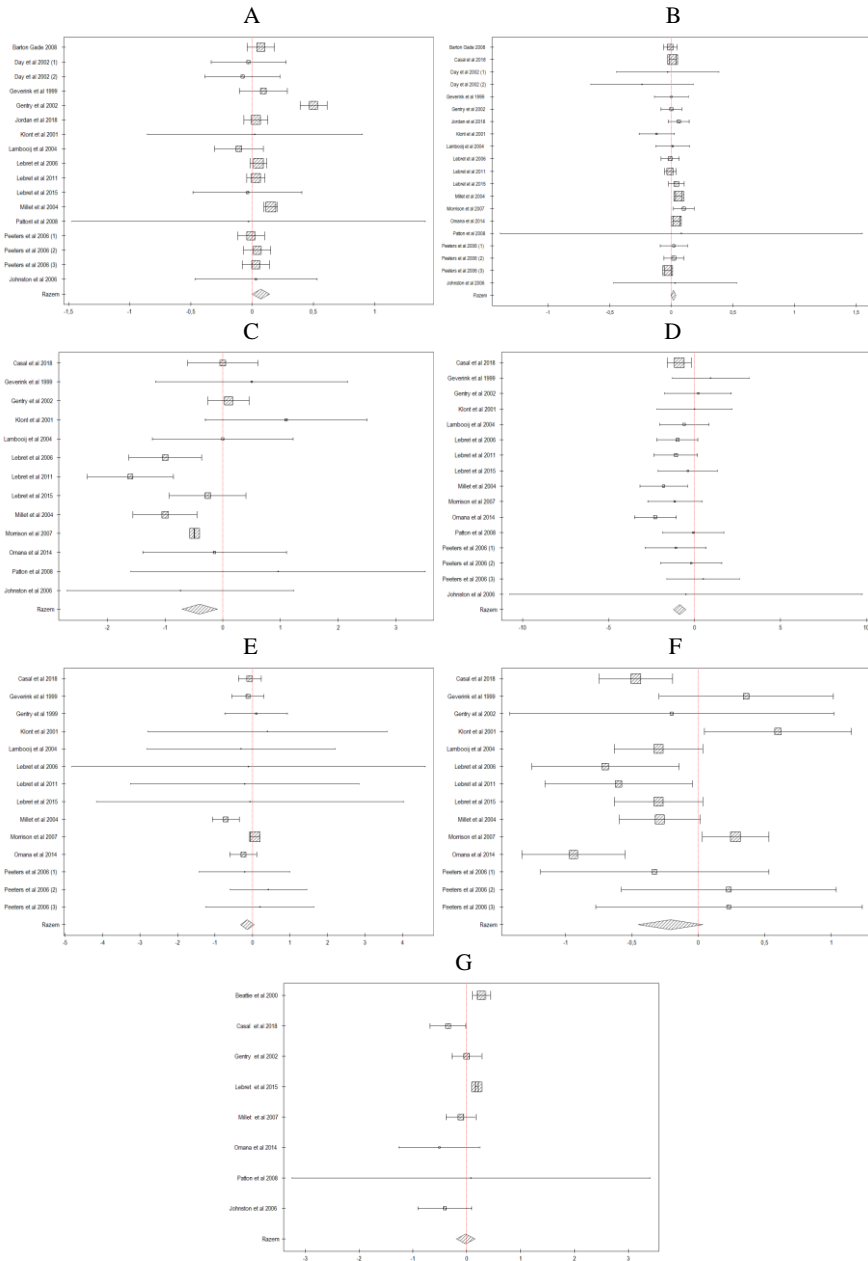
Drip loss is the next important quality attribute of pork, strongly associated with the appearance of meat cuts during retail and consumers' willingness to buy them.

The meta-analysis showed that straw-based housing may increase drip loss overall by 0,39 p.p. (Table 2, Figure 1C). However, there was a medium level of heterogeneity between studies, and when the data were split into subgroups, a greater effect size was obtained for pigs reared on straw with extra space in the pens or access to an outdoor area. Straw-based housing with normal space requirements had no effect on drip loss (Table 2).

Several studies (Morrison et al. 2007, Lebret et al. 2006, Lebret et al. 2011) have reported significantly greater drip loss from the loins of pigs finished on straw. Geverink et al. (1999), Millet et al. (2004) and Patton et al. (2008) found no significant differences in drip loss between pork from enriched and barren housing conditions. Klont et al. (2001), however, observed lower drip loss from the loins of pigs finished on straw. Water release from meat is associated with a variety of factors (Warner et al. 2010). The main physical factors responsible for water flow from the meat are myofibrillar shrinkage and contraction, changes in cell membrane permeability, and structural changes at the fibre and fibre bundle level leading to an increase in extracellular space (Schafer et al. 2002). Post-mortem degradation of myofibrillar proteins and shrinkage of the myofilament lattice due to pH decline also contribute to water release from meat. Authors generally link the effect of housing system on the water flow from pork to differences in the ability of animals to cope with pre-slaughter stress, which may affect both glycogen reserves in the muscles and the rate and range of pH decline post mortem (Klont et al. 2001, Lambooj et al. 2004). Bertram et al. (2004) demonstrated that loss of membrane integrity was significantly slower in muscles from pigs exposed to less pre-slaughter stress. The pre-slaughter condition of animals, however, is not only associated with the housing environment; other factors, such as loading, transport, and abattoir lairage, may also induce stress and alter the physicochemical properties of meat (Pearce et al. 2011). Salmi et al. (2012) performed a Bayesian meta-analysis of the effect of fasting, transport and lairage duration on selected pork attributes. Longissimus muscle drip loss decreased on average by 0,11 p.p. with prolonged transport, but was unaffected by lairage duration.

The colour of meat is another important attribute of pork quality, as consumers associate it with overall meat quality and freshness. The colour of meat is determined by its myoglobin concentration and oxidative state, whereas lightness is linked to structural changes in the muscles, driven by the rate and the range of pH decline and the relocation of water from the myofilament lattice into the extra-myofibrillar space (Hughes et al. 2014). The effect of housing system on pork colour is not completely clear. Lambooj et al. (2004), Lebret et al. (2006), Millet et al. (2004) and Morrison et al. (2007) reported no effect of housing on pork lightness.

*The effect of straw-based housing on selected quality attributes of pork – a meta-analysis*



**Fig. 1.** Forest plot of the effect of straw-based housing on the pH<sub>45</sub> (A), pH<sub>u</sub> (B), drip loss (C), lightness (D), redness (E), yellowness (F) and shear force (G) of pork loins

The meta-analysis showed that straw-based housing may result in an overall increase in lightness by 0,87 units, but with no effect on the redness or yellowness of pork colour (Table 2, Figure 1D, E, F). There was no heterogeneity between studies for lightness or redness. Thus, the homogeneity between studies indicates statistical evidence of an increase in lightness, but the true effect may differ with the range of 95%CI (Table 2). However, the subgroup analysis showed that the provision of more space to straw-housed pigs resulted in a significantly greater increase in lightness, but was beneficial both for the redness and yellowness of pork (Table 2).

The mechanism by which the rearing environment influences pork colour is not fully understood, but is attributed by authors to animals' response to stress at harvest. Muscle characteristics, including frequency of fibre types, may also be a source of colour variation. Pigs with a high proportion of fast-twitch, glycolytic fibres (type IIb) in the longissimus muscle have a more rapid pH decline post mortem and lighter colour (Choi et al., 2007). Muscle fibre characteristics may be influenced by the physical activity of animals (Petersen et al. 1997), with more type IIa and fewer type IIb fibres in the muscles of pigs reared outdoors compared with those reared indoors. Other extrinsic factors, such pre-slaughter treatment, stunning or chilling, may also play a role in the development of colour characteristics of pork. A Bayesian meta-analysis performed by Salmi et al. (2012) indicated no effect of transport or lairage duration on the colour of pork loins. A meta-analysis conducted by Zybert et al. (2019) indicated that fast chilling can improve pork lightness, but with a greater effect in CO<sub>2</sub>-stunned pigs.

Tenderness, like colour, is an attribute by which consumers judge the overall quality of meat (Warner et al. 2017). The tenderness of meat is associated with proteolysis of myofibrillar and myofibrillar-associated proteins, but variability in tenderness is also influenced by the amount of connective tissue, *post-rigor* sarcomere length, or, indirectly, the rate and the range of pH decline and water holding capacity (Warner et al. 2010, Hughes et al. 2014). Production system is reported as a weak determinant of pork tenderness (Channon et al. 2016). Loins from outdoor-housed pigs may be less tender than those from indoor systems (Enfalt et al. 1997, Pugliese et al. 2005). The majority of researchers, however, have found no significant differences in tenderness between pork from enriched and barren housing conditions (Geverink et al. 1999, Gentry et al. 2002, Lebret et al. 2015, Millet et al. 2004, Morrison et al. 2007, Omana et al. 2014).

Overall, the use of straw-based housing has no effect on pork tenderness (WBSF), but heterogeneity was high ( $I^2 = 71,90\%$ ), indicating that there are other factors influencing WBSF (Table 2, Figure 1G). When the data were split for the subgroup analysis, a significant increase in WBSF, with no evidence of heterogeneity ( $I^2 = 0\%$ ), was obtained for straw-housed pigs with normal/minimal space requirements. In contrast, an increase in the space allowance for straw-housed pigs had no effect on WBSF (Table 2). However, only eight experiments were included in the meta-analysis, so the reliability of these results may be disputable.

To conclude, the overall meta-analysis showed that pigs from straw-based systems may produce pork with a faster pH decline early post-mortem (pH<sub>45</sub>), higher drip loss, and greater lightness than pigs reared under the barren conditions associated with concrete (slatted) floors. However, the subgroup analysis showed that straw housing with normal/minimal floor space requirements may be more beneficial for pork quality than straw housing with increased space in pens or access to an outdoor area. A higher space allowance for straw-housed pigs may contribute to greater negative



changes than the overall effects in initial pH (pH<sub>45</sub>), drip loss, and lightness; however, there may be some benefits for the redness and yellowness of pork loins.

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