Improvement of pork characteristics under commercial conditions with small amount of straw or hay
Dušanka Jordan, Gregor Gorjanc, Ivan Štuhec and Silvester Žgur

Department of Animal Science, Biotechnical Faculty, University of Ljubljana, Domžale, Slovenia

ABSTRACT
The objective of this study was to evaluate the effect of small amount of straw or hay (100 g/animal/day) and gender on pork characteristics, measured on slaughter line in longissimus dorsi et lumborum (LD) and semimembranosus (SM) muscles. We performed two replicates, each including 96 fattening pigs (half gilts and half barrows) reared under commercial conditions. Treatment had no effect on carcass characteristics and pH45 in both muscles. The straw and hay treatments lowered pH24 in LD muscle (straw: 5.71, hay: 5.74, control: 5.85), while hay treatment increased Fibre Optic Probe value (FOP24) in SM muscle compared to straw treatment (hay: 33.15, straw: 29.26). Gender had no effect on meat characteristics, but the interaction between treatment and gender revealed differences in FOP24 in SM muscle in gilts but not in barrows. Based on pH24 in LD muscle, straw treatment lowered percentage of pigs with DFD meat (straw: 6.2%, control: 28.6%), whereas based on FOP24 in SM muscle, hay treatment lowered percentage of pigs with DFD meat (hay: 9.4%, straw: 32.8%; control: 27.0%). We conclude that a small amount of straw or hay has a beneficial effect on meat quality as it lowered the incidence of DFD meat.

Introduction
Meat characteristics, together with carcass composition, play a major role in defining pig carcass value. It is well known that meat quality is significantly influenced by stress induced via physiological and biochemical processes in the pig’s body in the period around slaughter, which affect perimortem muscle metabolism (Terlouw 2016). However, some studies (e.g. de Jong et al. 2000; Klont et al. 2001) indicate that enriching pigs’ barren housing conditions, characteristic for intensive production systems, influence not only pigs’ behaviour during rearing, but also their behavioural and physiological response to the stress associated with pre-slaughter procedures (e.g. handling and mixing at transport, being kept in lairage). Straw was recognized by numerous studies as valuable, functional, and effective environmental enrichment improving pigs’ welfare (e.g. Millet et al. 2005; Tuyttens 2005; Bracke et al. 2006; Van de Weerd and Day 2009) by decreasing harmful social behaviours, such as tail biting, aggressiveness (Kelly et al. 2000; Day et al. 2002a), and behaviours directed to pen fittings (Lyons et al. 1995; Petersen et al. 1995; Whittaker et al. 1998). Besides the positive influence of straw on the behaviour of pigs during rearing, it was also reported that pigs reared in straw enriched pens spend less time manipulating pen-mates during transport (de Jong et al. 2000), are less aggressive during lairage period (de Jong et al. 2000; Barton Gade 2008b) and have lower increase of salivary cortisol levels due to pre-slaughter procedures compared to pigs from barren housing conditions (Geverink et al. 1999; de Jong et al. 2000; Klont et al. 2001). These findings suggest that straw, as environmental enrichment, reduces pre-slaughter stress, which might result in better pork quality. However, the majority of studies that evaluated influence of straw on pork quality used straw as bedding (e.g. Geverink et al. 1999; Klont et al. 2001; Peeters et al. 2006; Barton Gade 2008b; Foury et al. 2011; Lebret et al. 2011), even though slatted floors dominate in intensive housing systems. It is well known that the use of a larger amount of straw is incompatible with the slatted floor system because it causes blockage of liquid manure handling systems (Broom et al. 2007). Furthermore, only few studies evaluated the effect of straw bedding alone (e.g. Day et al. 2002b; Lambooij et al. 2004). Usually it was evaluated in combination with increased space (e.g. Klont et al. 2001; Foury et al. 2011) or outdoor area (Barton Gade 2008b; Lebret et al. 2011), which itself is known to beneficially influence meat quality through pigs’ extended physical activity (Millet et al. 2005). Moreover, studies evaluating the effect of straw enriched environment on pork quality report inconsistent results. Only few studies revealed improved pork quality, reporting tender meat, lower cooking losses (Beattie et al. 2000), and lower drip loss (Klont et al. 2001; Lambooij et al. 2004). Other authors found either no influence (Geverink et al. 1999; Day et al. 2002b; Peeters et al. 2006; Barton Gade 2008b) or even negative effect of straw enrichment on pork quality measurements (Morrison et al. 2007; Lebret et al. 2011).

Some studies showed that beneficial influence of straw on the behaviour of pigs during rearing (Kelly et al. 2000; Day et al. 2002a) was achieved already with small quantities replenished every day. Small quantities of straw can be offered to pigs...
in such a way (e.g. in a rack placed above the trough) so that there is no risk of blockage of the dunging canal under the slatted floor (Jordan et al. 2008). In this way, straw can be used as environmental enrichment also in slatted floor housing systems. However, the question that arises is whether a small quantity of straw would have the same beneficial influence on pork quality as the straw bedding. In some regions hay, which meets all important characteristics of efficient environmental enrichment for pigs (Van de Weerd et al. 2003), is more available than straw. However, to our knowledge, it is not known whether hay has the same positive influence on pork quality as straw. Gilts were found to be more active (Elkmann and Hoy 2008; Jordan et al. 2008; Reimert et al. 2014) and less fearful than castrates (Reimert et al. 2014), which may contribute to differences in meat quality between genders through stress reactivity. Therefore, the aim of our study was to evaluate the effect of a small amount of straw or hay as environmental enrichment and gender on meat characteristics of fattening pigs under commercial rearing conditions.

Materials and methods

Animals

The study was performed on a commercial pig farm in two replicates, each lasting seven weeks. Pigs were kept according to the requirements of the Rules on the protection of farm animals (2010). Each replicate included 96 tail docked fattening pigs (48 gilts and 48 barrows) from 60 kg live weight to slaughter at the average live weight of 96 kg. Pigs were commercial crossbreds between maternal line (Swedish Landrace × Large White) and German Landrace sires. The animals were housed separately by gender in six fully slatted floor pens (4.90 × 2.45 m) divided with full fences containing 16 pigs each (three pens of gilts and three pens of barrows). They were fed with 2.4 kg of a complete feed mixture (12.9 MJ/kg ME, 14% CP) at 60 kg live weight with gradual increase up to 3.0 kg at the end of fattening period and 4 l of fresh whey per animal per day. The complete feed mixture and fresh whey were offered at 7.30 and 12.00. Animals did not eat the whole meal at once but left a part of it for later. Groups of animals were randomly allotted to one of three treatments. The pigs of the straw/hay treatment received 100 g of wheat straw/hay per animal per day. The control treatment received no roughage. Straw or hay was laid in the 115 cm long rack right after morning feeding. The racks were placed above the trough and designed in such a way that pigs were able to draw only blades of straw or hay from it in order to prevent the blockage of the dunging canal under the slatted floor. The lights in the pig house were on during working hours, namely between 6.00 and 14.00 o’clock.

Slaughtering of animals

Pigs from each replication were slaughtered at the two consecutive days (48 pigs per day). Pigs received feed for the last time at 7.30 the day before slaughter. Animals were slaughtered in a local slaughterhouse, which was only 2 km away from the pig farm. All the animals were loaded on the same truck, where they had 0.55 m² surface per animal. Animals from all three treatments were mixed and treated equally from loading to slaughter. All measures were taken to ensure that handling was the same for all animals in both replicates. After arrival at the slaughterhouse, pigs were individually weighed. The resting time before the slaughter was between 0.5 and 1.5 hours. Pigs were randomly driven to the stunning pen, where they were electrically stunned before bleeding. Carcass weight and muscle and fat thickness were measured 45 min after slaughter. Muscle thickness was defined as the distance between the cranial edge of *gluteus medius* muscle and dorsal edge of *canalis vertebralis*, whereas fat thickness was defined as the thinnest part over *gluteus medius* muscle. After slaughter (45 min and 24 hours) pH measurements (Mettler Toledo, Switzerland, calibrated at pH 4 and 7 buffer solutions, Mettler Toledo) were taken; pH₄₅ and pH₂₄, respectively. In addition, an internal light scattering measurement was taken at 24 hours after slaughter using the Fibre Optic Probe (FOP₂₄; TBL Fibres Ltd., Leeds, England). All measurements were taken at the *longissimus dorsi* et *lumborum* (LD) between the 2/3 last rib and at the *seминebranosus* (SM) muscles of the right carcass side.

We could not perform meat characteristics measurements in one gilt in the first replicate in the control treatment, so altogether 191 records were available for statistical analysis.

Statistical analysis

For the data analysis of carcass and meat characteristics, GLM procedure of the statistical program SAS (SAS 2001) was used. Replicate, treatment, gender, their two-way interaction, and date of slaughter nested within replicate were included in the model as a fixed effect. In the results, we present only the outcomes for the effect of treatment and gender, and their interaction where significant at *P* ≤ .05. In addition, the values of pH₄₅, pH₂₄, and FOP₂₄ were used to assign animals to discrete classes describing the pale, soft, and exudative (PSE) as well as dark, firm, and dry (DFD) quality status of both muscles. We assumed that pH < 5.8 at 45 min post-mortem indicates muscles that will become PSE meat and pH > 6.0 at 24 hours post-mortem indicates DFD meat (Honikel 2004b). Therefore, pH > 5.8 at 45 min post-mortem and pH ≤ 6.0 at 24 hours post-mortem indicates normal meat quality. According to TBL Fibres manual (Fibre optic probe) values in the range between 25 and 50 indicate normal quality meat, while values lower than 25 indicate DFD meat and values greater than 50 indicate PSE meat. These records were analysed with the threshold (ordered probit) model using the POLR procedure from the MASS R package (Venables and Ripley 2002). Since gender had no significant effect on measured meat characteristics, only the effect of treatment on the percentage of pigs in quality classes is presented in the results.

Table 1 shows carcass and meat quality measurements in LD and SM muscles by treatment. A small amount of straw and hay had no effect on pigs’ carcass characteristics. pH₄₅ values were characteristic for normal muscle glycolysis in both muscles and did not differ (*P* > .05) among treatments. In LD muscle, the pH₂₄ value was slightly elevated in the control
treatment ($P < .05$) compared to the straw and hay treatment. In SM muscle, the pH$_{24}$ values did not differ ($P > .05$) among treatments. Straw and hay enrichment did not influence ($P > .05$) FOP$_{24}$ values in LD muscle but in SM muscle the straw treatment had a lower value ($P < .05$) compared to the hay treatment. The interaction between treatment and gender was significant only for FOP$_{24}$ values in SM muscle. There were no differences ($P > .05$) among treatments in barrows, whereas gilts in the hay treatment had higher ($P < .05$) FOP$_{24}$ values than gilts in the control and the straw treatment. Gender had a significant effect on most carcass characteristics but not on meat quality traits (Table 2).

The number and percentage of pigs that exhibited different meat quality are presented in Table 3. PSE meat characteristics were observed only in one pig based on the pH$_{45}$ in LD muscle and in two pigs based on the pH$_{45}$ in SM muscle. Based on the FOP$_{24}$, more pigs were classified to have PSE meat characteristics. However, differences in the percentage of pigs with PSE meat among treatments in LD as well as in SM were not statistically significant. The number of pigs that exhibited DFD meat was higher compared to pigs that exhibited PSE meat. The number of pigs with elevated pH$_{24}$ value in LD and SM muscle was higher in the control than in the straw or hay treatment, but only the difference in LD muscle between the control and straw treatment was statistically significant. Based on the FOP$_{24}$, no differences ($P > .05$) in the percentage of pigs with DFD meat were observed in LD among treatments. On the contrary, in the SM muscle, a lower number ($P < .05$) of pigs exhibited DFD meat in the hay than in the control or the straw treatment. Based on the pH$_{45}$ in LD muscle the highest percentage of pigs with a normal meat quality was observed in the straw treatment, while based on the FOP$_{24}$ in SM muscle the highest percentage of pigs with a normal meat quality was observed in the hay treatment.

### Discussion

Stress during pre-slaughter affects ante- and post-mortem metabolism in an animal’s body and consequently post-mortem glycolysis, which has a large effect on meat quality characteristics (Barton Gade 2004; Warriss 2010). Pigs respond to stressors such as loading, transport, unloading, and pre-slaughter handling in different ways. This stress reactivity depends on animals’ genotype and their previous experience during lifetime (Terlouw 2005). Accelerated glycolysis leads to PSE meat, whereas inadequate pH fall leads to DFD meat (Honikel 2004a). In our experiment pigs from all treatments showed the same pH$_{45}$ in LD and SM muscle. This indicates that both environmental enrichment substrates, straw and hay, had no effect on the rate of glycolysis. Similar conclusions could be drawn from the percentage of pigs classified in the PSE quality class based on the FOP$_{24}$ measurements in LD and SM muscle, where no significant differences among treatments were observed. In accordance with our results, no effect of environmental enrichment on the rate of glycolysis was reported also in scarce studies where pigs’ environment was enriched similar as in our experiment, that is only with the addition of small amount of straw (Day et al. 2002b; Peeters et al. 2006) and also in other studies where environmental enrichment was achieved through addition of varying amount

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**Table 1.** Least square means ± standard error by treatment for carcass and meat characteristics in two muscles of pigs

| Treatment | Control | Straw | Hay |
|-----------|---------|-------|-----|
| **Carcass characteristics** |         |       |     |
| Live weight at slaughter (kg) | 95.4 ± 1.2 | 95.1 ± 1.0 | 96.8 ± 1.0 |
| Carcass weight (kg) | 76.2 ± 1.0 | 76.3 ± 0.9 | 77.2 ± 0.9 |
| Muscle thickness (mm) | 63.2 ± 0.8 | 63.5 ± 0.7 | 64.5 ± 0.7 |
| Fat thickness (mm) | 17.2 ± 0.7 | 17.4 ± 0.6 | 17.3 ± 0.6 |
| **Meat characteristics** |         |       |     |
| M. longissimus dorsi et lumborum |         |       |     |
| pH$_{45}$ | 6.47 ± 0.04 | 6.42 ± 0.03 | 6.40 ± 0.03 |
| pH$_{24}$ | 5.85 ± 0.03* | 5.71 ± 0.03* | 5.74 ± 0.03b |
| FOP$_{24}$ | 34.60 ± 1.70 | 35.17 ± 1.48 | 37.56 ± 1.48 |
| **M. semimembranosus** |         |       |     |
| pH$_{45}$ | 6.48 ± 0.04 | 6.45 ± 0.03 | 6.43 ± 0.03 |
| pH$_{24}$ | 5.81 ± 0.03 | 5.75 ± 0.03 | 5.80 ± 0.03 |
| FOP$_{24}$ | 30.18 ± 1.49* | 29.26 ± 1.30* | 33.15 ± 1.30b |
| Barrows | 34.45 ± 1.94 | 30.02 ± 1.99 | 31.52 ± 1.94 |
| Gilts | 25.90 ± 2.10* | 28.50 ± 2.12* | 34.78 ± 2.08b |

*Least square means with different superscripts within a row differ according to treatment ($P < .05$).

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**Table 2.** Least square means ± standard error by gender for carcass and meat characteristics in two muscles of pigs

| Gender | Barrows | Gilts |
|--------|---------|-------|
| **Carcass characteristics** |         |       |
| Live weight at slaughter (kg) | 99.0 ± 0.9* | 92.5 ± 1.2b |
| Carcass weight (kg) | 78.8 ± 0.7* | 74.4 ± 1.0b |
| Muscle thickness (mm) | 64.0 ± 0.6 | 63.4 ± 0.8 |
| Fat thickness (mm) | 19.1 ± 0.5* | 15.5 ± 0.7b |
| **Meat characteristics** |         |       |
| M. longissimus dorsi et lumborum |         |       |
| pH$_{45}$ | 6.42 ± 0.03 | 6.44 ± 0.04 |
| pH$_{24}$ | 5.77 ± 0.02 | 5.77 ± 0.03 |
| FOP$_{24}$ | 37.99 ± 1.28 | 33.57 ± 1.68 |
| **M. semimembranosus** |         |       |
| pH$_{45}$ | 6.41 ± 0.03 | 6.51 ± 0.04 |
| pH$_{24}$ | 5.78 ± 0.02 | 5.79 ± 0.03 |
| FOP$_{24}$ | 32.00 ± 1.12 | 29.73 ± 1.47 |

*Least square means with different superscripts within a row differ between genders ($P < .05$).
of straw and additional space allowance (Geverink et al. 1999; Beattie et al. 2000; Klont et al. 2001). However, conclusions from studies where intensive and alternative housing systems were compared are not so consistent. Bee et al. (2004) and Terlouw et al. (2009), who compared indoor and outdoor fattening pigs, did not find any differences in the rate of post-mortem glycolysis. But Lambooji et al. (2004), who compared free-range and conventionally reared pigs, reported slightly lower rate of post-mortem glycolysis in longissimus lumborum muscle from free-range pigs. On the other hand, slightly faster post-mortem glycolysis was found by Barton Gade (2008a) in LD muscle but not in SM muscle from outdoor compared to conventionally reared pigs and by Lebret et al. (2011) in SM muscle but not in LD and biceps femoris muscle from alternative (bedding with outdoor area) compared to conventionally reared pigs. Authors did not give a possible explanation for the obtained results.

Contrary to the rate of the glycolysis, the addition of a small amount of hay or straw seems to affect the extent of glycolysis, though the results are not as unambiguous as for the rate of glycolysis. The pH24 value in LD muscle was significantly lower in the straw and hay treatment compared to the control and was closer to normal ultimate pH values in pigs. However, the effect of straw or hay on the extent of glycolysis was not confirmed with FOP24 values in LD muscle, as there were no significant differences between treatments. So, according to pH24 in LD muscle, a higher percentage of pigs in the control group was classified to have DFD meat and a lower percentage of pigs was classified to have normal meat quality, though only the difference between the control and the straw treatment was statistically significant. In contrast to the LD muscle, in SM muscle treatment had no significant effect on pH24 but it did influence FOP24 values. Significantly higher (P < .05) FOP24 values were found in hay compared to straw treatment. So, according to FOP24 values in SM muscle lower percentage of pigs exhibited DFD meat and a higher percentage of pigs exhibited the normal quality of meat in the hay compared to the control and the straw treatment. We have no reasonable explanation for the different response to straw in the two muscles. Our results are not in agreement with the results of Day et al. (2002b) and Peeters et al. (2006), who similarly as we enriched pig’s environment with a small quantity of straw, and found no effect of treatment on the pH24 values in LD. The results of our study are more comparable with experiments, where environmental enrichment included varying amount of straw and also additional space. Enfält et al. (1997), Bee et al. (2004) and Foury et al. (2011) reported lower ultimate pH values in muscles from pigs in enriched treatment. On the other hand Beattie et al. (2000), who also enriched pig’s environment with additional space and small amount of straw, found no effect of treatment on ultimate pH in LD muscle whereas Klont et al. (2001) found even higher ultimate pH values in LD and biceps femoris muscle in pigs from enriched environment. Variable response in the extent of glycolysis can be seen also in other studies comparing different housing systems. No differences in ultimate pH in LD muscle were found between alternative and conventional housing systems in Switzerland (Bärlocher et al. 2008) and free-range and conventionally raised pigs (Barton Gade 2008b). Barton Gade (2008a) found in outdoor reared pigs higher ultimate pH values in SM, lower in semispinalis capitis muscle and no differences in LD and biceps femoris muscle than in conventionally raised pigs. Results from our study indicate that rearing conditions could affect pig’s response to the pre-slaughter handling. Pigs from the enriched environment may be more resistant to pre-slaughter stress, which could increase the amount of glycogen at the time of slaughter and lower the ultimate pH. Resistance to pre-slaughter stress in pigs from the enriched environment and alternative housing systems was indicated also in studies where salivary cortisol concentration was recorded. Geverink et al. (1999), de Jong et al. (2000) and Klont et al. (2001) reported no significant change in salivary cortisol concentration after any stage of pre-slaughter handling and transport in pigs reared in an enriched environment (larger pens with straw bedding), as compared to home pen salivary cortisol concentration. On the other hand, salivary cortisol concentration increased significantly after transport and being in lairage in pigs reared in a barren environment. Additionally, de Jong et al. (2000) found that pigs from enriched environment tended to be less active during the pre-slaughter time (spent less time standing, walking, manipulating other pigs, fighting in the truck and in the lairage after mixing) and could consequently preserve higher glycolytic potential at the time of slaughter. Terlouw et al. (2009) too reported that pigs reared outdoor in comparison with pigs reared indoor were less aggressive during pre-slaughter mixing. This resulted in higher glycolytic potential in SM muscle, but not in LD and semispinalis capitis muscle from outdoor pigs. However, it seems that the difference in glycolytic potential between both treatments was not big enough to result in different ultimate pH values in the three muscles. This was clearly demonstrated by Foury et al. (2011) who related lower muscle activity (lower levels of plasma creatine kinase), lower stress (lower concentration of urinary catehola- mines) and less aggressive behaviour (lower number of carcass skin lesions) to higher glycolytic potential and lower ultimate pH in pigs reared outdoor compared to those reared on slatted floor. Another possible explanation for lower ultimate pH in our study might be a nutritional one. Dietary fibre can delay passage rate of digesta and nutrition absorption (Johansen et al. 1996) which can stabilize glucose and insulin levels (de Leeuw et al. 2004). This was reflected in the prolonged feeling of satiety, prolonged postprandial satiety and consequently reduced physical activity in limited-fed sows several hours after feeding (de Leeuw et al. 2004). Furthermore, dietary fibre provides additional energy in form of volatile fatty acids, which on one hand may contribute as an energy source to the preservation of glucose, glycogen reserves, and on the other hand, a part of them may represent also a substrate for glucose, glycogen and fatty acids formation. But, the relative importance of these is not known. However, the offered amount of straw or hay in our study was small as we estimated that it presents less than 1% of metabolic energy.

In our study, gender affected neither rate nor extent of post-mortem glycolysis (P > .05) in LD and SM muscles. According to our knowledge, none of the studies dealing with straw as environmental enrichment, reported the effect of gender on post-mortem glycolysis. The effect of gender was reported only in rare studies comparing alternative and conventional
housing systems, but the results are not consistent. In the line with our study are results of Lebret et al. (2011), who reported no differences between barrows and gilts in pH_{45} and pH_{24} in SM, LD and biceps femoris muscle. Similarly, Terlouw et al. (2009) found no differences between barrows and gilts in pH_{45} in SM, LD and semispinalis muscle, and pH_{24} in SM muscle, but the glycolytic potential was higher and pH_{24} was lower in LD and semispinalis muscle in gilts. Enfält et al. (1997) also reported lower ultimate pH and FOP values in semitendinosus and quadriceps femoris muscle from gilts compared to barrows. In our experiment, a significant interaction between treatment and gender revealed that addition of straw or hay had no significant effect on meat characteristics in barrows, whereas gilts in the hay treatment had significantly higher FOP_{24} values than in the straw and the control treatment. Jordan et al. (2008) reported increased total activity in gilts, but not in barrows due to environmental enrichment. Reimert et al. (2014) reported that gilts were less fearful and overall more active compared to barrows. The later was observed also by Elkmann and Hoy (2008). These features of gilts could probably enable them to better cope with pre-slaughter stress and to preserve higher glycolytic potential at the time of slaughter. As the effect of environmental enrichment with straw or hay on pig’s behaviour (total activity, biting pen bars and aggressive encounters) was the same (Jordan et al. 2008), we would expect similar FOP_{24} values in the straw and the hay treatment. We do not have any plausible explanation for the difference between both treatments.

Carcass characteristics in the current study were not influenced by the addition of small amount of straw or hay. This is important, because any negative effect of environmental enrichment on carcass quality would hamper its adoption in practice (Van de Weerd and Day 2009). Other studies that enriched pigs’ environment either with a small amount of straw (Peeters et al. 2006; Bulens et al. 2016, 2018) or with straw bedding and additional space (Geverink et al. 1999; Klont et al. 2001) reported similar results. However, Beattie et al. (2000) found significantly heavier carcass weights and greater levels of backfat thickness in pigs from environment enriched with straw in racks, pen, and additional space. On the contrary, Lebret et al. (2014) reported lighter carcass weights in pigs housed in a system with indoor straw bedding and outdoor area, and no difference in backfat thickness compared to pigs housed conventionally on slatted floors. A possible explanation for these contrasting results is differences between the systems studied. Gender in our study significantly influenced the majority of studied carcass characteristics, with barrows having heavier carcass weights and greater levels of backfat thickness. These results are expected, since it is well known that barrows grow faster than gilts (Bee et al. 2004; Elkmann and Hoy 2008) and have thicker backfat with similar muscle thickness, which results in lower lean meat content (Bee et al. 2004; Lebret et al. 2011; Maiorano et al. 2013).

Based on the presented results, we conclude, that a small amount of straw or hay as environmental enrichment has no negative effects on carcass characteristics and the rate and extent of post-mortem glycolysis. In fact, our results suggest that this environmental enrichment has a beneficial effect, because it lowered the percentage of pigs exhibiting DFD meat.

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Disclosure Statement

No potential conflict of interest was reported by the authors.

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