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PRE-MORTEM SOUND LEVEL MEASUREMENT: NON-INVASIVE TOOL FOR WELFARE AND MEAT QUALITY ASSESSMENT IN PIGS

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Abstract: The aim of this study was to investigate the effect of noise levels in the stunning box on oxidative stress biomarkers and meat quality traits in slaughter pigs. The experiment included 60 pigs, approximately six months old, with an average live weight of around 110 kg. For each animal, a comprehensive set of oxidative stress parameters was measured (glucose, AOPP, ceruloplasmin, GSH, TAC, TOS and the oxidative stress index), along with meat quality indicators (pH and temperature, sensory and instrumental colour, water-holding capacity and pork quality classes). Exposure of slaughter pigs to noise levels above 105 dB resulted in increased plasma TOS concentrations and the oxidative stress index. Furthermore, elevated noise levels adversely affected meat pH and temperature in the *musculus longissimus lumborum* 45 minutes post-mortem, cooking loss, *L**, *a** and *b** values, sensory colour score and the incidence of red, firm, non-exudative and pale, firm and non-exudative pork. In conclusion, the findings of this study indicate that monitoring noise levels in the stunning environment may represent a useful approach for assessing pig welfare and for predicting variations in pork quality.

Key words: noise level, oxidative stress, pig welfare, pork quality

Introduction

The meat industry and consumers are paying increasing attention to the production conditions of food, focusing on economic efficiency, animal welfare, and meat safety and quality (Sanchez et al., 2022; Svoboda et al., 2024). Conventional methods for evaluating well-being (behavioural observations, physiometabolic indicators and resource-based parameters) and meat quality (sensory evaluation, chemical composition, and technological traits) are often invasive, time-consuming, costly, and prone to errors, limiting their suitability for industrial application (Sanchez et al., 2022; Svoboda et al., 2024). Accordingly, there is a need for new, enhanced, non-invasive, rapid and reliable approaches that can be applied under practical industry conditions (Sanchez et al., 2022; Svoboda et al., 2024).

Previous studies have indicated that environmental noise intensity can act as a potential stressor for pigs (Grandin, 1996). Talling et al. (1996) reported increased heart rate and irregular behaviour in pigs when environmental noise level exceeded 85 dB. Furthermore, it has been shown that noise levels above 85 dB during the pre-slaughter period induce intense stress and negatively affect pig welfare and meat quality, leading to a higher incidence of pale, soft and exudative (PSE) meat (Vermeulen et al., 2015, 2016). Although noise measurement is considered a promising alternative approach for assessing welfare and indirectly predicting meat quality, previous studies (Vermeulen et al., 2015, 2016) have only investigated its effect on meat pH measured 30 minutes post mortem. To date, no studies have examined the impact of noise level on oxidative stress biomarkers in slaughter pigs.

Considering the aforementioned facts, the aim of this study was to investigate the impact of noise levels in the stunning box on oxidative stress biomarkers and meat quality traits in slaughter pigs.

Materials and Methods

Ethical approval

All procedures involving animals were conducted in accordance with institutional guidelines and were approved by the Local Ethics Committee for Animal Experimentation of the Faculty of Veterinary Medicine, University of Belgrade, Serbia (Approval No: 01-159 of 14 February 2025).

Experimental pigs and pre- and post-slaughter conditions

The experiment included 60 slaughter pigs (approximately 110 kg live weight and around six months old), all of uniform genetic background ([Yorkshire × Landrace] sows sired with Pietrain boars). Animals were divided into three

groups (Group 1 = 12 pigs, Group 2 = 18 pigs, Group 3 = 30 pigs). The pigs originated from two commercial production units (Farm A supplied Groups 1 and 2, while Group 3 came from Farm B), where they were kept under comparable housing and management conditions. All animals underwent identical pre-slaughter handling, including loading, transport, unloading and lairage. Slaughter and carcass processing took place at two commercial abattoirs, following standard industry procedures.

Measurement of noise levels in the stunning box

A sound level meter (Testo 815, Testo GmbH, Lenzkirch, Germany) was positioned near the pig stunning box to record ambient noise. The device was set to the Fast 125 ms response mode and A-weighted decibels [dB(A)], which approximates human auditory perception. The device was placed as close as possible to the group of pigs being observed (no more than 2 m), with the microphone directed toward the primary noise source. Measurements began when pigs entered the stunning box, and peak noise values were recorded every 15 minutes, with an accuracy of ± 1.0 dB. The total duration of noise monitoring depended on the daily slaughter throughput and line speed, and measurements covered the entire stunning period.

Determination of blood glucose and oxidative stress biomarkers

Blood glucose concentration at exsanguination was determined directly on the slaughter line, within one minute of bleeding, using a portable glucometer (Accu-Chek® Performa, Roche Diagnostics, Mannheim, Germany). For the evaluation of oxidative stress biomarkers, whole-blood samples were collected during bleeding into 10 mL EDTA vacutainers and immediately placed in an insulated container with ice packs, maintaining a temperature of 3±1ºC. Upon arrival at the laboratory (approximately 180 minutes post-collection), the samples were centrifuged at 3,000 rpm for 10 minutes to obtain plasma, which was aliquoted into pre-labelled tubes and stored at -80ºC until further analysis.

Plasma ceruloplasmin activity was quantified using its p-phenylenediamine (PPD) oxidase activity, following the procedure described by Hussein et al. (2019). Reduced glutathione (GSH) levels were measured according to a modified Ellman assay (Jollow et al., 1974) using 5,5'-dithio-bis-(2-nitobenzoic acid) (DTNB). Protein oxidation was assessed by determining advanced oxidation protein products (AOPP) following the method of Witko-Sarsat et al. (1996). Total antioxidant capacity (TAC) was evaluated using the ABTS-based method described by Erel (2004), while total oxidative status (TOS) was quantified according to Erel (2005), which measured the oxidation of a ferrous ion-o-dianisidine complex by plasma oxidants. The oxidative stress index (OSI) was calculated as the TOS/TAC ratio.

Determination of pork quality traits

Pork quality assessments were carried out on the left side of each carcass. Measurement of meat pH and temperature were taken in the cooling chamber at 45 minutes and 24 hours post-slaughter using a portable pH meter (Testo 205, Testo AG, Lenzkirch, Germany; accuracy ±0.01). The probe was inserted into the *musculus longissimus lumborum* (between the 3rd and 5th lumbar vertebrae) and the central portion of the *musculus semimembranosus.*

At 24 hours post-mortem, meat samples approximately 2.5 cm thick were excised from the longissimus lumborum muscle (between 3rd and 5th vertebrae of lumbar region) for the evaluation of color and water-holding capacity traits. Subjective color scoring was performed independently by three trained evaluators using the National Pork Producers Council (2000) scale (1 = pale, 6 = dark). Objective color parameters (*L**, *a**, *b**) were determined according to the CIELab system (1996) with portable colorimeter (NR110, 3NH Technology Co., Ltd, Shenzhen, China) fitted with a 4-mm aperture, 2º observer angle and D65 illumination. Nine measurements were recorded at randomly selected sites on both the medial and lateral surfaces of the longissimus lumborum muscle to obtain representative mean values (Hunt et al., 1991).

Water-holding capacity was quanitified using three established methods: drip loss, thawing loss and cooking loss, following the procedures described by Honikel (1998) and Klauke et al. (2013).

Classification of pork quality was based on ultimate pH, differences in drip loss and *L** values, applying the scheme proposed by Correa et al. (2007). According to these criteria, samples were assigned to one of the following catagories: pale, soft and exudative (PSE); moderate PSE; pale, firm and non-exudative (PFN); red, soft and exudative (RSE); red, firm and non-exudative (RFN); moderately dark, firm and dry (moderate DFD); or dark, firm and dry (DFD).

Statistical analysis

All statistical procedures were carried out using GraphPad Prism (version 9.5.1; GraphPad Software, San Diego, CA, USA). Prior to performing the statistical analyses, normality of residuals (Shapiro–Wilk test) were evaluated for all dependent variables. The data satisfied all the required assumptions for subsequent analysis. Based on the noise levels recorded in the stunning box, pigs were classified into two groups: (1) lower noise – animals exposed to noise levels ≤105 dB (n=12); and (2) higher noise – animals exposed to noise levels ≥105 dB (n=48). Differences between the two groups were analyzed using an unpaired two-tailed t-test with Welch's correction to account for unequal variances and sample sizes. Descriptive statistics (mean and standard deviation) were used to summarize the data. Fisher's exact test was applied to evaluate significant differences in the distribution of pork quality classes. Relationships between variables were

examined using Pearson's correlation coefficient (r_p). The strength of the correlation was categorized as follows: weak ($|r_p|<0.35$), moderate ($0.36\leq|r_p|<0.67$), and strong ($|r_p|\geq0.68$). Statistical significance was set at $P\leq0.05$, while P values between >0.05 and <0.10 were considered to indicate a tendency.

Results

The effects of noise levels in the stunning box on oxidative stress biomarkers in slaughter pigs are presented in Table 1. Noise levels in the stunning box significantly affected plasma TOS concentrations (P=0.050) and the oxidative stress index (P=0.050).

Table 1. The effect of noise levels in the stunning box on oxidative stress biomarkers in slaughter pigs (n=60)

Noise level	**Lower (≤105 db)**	**Higher (>105 db)**	***P*-value**	**Significance**
Number of pigs	12	48		
Glucose (mmol/L)	7.39 ± 1.66	7.50 ± 2.28	0.854	ns
AOPP (μM/L)	90.51 ± 16.79	93.12 ±11.21	0.617	ns
Ceruloplasmin (mg/dL)	32.93 ± 8.15	29.22 ± 12.26	0.219	ns
GSH (μmol/L)	0.70 ± 1.24	0.64 ± 1.37	0.868	ns
TAC (mmol/L)	0.69 ± 0.31	0.63 ± 0.39	0.614	ns
TOS (μmol/L)	93.31 ± 18.24	104.20 ± 64.95	0.049	*
Oxidative stress index	0.19 ± 0.07	0.32 ± 0.04	0.046	*

* Statistical significance $P<0.05$; *t*: tendency ($0.05<P<0.10$); ns: not statistically significant ($P>0.10$)

The effects of noise levels in the stunning box on meat quality traits of slaughter pigs are shown in Table 2. Noise levels in the stunning box significantly affected meat pH (P=0.018) and temperature (P=0.023) measured 45 minutes post-slaughter (in the *musculus longissimus lumborum*), cooking loss (P=0.002), sensory color score (P=0.050), as well as L^* (P=0.029), a^* ($P<0.001$) and b^* ($P<0.001$) values. In addition, slaughter pigs exposed to lower noise levels (≤105 dB) produced a higher percentage of RFN meat (P=0.048) and a lower frequency of PFN meat (P=0.050).

Pearson correlations between noise level in the stuning box and blood indicators in slaughter pigs are shown in Table 3. No associations (P>0.10) were found between noise level in the stunning box and blood glucose concentration, AOPP, ceruloplasmin, GSH, TAC, TOS and the oxidative stress index.

Table 2. The effects of noise levels in the stunninhg box on pork quality characteristics (n = 60)

Noise level	**Lower (≤105 db)**	**Higher (>105 db)**	***P*-value**	**Significance**
Number of pigs	12	48		
Physicochemical traits				
Musculus longissimus lumborum				
pH_{45min}	6.53 ± 0.18	6.37 ± 0.24	0.018	*
T_{45min} (°C)	35.12 ± 1.70	33.77 ± 1.36	0.023	*
pH_{24h}	5.60 ± 0.28	5.66 ± 0.23	0.464	ns
T_{24h} (°C)	6.61 ±0.55	5.17 ± 1.11	<0.001	*
Musculus semimembranosus				
pH_{45min}	6.52 ± 0.23	6.57 ± 0.21	0.548	ns
T_{45min} (°C)	34.63 ± 2.81	33.39 ± 2.32	0.176	ns
pH_{24h}	5.66 ± 0.13	5.58 ± 0.20	0.077	t
T_{24h} (°C)	6.74 ± 0.50	5.57 ± 1.10	<0.001	*
Water-holding capacity traits (%)				
Drip loss	1.54 ± 0.61	1.97 ± 1.06	0.077	t
Thawing loss	2.81 ± 1.15	2.89 ± 3.31	0.894	ns
Cooking loss	16.23 ± 3.58	20.76 ± 4.98	0.002	*
Pork color traits				
*L** value	46.76 ± 2.68	48.84 ± 2.85	0.029	*
*a** value	7.04 ± 1.70	4.16 ± 1.56	<0.001	*
*b** value	5.93 ± 0.99	7.69 ± 1.12	<0.001	*
Sensory color score	2.65 ± 0.63	2.24 ± 0.60	0.050	*
Pork quality classes				
Moderate PSE meat	0.00	8.16	>0.999	ns
RFN meat	81.82	46.94	0.048	*
PFN meat	0.00	30.61	0.050	*
Moderate DFD meat	18.18	14.29	0.664	ns

* Statistical significance $P<0.05$; t: tendency ($0.05 < P < 0.10$); ns: not statistically significant ($P>0.10$)

Table 3. Association between noise level in the stuning box and blood indicators and meat quality traits in slaughter pigs (n=60)

	Noise level (db)		
	r_p	*P*-value	Strength
Oxidative stress indicators			
Glucose (mmol/L)	0.013	0.921	-
AOPP (μM/L)	0.095	0.470	-
Ceruloplasmin (mg/dL)	-0.185	0.156	-
GSH (μmol/L)	-0.005	0.972	-
TAC (mmol/L)	-0.044	0.739	-
TOS (μmol/L)	0.153	0.188	-
Oxidative stress index	0.134	0.306	-

* Statistical significance $P<0.10$

Pearson correlations between noise level in the stuning box and meat quality traits in slaughter pigs are shown in Table 4. Weak positive correlations were found between noise level and drip loss ($P=0.050$), cooking loss ($P=0.010$),

and the *L** (*P*=0.039) values. Noise level in the stunning box showed weak to moderate negative correlation with the meat pH (*P*=0.025) (measured 45 minutes post-slaughter in the *musculus longissimus lumborum*), and *a** value (*P*=0.001). Additionally, noise level in the stunning box moderately positively corelated with meat temperature measured 45 minutes post-slaughter in the *musculus longissimus lumborum* (*P*=0.004) and *b** value (*P*=0.001). Moderate negative correlations were found between noise level and meat temperature measured 24 hours post-mortem in the *musculus longissimus lumborum* (*P*=0.001) and *musculus semimembranosus* (*P*=0.003). Furthermore, no associations (*P*>0.10) were observed between noise level in the stunning box and meat pH measured 24 hours post-mortem in the *musculus longissimus lumborum* and *musculus semimembranosus*, meat pH and temperature measured 45 minutes post-mortem in the *musculus semimembranosus*, thawing loss, and sensory colour score.

Table 4. Association between noise level in the stuning box and meat quality traits in slaughter pigs (n=60)

	Noise level (db)		
	r_p	*P*-value	Strength
Phyisicochemical traits			
Musculus longissimus lumborum			
pH_{45min}	-0.289*	0.025	weak
T_{45min} (°C)	0.371*	0.004	moderate
pH_{24h}	0.078	0.553	-
T_{24h} (°C)	-0.447*	0.001	moderate
Musculus semimembranosus			
pH_{45min}	0.057	0.666	-
T_{45min} (°C)	0.226	0.082	-
pH_{24h}	0.219	0.092	-
T_{24h} (°C)	-0.375	0.003	moderate
Water-holding capacity traits (%)			
Drip loss	0.246*	0.050	weak
Thawing loss	-0.001	0.989	-
Cooking loss	0.329*	0.010	weak
Meat color indicators			
*L** value	0.267*	0.039	weak
*a** value	-0.555	0.001	moderate
*b** value	0.551	0.001	moderate
Sensory color score	-0.236	0.070	-

* Statistical significance *P*<0.10

Discussion

In this study, pigs exposed to higher noise levels (>105 dB) in the stunning box had higher blood plasma TOS concentrations and a higher oxidative stress index (Table 1). These findings indicate that intense acoustic stimuli act as a

significant stressor just prior to slaughter that compromises animal welfare by impairing antioxidant defence and induction of oxidative stress (Abuelo et al., 2015). Acute stress immediately before slaughter activates neuroendocrine stress pathways, involving stimulation of the sympathetic–adrenal–medullary and hypothalamic–pituitary–adrenal axes and leading to pronounced physiological, biochemical, and oxidative alterations (Kanitz et al., 2005; Čobanović et al., 2024, 2025), which explaining the elevated oxidative stress indicators recorded in pigs exposed to higher noise levels. Previous studies (Geverink et al., 1998; Rabaste et al., 2007) have also shown that a noisy environment shortly before slaughter (82–108 dB), generated by machinery, pressure hoses and pig and human vocalisations, acts as a significant stressor and induces fear-related behaviours such as huddling and escape attempts in pigs.

Additionally, meat obtained from pigs exposed to the same noise levels (>105 dB) in the stunning box exhibited a higher pH and temperature in the *musculus longissimus lumborum* measured 45 minutes post-mortem, lower water-holding capacity (greater cooking loss), and paler colour (higher L^* and b^* values, lower a^* value and sensory colour score), which consequently resulted in a higher incidence of PFN meat (Table 2). Unlike classical PSE development, which is driven by rapid pH decline at high muscle temperatures following severe acute stress, the predominance of PFN meat observed in this study indicates a stress pattern that slows post-mortem metabolism, caused partial denaturation of sarcoplasmic and myofibrillar proteins, while still negatively affecting meat appearance and processing traits (Kovačević et al., 2025). Earlier studies (Talling et al., 1996; Vermeulen et al., 2015, 2016) reported that exposure of pigs to intense noise (>85 dB) activates stress defence mechanisms, increasing heart rate and muscle temperature, which accelerates early post-mortem glycolysis, resulting in lower early meat pH and a higher incidence of PSE meat (Talling et al., 1996; Vermeulen et al., 2015, 2016). The differences observed suggest that pigs in the present study, despite exposure to higher noise levels, experienced mild stress that slowed post-mortem muscle metabolism and induced partial denaturation of sarcoplasmic and myofibrillar proteins, resulting in a lower incidence of PSE and a predominance of PFN and RFN meat, a pattern distinct from classical PSE development driven by rapid pH decline under severe acute stress (Čobanović et al., 2021; Kovačević et al., 2025). The lack of association between noise level and most systemic oxidative stress biomarkers (Table 3) suggests that the stress induced in the stunning box was localized and short-term, primarily influencing muscle metabolism rather than causing a generalized oxidative imbalance. Nevertheless, the detected weak to moderate correlations between noise intensity and pork pH, temperature, drip loss, and colour parameters (Table 4) confirm that even moderate welfare impairments immediately before slaughter can translate into measurable deterioration of meat quality traits. These results support the hypothesis that mild to moderate pre-slaughter stress, such as excessive noise, may reduce the

incidence of PSE meat while increasing PFN meat frequency, which still represent economically undesirable outcomes due to poor visual quality and reduced processing suitability (Čobanović et al., 2021). Based on the results of this study, it can be argued that minimising noise exposure in stunning facilities is essential not only to safeguard animal welfare but also to optimize post-mortem muscle biochemistry and ensure consistent pork quality, reinforcing the strong welfare–quality interconnection in modern meat production systems.

Conclusion

The results of this study showed that measuring noise levels in the stunning box has potential to serve as a non-invasive tool for assessing well-being conditions and variations in pork quality. However, although a degree of association was established between noise level and certain oxidative stress biomarkers and meat quality traits the correlation coefficients were relatively low. Therefore, to more robustly validate the use of noise level as an indicator for monitoring welfare conditions and variation in meat quality, additional studies conducted under diverse pre-slaughter conditions and involving larger sample sizes are required.

Pre-mortem određivanje nivoa buke: neinvazivna metoda za ocenu dobrobiti i kvaliteta mesa svinja

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Rezime

Cilj ovog istraživanja bio je da se ispita uticaj nivoa buke u boksu za omamljivanje na pokazatelje oksidativnog stresa i kvaliteta mesa svinja. Ispitivanja su obavljena na 60 svinja, starosti oko šest meseci, prosečne telesne mase oko 110 kg. Kod svake jedinke, određivani su pokazatelji oksidativnog stresa (koncentracija glukoze, AOPP, ceruloplazmina, GSH, UAK, UOS, kao i indeks oksidativnog stresa) i kvalitet mesa (pH vrednost i temperatura, boja mesa, sposobnost vezivanja vode i klase kvaliteta mesa). Nivo buke iznad 105 dB značajno je uticao na koncentraciju UOS u krvnoj plazmi, indeks oksidativnog stresa, kao i na pH vrednost i temperaturu mesa (*musculus longissimus lumborum*) 45 minuta post-mortem, kalo kuvanja, *L**, *a** i *b** vrednosti instrumenatlno određene boje mesa, senzornu ocenu za boju mesa i na učestalost crvenog, čvrstog i nevodnjikavog i

bledog, čvrstog i nevodnjikavog mesa. Na osnovu rezultata ovog istraživanja može se zaključiti da se određivanje nivoa buke može potencijalno koristiti za ocenu dobrobiti i kvaliteta mesa svinja.

Ključne reči: dobrobit životinja, nivo buke, kvalitet mesa, oksidativni stres.

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Conflict interest
No potential conflict of interest was reported by the authors.

References

Abuelo A., Hernández J., Benedito J.L., Castillo C. 2015. The importance of the oxidative status of dairy cattle in the periparturient period: revisiting antioxidant supplementation. *Journal of Animal Physiology and Animal Nutrition,* 99, 1003-1016.

Čobanović N., Stanković S.D., Dimitrijević M., Suvajdžić B., Grković N., Vasilev D., Karabasil N. 2020. Identifying physiological stress biomarkers for prediction of pork quality variation. *Animals,* 10(4), 614.

Čobanović N., Novaković S., Tomašević I., Karabasil N. 2021. Combined effects of weather conditions, transportation time and loading density on carcass damages and meat quality of market-weight pigs. *Archives Animal Breeding,* 64(2), 425-435.

Čobanović N., Čalović S., Suvajdžić B., Grković N., Stanković S.D., Radaković M., Spariosu K., Karabasil N. 2024. Consequences of transport conditions on the welfare of slaughter pigs with different health status and RYR-1 genotype. *Animals,* 14(2), 191.

Čobanović N., Grković N., Vićić I., Radaković M., Spariosu K., Stanković S.D., Karabasil N. 2025. Relationship between skin lesion severity and physiometabolic blood profile, microbial counts and carcass and meat quality characteristics in slaughtered pigs. *Meat Science,* 229:109923.

Correa J.A., Methot S., Faucitano L. 2007. A modified Meat Juice Container (EZ-Driploss) Procedure for a more Reliable Assessment of Drip Loss and Related Quality Changes in Pork Meat. *Journal of Muscle Foods*, 18, 67-77.

Erel O. 2004. A novel automated direct measurement method for total antioxidant capacity using a new generation, more stable ABTS radical cation. *Clinical Biochemistry,* 37(4), 277-285.

Erel O. 2005. A new automated colorimetric method for measuring total oxidant status. *Clinical Biochemistry,* 38(12), 1103-1111.

Geverink N.A., Bühnemann A., van de Burgwal J.A., Lambooij E., Blokhuis H.J., Wiegant V.M. 1998. Responses of slaughter pigs to transport and lairage sounds. *Physiology and Behavior,* 63(4), 667-673.

Grandin T. 1996. Factors that impede animal movement at slaughter plants. *Journal of the American Veterinary Medical Association,* 209(4), 757-759.

Honikel K.O. 1998. Reference methods for the assessment of physical characteristics of meat. *Meat Science,* 49(4), 447-457.

Hunt M.C., Acton J.C., Benedict R.C., Calkins C.R., Comforth D.P., Jeremiah L.E., Olson D.G., Salm C.P., Savell J.W., Shivas S.D. 1991. Guidelines for meat colour evaluation. American Meat Science Association and National Live Stock and Meat Board, Chicago, Illinois, USA.

Hussein H.A., Bäumer J., Staufenbiel R. 2019. Validation of an automated assay for measurement of bovine plasma ceruloplasmin. *Acta Veterinaria Scandinavica,* 61, 34.

Jollow D.J., Mitchell J.R., Zampaglione N., Gillette J.R. 1974. Bromobenzene-Induced Liver Necrosis. Protective Role of Glutathione and Evidence for 3,4-Bromobenzene Oxide as the Hepatotoxic Metabolite. *Pharmacology,* 11(3), 151–169.

Kanitz E., Otten W., Tuchscherer M. 2005. Central and peripheral effects of repeated noise stress on hypothalamic–pituitary–adrenocortical axis in pigs. *Livestock Production Science,* 94(3), 213-224.

Klauke T.N., Piñeiro M., Schulze-Geisthövel S., Plattes S., Selhorst T., Petersen B. 2013. Coherence of animal health, welfare and carcass quality in pork production chains. *Meat Science,* 95(3), 704-711.

Kovačević S., Grković N., Suvajdžić B., Sindjić M., Dimitrijević V., Becskei Z., Čobanović N. 2025. Classification of broiler breast meat: Defining red, soft and exudative meat as a new quality class. *Poultry,* 4(4), 57.

National Pork Producers Council 2000. Pork Composition and Quality Assessment Procedures. NPPC, Des Moines, IA.

Rabaste C., Faucitano L., Saucier, L., Mormède P., Correa J.A., Giguère A., Bergeron R. 2007. The effects of handling and group size on welfare of pigs in lairage and their influence on stomach weight, carcass microbial contamination and meat quality. *Canadian Journal of Animal Science,* 87(1), 3-12.

Sanchez P.D.C., Arogancia H.B.T., Boyles K.M., Pontillo A.J.B., Ali M.M. 2022. Emerging non-destructive techniques for the quality and safety evaluation of pork and beef: Recent advances, challenges, and future perspectives. *Applied Food Research,* 2, 2, 100147.

Svoboda M., Nemeckova M., Medkova D., Sardi L., Hodkovicova N. 2024. Non-invasive methods for analysing pig welfare biomarkers. *Veterinarni Medicina,* 69(5), 137.

Talling J.C., Waran N.K., Wathes C.M., Lines J.A. 1996. Behavioural and physiological responses of pigs to sound. *Applied Animal Behaviour Science,* 48(3–4), 187-201.

Vermeulen L., Van de Perre V., Permentier L., De Bie S., Verbeke G., Geers R. 2015. Sound levels above 85 dB pre-slaughter influence pork. *Meat Science,* 100(2), 269-274.

Vermeulen L., Van de Perre V., Permentier L., De Bie S., Verbeke G., Geers R. 2016. Pre-slaughter sound levels and pre-slaughter handling from loading at the farm till slaughter influence pork quality. *Meat Science,* 116(6), 86-90.

Witko-Sarsat V., Friedlander M., Capeillère-Blandin C., Nguyen-Khoa T., Nguyen A. T., Zingraff J., Jungers P., Descamps-Latscha B. 1996. Advanced oxidation protein products as a novel marker of oxidative stress in uremia. *Kidney International,* 49(5), 1304-1313.

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