

THE INFLUENCE OF *PRE-MORTEM* CONDITIONS ON PALE, SOFT AND EXUDATIVE (PSE) AND DARK, FIRM AND DRY (DFD) PORK MEAT

ČOBANOVIĆ Nikola^{1*}, KARABASIL Nedjeljko¹, STAJKOVIĆ Silvana¹,
ILIĆ Nevena¹, SUVAJDŽIĆ Branko¹, PETROVIĆ Miloš², TEODOROVIĆ Vlado¹

¹Department of Food Hygiene and Technology of Animal Origin, Faculty of Veterinary Medicine, University of Belgrade, 11000 Belgrade, Serbia; ²Department of Animal Husbandry, Faculty of Agronomy Čačak University of Kragujevac, 32000 Čačak, Serbia

(Received 05 December 2015; Accepted 06 April 2016)

The aim of this study was to determine the effect of gender, stocking density in the transport vehicle, lairage time and season on the incidence of skin lesions on pig carcasses and PSE and DFD meat. Skin lesions on carcasses (480, in total) were assessed according to the Welfare Quality® protocol (2009). The pH and temperature measurements were performed 45 minutes after slaughter. The group of carcasses with skin lesions score 2 had significantly higher incidence of PSE and DFD meat compared to the groups of carcasses with skin lesions score 0 and 1. With regard to gender, there were no differences in meat quality parameters, as well as for the incidence of skin lesions and PSE and DFD meat. The results showed that a space allowance lower than 0.3 m²/100 kg and higher than 0.5 m²/100 kg pig had a detrimental effect to animal welfare and meat quality. Lairage time affected meat quality parameters, incidence of skin lesions score and PSE and DFD meat, where after long lairaging (> 17 h) mean pH₄₅ and t₄₅ values became significantly higher, as well as the incidence of skin lesions and DFD meat. After short lairaging (< 1 h) mean pH₄₅ value became significantly lower, while mean t₄₅ value and the incidence of PSE meat became significantly higher. A significantly higher number of skin lesions on the carcass were observed in winter compared to all other seasons. High temperatures during summer and low temperatures during winter had a negative influence on meat quality parameters and incidence of PSE and DFD meat.

Key words: pigs, *pre-mortem* conditions, skin lesions, PSE meat, DFD meat

INTRODUCTION

Skin lesions on pig carcasses represent a severe welfare problem and have a negative impact on pork quality and carcass grading. It has been reported that skin lesions can be a very useful predictor of pork quality [1]. Nielsen et al. [2] found that the primary influence of skin lesions is on meat quality rather than animal welfare. Skin lesions

*Corresponding author: e-mail: cobanovic.nikola@vet.bg.ac.rs

can cause severe economic losses to the meat industry [1]. Furthermore, skin lesions reflect the quality of the animal's physical and social environment. Consequently, the number of skin lesions on the carcasses could provide a valuable database, regarding the management of the animals in the farm of origin, transport or in the lairage pens [3]. Guàrdia *et al.* [1] reported the association between carcass skin lesions and the risk of obtaining PSE and DFD meat.

Pale, soft and exudative (PSE) and dark, firm and dry (DFD) meat are the two main defects with regard to meat quality in pigs [4]. The first occurs after exposing animals to acute stress just prior to slaughter, when the pigs still have sufficient reserves of muscle glycogen to cause a rapid increase in lactic acid content early post-mortem. This brings the muscle pH to values below 6.0 prior to the first hour after slaughter [5]. On the other hand, high pH values appear when animals suffer chronic stress and the muscle glycogen is used up rapidly during the pre-slaughter period and after slaughter, there is little lactic acid production which results in DFD meat [6].

Several practices, prior to slaughter, are associated with the occurrence of skin lesions on pig carcass, PSE and DFD meat, such as, facility design, handling during loading or unloading of pigs on or from the transport vehicle, fighting between pigs after mixing unfamiliar animals, the floor type in the transport vehicle, the stocking density and time of transportation and lairaging, the duration of total fasting time before slaughter and season [5,7,8,4,9]. Guàrdia *et al.* [10] found that high stocking density during transport represents a risk for occurring of PSE pork meat. As opposed to this, lowering the stocking density from 0.37 to 0.50 m² per 100 kg pig during transport increases the incidence of DFD pork and skin lesions [5]. Based on the previously published scientific literature [11,12], lairaging shorter than one hour poses a risk for developing of PSE pork, conversely lairaging longer than three hours increases the incidence of DFD pork and skin lesions on the carcasses. Season, i.e. environmental temperatures may have a negative influence on welfare of pigs and pork quality, where heat stress results in a higher incidence of PSE pork, while cold stress leading to higher incidence of DFD pork and skin damages [13].

The aim of this study was to determine the effect of gender, stocking density in the transport vehicle, lairage time and season on the incidence of skin lesions on pig carcasses and PSE and DFD meat.

MATERIALS AND METHODS

The study was carried out during autumn of 2014 (October and November), winter (February and March), spring (April and May) and summer (July and September) of 2015 on 30 fatteners per sampling day (480 in total, 295 barrows and 185 gilts, crossbreeds Yorkshire x Landrace, with average live weight of approximately 120 kg and 6 months old). All pigs were fattened on the same farm of origin under identical conditions. After loading, the pigs were transported for about 1-2 hours to the

slaughter facility, at a mean speed of 60 km/h. The same transport vehicle and the same driver, but different stocking densities (ranged from 0.27 to 0.53 m²/100 kg pig) were used. Depending on the dynamics of slaughter, after unloading, pigs (n=300) were held in a lairage less than one hour - short lairaging (on average 44.60±8.24 minutes) or more than 17 hours (n=180) - long lairaging (20.00±2.37 hours), when stayed overnight and slaughtered in the morning. During lairaging stocking density in the lairage pen was 0.65 m² per pig. The ambient temperature during transport and lairaging varied: in autumn from 2 to 11 °C (on average 6.14±2.91°C), in winter from 1 to 3 °C (on average 2±1 °C), in spring from 16 to 20 °C (on average 16.67±3.06 °C) and in summer from 25 to 33 °C (on average 29.22±4.04 °C). The pigs were slaughtered at the same slaughterhouse with a throughput of 13,000 pigs a year and a slaughter rate of approximately 35 pigs per day. Head-only electrical stunning was used with a pair of stunning tongs. In the first 15 seconds after stunning, the animals were shackled by one hind leg and exsanguinated. Following bleeding, the carcasses were processed using conventional industry practice.

Skin lesions score

Skin lesions on the left side of the pig's carcasses were visually assessed 45 minutes postmortem according to the Welfare Quality® protocol [14]. The carcass was divided into five sections: 1) ears; 2) front (from the head to the back of the shoulder); 3) middle (from the back of the shoulder to the hind-quarters); 4) hindquarters and 5) legs (from the accessory digit upwards). Each part of the carcass was scored using a three-point scale: 0) no visible skin damage, only one lesion greater than 2 cm or lesions smaller than 1 cm; 1) between two and 10 lesions greater than 2 cm and 2) any wound penetrated into muscle tissue, or more than 10 lesions greater than 2 cm. The scoring of the five parts of the carcass was combined in one scoring as follows: 0) all body parts with a score of zero; 1) at least one body part with a score of one; and 2) at least one body part with a score of two.

Meat quality

The pH (pH₄₅) and temperature (t₄₅) measurements were performed 45 minutes after slaughter on carcasses using the pH-meter "Testo 205" (Testo AG, Lenzkirch, Germany). Both measurements were done on the Longissimus dorsi muscle, pars lumbalis (central area of the loin). The arithmetic mean of the two consecutive pH/temperature values measured at the same point was taken as the final result. The carcasses showing pH₄₅ values lower than 6.0 were classified as PSE meat, whilst the carcasses showing pH₄₅ values higher than 6.4 were classified as DFD meat [4]. The carcasses with pH₄₅ between 6.0 and 6.4 were classified as normal pork quality.

Statistical analysis

Statistical analysis of the results was conducted using software GraphPad Prism version 6.00 for Windows (GraphPad Software, San Diego California USA, www.

graphpad.com). Pig carcasses were classified in two groups according to the intensity of carcass skin lesions to determine the effect of skin lesions, gender, stocking density in the transport vehicle, lairage time and season on meat quality parameters (pH_{45} and t_{45}) and the incidence of PSE and DFD meat: **low skin lesions score group** - group of carcasses with the score 0 and 1 and **high skin lesions score group** - group of carcasses with the score 2. The pH and temperature values of two groups of carcasses were presented by descriptive statistical parameters (mean value and standard error). Student t-test was used to examine the differences in the pH and temperature values between the two groups. Two-way ANOVA with Tukey's multiple comparison test was performed to test the effect of gender (gilts and barrows), stocking density (high - $< 0.3 \text{ m}^2/100 \text{ kg pig}$, medium - $0.3 - 0.5 \text{ m}^2/100 \text{ kg pig}$ and low - $> 0.5 \text{ m}^2/100 \text{ kg pig}$), lairage time (long $> 17 \text{ h}$ and short $< 1 \text{ h}$) and season (autumn, winter, spring and summer) in relation to the skin lesions score and their interaction on meat quality parameters. According to gender (gilts and barrows) and intensity of carcass skin lesions (high and low skin lesions score) pigs were distributed in 2×2 factorial design. Pigs were assigned to one of the six treatments arranged in a 3×2 factorial design according to stocking densities (high, medium and low) and intensity of carcass skin lesions (high and low skin lesions score). Furthermore, according to lairage time (long and short) and intensity of carcass skin lesions (high and low skin lesions score) pigs were distributed in a 2×2 factorial design. In addition, pigs were assigned to one of the eight groups arranged in a 4×2 factorial design according to season (autumn, winter, spring and summer) and intensity of carcass skin lesions (high and low skin lesions score). The differences among genders, stocking densities, lairage times and seasons in relation to the skin lesions score were determined by Chi-square test. The same test was used to detect the differences among genders, stocking densities, lairage times and seasons in incidence of meat quality classes in relation to the skin lesions score. In all cases, significance was fixed at level $P < 0.05$.

RESULTS

From a total of 480 examined pig carcasses, 31.66% ($n=152$) were found with a skin lesion score 2, 28.96% ($n=139$) with score 1, while 39.38% ($n=189$) were found with skin lesion score 0 (Table 1) (Figure 1).

Classification of examined pig carcasses based on gender, stocking density in the transport vehicle, lairage time and season in relation to the skin lesions score is given in Table 1. No significant difference was found between the barrows and gilts for the percentage of carcasses with skin lesions score 1 and 2 ($P > 0.05$). The group of pigs transported in low stocking density had significantly higher incidence of skin lesions compared to the groups of pigs transported at medium and high stocking density ($P < 0.05$). Skin lesions score was significantly higher in the group of pigs after long lairaging ($P < 0.05$) compared to the group of pigs after short lairaging. The highest skin lesions score was found in the group of pigs slaughtered during winter ($P < 0.05$),

while the lowest skin lesions score was observed in the group of pigs slaughtered during spring ($P<0.05$).

Table 1. Classification of examined pig carcasses based on gender, stocking density in the transport vehicle, lairage time and season in relation to the skin lesions score

Parameter	Skin lesions score (%)			
	0	1	2	
Total (n=480)	39.38	28.96	31.66	
Gender	Barrows (n=295)	33.9 ^a	31.18	34.92
	Gilts (n=185)	48.11 ^a	25.41	26.48
Stocking density	High (n=210)	38.57 ^b	29.52	31.91 ^{bc}
	Medium (n=120)	54.17 ^{bc}	28.33	17.50 ^{bd}
	Low (n=150)	28.67 ^c	28.67	42.66 ^{cd}
Lairage time	Long (n=180)	27.78 ^e	32.22	40.00 ^e
	Short (n=300)	46.33 ^e	27.00	26.67 ^e
Season	Autumn (n=210)	42.85 ^{fg}	26.67	30.48 ^{fg}
	Winter (n=90)	18.89 ^h	30.00	51.11 ^{hi}
	Spring (n=90)	58.89 ^{ghi}	27.78	13.33 ^{ghj}
	Summer (n=90)	32.22 ⁱ	34.44	33.34 ^{ij}

Stocking density: High - $< 0.3 \text{ m}^2/100 \text{ kg pig}$; Medium - $0.3\text{--}0.5 \text{ m}^2/100 \text{ kg pig}$; Low - $> 0.5 \text{ m}^2/100 \text{ kg pig}$. **Lairage time:** Long $> 17 \text{ h}$; Short $< 1 \text{ h}$. ^{a,b,c,d,e,f,g,h,i,j} - within a column the same letters indicate a significant difference between groups at $P < 0.05$.

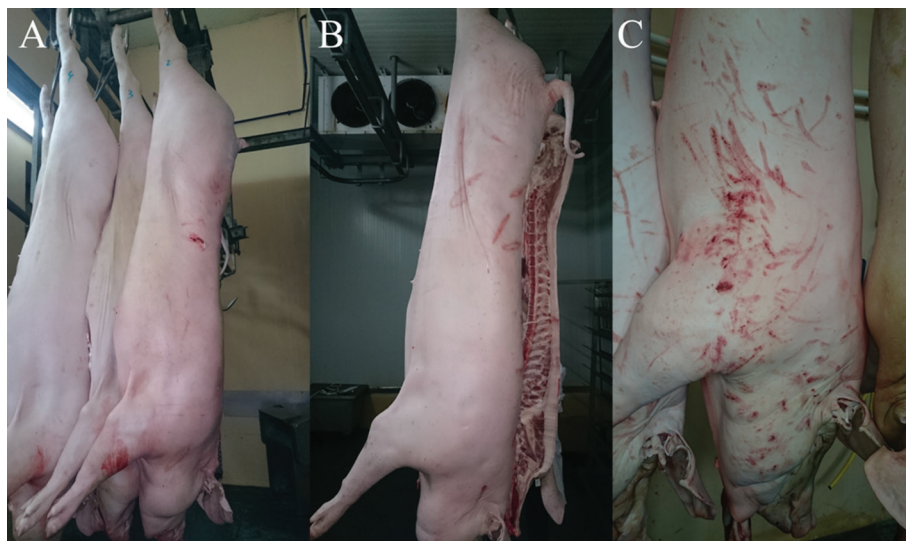


Figure 1. Skin lesions on pig carcasses (Legend: **A** – skin lesions score 0; **B** – skin lesions score 1; **C** – skin lesions score 2)

The incidences of PSE and DFD meat in relation to the carcass skin lesions are shown in Figure 2. Pig carcasses with skin lesions score 2 had a significantly higher percentage of PSE and DFD meat compared to pig carcasses with skin lesions score 1 and 0 ($P < 0.05$). The mean values of pH_{45} and t_{45} between the two groups of carcasses divided according to intensity of skin lesions are given in Table 2. The group of the carcasses with high skin lesions score had significantly higher mean t_{45} value compared to the group of the carcasses with low skin lesions score ($P < 0.05$). In contrast, no significant difference was found among two groups for the mean pH_{45} value ($P > 0.05$).

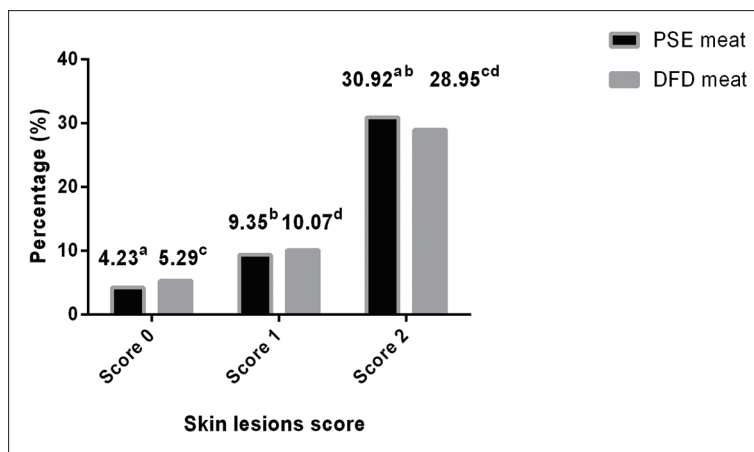


Figure 2. The incidences of PSE and DFD meat in relation to the carcass skin lesions

Table 2. Differences in pH and temperature values between groups of carcasses with low and high skin lesions score (n=480)

Meat quality parameters	Low skin lesions score (n=328)	High skin lesions score (n=152)
pH_{45}	6.17±0.01	6.21±0.02
t_{45} (°C)	39.26±0.05 ^a	40.22±0.09 ^a

Low skin lesions score – skin lesions score 0 and 1, **High skin lesions score** – skin lesions score 2; ^a – within a row the same letters indicate a significant difference between groups at $P < 0.05$.

The effect of skin lesions score and gender and their interaction on meat quality parameters and the incidence of meat quality classes are presented in Table 3. The pH_{45} values, t_{45} values and the incidence of PSE and DFD meat were significantly influenced by the skin lesions score ($P < 0.05$). Gender had no significant influence on meat quality parameters ($P > 0.05$). No significant interaction effect between skin lesions score and gender was found for meat quality parameters ($P > 0.05$).

In Table 4 are represented the effects of skin lesions score and stocking density and their interaction on meat quality parameters and the incidence of meat quality classes. Skin lesions had no significant influence on the pH_{45} value, whilst significant influence

of skin lesions was found on the t_{45} value. The pH_{45} and t_{45} values were significantly influenced by stocking density ($P<0.05$). A significant interaction effect between skin lesions score and stocking density was found for meat quality parameters, as well as for the incidence of PSE and DFD meat ($P<0.05$).

Table 3. The effect of skin lesions score and gender on meat quality parameters and the incidence of meat quality classes (n=480)

Parameter	Low skin lesions score Gender		High skin lesions score Gender		SLC	G	SLC x G
	Barrows (n=192)	Gilts (n=136)	Barrows (n=103)	Gilts (n=49)			
pH_{45}	6.18±0.01	6.17±0.01	6.20±0.03	6.23±0.04	*	ns	ns
t_{45} (°C)	39.31±0.07 ^{ab}	39.23±0.07 ^{cd}	40.23±0.12 ^{ac}	40.19±0.15 ^{bd}	*	ns	ns
PSE (%)	5.73 ^{ab}	7.35 ^{cd}	31.07 ^{ac}	28.58 ^{bd}			
Normal (%)	86.98 ^{ab}	85.30 ^{cd}	43.69 ^{ac}	34.69 ^{bd}			
DFD (%)	7.29 ^{ab}	7.35 ^{cd}	25.24 ^{ac}	36.73 ^{bd}			

Low skin lesions score – skin lesions score 0 and 1, **High skin lesions score** – skin lesions score 2; **SLC** – skin lesions score factor, **G** – gender factor, **SLC x G** – interaction between skin lesions score and gender factor; * - $P<0.05$; ns – no significance ($P>0.05$); ^{a,b,c,d} - within a row the same letters indicate a significant difference between groups at $P<0.05$.

Table 4. The effect of skin lesions score and stocking density in the transport vehicle on meat quality parameters and incidence of meat quality classes (n=480)

Parameter	Low skin lesions score Stocking density			High skin lesions score Stocking density			SLC	SD	SLC x SD
	High (n=143)	Medium (n=99)	Low (n=86)	High (n=67)	Medium (n=21)	Low (n=64)			
pH_{45}	6.16 ± 0.01 ^{ab}	6.17 ± 0.01 ^{cd}	6.19 ± 0.02 ^{ef}	6.02 ± 0.03 ^{ac}	6.19 ± 0.03 ^{gi}	6.41 ± 0.02 ^{bd}	ns	*	*
t_{45} (°C)	39.35 ± 0.08 ^{ab}	39.24 ± 0.09 ^{cd}	39.13 ± 0.08 ^{ef}	40.41 ± 0.12 ^{ac}	39.32 ± 0.36 ^{gi}	40.31 ± 0.12 ^{bd}	*	*	*
PSE (%)	6.99 ^a	3.03 ^{bc}	9.30 ^d	55.23 ^{ab}	4.76 ^e	12.50 ^{cf}			
Normal (%)	86.72 ^{ab}	90.91 ^{cd}	80.23 ^{ef}	37.31 ^{ac}	90.48 ^{gh}	28.12 ^{bd}			
DFD (%)	6.29 ^a	6.06 ^b	10.47 ^c	7.46 ^d	4.76 ^e	59.38 ^{abcde}			

Low skin lesions score – skin lesions score 0 and 1, **High skin lesions score** – skin lesions score 2; **Stocking density: High** – $< 0.3\text{m}^2/100\text{ kg pig}$; **Medium** – $0.3 - 0.5\text{ m}^2/100\text{ kg pig}$; **Low** – $> 0.5\text{ m}^2/100\text{ kg pig}$; **SLC** – skin lesions score factor, **SD** – stocking density factor, **SLC x SD** – interaction between skin lesions score and stocking density factor; * - $P<0.05$; ns – no significance ($P>0.05$); ^{a,b,c,d,e,f,g,h,i} - within a row the same letters indicate a significant difference between groups at $P<0.05$.

The effect of skin lesions score and lairage time and their interaction on meat quality parameters and the incidence of meat quality classes are shown in Table 5. The pH_{45}

and t_{45} values were significantly influenced by the skin lesions score ($P<0.05$). Lairage time had a significant influence on pH_{45} value, while no significant influence of this factor was found on t_{45} value. A significant interaction effect between skin lesions score and lairage time was found for meat quality parameters and incidence of PSE and DFD meat ($P<0.05$).

Table 5. The effect of skin lesions score and lairage time on meat quality parameters and incidence of meat quality classes (n=480)

Parameter	Low skin lesions score Lairage time		High skin lesions score Lairage time		SLC	LT	SLC x LT
	Long (n=108)	Short (n=220)	Long (n=72)	Short (n=80)			
pH_{45}	6.17±0.02 ^{ab}	6.18±0.01 ^{cd}	6.42±0.02 ^{ace}	6.02±0.02 ^{bde}	*	*	*
t_{45} (°C)	39.19±0.08 ^{ab}	39.30±0.06 ^{cd}	40.38±0.12 ^{ac}	40.07±0.14 ^{bd}	*	ns	*
PSE (%)	12.04 ^{ab}	3.64 ^{acd}	11.11 ^{ce}	47.5 ^{bde}			
Normal (%)	79.63 ^{abc}	89.55 ^{ade}	30.56 ^{bdf}	50.00 ^{cef}			
DFD (%)	8.33 ^a	6.81 ^b	58.33 ^{abc}	2.50 ^c			

Low skin lesions score – skin lesions score 0 and 1, **High skin lesions score** – skin lesions score 2; **Lairage time: Long** > 17 h; **Short** < 1 h. **SLC** – skin lesions score factor, **LT** – lairage time factor, **SLC x LT** – interaction between skin lesions score and lairage time factor; * - $P<0.05$; ns – no significance ($P>0.05$); ^{a,b,c,d,e,f} - within a row the same letters indicate a significant difference between groups at $P<0.05$.

Table 6. The effect of skin lesions score and season on meat quality parameters and incidence of meat quality classes (n = 480)

Parameter	Low skin lesions score Season				High skin lesions score Season				SLC	S	SLC x S	
	A	W	Sp	Su	A	W	Sp	Su				P-value
	(n=146)	(n=44)	(n=78)	(n=60)	(n=64)	(n=46)	(n=12)	(n=30)				
pH_{45}	6.16 ± 0.01 ^{ab}	6.23 ± 0.03 ^{cd}	6.19 ± 0.02 ^{ef}	6.17 ± 0.02 ^{gh}	6.21 ± 0.03 ^{ij}	6.41 ± 0.03 ^{acegikl}	6.20 ± 0.03 ^{km}	5.90 ± 0.03 ^{bdfhjlm}	ns	*	*	
t_{45} (°C)	39.17 ± 0.07 ^{abc}	39.21 ± 0.10 ^{dek}	39.24 ± 0.10 ^{fgh}	39.55 ± 0.15 ^{ij}	40.06 ± 0.17 ^{afk}	40.38 ± 0.15 ^{bdgi}	39.50 ± 0.32 ^l	40.60 ± 0.12 ^{cehjl}	*	*	ns	
PSE (%)	8.90 ^{abc}	4.55 ^{de}	1.28 ^{afgh}	8.33 ^{ij}	21.88 ^{bdfik}	13.04 ^{dl}	0.00 ^m	86.67 ^{cehijkm}				
Normal (%)	87.68 ^{abc}	79.55 ^{def}	91.03 ^{ghi}	81.67 ^{jkl}	53.12 ^{adgjmn}	28.26 ^{behkmp}	100.00 ^{nq}	10.00 ^{efiloq}				
DFD (%)	3.42 ^{abc}	15.90 ^{ad}	7.69 ^{ef}	10.00 ^{gh}	25.00 ^{begij}	58.70 ^{cdfhikl}	0.00 ^k	3.33 ^{jl}				

Low skin lesions score – skin lesions score 0 and 1, **High skin lesions score** – skin lesions score 2; **Season: A** – Autumn, **W** – Winter, **Sp** – Spring; **Su** – Summer. **SLC** – skin lesions score factor, **S** – season factor, **SLC x S** – interaction between skin lesions score and season factor; * - $P<0.05$; ns – no significance ($P>0.05$); ^{a,b,c,d,e,f,g,h,i,j,k,l,m,n,o,p,q} - within a row the same letters indicate a significant difference between groups at $P< 0.05$.

The effect of skin lesions score and season and their interaction on meat quality parameters and the incidence of meat quality classes are given in Table 6. The pH_{45} value was not significantly influenced by the skin lesions score ($P>0.05$). Contrarily, skin lesions score had a significant influence on the t_{45} value ($P<0.05$). Season had a significant influence on pH_{45} and t_{45} values. A significant interaction effect between skin lesions score and season was found for the pH_{45} value and the incidence of PSE and DFD meat ($P<0.05$), but not for the t_{45} value ($P>0.05$).

DISCUSSION

The percentage of pig carcasses with different skin lesions score (score 0 – 39.38%, score 1 – 28.96%, score 2 - 31.66%), found in this study, is comparable to Dalmau et al. [3] results, who examined skin lesions according to the Welfare Quality® protocol [14] in 10 Spanish pig slaughterhouses based on a four point scale. Their study showed that the percentage of pig carcasses with different skin lesions scores varied from 58.3% to 85% for score 1, from 5% to 30% for score 2 and from 1.7% to 10% for score 3. Guàrdia et al. [1] assessed skin lesions on pig carcasses based on a five point scale. They reported that 72.4% of examined pig carcasses were scored as seriously damaged, 16.6% as slightly damaged and only 11% carcasses were found to be without any evidence of damage.

In this study, pig carcasses with skin lesions score 2 had significantly higher percentage of PSE (30.92%) and DFD (28.95%) meat compared to pig carcasses with skin lesions score 1 (PSE - 9.35%, DFD -10.07%) and 0 (PSE - 4.23%, DFD – 5.29%) ($P<0.05$) (Figure 2). This indicates that the carcasses with higher skin lesions score are more prone to PSE and DFD meat. It has been found that the risk of obtaining PSE meat is doubled in carcasses with skin lesions as compared to carcasses without skin lesions (43.7% vs. 28.8%) [1]. The presence of skin lesions on the carcass was also associated with an almost four times higher risk of DFD pork (11.70% vs. 3.30%) [1]. Data showed that carcasses being scored as very slight or without skin lesions (score 0) and slightly damaged (score 1) belong to the same group, because no difference was found among these two classes for the risk of PSE and DFD meat [1]. This was also confirmed in the present study, where no significant difference was detected among carcasses with skin lesions score 1 and 0 (PSE - 9.35% vs. 4.23%, DFD -10.07% vs. 5.29%) ($P>0.05$) (Figure 2).

The group of the carcasses with high skin lesions score had significantly higher mean t_{45} value compared to the group of carcasses with low skin lesions score ($P<0.05$) (Table 2). Contrary to the above-mentioned findings of meat quality classes according to the skin lesions score, the group of pig carcasses with low skin lesions score had lower mean pH_{45} compared to the group of pig carcasses with high skin lesions score, but not significantly ($P>0.05$) (Table 2). Pre-slaughter procedures, imposed during transportation and lairaging at the slaughterhouse, are the most important factors influencing the pH of the carcass [15,16]. Therefore, if the severity of skin damages

arises from aggressive activity at an early time, higher pH values and consequently increased incidence of DFD might be expected with increasing severity of skin lesions [1]. On the other hand, if fighting occurs just prior to slaughter, then skin lesions cause the rapid decrease of the pH value, which results to an increased occurrence of PSE meat [1].

In the present trial, similarly to the findings of D'Eath *et al.* [17], significant differences were not found between barrows and gilts for the percentage of carcasses with high score of skin lesions (34.92 vs. 26.48%, $P > 0.05$) (Table 1). In addition, significant differences were not found between barrows and gilts for meat quality parameters ($P > 0.05$), as well as for the incidence of PSE and DFD meat ($P > 0.05$) (Table 3). The same was observed by Alonso *et al.* [18], who did not find any differences among barrows and gilts for meat quality parameters. This can be explained by the fact that boars are more aggressive than castrated male pigs or gilts and this behavior in entire males causes a high level of fights among them, which lead to higher skin lesions score [4]. As well as skin damage, the carcasses from boars also tended to show a higher incidence of PSE and DFD meats, due to stress and physical activity associated with fighting [4].

As observed in this study, the group of pigs transported at low stocking density (42.66%) had a significantly higher incidence of skin lesions compared to the groups of pigs transported at medium and high stocking density (17.50% and 31.91%, respectively) ($P < 0.05$) (Table 1). In addition, the interactive effects of excessive space allowance during transportation ($> 0.5 \text{ m}^2/100 \text{ kg}$) and higher skin lesions score significantly increased mean pH_{45} ($P < 0.05$), mean t_{45} ($P < 0.05$) and the incidence of DFD meat ($P < 0.05$) (Table 4). The negative impact of excessive space allowance during transportation to slaughterhouse could be explained by the fact that pigs can be thrown around and get struck and bruised as a result of unexpected movements of the transport vehicle [19]. Likewise, if pigs can move around, they may be involved in fights and this can cause muscular fatigue and glycogen breakdown which contributes to the increased incidence of DFD meat [5]. Contrarily, the interactive effects of low space allowance during transportation ($< 0.3 \text{ m}^2/100 \text{ kg pig}$) and higher skin lesions score significantly decreased mean pH_{45} ($P < 0.05$) and significantly increased mean t_{45} ($P < 0.05$), as well as the incidence of PSE meat ($P < 0.05$) (Table 4). The pigs transported in high stocking density have reduced space allowance which leads them to fight with each other for resting place, resulting in a higher incidence of skin lesions, and, therefore, produce lower meat quality [1]. The results obtained in our study, showed the negative effect of insufficient ($< 0.3 \text{ m}^2/100 \text{ kg pig}$) and excessive ($> 0.5 \text{ m}^2/100 \text{ kg}$) space allowance on the pH_{45} and t_{45} values, and, consequently, on meat quality. When the space availability was between $0.3 \text{ m}^2/100 \text{ kg pig}$ and $0.5 \text{ m}^2/100 \text{ kg}$, the results indicated significantly lower risks of production of PSE and DFD meat. This suggests that the pigs transported in the high and low stocking density were under greater stress and, therefore, produce inferior meat quality. The EC Directive on the protection of animals during transportation emphasizes that each pig must at least be

able to stand or lie down in its natural position [10]. This could be achieved with a space allowance of around 235 kg/m² or 0.425 m² per 100 kg pig (as recommended by the EC Directive 95/29/EC and the Council Regulation (EC) No.1/ 2005 on the protection of animals during transport), as a suitable compromise among transport economy, meat quality and animal welfare [10,5].

The data observed in this study showed that incidence of skin lesions increases with longer lairage time, with the risk of skin blemish occurrence being almost twofold higher at 17 h compared to 1 h lairaging (40.00% vs. 26.67%) (Table 1), which is in line with previous studies [20,11,12,1]. Furthermore, we observed that the interactive effects of increased lairage time (>17 h) and higher skin lesions score significantly increased mean pH₄₅ ($P<0.05$), mean t_{45} ($P<0.05$) and the incidence of DFD meat ($P<0.05$) (Table 5). A long lairaging improves the colour of the pork, reduces the incidence of PSE meat and allows the pigs to rest, but at the same time stimulates aggression and fighting between animals and as a consequence, increases skin lesions and the risk of DFD pork [11,12,21]. It was also found that the interactive effects of decreased lairage time (<1 h) and higher skin lesions score significantly decreased mean pH₄₅ ($P<0.05$), significantly increased mean t_{45} ($P<0.05$) and the incidence of PSE meat ($P<0.05$) (Table 5). The main cause for the occurrence of PSE meat is acute stress just before slaughter [22]. It is generally accepted that the most stressful moments, prior to slaughter, are transport and lairaging [23]. It has been found that a short transportation and slaughter of pigs after a short stay in lairage (15-60 minutes), does not allow pigs to recover from loading stress and to acclimate to transport stress [24]. Slaughter of pigs, immediately after unloading or after a short stay in lairage (15-60 minutes), is not recommended, because animals are exhausted and agitated. This results in an increase in muscle temperature (+1°C) and lactic acid just prior to slaughter, which contributes to the increased incidence of PSE meat [25,12,26]. The main purpose of lairage is to allow pigs to recover from the stress caused by transportation and unloading to the slaughterhouse, and it is expected to improve the meat quality [1]. From an animal welfare and meat quality perspective, it is considered that the optimal lairage time is 2–4 h [20,24].

The risk of incidence of skin lesions, according to the season, was almost twofold higher in the winter (51.11%) than in autumn and summer (30.48% and 33.34%, respectively) ($P<0.05$), i.e. fourfold higher than in spring (13.33%) ($P<0.05$) (Table 1). This is in concordance with Gosálvez et al. [27] results, who found higher skin lesions score in the winter, which led them to conclusion that low temperatures, acting as a grouping stimulator, increase fighting behavior. According to the results obtained in the present study, the interactive effects of low temperatures during winter and higher skin lesions score significantly increased mean pH₄₅ ($P<0.05$) and the incidence of DFD meat ($P<0.05$) (Table 6). Over colder months, pigs tend to huddle in order to reduce the heat loss and to create a microclimate that increases the surrounding temperature at the expense of energetic reserves in the muscle, which contributes to the increased incidence of DFD meat [5]. About 80% of the transports during winter,

were carried out at temperatures lower than 15 °C, which is not inside the neutral thermal range for pigs (15–25 °C) [13]. Opposite to this, the interactive effects of high temperatures during summer and higher skin lesions score significantly decreased mean pH_{45} ($P < 0.05$) and significantly increased the incidence of PSE meat ($P < 0.05$) (Table 6). Guàrdia *et al.* [10] found almost twofold higher risk of the PSE condition in summer than in winter (6.5% vs. 3.4%). Their study confirmed that pigs are very sensitive to high temperatures, because they have ineffective sweat glands that affect an animal's ability to dissipate body heat after being exposed to hot weather conditions [10].

CONCLUSION

The group of carcasses with skin lesions score 2 had a significantly higher incidence of PSE and DFD meat compared to the groups of carcasses with skin lesions score 0 and 1. With regard to gender, there were no differences in meat quality parameters, as well as for the incidence of skin lesions and PSE and DFD meat. The results showed that a space allowance lower than 0.3 m²/100 kg pig and higher than 0.5 m²/100 kg had detrimental effect to animal welfare (significantly higher skin lesions score) and meat quality (significantly lower pH_{45} value and significantly higher incidence of PSE meat for stocking density < 0.3 m²/100 kg pig, while significantly higher pH_{45} value and incidence of DFD meat for stocking density > 0.5 m²/100 kg). Lairage time affected meat quality parameters and the incidence of skin lesions score and PSE and DFD meat, where after long lairaging (> 17 h) mean pH_{45} and t_{45} values became significantly higher, as well as the incidence of skin lesions and DFD meat. On the other hand, after short lairaging (< 1 h) mean pH_{45} value became significantly lower, while mean t_{45} value and the incidence of PSE meat became significantly higher. A significantly higher number of skin lesions on the carcass were observed in winter compared to the all other seasons. In addition, high and low temperatures had a negative influence on meat quality parameters and the incidence of PSE and DFD meat.

Acknowledgements

This paper was supported by Ministry of Education, Science and Technological development, Republic of Serbia, Project “Selected biological hazards to the safety/quality of food of animal origin and the control measures from farm to consumer” (No. 31034).

Authors' contributions

NK defined the research theme and gave the conception of the research. NK, NČ, NI, BS and MP carried out experimental part of the study. NK, NČ and SS have made substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data. NK and VT have been involved in drafting the manuscript

or revising it critically for important intellectual content. All authors have read and approved the final manuscript.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

REFERENCES

1. Guàrdia MD, Estany J, Balasch S, Oliver MA, Gispert M, Diestre A: Risk assessment of skin damage due to pre-slaughter conditions and RYR1 gene in pigs. *Meat Sci* 2009, 81:745–751
2. Nielsen SS, Michelsen AM, Jensen HE, Barington K, Opstrup KV, Agger JF: The apparent prevalence of skin lesions suspected to be human-inflicted in Danish finishing pigs at slaughter. *Prev Vet Med* 2014, 117: 200-206.
3. Dalmau A, Temple D, Rodríguez P, Llonch P, Velarde A: Application of the Welfare Quality® protocol at pig slaughterhouses. *Anim Welfare* 2009, 18: 497-505.
4. Adzitey F, Nurul H: Pale Soft Exudative (PSE) and Dark Firm Dry (DFD) Meats: Causes and measures to reduce these incidences. *Int Food Res J* 2011, 18: 11–20.
5. Guàrdia MD, Estany J, Balasch S, Oliver MA, Gispert M, Diestre A: Risk assessment of DFD meat due to pre-slaughter conditions in pigs. *Meat Sci* 2005, 70: 709-716.
6. Gajana CS, Nkukwana TT, Marume U, Muchenje V: Effects of transportation time, distance, stocking density, temperature and lairage time on incidences of pale soft exudative (PSE) and the physico-chemical characteristics of pork. *Meat Sci* 2013, 95: 520–525.
7. Karabasil N, Dokmanović M, Dimitrijević M, Teodorović V, Kojičić Stefanović J, Glamočlija N, Baltić ŽM: Assessment of welfare conditions during stunning of pigs with respect to the day of the week. *Tehnologija mesa* 2013a, 54 (2): 89-96.
8. Karabasil N, Vasiljević M, Dimitrijević M, Vučinić M, Đorđević V, Ivanović J, Kureljušić J: The study of transport conditions of pigs to the slaughterhouse. *Tehnologija mesa* 2013b, 54(1): 1-7.
9. Adamović I, Vitorović D, Blagojević M, Nešić I, Brkić Z: Histological and histochemical properties of *M. semitendinosus* in German Landrace pigs at birth and market weight. *Acta Veterinaria-Beograd* 2014, 64 (3): 319-326.
10. Guàrdia MD, Estany J, Balasch S, Oliver MA, Gispert M, Diestre A: Risk assessment of PSE condition due to pre-slaughter conditions and RYR1 gene in pigs. *Meat Sci* 2004, 67: 471–478.
11. Nanni Costa L, Lo Fiego DP, de Grossi IA, Russo V: Combined effects of pre-slaughter treatments and lairage time on carcass and meat quality in pigs of different halothane genotype. *Meat Sci* 2002, 61: 41–47.
12. Warriss PD: Optimal lairage times and conditions for slaughter pigs: A review. *Vet Rec* 2003, 153: 170–176.
13. Dalla Costa OA, Faucitano L, Coldebella A, Ludke JV, Peloso JV, Dalla Roza D, Paranhos da Costa MJR: Effects of the season of the year, truck type and location on truck on skin bruises and meat quality in pigs. *Livest Sci* 2007, 107: 29–36.

14. Welfare Quality®. Welfare Quality® assessment protocol for pigs (sow and piglets, growing and finishing pigs). Welfare Quality® Consortium 2009, Lelystad, The Netherlands.
15. Pineiro C, Lorenzo E, Pineiro A, Mateos GG: Effects of induced stresses on productive performance and serum concentration of acute phase proteins in growing-finishing pigs [abstract]. *J Anim Sci* 2001, 79(1): 211.
16. Dokmanović M, Baltić ŽM, Marković R, Bošković M, Lončina J, Glamočlija N, Đorđević M: Relationships among pre-slaughter stress, rigor mortis, blood lactate, and meat and carcass quality in pigs. *Acta Veterinaria-Beograd* 2014, 64 (1): 124-137.
17. D'Eath RB, Turner SP, Kurt E, Evans G, Thölking L, Looft H, Wimmers K, Murani E, Klont R, Foury A, Ison SH, Lawrence AB, Mormède P: Pigs' aggressive temperament affects pre-slaughter mixing aggression, stress and meat quality. *Animal* 2010, 4: 604-616.
18. Alonso V, del Mar Campo M, Español S, Roncalés P, Beltrán JA: Effect of crossbreeding and gender on meat quality and fatty acid composition in pork. *Meat Sci* 2009, 81: 209–217.
19. Barton-Gade P, Christensen L: Effect of different stocking densities during transport on welfare and meat quality in Danish slaughter pigs. *Meat Sci* 1998, 48(3/4): 237–247.
20. Warriss PD, Brown SN, Edwards JE, Knowles TG: Effect of lairage time on levels of stress and meat quality in pigs. *Anim Sci* 1998, 66: 255–261.
21. Faucitano L: Invited Review: Effects of lairage and slaughter conditions on animal welfare and pork quality. *Can J Anim Sci* 2010, 90: 461-469.
22. Vermeulen L, Van de Perre V, Permentier L, De Bie S, Geers R: Pre-slaughter handling and pork quality. *Meat Sci* 2015, 100: 118–123.
23. Grandin T: The welfare of pigs during transport and slaughter. *Pig News and Information* 2003, 24: 83–90.
24. Pérez MP, Palacio J, Santolaria MP, Aceña MC, Chacón G, Gascón M, Calvo JH, Zaragoza P, Beltran JA, Garcia-Belenguer S: Effect of transport time on welfare and meat quality in pigs. *Meat Sci* 2002, 61, 425–433.
25. Gispert M, Faucitano L, Oliver MA, Guàrdia MD, Coll C, Siggens K, Harvey K, Diestre A: A survey of pre-slaughter conditions, halothane gene frequency, and carcass and meat quality in five Spanish pig commercial abattoirs. *Meat Sci* 2000, 55 (1): 97–101.
26. Shen QW, Means WJ, Thompson SA, Underwood KR, Zhu MJ, McCormick RJ, Ford SP, Du M: Pre-slaughter transport, AMP-activated protein kinase, glycolysis, and quality of pork loin. *Meat Sci* 2006, 74: 388-395.
27. Gosálvez LF, Averós X, Valdevira JJ, Herranz A: Influence of season, distance and mixed loads on the physical and carcass integrity of pigs transported to slaughter. *Meat Sci* 2006, 73: 553–558.

UTICAJ *PRE-MORTEM* USLOVA NA BLEDO, MEKO I VODENASTO (BMV) I TAMNO, ČVRSTO I SUVO (TČS) MESO SVINJA

ČOBANOVIĆ Nikola, KARABASIL Nedjeljko, STAJKOVIĆ Silvana,
ILIĆ Nevena, SUVAJĐIĆ Branko, PETROVIĆ Miloš, TEODOROVIĆ Vlado

Cilj ovog istraživanja bio je da se utvrdi uticaj pola, gustine svinja u transportnom sredstvu, dužine boravka u depou i godišnjeg doba na učestalost lezija na koži trupova svinja i pojavu bledog, mekog i vodenastog mesa (BMV) i tamnog, čvrstog i suvog mesa (TČS). Lezije na trupu svinja (n=480) su ocenjivane na osnovu Welfare Quality®

protokola (2009). Vrednosti pH (pH_{45}) i temperature (t_{45}) su određivane 45 minuta *post-mortem*. U grupi svinja sa skorom 2 lezija na koži uočena je značajno veća učestalost BMV i TČS mesa u poređenju sa grupama svinja sa skorom 0 i 1. Nije utvrđena statistički značajna razlika između polova u pojavi lezija na koži, kao i u učestalosti BMV i TČS mesa. Rezultati ovog ispitivanja su pokazali da je podna površina manja od 0.3 m^2 i veća od 0.5 m^2 na 100 kg telesne mase svinja imala negativan uticaj kako na dobrobit životinja tako i na kvalitet mesa. Pored toga, utvrđeno je da dužina boravka u depou utiče na parametre kvaliteta mesa, kao i na učestalost lezija na trupu svinja i pojavu BMV i TČS mesa, pri čemu su posle dugotrajnog boravka u depou ($> 17 \text{ h}$) utvrđene statistički značajno veće pH_{45} i t_{45} vrednosti, kao i veća učestalost lezija na trupu i TČS mesa. Sa druge strane, nakon kratkotrajnog boravka u depou ($< 1 \text{ h}$) utvrđena su statistički značajno niže pH_{45} vrednosti, odnosno statistički značajno više t_{45} vrednosti, kao i učestalost lezija na trupu i BMV mesa. Isto tako, utvrđena je statistički značajno veća pojava lezija na trupu svinja u zimskoj sezoni u odnosu na sva ostala godišnja doba. Takođe, visoke temperature tokom letnje sezone i niske temperature tokom zimske sezone imale su negativan uticaj na parametre kvaliteta mesa, a posledično i na pojavu BMV i TČS mesa.