Ann. Anim. Sci., Vol. 23, No. 2 (2023) 597–609 *DOI: 10.2478/aoas-2022-0093*

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PREVALENCE OF CARCASS LESIONS AND THEIR EFFECTS ON WELFARE, CARCASS COMPOSITION AND MEAT QUALITY IN SLAUGHTERED PIGS*

Nikola Čobanović♦, Branko Suvajdžić, Ivan Vićić, Dragan Vasilev, Nedjeljko Karabasil

Department of Food Hygiene and Technology, Faculty of Veterinary Medicine, University of Belgrade, Bulevar oslobodjenja 18, 11000 Belgrade, Serbia
♦Corresponding author: cobanovic.nikola@vet.bg.ac.rs

Abstract

The aims of this study were to determine the prevalence of carcass lesions in slaughtered pigs and to quantify their relationships with different animal characteristics, pre-slaughter factors, blood measurements, performance indices, carcass composition and meat quality traits. Data was recorded for 30 journeys referring to 1080 market-weight pigs that originated from 15 commercial small-scale finishing farms. Carcass lesions were visually assessed on the slaughterline in different parts of the carcass, i.e., anterior, middle and posterior, using a three-point scale. Complete blood count was investigated. The following performance indices and carcass composition traits were measured: average lifetime daily weight gain, live, hot and cold carcass weights, cooler shrinkage, dressing percentage, backfat thickness and meatiness. Meat pH and temperature were measured 45 minutes postmortem. Of the 1080 pigs slaughtered in 30 batches, 70.28% displayed some degree of lesions on the carcass (moderate – 30.00%; severe – 40.28%). The carcass lesions were the most prevalent (50.20%) in the posterior part of the pig carcass. RYR1 genotype, live weight, loading density, lairage time, lairage density and slaughter season affected the carcass lesion prevalence. The presence of carcass lesions, irrespective of severity, was associated with alterations in blood measurements in slaughtered pigs, indicating compromised animal welfare. The presence of severe carcass lesions in slaughtered pigs was significantly associated with increased meat pH_{45min}, which led to the highest occurrence of dark, firm and dry pork. In contrast, there was strong evidence of association between the presence of moderate carcass lesions in slaughtered pigs and both decreased meat pH_{45min} and increased meat T_{45min}, which led to the highest occurrence of pale, soft and exudative pork among the carcass lesion groups. In conclusion, this study showed a high prevalence of carcass lesions in slaughtered pigs, whereby the risk of their occurrence was affected by both animal characteristics and pre-slaughter conditions. Also, the presence of carcass lesions in slaughtered pigs, irrespective of severity, was significantly associated with alterations in the blood measurements and pork quality.

Key words: carcass lesions, critical control points, pig welfare, pork quality, stress indicators

Carcass lesions are one of the earliest, most common and easily recognisable signs of suboptimal welfare, which reflect poor social and physical environments and cause unnecessary pain, depicting escalating inefficiency and neglect within a pork production chain (Bottacini et al., 2018; Carroll et al., 2016; Driessen et al., 2020 a; Guàrdia et al., 2009; Teixeira and Boyle, 2014). Together with tail lesions, carcass lesions were recently considered as one of the main pig welfare indicators by a panel of international animal welfare experts, highlighting their potential use as iceberg indicators, meaning that these relatively simple measurements should function as a warning signal of underlying welfare problems (Bottacini et al., 2018; Carroll et al., 2016; European Food Safety Authority, 2012). Considering that skin lesions measured on the carcass are more sensitive animal welfare indicators than those measured on the live pig (Brandt and Aaslyng, 2015; van Staaveren et al., 2015), monitoring of carcass lesions at the abattoir can be used as a valuable practical tool when documenting pig welfare on the day of slaughter (Aaslyng et al., 2013; Driessen et al., 2020 b). During carcass lesion assessment on the slaughterline, it is also possible to identify the causes and to unravel the moment of infliction (fighting, rough handling and mounting) based on their number, the diversity of lesion characteristics and anatomical location on the pig body (Aaslyng et al., 2013; Driessen et al., 2020 a; Faucitano et al., 2001; Strappini et al., 2012). Accordingly, differences in prevalences on different parts can be expected, so it is very important to score the carcass lesions per carcass part (Driessen et al., 2020 a).

The vast majority of earlier studies (Bottacini et al., 2018; Dalla Costa et al., 2007; Driessen et al., 2020 a; Faucitano et al., 2001) only focused on one or two impor-

*The study was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Contract number 451-03-68/2022-14/200143).

tant factors affecting the prevalence of carcass lesions in slaughtered pigs. However, carcass lesions can occur at any point within the pork production chain, due to inappropriate housing and handling of the pigs on the farm, during loading (mixing of unfamiliar animals, poor handling and inadequate infrastructure and facility design), transportation (poor lorry design, careless driving style, short/long transportation time, high/low loading density, inadequate floor, and poor environmental conditions), unloading at the abattoir, lairaging (inadequate infrastructure and facility design, poor environmental conditions, long lairage time, high/low density and prolonged fasting) and even during stunning procedures (Driessen et al., 2020 a; Guàrdia et al., 2009; Scheeren et al., 2014). Animal characteristics such as breed, gender, live weight, age and genotype can also affect the prevalence of carcass lesions in slaughtered pigs (Čobanović et al., 2016 a; Guàrdia et al., 2009). Therefore, understanding the causes of carcass lesions is challenging due to the diversity of factors that have been shown to be related to their prevalence (Bottacini et al., 2018; Driessen et al., 2020 a). Moreover, animal characteristics and pre-slaughter factors can interact with one another and have a cumulative effect on carcass lesion risk. The before-mentioned factors, and the multiple time points in the pork production chain during which pigs might be exposed to them, have made it difficult to pinpoint the crucial events within the supply chain that impact carcass lesions the most. Consequently, there is still a need to further understand the impact of these factors on the prevalence of carcass lesions and to determine the critical control point or points in the pre-slaughter procedure at which pigs sustain carcass lesions.

Besides the negative influence on pig welfare, carcass lesions are serious problems in the fresh pork market and cause financial losses to pig producers, transporters, the meat industry and the country. The pig producers and transporters suffer from financial losses arising from reduced carcass price or even from the rejection of entire carcasses with skin lesions by the abattoir, whereby purchase can no longer be guaranteed (Driessen et al., 2020 a; Faucitano et al., 2001; Harley et al., 2012). Also, penalties may be imposed by the official meat inspectors or abattoir organisations (Driessen et al., 2020 a). Considering that areas of the carcass with skin lesions necessitate trimming during postmortem processing, the abattoirs bear financial losses due to poor presentation, decreased yield and grade of the carcass, and depending on lesion anatomical location, potential devaluing of primary carcass cuts (Driessen et al., 2020 a; Pereira et al., 2017; Teixeira and Boyle, 2014). Furthermore, abattoir financial losses arise from the rejection of pork from the high-quality markets, because meat obtained from slaughtered pigs with carcass lesions is not acceptable to consumers or for processing, as it yields a poor product, which requires meat producers to discount the value of carcass or primary carcass cuts and, consequently, ends up in the wastage of the product (Faucitano et al., 2001). In addition, carcass lesions can lead to the spread of secondary infection, which may be the cause of single-site abscessation in the legs, flank and shoulders of pigs, resulting in the condemnation of the affected part of the carcass (Carroll et al., 2016).

In addition to assessing the carcass lesion prevalence, understanding lesions' associations with physiological stress indicators, performance indices, carcass composition and pork quality traits is also important in establishing priorities for addressing them. Although there are many reasons to suppose that carcass lesions are linked to underlying stress and that being a victim is stressful, only a few published papers investigated the relationships between the presence and/or severity of carcass lesions and physiological stress indicators (Brandt and Aaslyng, 2015; D'Eath et al., 2010; Guàrdia et al., 2012; van Staaveren et al., 2015). It has been demonstrated that carcass lesions in slaughter pigs may reduce growth rate and final body weight, and cause a significant deterioration in carcass quality (Carroll et al., 2016; Coutellier et al., 2007; Driessen et al., 2020 a). Also, several studies reported that the presence of carcass lesions in slaughtered pigs is associated with increased meat pH and dark, firm and dry (DFD) pork prevalence (Gispert et al., 2000; Guàrdia et al., 2009; Faucitano et al., 2001). Based on the above review of related scientific literature, the main aims of this study were to determine the prevalence of carcass lesions in slaughtered pigs and to quantify their relationships with different animal characteristics and pre-slaughter factors. A secondary aim was to establish the associations between carcass lesions and blood measurements, performance indices, carcass composition and meat quality traits in slaughtered pigs. The hypothesis was that the carcass lesions cause stress to the victim, which would be reflected in alteration in blood measurements and in deterioration in performance indices, and carcass and meat quality of slaughtered pigs.

Material and methods

Experimental animals, pre-slaughter handling and slaughter procedure

Data was recorded for 30 journeys referring to 1080 market-weight pigs (560 barrows and 520 gilts) of the same genetics ([Yorkshire × Landrace] sows sired with Pietrain boars) with an average live weight of 114±6.95 and about 6 months old. Pigs originated from 15 commercial small-scale finishing farms with similar rearing conditions. All small-scale farms consisted of one fattening unit comprised of two pens and practicing all-in–all-out management. The pens had fully slatted concrete floors without bedding at an average density of 1 m^2 per pig. Pigs were fed *ad libitum* with dry pelleted finisher diet in a multi-space feeder, while water was freely available from a single bite-drinker in each pen. The fattening period started at about 30 kg live weight, and pigs were kept within the same group during the entire fattening period. Pigs were sent to slaughter when they reached approximately 110 kg liveweight. At this stage they were 180 days old. Before transportation, pigs were deprived of food 24 hours, while they always had free access to drinking water during housing.

At the farm, the pigs were loaded in groups of 4–5 pigs by the same lorry driver. The lorry departed from the farm immediately after loading. All transports were conducted by the same driver and the same lorry with two compartments. Each farm was used for two journeys, so that pigs from the first pen were transported in the front lorry compartment, while individuals from the second pen were transported in the rear lorry compartment to avoid the confounding effect of the lorry compartment on the pig responses to transportation. Pigs were transported in batches of, on average, 36 (minimum 28; maximum 44) pigs, whereby individuals were divided into two subgroups (one per lorry compartment), formed based on the compartment size and number of pigs in each batch. Pigs were transported to the abattoir for less than one hour (on average 44.24±13.75 minutes) or more than three hours (on average 217.5±15.37 minutes), depending on the farm distance, transport route and traffic jams. Depending on the number of pigs in the lorry compartments, the loading density ranged from 0.28 to 0.60 m^2/100 kg. Each group of pigs was unloaded as soon as possible after the arrival at the abattoir. After the pigs were unloaded, they were moved to a designated lairage pen by the same abattoir personnel. During lairaging, water was freely available, but there was no access to food. Groups of pigs unloaded in the morning were slaughtered on the same day (lairage time between zero and three hours), while groups of pigs unloaded in the late afternoon were accommodated overnight and were slaughtered the next morning (lairage time longer than 16 hours). Depending on the number of pigs in the lairage pens, the lairage density varied from 0.40 to 1.2 m^2/pig. Slaughter dates were recorded so that possible seasonal influence could be taken into account. The seasons wherein the pigs were slaughtered were categorised by the Gregorian calendar: spring (21 March–20 June), summer (21 June–20 September), autumn (21 September–20 December) and winter (21 December–20 March). Pigs were slaughtered in accordance with the standard industry-accepted practices in the same low-input commercial abattoir that operates from Monday to Saturday (07:00–15:00 h) and has a slaughtering capacity of 175 pigs/week.

Sample size determination

The sample size to reliably estimate the prevalence and severity of carcass lesions in the pig population was calculated using the formula given by Thrusfield (2005) with 95% confidence interval, 70% expected prevalence and 5% desired absolute precision. Accordingly, the minimum sample size was 743; to increase precision, the number was adjusted to 1080 carcasses. Expected prevalence was determined based on the previously found prevalence of carcass lesions in slaughtered pigs (Aaslyng et al., 2013; Carroll et al., 2016; Guàrdia et al., 2009; Warriss et al., 1998).

The sample size calculation for each statistical test used was performed using the program G*Power (Version 3.1.9.7, Kiel University, Germany) (Faul et al., 2007). For the power analysis using a F-test ANOVA (Fixed effects, omnibus, and one-way), with input parameters of effect size 0.30, alpha level 0.05, power 0.95 and three groups, the required sample size (n) was a total of 177 pigs (59 pigs per group). For the power analysis using a Chi-squared Goodness-of-fit tests (Contingency tables), with input parameters of effect size 0.30, alpha level 0.05, power 0.95 and degrees of freedom (df) 11, the required sample size (n) was a total of 280 pigs.

RYR1 genotype determination

To determine RYR1 genotypes (NN – stress-resistant; Nn – stress carrier; nn – stress-susceptible), blood samples were taken from 10 pigs from every of the 30 loads included in the study (n=300), blinded in relation to carcass lesion evaluation and labelled with the number which corresponded to the carcass kill/line number. Collection of blood samples was done during slaughtering, at the beginning of exsanguination, into a plastic cup containing 1 ml of 0.5M EDTA and immediately transferred to vacutainers (2 mL) coated with EDTA. After collection, all blood samples were frozen and kept at −20°C until required for testing (within one month of collection). Polymorphism in RYR1 locus was determined using PCR-RFLP (Polymerase Chain Reaction – Restriction Fragment Length Polymorphism) method according to Brenig and Brem (1992), as outlined in Čobanović et al. (2019).

Blood measurements

To evaluate the association between carcass lesions and haematological stress indicators, blood samples were taken from six pigs from every of the 30 loads included in the study (n=180), blinded in relation to carcass lesion evaluation and labelled with the number which corresponded to the carcass kill/line number. For determination of complete blood count, samples consisting of 50 ml of trunk blood were taken during bleeding, directly after stunning, into a plastic cup containing 1 ml of 0.5M EDTA and immediately transferred to vacutainers (2 mL) coated with EDTA. After blood collection, the EDTA tubes were placed on ice packs (4±1ºC) during transportation to the laboratory. The complete blood count was implemented using an automatic haematological analyser (Abacus Junior Vet 5, Diatron MI PLC, Hungary) approximately six hours after slaughter. The parameters measured included leukocytes, lymphocytes, middle-sized cells (monocytes, eosinophils, basophils), neutrophils, erythrocytes, haemoglobin, haematocrit, mean corpuscular volume, mean corpuscular haemoglobin, mean corpuscular haemoglobin concentration and thrombocytes. Differential leukocyte counts (lymphocytes, middle-sized cells and neutrophils) were determined on the same device. In addition, the neutrophil-to-lymphocyte ratio was calculated. Blood glucose levels were obtained directly from the plastic cup within 15 seconds postmortem at the slaughterline using a handheld device (GlucoSure AutoCode, ApexBio, Taiwan).

Performance indices

Live weight was determined using the known hot carcass weight based on the following equation (Vítek et al., 2011): y = 1.27 * x, where y = live weight (kg) and x = hot carcass weight (kg). Average lifetime daily weight gain was obtained by subtracting average piglet weight at birth (1.1 kg) from live weight at slaughter, and the result was divided by the average slaughter age (180 days) (Čobanović et al., 2020).

Carcass composition and meat quality measurements

The slaughterhouse personnel provided the data about carcass composition, including hot carcass weight, cold carcass weight, cooler shrinkage, dressing percentage, fat thickness at two carcass points, and meatiness. Hot carcass weight was determined 45 minutes after slaughter, while cold carcass weight was obtained 24 hours after chilling. The cooler shrinkage was calculated as the hot carcass weight minus the cold carcass weight, expressed as a proportion of the hot carcass weight. The dressing percentage was determined as follows: hot carcass weight divided by live weight and the total multiplied by 100. Meatiness (%) was determined 45 minutes postmortem based on the Official Gazette (1985) method, and necessitated measuring hot carcass weight and backfat thickness with skin. The fat thickness measurements were determined in all carcasses using a stainless steel ruler (accuracy of 1.0 mm) on two carcass points on the midline of the split carcass in millimetres: on the back (between the 13th and 15th dorsal vertebrae) and at the sacrum (minimum fat thickness with skin over the *Musculus gluteus medius*). The sum of fat measurements on two carcass points represented the backfat thickness with the skin. Then, tables, which are an integral part of the Official Gazette (1985), were used to determine meatiness based on previously conducted measurements (hot carcass weight and backfat thickness with skin).

Meat pH (pH_{45min}) and temperature (T_{45min}) were measured 45 minutes after slaughter using a portable pH meter (Testo 205, Testo AG, Lenzkirch, Germany) by inserting the glass probe into the *Musculus longissimus dorsi*, *pars lumbalis* (central area of the loin), on the left half of the carcass, at the level of the 10th and 11th ribs. Pork quality parameters were both measured in triplicate, and the average of the three measurements was taken as a final result. Pork quality classes were determined using meat pH measured 45 minutes postmortem (Čobanović et al., 2019): (i) pale, soft, and exudative (PSE) pork – pH_{45min} values below 6.0; (ii) normal pork quality – pH_{45min} values between 6.0 and 6.4; (iii) dark, firm, and dry (DFD) pork – pH_{45min} values above 6.4.

Carcass lesion evaluation

Carcass lesions were visually assessed on the left carcass side in the cold chamber 45 minutes after slaughter using a visual scoring system based on Welfare Quality® protocol (2009). Carcass lesions were assessed by a single observer throughout the study to eliminate interobserver variation. The same observer recorded gender, herd identification number and kill number. Approximately one minute per pig was needed to record lesions on the carcass. During evaluation of the number and extent of damages, the carcasses were visually split into the following five parts: (i) ears; (ii) anterior part of the carcass (from the head to the end of the shoulder); (iii) middle part of the carcass (from the end of the shoulder to the rear part of the carcass); (iv) posterior part of the carcass (hindquarters); and (v) legs (from the accessory digit upwards). Tails were not included in the scoring of carcass lesions. Each of the previously mentioned carcass parts was scored using a three-point scale: (i) score 0: no visible carcass lesions, or only one lesion bigger than two centimetres or lesions smaller than one centimetre; (ii) score 1: between two and 10 carcass lesions bigger than two centimetres; and (iii) score 2: any carcass lesion penetrated into muscles or more than 10 carcass lesions larger than two centimetres. Each pig was given an overall carcass lesion score according to the highest score assigned to that animal in any carcass part. Only recent/fresh carcass lesions were recorded. The lesion was considered to be fresh if it was bright red in colour or with apparently recent and intact scabs. Carcass lesions smaller than two centimetres, bruised injection sites and reddening lesions on the left hind leg that looked like bruises (more likely caused after stunning by the tightening of the shackle chain) were not registered.

Statistical analysis

Statistical analysis of the results was conducted with SPSS software (Version 23.0, IBM Corporation, Armonk, NY, USA) (SPSS, 2015). The linearity, normality of residuals (Shapiro–Wilk and Kolmogorov–Smirnov test), outliers, and homogeneity of variance (Levene's test) of the dependent variables were determined before statistical analysis and data successfully passed all tests. Based on severity of carcass lesions pigs were classified into three groups: no carcass lesions (score 0); moderate carcass lesions (score 1); and severe carcass lesions (score 2). The prevalences of none (score 0), moderate (score 1) and severe (score 2) carcass lesions and lesions on carcass parts were calculated at the individual level. Due to low prevalences of carcass lesions on ears and legs, lesions on ears and front legs were included in the anterior part of the carcass (as they typically occur as a result of fighting behaviour), whereas lesions on hind legs were included in the posterior part of the carcass (as they typically occur as a result of harsh handling and/or mounting behaviour). Therefore, in carcasses, the following areas were considered: i) anterior part, ii) middle part; and iii) posterior part. According to RYR1 genotype, the pigs were allocated to two groups: Nn genotype:

stress-carriers (n=108) and NN genotype: stress-resistant pigs (n=192). Based on gender, pigs were assigned to two groups: barrows (n=560); and gilts (n=520). Pigs were divided into three weight groups: lightweight pigs: body weight ranged from 70 kg to 100 kg (n=136); middleweight pigs: body weight ranged from 101 kg to 120 kg (n=682); heavyweight pigs: body weight ranged from 121 kg to 145 kg (n=262). According to loading density in the lorry, pigs were classified in three groups: high loading density: <0.35 m^2/100 kg pig (n=468); medium loading density: between 0.40 and 0.45 m^2/100 kg pig (n=361) and low loading density: >0.50 m^2/100 kg pig (n=251), while animals were divided into two groups for transportation time: short transportation: < one hour (n=500); and long transportation: > three hours (n=580). Based on lairage density, pigs were classified in three groups: high lairage density: <0.45 m^2/100 kg pig (n=388); medium lairage density: between 0.65 and 0.80 m^2/100 kg pig (n=332) and low lairage density: >1 m^2/100 kg pig (n=360), while animals were divided into three groups for lairage time: short lairage time: < one hour (n=513); medium lairage time: between one and three hours (n=289) and long lairage time: >16 hours (n=278).

Chi-squared tests, and in some cases Fisher's exact tests, were performed to study the relationship between various animal and pre-slaughter factors and the carcass lesion severity. One-way analysis of variance (ANOVA) was performed to test the effects of carcass lesion severity on the blood measurements, performance indices, carcass composition and meat quality traits. Significant means at P<0.05 were further compared using Tukey's post-hoc test (multiple comparisons). All results were described by descriptive statistics – mean value and standard deviation. The Chi-squared test was used to determine the prevalence of pork quality classes with respect to the carcass lesion severity. Each individual pig was considered an experimental unit. In all tests, statistical significance was accepted at P<0.05, tendencies were accepted at 0.05<P<0.10.

Results

Prevalences of carcass lesions in slaughtered pigs in relation to the animal characteristics and pre-slaughter factors

Of the 1080 pigs slaughtered in 30 batches, 321 (29.72%) had no visible carcass lesions, while 759 pigs (70.28%) displayed some degree of lesions on the carcass. Moderate carcass lesions were recorded in 30.00% (n=324), while severe carcass lesions were detected in 40.28% (n=435) of slaughtered pigs. According to carcass part, lesions were the most prevalent in the posterior part, connected with rough handling and mounting behaviour, with a mean of 50.20% (n=381) of the pigs affected, followed by the anterior part (32.80%; n=249), which indicates the presence of fighting behaviour between pigs, and, finally, the middle part (17.00%; n=129).

Prevalences of carcass lesions in slaughtered pigs in relation to the animal characteristics are displayed in Table 1. With regard to RYR1 genotype, NN pigs had higher percentage of severe carcass lesions (P<0.0001), and lesions on anterior (P<0.0001) and middle (P=0.0053) parts of the carcass. In contrast, Nn pigs produced a higher percentage of carcasses free of lesions (P<0.0001), but had a higher prevalence of lesions on the posterior part of the carcass (P=0.0293). Prevalences of carcass lesions did not differ (P>0.05) across different gender class types. With respect to live weight, lightweight pigs (70–100 kg) produced the highest percentage of carcasses free of lesions (P<0.0001). On the contrary, heavyweight pigs (121–145 kg) had the highest prevalence (P<0.0001) of severe carcass lesions and frequency of lesions on the anterior part of the carcass.

Table 1. Prevalence of carcass lesions in slaughtered pigs in relation to the animal characteristics (n=1080)

Parameter	n			Carcass lesion severity (%)			Carcass part (%)		
				no carcass lesions	moderate carcass lesions	severe carcass lesions	anterior part	middle part	posterior part
RYR1 genotype	NN	192		20.83 a	31.25	47.92 a	40.63 a	26.32 a	17.71 a
	Nn	108		54.63 b	26.85	18.52 b	8.33 b	8.33 b	28.70 b
			P–value	<0.0001	0.5105	<0.0001	<0.0001	0.0053	0.0293
Gender	Barrows	560		30.54	30.18	39.28	23.04	10.71	35.71
	Gilts	520		28.85	29.81	41.34	23.08	13.27	34.81
			P–value	0.5495	0.9470	0.4953	>0.9999	0.2222	0.7988
Live weight (kg)	70–100	136		51.47 a	39.71 a	8.82 a	19.12 a	11.03	18.38 a
	101–120	682		29.33 b	29.62 b	41.05 b	18.77 a	13.34	38.56 b
	121–145	262		19.47 c	25.95 b	54.58 c	36.26 b	8.78	35.50 b
			P–value	<0.0001	0.0167	<0.0001	<0.0001	0.1442	<0.0001

Abbreviations: NN pigs – stress-resistant; Nn pigs – stress-carrier; lightweight pigs – from 70 to 100 kg; middleweight pigs – from 101 to 120 kg; heavyweight pigs – from 121 to 145 kg.

Note: Significant differences were evaluated using the Chi-squared and Fisher's exact test. Different letters in the same column indicate a significant difference at P<0.05 (a–c).

Table 2. Prevalence of carcass lesions in slaughtered pigs in relation to the transportation and lairaging conditions (n=1080)

Parameter		n		Carcass lesion severity (%) no carcass lesions	moderate carcass lesions	severe carcass lesions	Carcass part (%) anterior	middle	posterior
Loading density (m^2/100 kg)	High (<0.35)	468		11.75 a	32.05	56.20 a	29.70 a	20.30 a	38.25 a
	Medium (0.40–0.45)	361		59.56 b	26.59	13.85 b	12.47 b	8.59 b	19.39 b
	Low (>0.50)	251		20.32 c	31.08	48.60 a	25.90 a	1.20 c	52.59 c
			P-value	<0.0001	0.2153	<0.0001	<0.0001	<0.0001	<0.0001
Transportation time (h)	Short (<1)	500		32.20	30.40	37.40	23.80	12.00	34.00
	Long (>3)	580		27.59	29.66	42.75	22.41	11.90	36.39
			P-value	0.1090	0.7904	0.0815	0.6124	>0.9999	0.4436
Lairage time (h)	Short (<1)	513		38.99 a	35.09 a	25.92 a	11.70 a	13.45	35.87
	Medium (1–3)	289		27.69 b	37.02 a	35.29 b	29.76 b	11.42	31.14
	Long (>16)	278		14.75 c	13.31 b	71.94 c	43.46 c	11.39	38.49
			P-value	<0.0001	<0.0001	<0.0001	<0.0001	0.2867	0.1739
Lairage density (m^2/pig)	High (<0.45)	388		37.37 a	25.52 a	37.11 a	10.31 a	19.59 a	32.73 a
	Medium (0.65–0.80)	332		32.23 a	31.93	35.84 a	23.80 b	12.05 b	31.93 a
	Low (>1)	360		19.17 b	33.05 b	47.78 b	36.11 c	3.61 c	41.11 b
			P-value	<0.0001	0.0522	0.0017	<0.0001	<0.0001	0.0174
Season	Spring	258		40.70 a	32.95	26.35 a	20.16 a	8.91 a	30.23 a
	Summer	280		30.00 b	31.07	38.93 b	19.64 a	8.57 a	41.79 b
	Autumn	281		31.67 b	28.47	39.86 b	18.15 a	9.96 a	40.21 b
	Winter	261		16.47 c	27.59	55.94 c	34.87 b	20.69 b	27.97 a
			P-value	<0.0001	0.5209	<0.0001	<0.0001	<0.0001	0.0007

Abbreviations: Spring – from 21 March to 20 June; summer – from 21 June to 20 September; autumn – from 21 September to 20 December; winter – from 21 December to 20 March.

Note: Significant differences were evaluated using the Chi-squared and Fisher's exact test. Different letters in the same column indicate a significant difference at P<0.05 (a–c).

Prevalences of carcass lesions in slaughtered pigs in relation to the pre-slaughter factors are shown in Tables 2 and 3. Loading density affected (P<0.0001; Table 2) the prevalence of carcass lesions, whereby the highest prevalences of severe lesions and lesions on the anterior part of the carcass were recorded in pigs subjected to both high (<0.35 m^2/100 kg) and low (>0.50 m^2/100 kg) loading densities. Additionally, pigs that underwent high loading density (<0.35 m^2/100 kg) had the highest (P<0.0001) proportion of lesions on the middle part of the carcass, while pigs subjected to low loading density (>0.50 m^2/100 kg) had the highest (P<0.0001) prevalence of lesions on the posterior part of the carcass. Transportation time had no significant effect (P>0.05; Table 2) on the prevalence of carcass lesions in slaughtered pigs. Lairage time affected (P<0.0001; Table 2) the prevalence of carcass lesions, whereby the highest prevalence of severe lesions and lesions on the anterior part of the carcass were detected in pigs that underwent long lairaging (>16 h). Also, lairage density affected (P<0.0001; Table 2) the prevalence of carcass lesions, shown by the highest occurrence of severe lesions (P=0.0017) and lesions on the anterior (P<0.0001) and posterior (P=0.0174) parts of the carcass in pigs exposed to low lairage density (>1 m^2/pig). Contrarily, the highest percentage (P<0.0001) of lesions on the middle part of the carcass was recorded in pigs subjected to high lairage density (<0.45 m^2/pig). Pigs slaughtered in wintertime had the lowest (P<0.0001) prevalence of carcasses free of lesions, but the highest (P<0.0001) prevalence of severe carcass lesions and lesions on the anterior and middle parts of the carcass (Table 3). In contrast, pigs slaughtered in the springtime had the lowest (P<0.0001) prevalence of severe lesions and the highest (P<0.0001) percentage of carcasses free of lesions (Table 3).

Effects of carcass lesion severity on blood measurements, performance indices, carcass composition and meat quality of slaughtered pigs

Effects of carcass lesion severity on blood measurements of slaughtered pigs are reported in Table 4. There was strong evidence of association (P<0.0001) between the presence of severe carcass lesions in slaughtered pigs and increased leukocyte count, neutrophil/lymphocyte ratio, number of neutrophils and percentage of neutrophils. In addition, the presence of severe carcass lesions in slaughtered pigs was significantly associated with increased erythrocyte count (P<0.0001), haemoglobin concentration (P=0.0381), haematocrit (P<0.0001) and decreased blood glucose concentration (P<0.0001).

Table 3. Effects of carcass lesion severity on blood measurements (mean value ± standard deviation) of slaughtered pigs (n=180)

Carcass lesion severity	No carcass lesions	Moderate carcass lesions	Severe carcass lesions	Reference values (Fielder, 2015)	P-value
n	52	66	62		
Leukocytes (10^9/L)	18.14±4.25 a	22.70±3.90 b	27.22±6.73 c	11–22	<0.0001
Lymphocytes (10^9/L)	11.07±1.90 a	17.35±3.27 b	15.16±6.07 c	3.8–16.5	<0.0001
Middle-sized cells (10^9/L)	0.19±0.29	0.18±0.09	0.22±0.06	–	0.7962
Neutrophils (10^9/L)	5.38±2.24 a	5.75±1.79 a	15.20±3.29b	2–15	<0.0001
Neutrophil/lymphocyte ratio	0.50±0.21 a	0.34±0.12 b	1.12±0.38 b	–	<0.0001
Lymphocytes (%)	61.62±15.15 a	72.64±11.16 b	55.06±17.19 c	39–62	<0.0001
Middle-sized cells (%)	0.75±0.31	1.00±1.46	0.77±0.12	–	0.3425
Neutrophils (%)	33.30±12.53 a	25.82±6.61 b	43.73±19.03 c	28–47	<0.0001
Erythrocytes (10^{12}/L)	6.97±1.10a	7.80±0.95 b	8.42±0.89 c	5–8	<0.0001
Haemoglobin (g/L)	133.90±16.98 a	141.10±16.01 b	143.30±19.52 c	100–160	0.0381
Haematocrit (%)	38.50±3.37 a	39.26±2.95 a	44.95±1.85 b	36–43	<0.0001
MCV (fl)	49.53±3.23	50.54±3.57	50.76±3.38	50–68	0.2143
MCH (pg)	18.10±0.95	17.92±1.19	18.23±1.13	17–21	0.5581
MCHC (g/L)	360.60±10.59	358.60±7.43	360.60±8.30	300–340	0.5259
Thrombocytes (109/L)	243.90±117.30	268.10±111.30	220.20±111.30	200–500	0.2787
Blood glucose (mmol/L)	5.82±1.20 a	9.73±3.83 b	3.93±0.39 c	4.7–8.3	<0.0001

Abbreviations: MCV – mean corpuscular volume; MCH – mean corpuscular haemoglobin; MCHC – mean corpuscular haemoglobin concentration.

Note: Significant differences were evaluated using the ANOVA test and post hoc pairwise comparisons using Tukey's test. Different letters in the same row indicate a significant difference at P<0.05 (a–c).

Table 4. Effects of carcass lesion severity on performance indices, carcass composition and meat quality traits (mean value ± standard deviation) of slaughtered pigs (n=1080)

Carcass lesion severity	No carcass lesions	Moderate carcass lesions	Severe carcass lesions	P-value
n	321	324	435	
Performance indices				
ALDWG (kg)	0.617±0.04 a	0.631±0.03 b	0.630±0.05 b	<0.0001
live weight (kg)	112.40±7.47 a	114.60±5.26 b	114.70±7.51 b	<0.0001
Carcass composition traits				
hot carcass weight (kg)	91.46±7.34 a	93.56±4.60 b	93.33±6.67 b	<0.0001
cold carcass weight (kg)	89.36±6.48 a	91.23±4.49 b	91.02±6.44 b	<0.0001
cooler shrinkage (%)	2.47±0.97 a	2.57±0.93	2.68±1.04 b	0.0384
dressing percentage (%)	81.89±1.57	81.83±1.60	81.97±1.72	0.6051
backfat thickness (mm)	18.92±7.19	18.46±7.45	17.81±6.75	0.0978
fat thickness at sacrum (mm)	34.83±17.16	33.38±17.68	32.98±17.09	0.4404
meatiness (%)	43.77±8.81	43.92±7.60	44.41±6.66	0.4771
Pork quality traits				
pH_{45min}	6.15±0.09 a	5.93±0.19 b	6.36±0.15 c	<0.0001
T_{45min} (º)	38.27±0.95 a	40.01±0.96 b	38.20±1.22 a	<0.0001
Pork quality classes (%)				
PSE pork (pH_{45min}<6.0)	11.84 a	37.04 b	14.64 a	<0.0001
normal pork (pH_{45min} 6.0–6.4)	83.80 a	57.41 b	39.08 c	<0.0001
DFD pork (pH_{45min}>6.4)	4.36 a	5.56 a	45.98 b	<0.0001

Abbreviations: ALDWG – Average lifetime daily weight gain; pH_{45min} – meat pH measured 45 minutes postmortem; T_{45min} – meat temperature measured 45 minutes post-mortem; PSE – pale, soft, and exudative pork; DFD pork – dark, firm, and dry pork.

Note: Significant differences were evaluated using the ANOVA test and post hoc pairwise comparisons using Tukey's test. Different letters in the same row indicate a significant difference at P<0.05 (a–c).

On the other hand, the presence of moderate carcass lesions in slaughtered pigs was significantly associated (P<0.0001; Table 4) with increased lymphocyte count, percentage of lymphocytes and blood glucose concentration.

Effects of carcass lesion severity on performance indices, carcass composition and meat quality traits of slaughtered pigs are reported in Table 5. Irrespective of severity, the presence of carcass lesions in slaughtered pigs was significantly associated (P<0.0001) with increased average lifetime daily weight gain, live weight, hot carcass weight and cold carcass weight.

The presence of severe carcass lesions in slaughtered pigs was significantly associated (P<0.0001) with increased meat pH_{45min}, which led to the highest occurrence of DFD pork among the carcass lesion groups. In contrast, there was strong evidence of association (P<0.0001) between the presence of moderate carcass lesions in slaughtered pigs and decreased meat pH_{45min} and increased meat T_{45min}. Consequently, pigs having moderate carcass lesions produced the highest percentage of PSE pork (P<0.0001). On the other hand, pigs without carcass lesions produced the highest percentage of normal pork (P<0.0001).

Discussion

The prevalence of carcass lesions in slaughtered pigs in the Republic of Serbia was established for the first time in this study. The overall prevalence of carcass lesions (70.28%) recorded in the present study was lower than those obtained in Spain (89.00%, Guàrdia et al., 2009) and in Brazil (83.00%; Dalla Costa et al., 2007), but was higher than prevalences recorded in five European countries (United Kingdom, Denmark, Portugal, Italy and The Netherlands) (63.00%; Warriss et al., 1998). However, the prevalence of severe carcass lesions (40.28%) detected in this study was higher than results (10.00–16.60%) reported by other researchers (Gispert et al., 2000; Guàrdia et al., 2009; Warriss et al., 1998), indicating a serious welfare problem during the pre-slaughter period. For most commercial applications, severe carcass lesions are considered unacceptable, while even moderate carcass lesions may be considered unacceptable for pork destined for sensitive markets (Driessen et al., 2020 a; Faucitano et al., 2001). This would mean that in this investigation, 59.72% of the carcasses should be acceptable (carcass lesion scores 0 and 1), while only 29.72% (carcass lesion score 0) of the carcasses are acceptable for these sensitive markets. Translated to animal welfare, this would mean that 29.72% (carcass lesion score 0) of pigs were subjected to good welfare conditions, 30.00% (carcass lesion score 1) of pigs underwent acceptable but not superior welfare conditions, while 40.28% of individuals were exposed to unacceptable welfare conditions (carcass lesion score 2).

Features of carcass lesions in slaughtered animals, such as anatomical location, size, colour, shape and grade may provide information about the extent of welfare conditions during the pre-slaughter period (Strappini et al., 2012). In this study, more than half of the slaughtered pigs (50.20%) had lesions on the posterior carcass part, presumably indicating poor quality of the human–animal relationship during the pre-slaughter period. There is a possibility that most slaughtered pigs were hit by sticks or electric goads during handling, injured from slipping/falling down during loading, transportation, unloading and/or in the stunning box, or collided with facilities such as weighing box, gates, ramps and crush (Birhanu et al., 2020; Strappini et al., 2012). It is important to emphasise the presence of lesions in the posterior carcass part, irrespective of severity, has serious financial consequences (25–30% depreciated price or rejection of the cuts), given that this carcass cut is destined mainly to be processed into dry-cured ham (Arduini et al., 2014; Driessen et al., 2020 a; Harley et al., 2012).

During this investigation, significant differences were not recorded between the barrows and gilts for the prevalence of carcass lesions, which is in accordance the previous studies (Čobanović et al., 2016 a, b; D'Eath et al., 2010; Guàrdia et al., 2009). This can be ascribed to the fact that entire males are more aggressive and more sensitive to stress than gilts and castrated male pigs, especially in unstable social settings when mixed with unacquainted animals and, therefore, have a higher predisposition for pre-slaughter fights and are more prone to suffer carcass lesions and fighting-type bruises (Dokmanović et al., 2017; Teixeira and Boyle, 2014). However, some researchers (Driessen et al., 2020 b; Mota-Rojas et al., 2006; Pereira et al., 2017; Sutherland et al., 2009) found that barrows suffered more carcass lesions, especially in the anterior part, suggesting that they were more prone to fights, probably as a consequence of the greater agitation and restlessness as compared to gilts. Other authors (Dokmanović et al., 2017) reported a higher prevalence of carcass lesions in gilts, indicating that they show higher levels of fighting behaviour compared to castrated male pigs. Therefore, it can be argued that pre-slaughter conditions are important factors that affect the occurrence of carcass lesions, and, hence, various stressful situations might affect gilts and barrows differently.

The current research revealed that heavyweight pigs (121–145 kg) had the highest percentage of severe carcass lesions and lesions in the anterior carcass part. The findings of this study confirm earlier investigations (Driessen et al., 2020 a, b; Guàrdia et al., 2009; Teixeira and Boyle, 2014), that heavyweight pigs within a batch fight more with each other and are more likely to win a fight, suggesting higher risk of carcass lesions in heavier than in lighter pigs. Another possible explanation is that heavy pigs have much more sensitive skin than lighter pigs, which can be easily injured (Driessen et al., 2020 b). Hence, handling on the day of slaughter should be conducted with a great care if heavyweight individuals are included.

In the present study, higher frequencies of severe carcass lesions and lesions on the anterior and middle carcass parts were recorded in NN pigs. This could be connected with the fact that stress resistant pigs show less anxiety, higher levels of activity and pronounced exploratory behaviour, which leads to contacts with other pigs within the batch and provokes aggressive and fighting behaviour (Čobanović et al., 2019; Guàrdia et al., 2009). On the contrary, stress-carrier pigs are more fearful and less prone to explore, and, thus, infrequently come into confrontation with other conspecifics (Čobanović et al., 2019; Guàrdia et al., 2009). However, the higher percentage of lesions on the posterior carcass part recorded in Nn pigs could be, presumably, connected to their greater sensitivity to stressful situations (Čobanović et al., 2019; Guàrdia et al., 2009). Therefore, handling of Nn pigs was more difficult to perform, which led to the use of force (hitting, kicking and use of sticks and electric prods) during the pre-slaughter period, which resulted in a higher occurrence of lesions on the posterior carcass part (Čobanović et al., 2019; Fàbrega et al., 2004; Guàrdia et al., 2009).

In this study, the highest percentages of severe lesions and lesions on the anterior and posterior parts of the carcass were recorded in pigs exposed to low loading density (>0.50 m^2/100 kg). In the case of low loading density combined with poor road surfaces and/or careless driving, which consists of sudden acceleration and, hence, violent braking, pigs experience difficulties in standing up, lose balance, topple, slip and use excessive corrective muscular action, resulting in falling, trampling, knocks against the body and the occurrence of skin lesions (Driessen et al., 2020 a, b; Pereira et al., 2017; Sionek and Przybylski, 2016). Also, when the lorry comes to a halt, pigs exposed to low loading density are no longer occupied by keeping themselves balanced, but redirect their attention to their pen mates to fight out a new dominance hierarchy, which further increases carcass lesion scores (Driessen et al., 2020 c). Contrarily, overcrowding during transportation prevents the pigs from lying down, so they disturb each other to find a space to rest, which causes fighting and mounting between pigs, leading to injuries on the shoulder and back with teeth and the forelimb hoofs (Faucitano et al., 2001; Pereira et al., 2017; Sionek and Przybylski, 2016), which can explain the highest percentages of severe lesions and lesions on the anterior and middle parts of the carcass in pigs exposed to high loading density (<0.35 m^2/100 kg). According to the results of this study, the high risk of carcass lesions is related to both high (<0.35 m^2/100 kg) and low (>0.50 m^2/100 kg) loading densities, and, therefore, it is recommended to work with medium loading density (0.40–0.45 m^2/100 kg), such as those suggested by the European Union (EU) regulations (European Commission, 2005). Several loading densities during pig transportation are proposed in different parts of the world: 0.425 m^2/100 kg in the EU and Ireland, 0.33 m^2/pig in the United States, 0.36 m^2/100 kg in Canada, New Zealand and Australia, 0.30 m^2/100 kg in South Africa and 0.40 m^2/100 kg in Brazil (Bench et al., 2008; Pereira et al., 2017). To date, firm agreement has not been reached on how much loading density should change according to extreme weather conditions, pig live weight and transportation time to ensure transport economy, animal welfare, and especially high carcass and pork quality. Accordingly, further investigations are needed to determine the optimal loading densities under different transport conditions.

Despite the fact that transportation time influenced carcass lesions in previous studies (Arduini et al., 2014, 2017; Mota-Rojas et al., 2006; Sutherland et al., 2009; Warriss et al., 1990), no association between transportation time and carcass lesions was measured in the present study. The most probable reason for the discrepancy with the before-mentioned investigations is the small difference between our long (on average 230±23.56 min) and short (on average 55.36±4.44 min) transportation, indicating that slightly prolonged transport duration did not increase the risk of carcass lesions occurring.

The present investigation found the highest percentage of severe lesions and lesions on the anterior carcass part in pigs after long lairaging (>16 h). The obtained results could be attributed to longer fasting periods in those groups of pigs (>40 h), which together with prolonged lairaging, leads to a considerable increase in the fighting extent and degree of social dominance assertion, especially after commingling with unfamiliar pigs, which contribute to increased prevalence of carcass lesions and lesions on the anterior part (Bottacini et al., 2018; Dokmanović et al., 2017; Driessen et al., 2020 a; Faucitano, 2010). In addition, the highest percentages of severe lesions and lesions on the anterior carcass part were recorded in pigs subjected to low lairage density (>1 m^2/pig). This can be attributed to the fact that the supply of pigs to the abattoir is sometimes unsatisfactory for several hours, leading to a decreased number of pigs in lairage pens (Driessen et al., 2020 a). In such case, the intensity of fighting behaviour increases due to the greater possibility of pigs coming into contact with other pen mates, which contributes to the occurrence of carcass lesions (Weeks, 2008). The highest occurrence of lesions on the middle carcass part was detected in pigs exposed to high lairage density (<0.45 m^2/pig). In overcrowded lairage pens there is continuous disturbance from other pigs, resulting in the impossibility of pigs to avoid an attack by an aggressor and/or by the forelimb hoofs during pig's mounting behaviour, leading to the occurrence of lesions on the middle and posterior carcass parts (Driessen et al., 2020 a; Faucitano et al., 2001). Based on the results of this study, the high risk of carcass lesions is related to both high (<0.45 m^2/pig) and low (>1 m^2/pig) loading densities, and, therefore, it is suggested medium lairage density (0.65–0.80 m^2/pig) be used. The prevalence of carcass lesions during lairaging can be reduced by keeping pigs in smaller contained batches, by optimising lairaging density and by limiting the lairage time at the abattoir.

The prevalence of carcass lesions showed a seasonal pattern, with the lowest occurrence observed in springtime and peaks occurring in winter. The greater prevalence of carcass lesions during winter is linked with more frequent standing behaviour during transportation, to avoid contact with the cold lorry floor or walls, combined with the slipperiness of wet (un)loading ramps and lorry floors (Arduini et al., 2014; Bottacini et al., 2018; Scheeren et al., 2014). These inappropriate conditions may result in pigs losing their balance during handling and/or careless driving, resulting in a higher occurrence of carcass lesions due to trampling or falls (Scheeren et al., 2014). Likewise, when kept in cold ambient, pigs will bunch or pile up together for warmth to reduce heat loss, which protects them from cold (Dalla Costa et al., 2007; Gosálvez et al., 2006; Guàrdia et al., 2009). However, grouping behaviour decreases the available floor space in the lorry/lairage pens, which leads to fights or higher frequencies of pigs climbing over the backs of their pen mates to find some room to lie down and rest, resulting in the higher number of carcass lesions (Dalla Costa et al., 2007; Gosálvez et al., 2006; Guàrdia et al., 2009). Furthermore, because of increased body weight in winter due to more feed intake in accordance with lower temperatures than in summer, pigs were more difficult to handle, and thus, more coercion was needed at loading, unloading and through the lairage raceways, which leads to more carcass lesions (Arduini et al., 2014; Dalla Costa et al., 2007; Scheeren et al., 2014). In contrast, the low prevalence of carcass lesions in spring can be ascribed to more careful pre-slaughter handling to decrease the risk of transportation mortality at higher ambient temperatures (Arduini et al., 2014). Contrary to the previous findings, several studies (Arduini et al., 2017; Correa et al., 2014; Driessen et al., 2020 a) reported higher prevalences of carcass lesions in summer. During hot and wet ambient conditions and high stocking density, pigs are more active, irritated and, thus, prone to hits against loading, unloading and lairage facilities, because they cannot find a place to cool down, which leads to increased aggression, even between well-acquainted individuals, resulting in higher number of carcass lesions in summer (Arduini et al., 2017; Driessen et al., 2020 b). The observed differences between the studies indicate the existence of multifactorial influence of the slaughter season on the carcass lesion occurrence with confounded and unknown factors, and so they are not easy to disentangle. Therefore, the precise aetiology of carcass lesions during different slaughter seasons is still unclear.

Haematological analysis revealed that the presence of moderate carcass lesions in slaughtered pigs resulted in an elevated lymphocyte count, percentage of lymphocytes and blood glucose concentration, which were outside the normal ranges for the species (Table 4). This can be connected with epinephrine-induced alterations within minutes following its release manifested by a temporary increase in white blood cells and with lymphocytosis and catecholamine-mediated glycogenolysis as a response to acute stressful conditions in pigs (Čobanović et al., 2017). In contrast, chronic stressful stimuli induce the anterior pituitary gland to produce adrenocorticotropic hormone, which stimulates the adrenal cortex to secrete glucocorticoids, resulting in the increased leukocyte count in conjunction with increased neutrophil and eosinophil count and decreased lymphocyte count, which can be seen several hours after their liberation (Koomkrong et al., 2017). Thus, a typical response to corticosteroids with increased number of white blood cells, neutrophils and neutrophil/lymphocyte ratio, can be seen in pigs with severe carcass lesions. In addition, longer-lasting stresses, such as inadequate pre-slaughter conditions, decrease the concentration of blood glucose, because pigs are exhausted due to increased physical activity (Grandin, 2013), which can explain the lowest blood glucose level being found in pigs with severe carcass lesions. Changes in erythrocyte count, haemoglobin concentrations and haematocrit in pigs with severe carcass lesions indicate adaptation or resistance condition, in which pigs, after experiencing a longer-lasting severe stress, need plenty of oxygen-carrying capacity of blood (Čobanović et al., 2017). In such case, the spleen, as a reservoir of erythrocytes, contracts and releases erythrocytes into the circulation, which provides the skeletal muscles with a large number of oxygenated red blood cells, allowing the pig to increase physical activity (Čobanović et al., 2017). On the other hand, in slaughtered pigs free of carcass lesions, all blood measurements were in the ranges considered normal for slaughter pigs, except for MCV and MCHC which were close to the basal levels for the species (Table 4), suggesting that those pigs were not under stress. The results of the analysed haematological parameters suggest that pigs with moderate carcass lesions experienced intense acute pre-slaughter stress, while pigs with severe carcass lesions were under chronic stress. Accordingly, it may be argued that in both cases, pig welfare was seriously endangered.

The performance results and carcass composition analysis revealed that pigs with carcass lesions, irrespective of severity, had the highest average lifetime daily weight gain, live weight, hot carcass weight and cold carcass weight. Even though exact times when carcass lesions occurred (freshness) were not evaluated in this study, all lesions were red coloured, indicating recent (acute) changes contracted during pre-slaughter treatment, which might help explain the difference in performance indices and carcass weights. Therefore, the results of this study can be explained by the fact that heavyweight pigs express a higher level of fighting behaviour and consequently have a higher number of carcass lesions (Teixeira and Boyle, 2014), as already mentioned before. In contrast, other studies (Carroll et al., 2016; Coutellier et al., 2007) reported that the presence of carcass lesions is associated with changes in the stress physiology and carcass composition traits of slaughter pigs. Chronic (old) skin lesions in slaughter pigs, contracted during the growing-finishing period on the farm, are associated with decreased feed intake, daily weight gain and growth rate due to the influence of infection and stress, resulting in reduced carcass weight and financial loss to pig producers (Carroll et al., 2016). Another theory is that reduced live and carcass weight of pigs with carcass lesions resulted from greater energy loss rather than being impeded by the production performance of slaughter pigs in terms of lower feed intake and average daily gain (Coutellier et al., 2007; Driessen et al., 2020 b).

Pork quality analysis revealed that pigs with severe carcass lesions produced the lowest meat quality in terms of the highest pH_{45min} and prevalence of DFD meat. It is likely that severe physical injuries in slaughtered animals resulted in chronic pre-slaughter stress and in the depletion of muscle glycogen reserves prior to slaughter (Cruz-Monterrosa et al., 2017; Faucitano et al., 2001; Strappini et al., 2010). In pigs with severe carcass lesions production of lactic acid is limited by the low levels of glycogen, preventing the meat pH decrease, and so leading to abnormally high pH and increased DFD pork incidence (Čobanović et al., 2016 b; Faucitano et al., 2001; Guàrdia et al., 2009). Hence, in pigs with severe carcass lesions, the meat tends to have poor technological characteristics (increased pH and water holding capacity, darker colour and lower tenderness) and has a greater ability to support bacterial growth than normal quality meat (Faucitano et al., 2001). Consequently, such meat decomposes and spoils more rapidly and is not suitable for longer storage (Birhanu et al., 2020; Cruz-Monterrosa et al., 2017).

On the other hand, the presence of moderate carcass lesions in slaughtered pigs resulted in the lowest pH_{45min} and the highest T_{45min} and percentage of PSE pork. It can be hypothesised that moderate carcass lesions resulted in acute pre-slaughter stress, so the pigs were not so exhausted and their skeletal muscles had enough glycogen reserves (Čobanović et al., 2016 a). This contributes to elevated generation of lactic acid through the anaerobic metabolism combined with its lower evacuation, which decreases meat pH and increases meat temperature (+1°C), thus resulting in the production of PSE pork (Čobanović et al., 2016 a). The association with different pork quality classes confirmed previous findings (Guàrdia et al., 2009) that carcass lesions can be considered as a proxy indicator for acute and chronic pre-slaughter stress. Hence, if carcass lesions occur at an earlier time, higher meat pH and, thereby, higher DFD pork prevalence might be expected with increasing degree and extent of carcass lesions (Guàrdia et al., 2009). On the other hand, if carcass lesions occur shortly preceding the slaughter, then they lead to a fast pH drop and development of PSE pork (Čobanović et al., 2016 b; Guàrdia et al., 2009). Therefore, it can be argued that meat obtained from pigs having carcass lesions was of a lower quality class and might not meet the high quality standards for market placement.

Conclusions

This study showed a high prevalence of carcass lesions, especially severe carcass lesions, indicating suboptimal welfare conditions during the pork production chain and highlighting the need for the Serbian pork industry to improve pre-slaughter treatment of animals. Based on the results of this study, the following five main problems that increase the risk of carcass lesions during pre-slaughter management in order of significance were identified: i) poor handling practice of slaughter pigs from farm to abattoir (shown by the 50.20% individuals with lesions in the posterior carcass part); ii) fighting behaviour probably due to mixing of unacquainted conspecifics (shown by the 32.80% of slaughtered pigs with lesions in the anterior carcass part); iii) inadequate transportation (too high and too low loading density); iv) inadequate lairage conditions (prolonged lairage time and too high and too low lairage density); v) adverse weather conditions (slaughtering in winter season). The animal characteristics, such as RYR1 genotype and live weight at slaughter, also contribute to the development of carcass lesions in slaughtered pigs. In addition, the presence of carcass lesions, irrespective of severity, was associated with alterations in blood measurements in slaughtered pigs, indicating compromised animal welfare. Furthermore, the presence of moderate (the lowest pH_{45min} and the highest T_{45min} and prevalence of PSE pork) and severe (the highest pH_{45min} and prevalence of DFD pork) carcass lesions in slaughtered pigs was significantly associated with deterioration in meat quality.

It can, therefore, be concluded that the recording of carcass lesions in slaughtered pigs has potential to serve not only as a reliable measure of pig welfare during the pre-slaughter period, but can also be used as a rapid indicator of pork quality. Hence, carcass lesion monitoring at the abattoir should be included in routine postmortem inspection procedures of slaughtered pigs as a complementary tool to identify critical points along the pork production chain. Providing a good feedback system of the results of carcass lesions in slaughtered pigs from the abattoirs to the farmers and transporters could contribute to the development, adaptation and implementation of preventive measures (training programme for transporters and animal handlers, dissemination process of current laws, an incentive policy for pig producers, a decrease of lairage time, optimisation of loading and lairage density, improvement of farm, transport and abattoir infrastructure), which in turn would improve pig welfare standards and carcass and pork quality important for the economic aspect and consumer satisfaction. Additional research is necessary to further understand the relationships between the presence and severity of carcass lesions in slaughtered pigs and alterations in the biochemical indicators, growth performance and carcass and meat quality and to determine their potential causal effects.

Acknowledgment

The study was supported by the Ministry of Education, Science and Technological Development of the

Republic of Serbia (Contract number 451-03-68/2022-14/200143).

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Received: 6 III 2022
Accepted: 30 XI 2022