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Research Article

The Effect of PSE and Non-PSE *Adductor* and *Semimembranosus* Pig Muscles on the Occurrence of Destructured Zones in Cooked Hams

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The aim of this study was to analyse pig muscles used in the production of cooked hams with a view to the occurrence of PSE-type defects and their potential effect on the frequency of destructured zones in finished products. One hundred and six samples of *m. adductor* (AD) and *m. semimembranosus* (SM) pig muscles were studied. The two kinds of muscle differed from each other in terms of their pH values and colour (L^*: lightness, a^*: redness, and b^*: yellowness); these differences between the two categories were statistically significant ($P < 0.001$). The AD muscles were divided into meat with PSE (pale, soft, and exudative) defects and non-PSE meat by sensory examination. A total of 44.3% of AD muscles showed PSE defects. Lightness L^* fell within a range of 50.68–55.23 in non-PSE meat (AD) and was statistically significantly lower ($P < 0.001$) than in PSE meat (56.25–58.78). Drip loss (AD) was higher ($P < 0.001$) in PSE meat (4.83–6.27%) than in non-PSE meat (3.53–5.0%). Cooked hams prepared from pig muscles showed evident destructured zones when sliced, the number and overall area of which were not affected by the occurrence of PSE defects in the raw meat used.

1. Introduction

Cooked hams are popular meat products in Europe and throughout the world [1–3]. The basic raw meat used in the production of cooked hams is pork leg which is comprised of a number of anatomically different muscles.

PSE (pale, soft, and exudative) defects are most commonly encountered in pork meat [4]. PSE defects cause a serious economic problem in the production of cooked hams [5–7]. Efforts have been made for a number of years to reduce the occurrence of PSE meat and to find reliable indicators (pH, colour, texture, electrical conductivity, etc.) that would make it possible to identify such defects before processing. Final products with improved properties that are acceptable to the consumer can be obtained by separating PSE meat from defect-free meat showing the standard parameters of fresh meat [4].

In the European Union, primarily in its eastern part, meat processors import pork from abroad. This has significant disadvantages, including great variability in the quality of the pork and the difficulties associated with checking quality at the slaughterhouse immediately after slaughter. The application of the routine analytical methods used for the classification of PSE meat defects is debatable when imported meat can be examined around 72 hours postmortem at the earliest, the principal reason being that the majority of parameters such as pH, colour, and drip loss are determined within one and/or 24 hours postmortem [8–11].

Deviations in meat quality may appear in cooked hams in the form of destructured zones [6, 12–15] and have been a fundamental problem for meat processors in recent decades [16, 17]. The occurrence of destructured zones differs according to various authors and between individual countries [12, 14, 18]. Destructured zones are described as "pale, soft, and exudative" zones inside cooked ham that are unsuitable for mechanical slicing after cooking in view of their impaired consistency [15].

Modern methods including image analysis are currently used for the evaluation of foodstuffs. The advantages of these methods are noninvasive acquisition of information from spatially complex samples [19–21] and this information can be obtained when analyses are based on a single photo [22]. Image analysis can substitute for many expensive and time-consuming laboratory methods [23] and is often used to establish correlations between parameters obtained by image analysis and physicochemical methods [24].

Image analysis has been applied in many studies for the quality evaluation of meat and meat products [25–27]. Faucitano et al. [28] used it to determine the amount of fat in meat, while Nam et al. [10], Bañón et al. [8], and Warriss et al. [29] used it to detect PSE meat. Valous et al. [30] utilised image analysis as a quantitative descriptor in the evaluation of texture in cooked ham slices.

The aim of this study was to perform an analysis of AD and SM pig muscles (topside muscles) used in the production of cooked hams with a view to the occurrence of PSE-type defects and their potential effect on the frequency of destructured zones in cooked hams. Image analysis was used to examine cooked hams for the occurrence of destructured zones in the second part of the study. The correlation between the frequency of destructured zones in cooked hams and PSE defects in meat used in their preparation was then determined.

2. Materials and Methods

2.1. Meat Samples. Selected quality traits in AD and SM pig muscles from six foreign suppliers: R (BE), S (AT), T (DE), U (DE), V (DK), and Z (NL) were assessed 72 hours postmortem. The meat was tested using subjective and objective (instrumental) methods. Sensory tests were performed by three experienced evaluators who adjudged meat colour, water binding capacity, and texture. Pork Quality Standards [31] were used for the subjective evaluation. All evaluators had to agree on sample classification. The meat was divided into two groups, the first group showing signs of PSE (PSE-inclined) and the second being non-PSE meat (standard, normal quality) on the basis of this sensory assessment. Evaluation was also performed using instrumental methods (colour in the CIEL$^*a^*b^*$ system, texture using a Warner-Bratzler test) and pH and drip loss values were measured. Twenty AD and 20 SM muscles from each supplier were tested, with the exception of supplier U, from which only 6 muscles were tested. A total of 106 AD and 106 SM muscles were tested. The values of pH, colour (L^*, a^*, b^*), drip loss, and texture by Warner-Bratzler were determined for AD muscle and the values of pH and colour (L^*, a^*, b^*) for SM muscle.

2.2. Measurement of pH and Meat Colour. Measurement of pH value and meat colour was performed in the cutting room at a production plant. The pH value was measured using a WTW pH 340i (WTW GmbH, Weilheim, Germany) pH meter with a Double Pore needle probe (Hamilton Bonaduz AG, Bonaduz, Switzerland). The instrument was calibrated to pH 4 and pH 7 before measurements were taken. The pH value was determined at two different places in the core of each muscle (AD, SM). Colour was instrumentally measured by the CIEL$^*a^*b^*$ system using a Minolta CM-2600d spectrophotometer (Konica Minolta, Osaka, Japan) on the cut of raw meat samples. The instrument was calibrated on a white reference plate. Each sample was measured in triplicate with an aperture opening of 8 mm, 10° viewing angle, and D65 illuminant. L^*, lightness, a^*, redness, and b^*, yellowness, were calculated using available software (Spectra Magic 3.61).

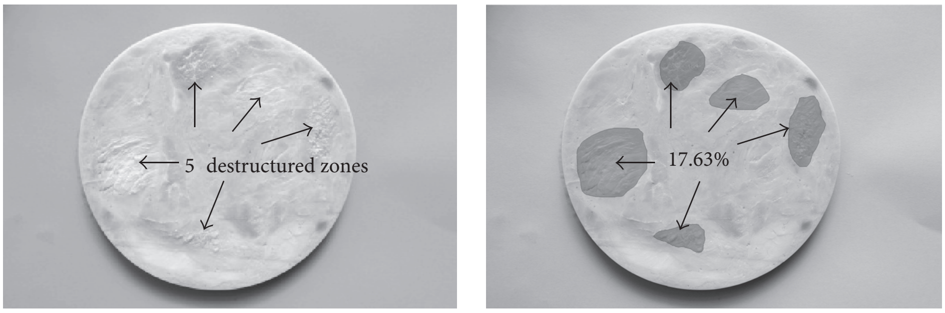
2.3. Drip Loss and Texture Determination Using a Warner-Bratzler Test. The drip loss of AD samples was determined by Honikel [32]. Samples (100 g ± 0.01 g) were placed in polyethylene bags and stored flat for 24 hours in a refrigerator at approximately $5 \pm 2^\circ$C and weighed again. Percent drip loss was calculated using the following formula:

$$\text{Drip loss} = \frac{m_1 - m_2}{m_1} \times 100\,[\%], \tag{1}$$

where m_1 is weight before refrigerated storage and m_2 is weight after refrigerated storage.

The objective measurement of texture was performed using a Warner-Bratzler test (W-B) on an INSTRON 5544 system (Instron Corporation, Norwood, USA). Meat texture was evaluated in raw samples [33] of 1 cm × 1 cm × 2.5 cm in size to assess the maximum shear force (N) of the meat. The specimen was sheared perpendicularly to the muscle fibres at a constant speed of 50 $\text{mm}\cdot\text{s}^{-1}$ and then pushed through the slot. Six determinations were performed for each raw sample.

2.4. Production of Cooked Hams. Two groups of cooked hams (PSE CH and STANDARD CH) were produced from the meat of three selected suppliers (U, V, and Z). The meat was injected (Metalquimia, Girona, Spain) with brine at a quantity of 13% of the meat by volume. The composition of the brine was water and Naturham (Natura Food Additives, Havlíčkův Brod, Czech Republic) containing phosphates, dextrose, sodium ascorbate, and carrageenans. The proportion of nitrite curing salt (0.5% $NaNO_2$) was 2.0% in the finished product. The injected meat was tumbled 20 minutes at 4°C, under a vacuum in a VSM-CC tumbler (GLASS GmbH & Co. KG, Paderborn, Germany), rested for 12 hours at 2°C, filled into technological packing (PA/EVOH/PA/PE bags with oxygen transmission rate $< 5\,\text{cm}^3/\text{m}^2/24\,\text{h}/23^\circ\text{C}$) by hand, vacuum packed (S 223, VAC-STAR, Pardubice, Czech Republic), put into the mould (internal length 220 mm; internal diameter 150 mm) and cooked (core temperature 70°C/10 minutes) in a Convotherm (OSP, Eglfing, Germany), and cooled to 2°C. The weight of each ham was 3 kg. A total of



(a) (b)

Figure 1: The cut surface of a cooked ham with determination of the number of destructured zones (a) and the total area of these zones (b).

nine cooked hams were prepared from meat classified as PSE and nine cooked hams made from standard meat (non-PSE).

2.5. Image Analysis of Cooked Hams. Samples of cooked hams were cut into slices 1.5 cm thick × 15.0 cm in size on which the number and extent of destructured zones were evaluated. The occurrence of destructured zones was evaluated in 20 slices of STANDARD CH and 20 slices of PSE CH using image analysis under daylight conditions (overcast, 6000–6200 K). The camera was mounted above the sample with a focal distance of 25 cm. To ensure uniform conditions, a calibrated 30 cm ruler was used (KINEX, CSN251125, Czech Republic). Photographs of the slices of cooked ham were taken with a Canon EOS 450 D camera (Canon, Tokyo, Japan) in daylight, contrast blue background, and standard camera settings (MANU, ISO 100, shutter speed 1/100, aperture F 6.3, RAW format). The photographs were subsequently analysed in the program Adaptive Contrast Control Structure and Object Analyser version 6.1, Sofo-ACC (Brno, Czech Republic). In the first step, the number of destructured zones was calculated (Figure 1(a)). The total area of the cooked ham slice on the photograph (100%) was then determined automatically from the contrast in colour of the background and the cooked ham slices. Destructured zones were delineated (Figure 1(b)) and their total area on each slice was calculated in % of the total sample area using ACC tools.

2.6. Statistical Evaluation. The results obtained were processed statistically in the program Statistica CZ 7 (Statsoft, Prague, Czech Republic). Differences in muscles (*m. adductor* and *m. semimembranosus*) from different suppliers (R, S, T, U, V, and Z) and between PSE meat and non-PSE meat in colour (L^*, a^*, and b^*), pH, drip loss, and texture were compared using one-way ANOVA with a post hoc Tukey HSD test ($P < 0.05$, 0.01, and 0.001). The parameters were subjected to a correlation analysis (Pearson's coefficient and Goodman and Kruskal's gamma coefficient for the appearance of PSE) in order to determine potential statistical relationships.

The data related to the occurrence of destructured zones was processed statistically using an independent two-sample t-test ($P < 0.05$). Differences in the number and area of destructured zones between cooked hams made from meat identified as non-PSE (STANDARD CH) and meat identified as PSE (PSE CH) were compared.

3. Results and Discussion

3.1. PSE and Non-PSE AD and SM Pig Muscles. The physicochemical traits are given in Table 1. A pH value within a range of 5.43–5.59 in AD and 5.52–5.80 in SM ($P < 0.001$) was measured in the meat from all suppliers. Our results differ from those published by Hugenschmidt et al. [15] who measured a higher pH in AD (5.49–6.16) than in SM (5.45–5.83) 72 hours postmortem. Bucko et al. [34] reported pH values 24 hours postmortem (pH_{24}) of 5.72 in AD and 5.73 in SM, with no significant difference between the individual muscles. Weschenfelder et al. [35] measured a pH_{24} of 6.07 in AD muscle and 5.69 in SM muscle.

Similar to pH values, the values of lightness L^* ($P < 0.001$), a^* ($P < 0.001$), and b^* ($P < 0.001$) also differed between AD and SM (Table 1). Lightness L^* values measured in SM in this study were similar to those reported by Scheier et al. [36] who measured an average L^* value of 48.1 after 24 hours postmortem in SM. Similar values of a^* were recorded in SM (5.99–8.04) as in AD (3.85–8.73). Texture differed in AD from individual suppliers. The greatest value of shear force was measured in samples from supplier S (103.27 N), the lowest from supplier Z (63.36 N). Minimal differences between suppliers were observed in relation to the values of drip loss in AD muscle ($P > 0.05$).

Table 2 shows the values of colour (L^*, a^*, and b^*), pH value, texture according to the Warner-Bratzler test, and drip loss in AD muscles classified as non-PSE and PSE, indicating that PSE defects were identified in 47 samples (44.3%). Some pieces of pork meat were extremely light in colour, even pink, and looked rather like fish muscle. A texture of a spongy nature was found when the piece of muscle was squeezed. Our results indicate an occurrence considerably higher than that given in the literature which states an occurrence of PSE of 2–30% [11, 37].

Clear differences in the values measured for non-PSE and PSE meat can be seen in Table 2 for all suppliers. Lightness L^* fell within a range of 50.68–55.23 for non-PSE meat and was statistically significantly lower ($P < 0.001$) than for meat with PSE defects which ranged from 56.25 to 58.78. Values of pH differ between PSE (5.40–5.47) and non-PSE (5.45–5.71) meat ($P < 0.001$). The drip loss supports the sensory identification of PSE meat. Drip loss was higher in PSE meat which showed

Table 1: Physical properties of *m. adductor (AD)* and *m. semimembranosus (SM)* (mean ± SD). The colour of *m. adductor (AD)* and *m. semimembranosus (SM)* was measured by the CIELAB system, the pH value was detected 72 hours p.m. by pH meter with a Double Pore needle probe, the Warner-Bratzler test (W-B) was performed on an INSTRON 5544 instrument, and drip loss was evaluated using polyethylene bag and filter paper.

Supplier	Muscle	L^*	a^*	b^*	pH	W-B (N)	Drip loss (%)
R	AD	56.12 ± 2.78	$8.37^{B} \pm 2.49$	$15.19^{B} \pm 2.71$	$5.44^{A} \pm 0.08$	$94.35^{A} \pm 15.48$	4.71 ± 1.17
($n = 20$)	SM	$46.57^{a,b,c} \pm 2.49$	$7.83^{a} \pm 1.56$	10.40 ± 1.28	$5.52^{a} \pm 0.12$	—	—
S	AD	55.81 ± 2.56	$6.24^{A,B} \pm 2.99$	$13.47^{B} \pm 2.82$	$5.43^{A,B} \pm 0.06$	$103.27^{A} \pm 9.97$	5.12 ± 1.65
($n = 20$)	SM	$47.56^{a,b,c} \pm 3.59$	$6.85^{a,b} \pm 1.68$	$10.12^{a} \pm 2.06$	$5.56^{a,b} \pm 0.12$	—	—
T	AD	57.18 ± 1.83	$5.46^{A} \pm 3.14$	$13.81^{B} \pm 2.59$	$5.46^{A,B} \pm 0.11$	$67.70^{B} \pm 9.61$	5.07 ± 1.42
($n = 20$)	SM	$48.53^{a,b,c} \pm 3.02$	$5.72^{b} \pm 2.51$	10.14 ± 2.33	$5.57^{a,b} \pm 0.19$	—	—
U	AD	54.03 ± 3.52	$5.33^{A} \pm 1.44$	$12.31^{A} \pm 1.75$	$5.59^{B} \pm 0.17$	$86.25^{A} \pm 8.52$	4.81 ± 1.34
($n = 6$)	SM	$42.91^{a} \pm 2.15$	$6.75^{a,b} \pm 0.90$	8.63 ± 0.90	$5.80^{b} \pm 0.24$	—	—
V	AD	55.01 ± 2.97	$4.63^{A} \pm 2.29$	$12.78^{A} \pm 2.08$	$5.49^{A,B} \pm 0.10$	$98.08^{A} \pm 12.85$	5.27 ± 1.58
($n = 20$)	SM	$43.83^{a} \pm 2.91$	$6.92^{a,b} \pm 1.38$	$8.83^{b} \pm 0.90$	$5.64^{a,b,c} \pm 0.20$	—	—
Z	AD	56.29 ± 2.94	$4.03^{A} \pm 2.01$	$12.25^{A} \pm 1.71$	$5.46^{A} \pm 0.09$	$63.36^{B} \pm 13.89$	4.78 ± 0.75
($n = 20$)	SM	$46.24^{a,b,c} \pm 2.83$	$6.46^{a,b} \pm 1.87$	9.70 ± 1.18	$5.56^{a,c} \pm 0.18$	—	—

^{A,B}Different letters in the same column show statistically significant differences between individual suppliers ($P < 0.05$) for AD muscles. ^{a,b,c}Different letters in the same column show statistically significant differences between individual suppliers ($P < 0.05$) for SM muscles. L^*: lightness, a^*: redness, b^*: yellowness, W-B: Warner-Bratzler test-maximum shear force, AD: *m. adductor*, and SM: *m. semimembranosus.*

Table 2: Physical properties of *m. adductor* muscle identified as PSE and non-PSE (mean ± SD). The colour of *m. adductor (AD)* was measured by the CIELAB system, the pH value was detected by a pH meter with a Double Pore needle probe, the Warner-Bratzler test (W-B) was performed on an INSTRON 5544 instrument, and drip loss was evaluated using a polyethylene bag and filter paper.

Supplier	PSE/ non-PSE	n	L^*	a^*	b^*	pH	W-B (N)	Drip loss (%)
R	Non-PSE	10	$54.85^{A} \pm 2.80$	8.01 ± 2.72	14.34 ± 2.90	5.45 ± 0.09	90.74 ± 18.07	4.59 ± 1.27
	PSE	10	$57.40^{B} \pm 2.10$	8.73 ± 2.18	16.04 ± 2.19	5.42 ± 0.08	97.95 ± 11.26	4.83 ± 1.06
S	Non-PSE	11	$54.47^{A} \pm 2.45$	5.08 ± 2.58	$12.14^{A} \pm 2.32$	5.45 ± 0.06	101.02 ± 9.96	$4.31^{A} \pm 1.10$
	PSE	9	$57.46^{B} \pm 1.50$	7.65 ± 2.86	$15.09^{B} \pm 2.53$	5.40 ± 0.04	105.77 ± 9.37	$6.10^{B} \pm 1.68$
T	Non-PSE	11	56.68 ± 2.10	5.87 ± 2.88	13.96 ± 2.83	5.49 ± 0.13	67.79 ± 10.81	5.01 ± 1.67
	PSE	9	57.80 ± 1.17	4.96 ± 3.36	13.61 ± 2.25	5.43 ± 0.06	67.58 ± 7.89	5.13 ± 1.04
U	Non-PSE	3	$50.68^{A} \pm 1.38$	4.37 ± 1.14	10.72 ± 0.69	5.71 ± 0.17	92.75 ± 4.15	$3.53^{A} \pm 0.41$
	PSE	3	$57.39^{B} \pm 0.59$	6.29 ± 1.00	13.90 ± 0.77	5.47 ± 0.04	79.75 ± 6.60	$6.09^{B} \pm 0.36$
V	Non-PSE	10	53.76 ± 3.25	3.85 ± 2.05	11.95 ± 1.98	5.55 ± 0.09	95.27 ± 13.32	$4.26^{A} \pm 1.26$
	PSE	10	56.25 ± 1.99	5.41 ± 2.25	13.60 ± 1.84	5.42 ± 0.04	100.90 ± 11.71	$6.27^{B} \pm 1.16$
Z	Non-PSE	14	$55.23^{A} \pm 2.70$	4.10 ± 1.70	11.89 ± 1.53	5.48 ± 0.10	66.21 ± 14.28	4.70 ± 0.67
	PSE	6	$58.78^{B} \pm 2.13$	3.87 ± 2.71	13.11 ± 1.92	5.42 ± 0.06	56.72 ± 11.66	4.97 ± 0.93

L^*: lightness, a^*: redness, b^*: yellowness, and W-B: Warner-Bratzler test-maximum shear force. ^{A,B}Different letters in the same suppliers show statistically significant differences between non-PSE and PSE ($P < 0.05$).

a range of 4.83–6.27% than in non-PSE meat, with a range of 3.53–5.01% ($P < 0.001$) for all suppliers.

The values of L^*, a^*, and b^* and pH in SM are given in Table 3. The values of lightness L^* in SM fall within a range of 44.00–49.38 in PSE meat and 41.82–47.84 in non-PSE meat ($P < 0.001$).

The results of the measurements taken by instrumental and physical methods correlate statistically significantly with the subjective classification of AD muscles into the PSE group (Table 4). A significant negative correlation between the values of L^* ($r = -0.449, P < 0.01$), b^* ($r = -0.321, P < 0.01$), and drip loss ($r = -0.371, P < 0.01$) and a positive correlation with the pH value ($r = 0.355, P < 0.01$) were recorded in PSE meat from AD. A significant positive correlation between PSE and lightness L^* ($r = 0.345$, $P < 0.01$) and b^* ($r = 0.202$, $P < 0.05$) and a negative correlation between PSE and pH ($r = -0.352, P < 0.01$) were recorded in SM.

Meat is most often classified as PSE by drip loss and the values of lightness L^* and pH, though various authors state differing threshold values. Identification of PSE defects is most commonly determined in m. longissimus [4, 11, 38, 39]. There are not so many studies in the literature concerning the

Table 3: Physical properties of *m. semimembranosus* muscle identified as PSE and non-PSE (means ± SD). The colour of *m. semimembranosus (SM)* was measured by the CIELAB system; the pH value was detected by a pH meter with a Double Pore needle probe.

Supplier	PSE/non-PSE	n	L^*	a^*	b^*	pH
R	Non-PSE	10	45.53 ± 2.31	8.04 ± 1.58	10.00 ± 1.28	5.54 ± 0.14
	PSE	10	47.61 ± 2.21	8.04 ± 1.58	10.80 ± 1.14	5.50 ± 0.09
S	Non-PSE	11	46.39 ± 3.49	6.76 ± 1.42	9.78 ± 1.76	5.59 ± 0.13
	PSE	9	48.87 ± 3.24	6.95 ± 1.93	10.49 ± 2.30	5.53 ± 0.09
T	Non-PSE	11	47.84 ± 2.26	6.15 ± 2.59	10.07 ± 2.60	5.60 ± 0.18
	PSE	9	49.38 ± 3.57	5.18 ± 2.30	10.23 ± 1.94	5.53 ± 0.18
U	Non-PSE	3	41.82 ± 2.07	6.24 ± 1.00	8.45 ± 1.13	6.00^{a} ± 0.13
	PSE	3	44.00 ± 1.61	7.27 ± 0.31	8.81 ± 0.54	5.60^{b} ± 0.13
V	Non-PSE	10	42.17^{a} ± 2.13	6.46 ± 1.25	8.20^{a} ± 0.67	5.79^{a} ± 0.17
	PSE	10	45.50^{b} ± 2.62	7.39 ± 1.35	9.46^{b} ± 0.61	5.50^{b} ± 0.11
Z	Non-PSE	14	45.20^{a} ± 2.72	6.66 ± 2.10	9.45 ± 1.23	5.61 ± 0.19
	PSE	6	48.68^{b} ± 1.50	5.99 ± 1.31	10.26 ± 0.94	5.46 ± 0.10

L^*: lightness, a^*: redness, and b^*: yellowness. ^{a,b}Different letters for the same suppliers show statistically significant differences between non-PSE and PSE ($P < 0.05$).

Table 4: Correlation coefficients and levels of significance in PSE and physical parameters. The parameters were subjected to a correlation analysis (Pearson's coefficient) in order to determine potential statistical relationships between PSE and colour, pH, Warner-Bratzler shear force, and drip loss in *m. adductor (AD)* and *m. semimembranosus (SM)*.

	M. adductor (n = 106)						*M. semimembranosus* (n = 106)			
	L^*	a^*	b^*	pH	W-B	Drip loss	L^*	a^*	b^*	pH
a^*	0.284^{**}						0.050			
b^*	0.597^{***}	0.893^{***}					0.733^{***}	0.582^{***}		
pH	-0.447^{***}	-0.270^{**}	-0.331^{***}				-0.591^{***}	-0.364^{***}	-0.510^{***}	
W-B	−0.162	0.229^{*}	0.098	0.096			—	—	—	—
Drip loss	0.389^{***}	0.365^{***}	0.442^{***}	-0.437^{***}	0.027		—	—	—	—
PSE	-0.449^{***}	−0.190	-0.321^{***}	0.355^{***}	−0.116	-0.371^{***}	0.345^{***}	−0.005	0.202^{*}	-0.352^{***}

$^{***}P < 0.001$, $^{**}P < 0.01$, and $^{*}P < 0.05$; L^*: lightness, a^*: redness, b^*: yellowness, W-B: Warner-Bratzler test-maximum shear force, and PSE: the appearance of PSE meat.

detection of PSE in SM and AD muscles as there are regarding detection in m. longissimus. Schilling et al. [40], for example, classify PSE in AD and SM by a value of lightness L^* higher than 53 and a pH beneath 5.5. This author measured average values of L^* 57.6 and pH 5.36 for PSE and L^* 45.8 and pH 5.99 for non-PSE in AD and SM. Warriss et al. [29] measured values of lightness L^* of 46.6 for AD muscle identified as PSE and 44.6 for non-PSE. Bañón et al. [8] state values of L^* 49.2/pH 5.7 for PSE and L^* 49.4/pH 5.6 for non-PSE in SM, with the differences between PSE and standard meat being minimal. In this study, lightness L^* attains values < 50, as in the study by Bañón et al. [8], and there were differences here between PSE and non-PSE for both lightness L^* ($P < 0.001$) and pH ($P < 0.001$).

3.2. Destructured Zones in Cooked Hams. The results relating to the number and area of destructured zones in cooked hams are given in Table 5. The largest occurrence of destructured zones in STANDARD CH made from non-PSE meat was found in samples from supplier V (25.81%). The lowest occurrence was recorded in suppliers U (15.48%) and Z (18.73%). The average occurrence of destructured zones attained similar values in the second group of cooked hams, that is, PSE CH The largest occurrence of destructured zones was recorded, similarly as in the case of STANDARD CH, in supplier V (25.73%). A statistically significantly ($P < 0.01$) lower occurrence of destructured zones was recorded in suppliers U (12%) and Z (10.62%) in comparison with supplier V. When STANDARD CH were compared with PSE CH, no statistically significant difference ($P > 0.05$) was found in the occurrence of destructured zones between STANDARD CH and PSE CH made from pork from all three suppliers (U, V, and Z). The total average area (regardless of supplier) of destructured zones was 18.87% in slices of STANDARD CH and 15.09% in PSE CH ($P > 0.05$). The number of destructured zones does not always correlate with the total area of the destructured zones on the slice examined. The largest number of destructured zones was recorded in supplier Z in both groups of cooked hams — the number of destructured zones per slice was 4.2 for STANDARD CH and 3 for PSE CH — while their area was 18.73% and 10.62%, respectively. Fewer destructured zones were recorded in supplier V than in supplier Z — an average of 1.8 destructured zones per slice in STANDARD CH and 3 in PSE CH — while the area they covered was the highest in supplier V (25.73%). The average number of destructured zones in STANDARD CH and PSE

Table 5: The number and area of destructured zones (DZ) in hams (means ± S.D.). The occurrence of destructured zones was evaluated in 20 slices of STANDARD CH and 20 slices of PSE CH with the use of image analysis. The area covered by destructured zones was indicated in % on each slice and their total area on the slice.

Supplier	n (number of slices)	Area of DZ (%)		Number of DZ	
		STANDARD CH	PSE CH	STANDARD CH	PSE CH
U	10	15.48 ± 7.34	12.00 ± 9.20	2.50 ± 0.85	2.50 ± 0.85
V	5	25.81 ± 8.90	25.73 ± 5.00	$1.80 \pm 0.45^*$	$3.00 \pm 0.71^*$
Z	5	18.73 ± 6.45	10.62 ± 4.49	4.20 ± 0.84	3.00 ± 1.41
Total	20	18.87 ± 8.45	15.09 ± 9.31	2.75 ± 1.16	2.75 ± 0.97

DZ: destructured zones; STANDARD CH: cooked ham made of non-PSE meat; PSE CH: cooked ham made of PSE meat; $^*P < 0.05$.

CH from supplier U was the same at 2.5, with the area they covered being 15.48% (STANDARD CH) and 12.00% (PSE CH). When the number of destructured zones was compared in both groups of cooked hams, no statistically significant difference was found between the individual suppliers, with the exception of supplier V ($P < 0.05$), as in the case of the area of destructured zones.

Laville et al. [13] stated that destructured zones are observed most commonly in SM, AD, and *biceps femoris* muscles, while Hugenschmidt et al. [15] indicated that AD is the muscle most susceptible to the occurrence of such defects. They also stated that such defects inside the muscle cannot be seen during the visual inspection of fresh meat which may be the reason for the occurrence of destructured zones in cooked hams made from PSE meat. The classification of meat into non-PSE and PSE was based on sensory analysis. Signs of PSE were not observed on the surface of pieces of meat identified as non-PSE, though the areas inside the muscle may have been affected by changes to meat proteins that may have appeared as a destructured zone in the final product. Defects to pork meat need not be merely PSE-type defects. Altmann et al. [41] investigated 20,364 pig sides at slaughterhouses in Germany and found an occurrence of PSE defects of between 1.2 and 8.8%, though only 48.7% of the pig carcasses showed meat of good quality.

Structural defects in cooked hams often correlate with lower yields, problems with slicing, and higher water loss [16, 42]. The occurrence of destructured zones is reported differently in different European countries and by different authors. Balac et al. [12], for example, stated a 20–50% occurrence of destructured zones. Franck et al. [42] reported around 20% destructured zones in cooked hams. Hugenschmidt et al. [14] conducted research in seven meat-processing plants in Switzerland. Destructured zones appeared in 7-8% of slices of cooked ham resulting in considerable economic losses [14]. Neyrinck et al. [43] assessed 55 cooked hams following slicing, of which 79.9% were visually assessed as being of normal quality, with the presence of destructured zones being found in 29.1% of samples. Hugenschmidt et al. [15] stated that a reduced pH and the temperature immediately following slaughter may be identified in the raw muscle as an important predictor of the occurrence of destructured zones in cooked hams. The temperature immediately after slaughter, which may reach as much as 41°C, contributes directly to the development of defects in ham by means of denatured proteins.

The authors of the study believe that mechanical stress during the tumbling process acts on muscle fibres altered by the effect of biochemical processes in the early stages postmortem. These factors taken together lead to the formation of the destructured zones evident on slices of cooked hams. The extent to which these changes result from biochemical processes in the muscle fibres and the extent to which the technology itself is responsible for these changes should be the subject of further studies.

4. Conclusion

The AD and SM pig muscles differed from one another with regard to traits such as pH value and meat colour ($L^* a^* b^*$). These differences were statistically significant ($P < 0.001$) and possible to determine even 72 hours postmortem. Subjective assessment was backed up by measurement of selected meat parameters, and statistically significant differences ($P < 0.001$) were found between the two groups of meat (PSE and non-PSE) in terms of pH value, lightness L^*, and drip loss. The number and area of destructured zones in slices of cooked hams are not related to the occurrence of PSE-type defects. The number and area of destructured zones did not differ between the groups of PSE cooked hams and STANDARD cooked hams. It is likely that factors other than PSE meat deviations also play a part in defects to cooked hams described as destructured zones. Determination of the precise cause of these defects requires further investigation, including investigation into the technology of cooked ham production.

Additional Points

Practical Applications. The number and area of destructured zones in slices of cooked hams are not related to the occurrence of PSE-type defects in raw pork topside muscles. It is likely that factors other than PSE meat deviations also play a part in defects to cooked hams described as destructured zones. Determination of the precise cause of these defects requires further investigation, including investigation into the technology of cooked ham production. *Highlights*. Samples of *m. adductor* (AD) and *m. semimembranosus* (SM) pig muscles were studied. A total of 44.3% of AD muscles showed PSE defects. Two groups of cooked hams were prepared from selected pig muscles. The cooked hams prepared showed evident destructured zones when sliced. The number and overall area of these zones were not affected by PSE defects.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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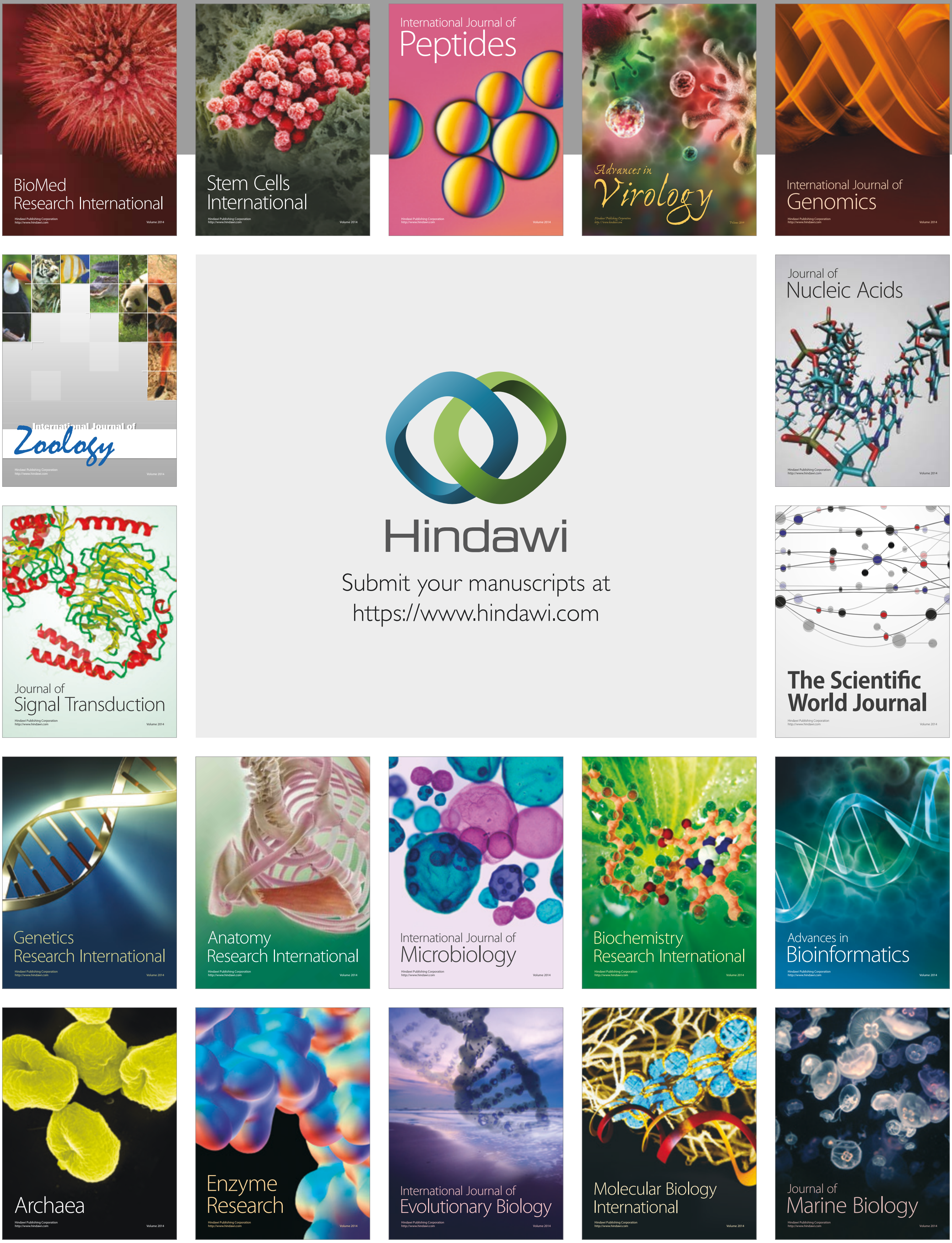
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