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ASSOCIATION BETWEEN SINGLE AND MULTIPLE ELECTRICAL CONDUCTIVITY MEASUREMENTS AND PORK QUALITY ATTRIBUTES

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ABSTRACT

The aim of this study was to determine the usefulness of single and multiple electrical conductivity measurements done directly in abattoir in pork quality attributes evaluation. 82 commercial hybrid fatteners (41 barrows and 41 gilts) originated from the same breeder and reared under the same environmental conditions were slaughtered at approximately 110 kg live weight. Electrical conductivity was measured at 35 min. (EC_{35}) and 2 (EC_2), 3 (EC_3) and 24 hours *post mortem* (EC_{24}). Pork quality was characterised after slaughter by meat acidity (pH) measured at 35 min. and 24 hours, meat colour parameters (CIE-$L^*a^*b^*$ system) at 24 h, drip loss at 48 h (DL_{48}), 96 h (DL_{96}) and 144 h (DL_{144}), water holding capacity (WHC) and tenderness at 48 h and 144 h expressed by shear force (N/cm^2). Electrical conductivity was rather weakly correlated with pork quality traits (the highest Pearson's r, e.g. 0.30 was noted both for EC_2 and a^* and DL_{48}). Highest C_r and C_r^2 values for single and multiple electrical conductivity measurements and sets of pork quality traits were noted for drip loss and water holding capacity (0.42^{**} and 0.29 and 0.57^{**} and 0.32 respectively) while for most of remaining sets no statistical significance were found. It could be presumed then that electrical conductivity are not useful predictor of pork quality attributes that could be performed directly in abattoirs (besides drip loss and water holding capacity to some extent). Therefore it is suggested to revise this parameter use in pork quality evaluation however further examination covering larger population of fatteners should be performed.

Keywords: pork, fatteners, electrical conductivity

INTRODUCTION

For several decades pig breeding strategies were oriented directly on production of lean and fast growing fatteners which contributed to deterioration in pork quality (**Lonergan *et al.*, 2001, Dokmanović *et al.*, 2015**). However recent consumers demands of pork/pork products quality and uniformity are constantly increasing and became a major concern for meat industry (**Ngapo *et al.*, 2007**). As a result, some countries introduced high quality pork production systems and chains that matches consumer demands in 21st century (**Verbeke *et al.*, 2010; Grunert *et al.*, 2011; Font-i-Furnols & Guerrero, 2014**). The rise of consumers demands also imposed pork industry to perform pork quality evaluation *on a continuous basis* where electrical conductivity (EC) is of high interest due to its ability of direct use in abattoirs (**Morel *et al.*, 2006; Mörlein *et al.*, 2007b; Jukna *et al.*, 2012; Karamucki *et al.*, 2015**). In meat, direct electrical current can flow only around cells due to insulation of plasma membranes. However, when cell membranes are permeable (for instance by protein denaturation) electrical current can also flow through the interior of the cells (fluid can move between intracellular and extracellular spaces). That increase electrical conductivity which is governed mainly by small ions, e.g. Cl^-, K^+ and Na^+ and therefore indication of cell membranes integrity is possible. Enhanced electrical conductivity can then be used as an indicator of drip loss and tenderness of meat (**Pliquett *et al.*, 1990; 2003**). Although electrical conductivity is widely used as pork quality predictor there is still not enough information in literature about its measuring efficiency. Moreover, discordant opinions about its usefulness are noted and sparse knowledge about the potential of multiple measurements is available (**Lee *et al.*, 2000; Morel *et al.*, 2006; Mörlein *et al.*, 2007b; Czyżak-Runowska *et al.*, 2010; Jukna *et al.*, 2012**). The aim of this study was to determine the usefulness of single and multiple electrical conductivity measurements in the abattoir at 35 minutes, 2, 3 and 24 hours *post mortem* in pork quality attributes evaluation.

MATERIAL AND METHODS

Animals rearing, transport and slaughter

The study was carried out in autumn on 82 commercial hybrid fatteners (41 barrows and 41 gilts) originated from the same breeder. Animals were characterised by similar live mass (ca. 110 kg) and slaughter age (ca. 160 days). Environmental conditions were the same for all animals throughout the rearing (concrete floor). Fatteners were fed complete feed mixtures according to age (12-13 MJ ME). The animals were transported in specialized pig transport vehicles to slaughterhouse (c.a. 300 km) after loading by qualified personnel without using of electrical pods. The fatteners were slaughtered 2-4 hours after transportation using an electric stunner INARCO Dutch line (250 V, 1.5 s) and bled lying down in accordance with the procedure accepted at the abattoir. Lean meat content was determined 35 min. *post mortem* by ULTRA-FOM 300 (SFK-Technology, Denmark) and hot carcass weight (HCW) was measured immediately afterwards (accuracy up to 0.1 kg). Next, carcasses were chilled in three-phase chilling tunnel (–10°C for 15 min., –15°C for 25 min. and –5°C for 40 min. with air velocity of 3 m/s) and stored at 4°C up to 24 h after the slaughter.

Meat quality measurements

Electrical conductivity was measured directly on the hanging carcasses in the *Longissimus dorsi* muscle (*Longissimus lumborum – LL*, behind the last rib) 35 min (EC_{35}), 2 hours (EC_2), 3 hours (EC_3) and 24 hours (EC_{24}) *post mortem* using the LF-Star (Matthaüs, Germany) apparatus with a frequency of 1.2 kHz and automatic temperature compensation. Acidity of the muscle tissue (pH) was measured directly in hanging carcasses 35 min (pH_1) and 24 hours (pH_{24}) *post mortem* using a calibrated pistol pH-meter MASTER (Draminski, Olsztyn, Poland) with temperature compensation. The electrodes were placed crosswise to the muscle fibres. The samples for assessment of remaining parameters were separated from the bone, external fat and epimysium and then stored in plastic bags at 0-4°C. Meat colour light reflectance scores for CIE $L^*a^*b^*$ (Commission Internationale de l'Eclairage, 2007) were assessed 24 h *post mortem* using a Minolta CR310 apparatus (Japan) 24 h *post mortem* calibrated against the white plate (iluminat D65 and 10° standard observer) . Drip loss was assessed 48 h (DL_{48}), 96 h (DL_{96}) and 144 h (DL_{144}) according to **Prange *et al.* (1977)**. Water holding capacity (WHC) was determined with the filter paper method according to the method of **Grau & Hamm (1952)** as modified by **Pohja & Ninivaara (1957)**. Tenderness of meat was determined at 48 h and 144 h *post mortem* and expressed by shear force (N/cm^2) using an Instron 1140 (USA) apparatus with Warner – Bratzler device according to PN-ISO Norm 11036:1999.

Experiment layout

Firstly, phenotypic correlations (Pearson's r) between single electrical conductivity measurements and particular pork quality traits and canonical correlation were examined. Then canonical correlation analysis has been used to evaluate the relationships between single and multiple electrical conductivity measurements and pork quality attributes sets. Canonical correlation analysis is a generalization of multiple regression analysis with more than one set of dependent variables. It allows to determine how much of variance of one set is predictable by the other by quantifying the common variance between them (maximum correlation between variables is estimated by linear combinations). The correlations are expressed by canonical correlation (C_r). Squared canonical correlation (C_r^2) represent the amount of variance in one canonical variate that is accounted for by the other (**Weiss, 1972**). Therefore, the aim of canonical correlation analysis is to estimate square canonical correlation when the canonical correlation is maximum. In present study eight sets of independent variables (single and multiple measurements of electrical conductivity), e.g. X_1 – EC_{35}; X_2 – EC_2; X_3 – EC_3; X_4 – EC_{24}; X_5 – EC_{35}, EC_2; X_6 – EC_{35}, EC_3; X_7 – EC_2, EC_3; X_8 – EC_{35}, EC_2, EC_3 and ten sets of dependent variables (pork quality attributes), e.g. Y_1 – L^*, a^*, b^*; Y_2 – DL_{48}, DL_{96}, DL_{144}; Y_3 – DL_{48}, DL_{96}, DL_{144}, WHC; Y_4 – $WBSF_{48}$, $WBSF_{144}$; Y_5 – DL_{48}, $WBSF_{48}$; Y_6 – DL_{48}, WHC, $WBSF_{48}$; Y_7 – DL_{48}, WHC, $WBSF_{48}$, L^*; Y_8 – DL_{48}, WHC, TY; Y_9 – DL_{48}, WHC, TY, L^*; Y_{10} – DL_{48}, WHC, TY, L^*, $WBSF_{48}$ were analysed. Additionally an examination of the correlation between original variables and their related canonical variables was performed. Canonical variables (weighted average of the variables of two sets) are considered as implicit variables (U and V) that are synthetic index (rate) defining the correlation between both sets.

Statistical analysis

Both phenotypic correlation coefficients (Pearson's r) and canonical correlation analysis were performed by the use of STATISTICA 13.5 (StatSoft, Tulsa, OK, USA) software. Besides mean values and standard deviations (±SD), minimal and maximal values and respective coefficients of variances (CV) for all measured traits were presented.

RESULTS AND DISCUSSION

All research material was characterised by hot carcass weight of 85.27 kg±5.66 kg and lean meat content of 56.96%±4.53%. Electrical conductivity values measured up to 24 hours *post mortem* and meat quality traits values of analysed population were shown in Table 1 and 2 respectively.

Table 1 Electrical conductivity measured up to 24 hour *post mortem*

Trait	Min.	Max.	Mean	SD	CV [%]
EC_{35} [mS/cm]	2.40	11.70	3.89	1.53	39.20
EC_2 [mS/cm]	1.50	12.50	3.23	1.68	52.01
EC_3 [mS/cm]	1.30	12.90	4.10	2.08	50.64
EC_{24} [mS/cm]	1.50	11.20	4.94	1.75	35.41

Table 2 Meat quality traits of analysed population

Trait	Min.	Max.	Mean	SD	CV [%]
pH_1	5.82	6.90	6.48	0.24	3.75
pH_{24}	5.48	6.07	5.68	0.13	2.23
L^*	48.45	68.66	55.65	4.36	7.09
a^*	11.87	17.98	14.56	1.33	8.41
b^*	3.03	9.97	5.77	1.61	25.37
WHC [cm^2]	2.30	8.20	5.47	1.05	19.88
DL_{48} [%]	0.98	16.47	5.86	2.57	47.15
DL_{96} [%]	1.52	18.61	8.40	2.91	37.66
DL_{144} [%]	3.03	19.94	11.00	2.94	29.65
TY [%]	76.33	114.72	103.69	6.05	5.21
$WBSF_{48}$ [N/cm^2]	4.28	8.84	6.71	1.09	16.02
$WBSF_{144}$ [N/cm^2]	2.58	9.07	6.97	1.43	21.85

According to **Mörlein *et al*. (2007a)** EC_{24} could be successfully used to sort carcasses and therefore to decrease drip loss in pork (choosing carcasses with lowered drip loss for culinary purposes). However, in present study Pearson's correlations between EC_{24} and DL_{48}, DL_{96} and DL_{144} were very low (0.10, 0.01 and -0.07 respectively) – (Table 3). Also, in study of **Jukna *et al.* (2012)** EC_{24} was rather weakly associated with pork shear force, colour and water binding capacity (r=-0.34, r=-0.19 and r=0.28 respectively) with similar results noted for EC_2. Cited authors suggested that proper carcass sorting on the basis of electrical conductivity could be obtained in *pre-rigor* state (r=0.49 for EC_{45} and shear force and r=0.61 for EC_{45} and water binding capacity). However, r value for EC_{45} and pork colour was still low (0.14). In our study Pearson's correlations between EC_{35}, EC_2 and EC_3 and pork quality traits were much lower (the highest r values, e.g. 0.30 were noted between EC_2 and a^* and EC_2 and DL_{48}). Also, in study of **Czyżak-Runowska *et al*. (2010)** EC_{24} was rather weakly associated with WHC ($r=0.344^{**}$) and tenderness (r=0.1173). However, **Mörlein *et al*. (2007b)** noted higher correlation between EC_{24} and DL_{48} in two groups (404 animals total) of (German Large White × German Landrace) × Piétrain fatteners (r=0.52 and r=0.59 respectively). In study of **Karamucki *et al*. (2015)** r values between EC_{48} and $L^*a^*b^*$ and WHC were 0.211^*, 0.258^*, 0.442^{**} and -0.338^* respectively. These values are higher than those obtained in present study but late time of measurement, e.g. 48 hours after slaughter limits its use for directly abattoirs purposes.

Table 3 Pearson's correlations between electrical conductivity measured up to 24 hours *post mortem* and pork quality traits.

Trait	L^*	a^*	b^*	WHC	DL_{48}	DL_{96}	DL_{144}	TY	$WBSF_{48}$	$WBSF_{144}$
EC_{35}	0.10	0.13	-0.03	-0.04	0.24	0.09	0.06	-0.28	-0.19	-0.18
EC_2	0.06	0.30^*	0.13	0.07	0.30^*	0.07	-0.02	-0.07	-0.09	-0.27
EC_3	0.22	0.16	0.09	0.13	0.21	-0.02	-0.07	-0.10	-0.09	-0.25
EC_{24}	0.14	0.09	0.09	0.06	0.10	-0.00	-0.07	-0.16	0.13	0.14

* – statistically significant at $P \le 0.05$

According to **Joo *et al*. (2000)** if only single predictor is used, the risk of incorrect pork evaluation occurs. Additionally, the potential of being able to predict broader quality description of pork could be advantageous **(Kauffmann *et al*., 1993)**. Therefore, canonical analysis correlation including single and multiple electrical conductivity measurements with pork quality attributes was performed. Canonical correlations (C_r) and square canonical correlations (C_r^2) between single electrical conductivity measurements (X_1-X_4) and sets of pork quality traits (Y_1-Y_{10}) were presented in Table 4. The highest C_r and C_r^2 values were obtained for EC_2 (X_2) and EC_3 (X_3) with higher values between X_2 and Y_2 and X_2 and Y_3 sets (both 0.54^{**} and 0.29 respectively). C_r and C_r^2 values between X_1 (EC_{35}) and almost all sets of pork quality traits (Y_2-Y_{10}) were low. The only exception was slightly higher values noted for X_1 and Y_1 ($C_r=0.40^*$ and $C_R^2=0.16$ respectively). In study of **Morel *et al.* (2006)** R^2 value for EC_3 and drip loss measured 72 hours after slaughter was 0.34. Abovementioned authors found higher R^2 between EC_6 and EC_{24} and cooking loss (0.72 and 0.70, respectively) however lower R^2 for EC_{24} and WBSF (below 0.20). No statistically significant C_r and C_r^2 values between EC_{24} (X_4) and all analysed sets of pork quality traits induced its exclusion from further examination.

Table 4 Canonical correlations (C_r) and square canonical correlations (C_r^2) between single electrical conductivity measurements (X_1-X_4) and sets of pork quality traits (Y_1-Y_{10}).

Dependent variables (Y)		Independent variables (X)			
		X_1 – EC_{35}	X_2 – EC_2	X_3 – EC_3	X_4 – EC_{24}
Y_1 – L^*, a^*, b^*	C_r	0.40^*	0.47^{**}	0.47^{**}	0.25^{NS}
	C_r^2	0.16	0.22	0.22	0.06
Y_2 – DL_{48}, DL_{96},	C_r	0.35^{NS}	0.54^{**}	0.49^{**}	0.27^{NS}
DL_{144}	C_r^2	0.12	0.29	0.23	0.07
Y_3 – DL_{48}, DL_{96},	C_r	0.36^{NS}	0.54^{**}	0.49^{**}	0.28^{NS}
DL_{144}, WHC	C_r^2	0.13	0.29	0.24	0.07
Y_4 – $WBSF_{48}$,	C_r	0.23^{NS}	0.27^{NS}	0.25^{NS}	0.16^{NS}
$WBSF_{144}$	C_r^2	0.05	0.07	0.06	0.03
Y_5 – DL_{48},	C_r	0.28^{NS}	0.31^{NS}	0.22^{NS}	0.19^{NS}
$WBSF_{48}$	C_r^2	0.08	0.09	0.05	0.03
Y_6 – DL_{48}, WHC,	C_r	0.30^{NS}	0.31^{NS}	0.23^{NS}	0.19^{NS}
$WBSF_{48}$	C_r^2	0.09	0.09	0.05	0.04
Y_7 – DL_{48}, WHC,	C_r	0.31^{NS}	0.31^{NS}	0.29^{NS}	0.22^{NS}
$WBSF_{48}$, L^*	C_r^2	0.10	0.09	0.08	0.05
Y_8 – DL_{48}, WHC,	C_r	0.35^{NS}	0.31^{NS}	0.23^{NS}	0.18^{NS}
TY	C_r^2	0.12	0.09	0.05	0.03
Y_9 – DL_{48}, WHC,	C_r	0.35^{NS}	0.31^{NS}	0.28^{NS}	0.20^{NS}
TY, L^*	C_r^2	0.12	0.09	0.08	0.04
Y_{10} – DL_{48}, WHC,	C_r	0.36^{NS}	0.31^{NS}	0.24^{NS}	0.26^{NS}
TY, L^*, $WBSF_{48}$	C_r^2	0.13	0.09	0.06	0.07

Legend: ** - statistically significant at $P \le 0.05$, * - statistically significant at $P \le 0.05$

In present survey conjunction of different electrical conductivity measurements only slightly rise determination of pork quality attributes sets (Table 5). The highest C_r and C_r^2 values were noted between X_8 and Y_2 and X_8 and Y_3 (both 0.57^{**} and 0.32 respectively). However, more favourable measurement for direct abattoir use was X_2 (EC_2) due to similar C_r and C_R^2 values with Y_2 and Y_3 (both 0.54^{**} and 0.29) with only one measurement needed (in comparison to three for X_8). In production conditions at the abattoirs the tendency of decreasing the number of different measurements is common and desirable. However, X_2 set was rather weakly associated with remaining pork quality attributes (Y_4-Y_{10}) with exception for Y_1 set (C_r and C_R^2 values of 0.47^{**} and 0.22 respectively) which reduces its utilisation ability. Although it has to be mentioned that in study of **Tarczyński *et al*. (2018)** EC_2 was useful in the same extent in pork quality classes assessment as pH measured 45 min after slaughter. In study of **Morel *et al*. (2006)** R^2 for EC_3 and set of four pork quality traits, e.g. DL_{72}, cooking loss, WBSF and colour was 0.631.

Table 5 Canonical correlations (C_r) and square canonical correlations (C_r^2) between multiple electrical conductivity measurements (X_5-X_8) and sets of pork quality traits (Y_1-Y_{10}).

Dependent variables (Y)		Independent variables (X)			
		$X_5 - EC_{35}$, EC_2	$X_6 - EC_{35}$, EC_3	$X_7 - EC_2$, EC_3	$X_8 - EC_{35}$, EC_2, EC_3
$Y_1 - L^*, a^*, b^*$	C_r	0.47^*	0.47^*	0.49^*	0.49^*
	C_r^2	0.23	0.22	0.24	0.24
$Y_2 - DL_{48}$, DL_{96}, DL_{144}	C_r	0.55^{**}	0.48^*	0.55^{**}	0.57^{**}
	C_r^2	0.30	0.23	0.30	0.32
$Y_3 - DL_{48}$, DL_{96}, DL_{144}, WHC	C_r	0.55^{**}	0.50^*	0.55^{**}	0.57^{**}
	C_r^2	0.30	0.25	0.30	0.32
$Y_4 - WBSF_{48}$, $WBSF_{144}$	C_r	0.27^{NS}	0.25^{NS}	0.28^{NS}	0.29^{NS}
	C_r^2	0.07	0.06	0.08	0.09
$Y_5 - DL_{48}$, $WBSF_{48}$	C_r	0.36^{NS}	0.28^{NS}	0.31^{NS}	0.31^{NS}
	C_r^2	0.16	0.08	0.09	0.10
$Y_6 - DL_{48}$, WHC, $WBSF_{48}$	C_r	0.36^{NS}	0.32^{NS}	0.31^{NS}	0.33^{NS}
	C_r^2	0.13	0.10	0.10	0.11
$Y_7 - DL_{48}$, WHC, $WBSF_{48}$, L^*	C_r	0.38^{NS}	0.32^{NS}	0.33^{NS}	0.34^{NS}
	C_r^2	0.14	0.10	0.11	0.12
$Y_8 - DL_{48}$, WHC, TY	C_r	0.37^{NS}	0.39^{NS}	0.31^{NS}	0.39^{NS}
	C_r^2	0.13	0.15	0.10	0.15
$Y_9 - DL_{48}$, WHC, TY, L^*	C_r	0.37^{NS}	0.40^{NS}	0.33^{NS}	0.40^{NS}
	C_r^2	0.14	0.16	0.11	0.16
$Y_{10} - DL_{48}$, WHC, TY, L^*, $WBSF_{48}$	C_r	0.39^{NS}	0.39^{NS}	0.31^{NS}	0.41^{NS}
	C_r^2	0.15	0.15	0.10	0.17

Legend: ** - statistically significant at P≤0.05, * - statistically significant at P≤0.05

Table 6 Correlation between canonical variables U (electrical conductivity measured up to 24 hours *post mortem*) and V (L^*, a^*, b^*, drip loss measured up to 144 hours *post mortem*, WHC, $WBSF_{48}$ and $WBSF_{144}$)

Traits	Canonical variables			
Variables explaining other variables	U1	U2	U3	U4
EC_{35}	0.69	-0.67	0.21	-0.18
EC_2	0.94	-0.03	0.17	-0.29
EC_3	0.82	-0.20	0.45	0.29
EC_{24}	0.26	-0.27	0.87	-0.32
Explained variables	V1	V2	V3	V4
L^*	0.12	-0.12	0.39	0.55
a^*	0.40	0.27	0.01	-0.42
b^*	0.16	0.42	0.27	-0.09
DL_{48}	0.42	-0.07	-0.04	-0.28
DL_{96}	0.07	-0.15	-0.19	-0.35
DL_{144}	-0.02	-0.27	-0.31	-0.18
WHC	0.12	0.30	0.28	0.30
$WBSF_{48}$	-0.53	-0.01	0.46	-0.43
$WBSF_{144}$	-0.23	0.43	0.51	-0.23

In present study canonical variables U1 and V1 were connected with EC_2 and EC_3 to high extent, e.g. 0.94 and 0.82 respectively (Table 6). This was in accordance with the highest C_r and C_r^2 values noted between sets containing this parameters and Y_2 and Y_3 sets (Table 4 and 5). Canonical variables U_2 and V_2 were connected to highest extent with EC_{35} (-0.67), U3 and V3 with EC_{24} (0.87) and U4 and V4 with L^* (0.55).

CONCLUSION

In this study weak Pearson's correlations between electrical conductivity measured up to 24 hours *post mortem* and pork quality traits were found. Moreover, on the basis of canonical correlation analysis it could also be presumed that its single and multiple measurements are not an useful predictor of pork quality attributes. The only exception (but only to some extent) was its potential in drip loss and water holding capacity assessment. This study should also be considered as preliminary because of its limited population (additional examination should be carried on much larger number of fatteners) however potential revision of the electrical conductivity use in pork quality evaluation should be taken into account.

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