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VARIATIONS IN PH DECLINE MEASURED FROM 45 MIN TO 48 H POSTMORTEM AS RELATED TO MEAT QUALITY OF (L × Y) × H FATTENERS*

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Abstract

The objective of this study was to investigate the effect of the range of pH decline from 45 min to 48 h after the slaughter on the quality of meat in (Landrace × Yorkshire) × Hampshire fattening pigs. The mean value and standard deviation for the range of pH fall from 45 min to 48 h postmortem served to create the following experimental groups: group I with pH decline less or equal to 0.88 units pH; group II with pH decline higher than 0.88 but lower than 1.26 pH units; and group III where pH decline was equal to 1.26 units or higher. This investigation showed that glycolytic resources in meat (glycogen and lactate) were connected with the range of pH decline from 45 min to 48 h postmortem. The different ultimate pH in meat with the same lactate concentration was noted (group I vs. II). Although the range and the rate of pH decline from 3 h postmortem was higher and significantly faster (P≤0.05 and 0.01) in both groups with a higher pH fall (groups II and III), there was no statistically confirmed influence of the investigated range of pH fall on drip loss and on colour. The average values for drip loss and colour obtained in this experiment were related to ultimate pH of meat of (L × Y) × H fatteners, being characteristic for acid meat.

Key words: pork meat quality, pH changes

One significant postmortem change in muscle due to anaerobic metabolism is the lowering in the pH of the muscle. The acidification of meat (pH) is an easy to measure parameter, and pH changes are widely used to monitor quality differences in fresh pork. The typical pattern of meat acidification does not have a linear character with the time postmortem (Przybylski et al., 1994; Warris, 2010). Normally, pH declines gradually from approximately 7.0–7.2 in living muscle to 5.3–5.7 at 24–48 h postmortem. In extreme cases, the pH falls from 7.0 to a value between

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5.4 and 5.8, during the first hour after slaughter. The combination of low pH and high temperature causes the denaturation of approximately 20% of the sarcoplasmic and myofibrillar proteins and additionally membrane disorders, leading to increased expulsion of water (Offer and Knight, 1988; Offer et al., 1989; Huff-Lonergan and Lonergan, 2005). In addition, greater precipitation of sarcoplasmic proteins is largely responsible for paler pork colour (Kauffman and Marsh, 1987; Offer, 1991). In contrast, muscles with normal pH decline early postmortem but subsequently faster and extended glycolysis which results in abnormally low ultimate pH (lower than 5.5) at 7–8 h after the slaughter is associated with elevated glycogen content and referred to as acid meat (Monin and Sellier, 1985; Monin, 1989, 2004; Koćwin-Podsiadła et al., 2006). The Hampshire breed is associated with a high glycogen content in muscles which makes a lower ultimate pH possible in meat.

Ultimate pH of meat is a major quality determinant which is also connected with several appearance attributes of fresh meat cuts during the retail and influences consumer's perception of meat quality and its purchase acceptance (Van Laack, 2000; Bredahl et al., 1998; Grunert et al., 2004). The importance of pH on functional and eating quality of whole pork is also confirmed by Bidner et al. (2004) who showed that ultimate pH explained 79% of the variation in colour, 57% of the variation in drip loss, and 77% of the variation in purge loss.

The objective of this study was to investigate how variations in the pH decline measured from 45 min to 48 h after the slaughter influence the quality of meat from (Landrace × Yorkshire) × Hampshire fatteners.

Material and methods

The present study was conducted on 50 (Landrace × Yorkshire) × Hampshire [(L × Y) × H] fatteners. All the animals were free of *RYR1*^{T} gene. The animals were kept under the same environmental conditions in Jagodne Breeding Centre and fed a complete feed. Pigs were slaughtered in the leading Polish Meat Plant located in Mazovia, 2–4 h after transport (300 km), using an electric stunner (MIDAS, Stork RMS, the Netherlands and INARCO constant voltage system) and the vertical bleeding, in accordance with the technology applied at the Meat Plant. The carcasses were chilled in three-phase chilling tunnel (–10ºC for 15 min, –15ºC for 25 min and –5ºC for 40 min with air velocity 3 m/s), then they were stored at 4ºC up to 24 h after the slaughter. The quality of meat (from 45 min to 24 h postmortem) was evaluated directly in carcasses in the *m. longissimus lumborum* (LL) behind the last rib, while at 48 h after the slaughter in meat samples taken at the last rib and 1st lumbar vertebra. The samples were separated from the bone, external fat and epimysium and stored in plastic bags at 0–4°C.

In this investigation the following parameters were measured: acidity of the muscle tissue (pH) measured directly in the LL muscle 45 min, 2 h, 3 h, 24 h and 48 h postmortem (pH_{45}, pH_{2}, pH_{3}, pH_{24}, pH_{48} respectively), using a pistol pH-meter MASTER (Draminski, Olsztyn, Poland) calibrated with temperature compensation; elec-

trical conductivity (EC) measured with an LF-Star conductometer (Ingenieurbüro Matthäus, Noblitz, Germany) 2 h, 24 h and 48 h postmortem (EC_2, EC_{24} EC_{48}); colour lightness (L*) of the muscle tissue, performed using a Minolta Portable Chroma Meter (model CR 310, Minolta, Osaka, Japan) and 50 mm orifice. The apparatus was calibrated using white calibration plate with D65 illuminant and 2° as standard observer. The colour parameters of the individual meat samples (with 15 mm thickness and, as mentioned above, samples taken after 24 h of chilling at the 1st lumbar vertebra without bone, external fat and epimysium and up to 48 h after the slaughter stored in plastic bags at 0–4°C) were determined at 24 h and 48 h postmortem in the CIELAB colour system (with 20 min blooming time prior to the colour measurements); rate of ATP breakdown, expressed by R_1 = IMP/ATP indicator, determined 45 min postmortem on meat samples taken behind the last rib, according to the method of Honikel and Fischer (1977); drip loss, determined according to Prange et al. (1977) at 48 h postmortem.

For determination of glycolytic potential (GP), muscle samples were taken 45 min after the slaughter from the *longissimus* muscle at the last vertebra and immediately put into the tubes with 1M $HClO_4$ and homogenized to inhibit glycolytic changes. The content of glycogen was determined using the enzymatic method according to Darymple and Hamm (1973) while lactate content according to Bergmeyer (1974). The glycolytic potential was calculated as the sum of: 2[glycogen] + [lactate] according to Monin and Sellier (1985) and expressed as µmol of lactic acid equivalent per g of fresh muscle.

The genomic DNA was isolated from white blood cells according to Kawasaki (1990) while the *RYR1* C1843T polymorphic site was analysed with DNA test using the PCR/RFLP method, according to Fujii et al. (1991).

The mean value (1.17) and standard deviation (±0.19) for the range of pH fall from 45 min to 48 h postmortem served to create the following experimental groups: group I with pH decline less than or equal to 0.88 units pH; group II with pH decline higher than 0.88 but lower than 1.26 pH units; and group III where pH decline was equal to 1.26 units or higher (Figure 1).

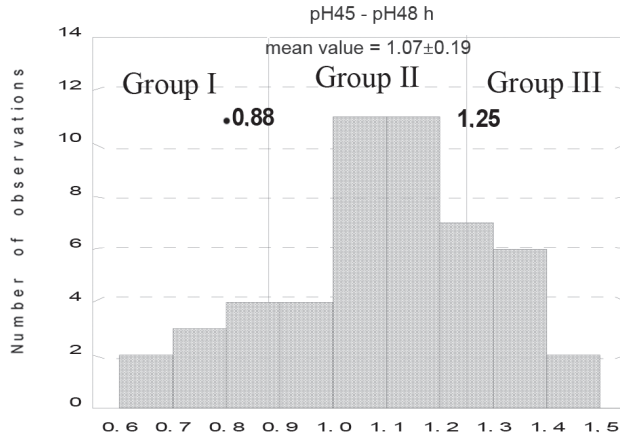

Figure 1. Distribution of pH fall ranges from 45 min to 48 h postmortem

The data were analysed using one-way analysis of variance in non-orthogonal design in Statistica 6.0 (StatSoft, Tulsa, OK, USA). The significance of differences between means was calculated using Duncan's test.

Results

The average lean meat content in the analysed population of fatteners was 56.02% (±2.92) with hot carcass weight of 81.46 kg (±9.09). As shown in Table 1, lowest glycogen content and highest lactate content were in loins with lowest pH decline from 45 min to 48 h postmortem, which did not exceed 0.88 units pH (group I). Loins with medium pH drop (from 0.88 to 1.25 units – group II) had similar glycogen content to loins with highest pH extent, greater than 1.26 units pH (group III) while lactate content was similar in groups I and II but significantly (P≤0.01) higher than in group III (Table 1). Although in this investigation the influence of pH decline on glycolytic potential (GP) was not statistically confirmed, the lowest GP was in loins with lowest pH decline while highest GP was in meat with medium pH drop. Furthermore, loins from group I with lowest extent of pH drop had significantly lower pH at 45 min, 2 h and 3 h after the slaughter compared to loins from groups II and III. There were no significant differences in pH_{24} among the analysed groups, while at 48 h after the slaughter loin pH from group I was significantly higher (at about 0.1 and 0.07 units, respectively) than in meat with a greater extent of pH fall (groups II and III).

Table 1. The influence of pH decline from 45 min to 48 h after the slaughter on analysed meat quality traits

Trait	Range of pH fall from 45 min to 48 h after the slaughter			Average	F-emp P-value
	group I pH≤0.88	group II pH 0.89–1.25	group III pH≥1.26		
1	2	3	4	5	6
No. of animals	8	31	11	50	
Glycogen (µmol/g)	43.63 a±22.89	68.83 b±25.58	62.85 b±26.48	63.48±26.48	3.13≤0.05
Lactic acid (µmol/g)	55.88 B±12.43	50.86 B±6.52	38.12 A±4.63	48.86±9.43	16.33≤0.01
Glycolytic potential (µmol/g)	143.15±44.93	188.51±50.53	163.81±53.82	175.82±52.45	2.97 NS
pH_{45}	6.19 A±0.15	6.39 B±0.12	6.69 C±0.08	6.43±0.20	44.90≤0.01
R_1	0.96±0.05	0.93±0.03	0.93±0.03	0.94±0.04	2.36 NS
pH_2	6.05 A±0.19	6.22 B±0.12	6.49 C±0.15	6.25±0.20	24.26≤0.01
pH_3	5.91 A±0.23	6.06 B±0.16	6.30 C±0.14	6.08±0.21	13.67≤0.01
pH_{24}	5.66±0.11	5.60±0.07	5.60±0.12	5.61±0.09	1.20 NS
pH_{48}	5.43 B±0.11	5.33 A±0.06	5.36 A±0.07	5.35±0.08	6.90≤0.01
EC_2 (mS/cm)	3.63 B±0.60	2.93 A±0.40	2.71 A±0.44	3.01±0.55	10.04≤0.01
EC_{24} (mS/cm)	5.93 C±1.65	4.57 B±0.89	3.68 A±0.94	4.59±1.25	10.51≤0.01

Table 1 – contd.

1	2	3	4	5	6
EC_{48} (mS/cm)	15.06±0.94	14.83±1.13	14.73±1.25	14.85±1.11	0.193 NS
L^*_{24}	55.34±2.72	55.32±2.51	56.85±2.30	55.66±2.53	1.58 NS
L^*_{48}	59.58±4.01	58.32±4.03	59.19±3.55	58.71±3.88	0.430 NS
Drip loss 48 h (%)	4.59±2.6	5.60±2.40	4.93±2.41	5.29±2.42	0.70 NS

Values in the table are given as means ± standard deviations; means denoted by capital letters A, B, C differ significantly at P≤0.01; means denoted by small letters a, b differ significantly at P≤0.05; NS – not significant.

The electrical conductivity at 2 and 24 h after the slaughter was significantly influenced by extent of pH decline, while meat lightness and drip loss did not have a significant influence. At 2 h postmortem, electrical conductivity of loins from group I was higher at about 0.70 and 0.92 mS/cm compared to groups II and III, while at 24 h after the slaughter it was higher at 1.36 and 2.25 mS/cm, respectively.

Table 2. The effect of range of pH decline from 45 min to 48 h after the slaughter on the range and rate of pH changes during that time

Trait	Range of pH fall from 45 min to 48 h after the slaughter			Average	F-emp P-value
	group I pH≤0.88	group II pH 0.89–1.25	group III pH≥1.26		
Range of pH changes (in pH units)					
pH_{45}-pH_2	0.13±0.07	0.18±0.07	0.20±0.12	0.18±0.09	1.489 NS
pH_2-pH_3	0.15±0.05	0.16±0.08	0.20±0.07	0.16±0.08	1.217 NS
pH_3-pH_{24}	0.25 A±0.17	0.46 B±0.14	0.69 C±0.15	0.48±0.20	22.40≤0.01
pH_{24}-pH_{48}	0.22 a±0.05	0.27 b±0.04	0.25 b±0.07	0.26±0.05	3.199≤0.05
Range of pH changes (in pH units/hour)					
pH_{45}-pH_2	0.11±0.06	0.14±0.06	0.16±0.10	0.14±0.07	1.489 NS
pH_2-pH_3	0.15±0.05	0.16±0.08	0.20±0.07	0.16±0.08	1.217 NS
pH_3-pH_{24}	0.01 A±0.008	0.02 B±0.007	0.04 C±0.008	0.03±0.01	22.40≤0.01
pH_{24}-pH_{48}	0.009 a±0.002	0.01 b±0.001	0.01 b±0.002	0.01±0.002	3.199≤0.05
pH_{45}-pH_{48}	0.01 A±0.001	0.02 B±0.002	0.03 C±0.001	0.02±0.004	102.66≤0.01

Values in the table are given as means ± standard deviations; means denoted by capital letters A, B, C differ significantly at P≤0.01; means denoted by small letters a, b differ significantly at P≤0.05 NS – not significant.

Table 2 provides the results concerning the influence of the range of pH decline on the scale of pH changes and its rate per hour in different terms of conversion of muscle to meat. Results indicate that from 3 h postmortem, carcasses with lowest extent of pH drop (group I) had significantly lower scale of acidification of LD muscle and lower rate of pH changes (expressed in pH units per hour) compared to meat from groups II and III.

Discussion

Considering the data shown in Table 1 and described in the results section, concerning the effect of extent of pH decline of *longissimus lumborum* muscle from 45 min to 48 h postmortem on meat quality traits, three elements must be taken into account: firstly, different glycogen concentrations at 45 min postmortem (group I vs. groups II and III); secondly, different lactate content at the same glycogen concentration (group II vs. III); and thirdly, different pHu at the same lactate concentration.

Probably, lower glycogen concentration at 45 min postmortem in group I is the result of faster glycolysis during the early postmortem period, which partly reflects higher R1 value than in groups II and III (but statistically confirmed at $P \leq 0.07$) (Table 1). On the basis of the data reported by Fernandez et al. (1995) and Choe et al. (2008), it can be assumed that muscle fibre type composition may affect metabolite content during the postmortem period. Choe et al. (2008) showed that the meat with high glycogen and lactate content (GH-LH group) had lower share of I type fibres, and significantly higher share of IIb fibres and R_1 value than meat with high glycogen and low lactate content (GH-LL group). Moreover, the above cited authors stated that meat with low glycogen and high lactate concentration (LG-HL group), had statistically lower pH_{45} and lower range of pH fall (from 45 min to 24 h after the slaughter) compared to meat with high glycogen and low lactate content (HG-LL group).

The different lactate concentration at the similar glycogen content is probably the result of differences in muscle fibre composition, and the presence or the share of muscle fibre IIb type. Choe et al. (2008) showed that muscles with high glycogen and lactate concentration compared to meat with high glycogen and low lactate content, had statistically higher percentage of IIb type fibres and lower share of I type fibers.

As mentioned in the introduction, after the slaughter glycogen is converted into lactate and hydrogen ions, whereas pH decline is a function of H+ accumulation and defined as the negative logarithm to the base 10 of hydrogen ion activity or concentration. Although the glycogen content is related to acidification of muscles, it does not fully explain pHu variation. Van Laack and Kauffman (1999) demonstrated that variation in glycolytic potential explains only 40% variation in pHu. It is not clear why muscles with the same lactate concentration may have a different pHu. Van Laack (2000) interprets this as due to differences in buffering capacity of muscles or in the concentration of strong ions such as Mg^{+2}, Ca^{+2} and Cl^{-}, two factors that influence the pH of a system.

For more than 30 years, the electrical properties of muscles have been investigated to determine pork quality. Schmitten et al. (1987) reported that intact muscle fibres act as an electric insulator but changes in muscle membranes which occur during postmortem glycolysis result in increase of fluids within the muscle tissue (Pliquett et al., 1995) and increase of electrical conductivity of meat (Schmitten et al., 1987). In this investigation, muscles with faster glycolysis early postmortem showed higher conductivity (group I vs. groups II and III), but in general, the range of EC values 2 h after the slaughter was relatively low, and typical of normal meat (Koćwin-Podsiadła et al., 2006).

The amount (percentage) of drip loss and the rate of its appearance are affected by several ante- and postmortem factors, and the knowledge of factors of influence on the drip loss of meat is important for the quality of meat (Honikel, 2004). Rate of pH decline is related to development of water holding capacity and drip loss. A reduced extent of acidification and high ultimate pH results in low drip loss, while high rates of initial acidification lead to increased drip loss. The low ultimate pH (especially when it is near 5.3–5.4 units) is also a factor that has the negative impact on drip loss (Huff-Lonergan and Lonergan, 2005). In this experiment, pH values at 2 and 3 h after the slaughter were differentiated by range of pH fall from 45 min to 48 h postmortem (where highest acidification was in group I), but all mean values for that trait up to 24 h after the slaughter were typical of normal meat. Moreover, at 24 h after the slaughter pH values in analysed groups were almost the same and statistically unconfirmed (Table 1). The pH_{24} higher than 5.5 units in meat of (L × Y) × H fatteners, also in groups with high glycogen stores after the slaughter (groups II and III) is probably connected with accelerated carcass chilling that slows pH decline. Milligan et al. (1998), Josell et al. (2003) and Zybert et al. (2007, 2008) showed that chilling methods (or chilling systems) used in commercial practices (especially accelerated compared with conventional chilling) affect the biochemical and physical processes taking place during conversion of muscle to meat and have an influence on the rate of meat acidification and distribution of water in the muscle. In this work, the influence of pH changes on drip loss measured 48 h postmortem was not statistically confirmed. Exudative and pale meat obtained in this experiment are related to ultimate pH of meat of (L × Y) × H fatteners, being characteristic of acid meat. Acid meat is pale and somewhat exudative but less than PSE (pale, soft, exudative) meat (Koćwin-Podsiadła et al., 2006). Then ultimate pH is close to the isoelectric point of the major proteins in muscle (5.3–5.4), electric charges on the amino and carboxyl groups on the proteins cancel each other, myofilaments move closer together resulting in release of the water from meat (Huff-Lonergan and Lonergan, 2005). Moreover, sarcoplasmic protein solubility declines with decreasing pHu and contributes to paler pork colour (Joo et al., 1999).

Increasing the rate of chilling leads to a slowing of metabolic processes (slows glycolysis) and reduces rate of pH decline. As claimed by Long and Tarrant (1990) and Milligan et al. (1998), chilling affects pH mainly between 3–4 h postmortem, which partly corresponds with results of this investigation. Between 2 and 3 h there were no statistically confirmed differences in the range and rate of meat acidification, between groups differentiated by pH decline from 45 min to 48 h after the slaughter, while in later periods (between 3–24 h and 24–48 h postmortem) lower and statistically confirmed range and slower rate of pH changes was in meat from group I.

Concluding, this investigation showed that glycolytic resources in meat (glycogen and lactate) were connected with the range of pH decline from 45 min to 48 h postmortem. The different ultimate pH in meat with the same lactate concentration was noted (group I vs. II). Although the range and the rate of pH decline from 3 h postmortem was higher and significantly faster ($P \leq 0.05$ and 0.01) in both groups with a higher pH fall (groups II and III), there was no statistically confirmed influence of the investigated range of pH fall on drip loss and on colour. The average

values for drip loss and colour obtained in this experiment were related to ultimate pH of meat of (L × Y) × H fatteners, being characteristic of acid meat.

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