Post-mortal changes of pH value and lactic acid content in the muscles of pigs and bulls

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ABSTRACT: The development of post-mortal changes was evaluated in *m. longissimus lumborum et thoracis* (MLLT) and *m. semimembranosus* (SM) of pigs and in *m. longissimus lumborum et thoracis* of bulls; both half-carcasses were compared. The lowest value of pH in MLLT of pigs was measured 36 h after slaughter (5.52) in the right side and 48 h in the left side of pork (5.48). The highest concentration of lactic acid was recorded 24 h *post mortem* (109.78 and 109.22 mmol/kg). The decrease in pH values in SM was slower while the lowest values 5.68 and 5.79 were found 48 h *post mortem*. An increase in lactic acid concentration was analogous to MLLT, but the amount of produced acid was lower. Differences between the right and the left side were not statistically significant. Significant differences were found between the muscles ($P < 0.01$). The lowest values of pH in MLLT of bulls were measured 48 h after slaughter (5.43 and 5.42). The maximum concentration of lactic acid was found 72 h after slaughter (113.33 and 116.00 mmol/kg). The differences between both sides of beef were not statistically significant. The correlation coefficients between pH value and lactic acid concentration were –0.87 ($P < 0.01$) for MLLT and –0.78 ($P < 0.01$) for SM in pigs, and –0.96 ($P < 0.01$) for MLLT in bulls.

Keywords: buffering capacity; meat quality; ultimate pH; pigs; bulls

One of the most important post-mortal changes in muscles is a decrease in pH value due to the production of lactic acid. The decrease in pH value from 7.4 to 5.6–5.7 (live muscle) occurs in pig muscles in six to eight hours after slaughter, then pH decreases to 5.3–5.7 (ultimate pH) within 24 h after slaughter (Hedrick *et al.*, 1994). The pH decrease is determined by the physiological condition of muscles at the time of stunning and can be related to lactate production, or to the capacity of the muscle to produce energy in the form of ATP (Henckel *et al.*, 2000). Muscle glycogen is the main metabolic substrate responsible for post-mortem accumulation of lactic acid and thus for normal pH decrease (Immonen *et al.*, 2000). Muscle glycogen concentration at the time of slaughter is one of the most important factors affecting meat quality. Glycogen is a metabolic substrate that fuels post-mortem lactate production, contributing to a pH decrease. The glycogenolysis continues and pH continues to decrease until the reserves of glycogen are used up or the metabolic processes stop due to enzymatic arrest caused by low pH. The accumulation of lactate in muscles causes the pH to decrease post mortem, and the reserves of glycogen in the muscles at slaughter will determine the value of ultimate pH (Maribo *et al.*, 1999).

The pH value of meat is influenced not only by lactic acid but also by phosphoric acid and high-powered ions. In proof of that, different pH values were found in poultry meat and pork with similar contents of lactic acid. It is caused by a different buffering capacity of meat. Light muscles usually have a notably better buffering capacity than dark muscles. This is consistent because they have a high content of glycolytic enzymes. The end product of glycolytic metabolism is lactic acid, which tends to lower the pH value. Thus white fibres need a more effective buffering mechanism than red ones. Buffering prolongs the time of effective fibre activity. The principal difference in the buffering capacity of different types of muscles is that white fibres

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have a higher content of histidine compounds than red ones. Consequent variations in buffering capacity can be explained by variations in the amounts of dipeptides (Puolanne and Kivikari, 2000). The correlation relationship was ascertained between pH and buffering capacity of pork (MLD) (correlation coefficient = –0.43) (Van Lack *et al.*, 2001). Besides buffering capacity of meat, the pH value is also influenced by other acids, especially free amino acids. The total amount of all acids is expressed as titratable acidity of meat. The objective of this study was to determine continuous changes of pH and lactic acid content in the muscles of pigs and bulls after slaughter and the influence of lactic acid on the range of pH values. The course of post-mortal changes was examined in two muscles of pigs and in one muscle of bulls, with concurrent comparison of both half-carcasses with respect to pH and lactic acid concentration.

MATERIAL AND METHODS

Pigs – four final hybrids (Czech Large White × Landrace) × (Large White × Belgian Landrace) of the average weight about 110 kg were used (gilts and barrows). The pigs were housed 12 h before slaughter. Stunning was performed by means of electrical current with electrical tongs in a dazing trap. The lying animals were exsanguinated on a conveyor belt. Thereafter, common slaughter operations and veterinary inspection followed. Meat samples (approximately 2 kg) of both *m. longissimus lumborum et thoracis* (MLLT) and *m. semimembranosus* (SM) were collected at the level of the last rib from each carcass.

Bulls – five crossbred bulls, Czech Pied × Holstein breed, at the age of 20 to 21 months and of the live weight about 610 kg were selected for the study. The bulls were not housed before slaughter contrary to the pigs. Stunning was carried out mechanically with the gun provided with a confined projectile. After exsanguination of the lying bulls, common slaughter operations and veterinary inspection were made. From each carcass, the sample of muscle (about 2 kg) was taken from *m. lumborum et thoracis* (MLLT) at the level of the ninth rib on both sides.

The samples were stored at 4°C. The pH value of the samples was measured 30 minutes (in pigs only), 1, 6, 12, 24, and 72 h (in bulls only) after slaughter. A sample of muscle (100 g) was collected at the same time (immediately after pH measurement) in order to establish the amount of lactic acid. This sample was frozen in liquid nitrogen (–196°C) and stored at –85°C.

The pH values were measured with Sentron Argus pH meter with the needle electrode Isfet (Sentron Inc.). Lactic acid concentration was determined spectrophotometrically (340 nm) from the homogenate using a commercial kit manufactured by Boehringer Mannheim (No. 0139084, FRG), which is based on the reaction catalyzed by lactate dehydrogenase and glutamate pyruvate transaminase.

All data were processed by the statistical programme STAT-Plus; the computed average, standard deviation, correlation analysis, and *t*-test were specified (Matoušková *et al.*, 1992).

RESULTS

The average values of pH and lactic acid content in MLLT of pigs at the individual times after slaughter are shown in Table 1. A decrease in pH within 24h *post mortem* was more intensive in the left side than in the right side of pork. The lowest value of pH was measured 36 h after slaughter (5.52) in the right side and 48 h after slaughter in the left side (5.48). The pH values within 12 h after slaughter were more variable. No statistically significant differences in pH values were found between the right and the left half-carcass. The concentration of lactic acid increased similarly in both sides. The highest concentration of lactic acid was recorded 24 h *post mortem* (109.78 and 109.22 mmol/kg). The decrease in lactic acid content was evident 48 h after slaughter. There was a higher variability in lactic acid content than in pH values.

In Table 2, the pH values and lactic acid content in SM of pigs are documented. The pH values were analogous to MLLT 30 min and 1 h after slaughter. The decrease in pH was slower in SM, with the lowest values 5.68 and 5.79 that were higher than in MLLT, detected 48 h *post mortem*. The variability was higher too. The differences between both sides were not statistically significant. The increase in lactic acid concentration was analogous to MLLT, but the amount of produced acid was lower. The highest concentration of lactic acid was determined in the right side 48 hours after slaughter, and in the left side 24 hours after slaughter. Significant differences between both sides were not confirmed.

Table 1. pH values and lactic acid content in *M. longissimus lumborum et thoracis* of pigs

Time *post mortem* (h)	pH		Lactic acid (mmol/kg)	
	right side	left side	right side	left side
0.5	6.29 ± 0.17	6.34 ± 0.22	66.22 ± 8.33	63.44 ± 10.22
1.0	6.26 ± 0.31	6.27 ± 0.32	75.11 ± 10.22	82.00 ± 4.33
6.0	5.99 ± 0.22	5.89 ± 0.11	92.56 ± 14.33	93.00 ± 12.89
12.0	5.92 ± 0.19	5.68 ± 0.18	107.11 ± 8.33	106.78 ± 9.67
24.0	5.72 ± 0.14	5.66 ± 0.16	109.78 ± 6.78	109.22 ± 10.22
48.0	5.53 ± 0.16	5.48 ± 0.07	104.22 ± 4.33	105.44 ± 4.78

Table 2. pH values and lactic acid content in *M. semimembranosus* of pigs

Time *post mortem* (h)	pH		Lactic acid (mmol/kg)	
	right side	left side	right side	left side
0.5	6.23 ± 0.13	6.33 ± 0.06	54.67 ± 11.67	56.11 ± 10.00
1.0	6.34 ± 0.31	6.31 ± 0.17	63.22 ± 8.33	61.89 ± 8.00
6.0	6.14 ± 0.24	6.10 ± 0.18	72.78 ± 6.00	71.11 ± 6.89
12.0	5.95 ± 0.16	6.02 ± 0.16	82.44 ± 7.89	83.56 ± 6.11
24.0	6.02 ± 0.22	6.00 ± 0.11	86.44 ± 7.89	92.00 ± 9.78
48.0	5.68 ± 0.03	5.79 ± 0.26	89.78 ± 7.00	91.56 ± 5.33

Table 3. pH values and lactic acid content in *M. longissimus lumborum et thoracis* of bulls

Time *post mortem* (h)	pH		Lactic acid (mmol/kg)	
	right side	left side	right side	left side
0.5	6.70 ± 0.14	6.54 ± 0.21	43.33 ± 8.43	46.78 ± 14.76
1.0	6.39 ± 0.15	6.37 ± 0.13	56.00 ± 8.40	54.67 ± 16.89
6.0	5.89 ± 0.26	5.93 ± 0.17	82.67 ± 7.46	82.56 ± 5.03
12.0	5.65 ± 0.06	5.65 ± 0.07	105.89 ± 2.52	105.56 ± 4.64
24.0	5.43 ± 0.03	5.42 ± 0.05	109.78 ± 5.91	110.11 ± 3.13
48.0	5.60 ± 0.03	5.58 ± 0.03	113.33 ± 5.52	116.00 ± 5.07

Average values of pH and lactic acid content in MLLT of bulls are given in Table 3. The decrease in pH value in both sides was almost identical and the difference was not statistically significant. The lowest pH value was measured 48 h after slaughter (5.43 and 5.42). Higher variability was found in pH values 12 h after slaughter. The increase in lactic acid concentration was similar in both sides. The highest concentration of lactic acid was determined 72 h after slaughter (113.33 and 116.00 mmol/kg). There were no statistically significant differences between both sides.

DISCUSSION

A decrease in pH values in pigs was typical. This rapid decrease within six hours after slaughter is in

conformity with published data (Stoier *et al.*, 2001). Between the first and the sixth hour after slaughter, the pH value decreased 0.054 and 0.076 units per hour in MLLT as well as 0.040 and 0.042 units in SM. The decrease in pH was lower in the subsequent hours *post mortem* (between 12 and 24 h after slaughter about 0.002 unit per hour in both muscles). The lowest value of pH was measured 48 h after slaughter. The ultimate pH value was reached 24 h after slaughter, but this result is not in concordance with the published data. The published values of pH_{24} were lower than our values. Rosenvold *et al.* (2002) reported the pH_{24} value 5.58 in MLLT and 5.64 in SM. The lower value of pH_{24} was found in SM (5.59) than in MLLT (5.66) according to Henckel *et al.* (2000). We found out the higher pH_{24} value in SM than in MLLT ($P < 0.01$). The differences between the right and the left half-carcass were not statistically significant. Significant differences were detected between the muscles ($P < 0.01$). However, these differences were not significant within one hour after slaughter, which is important for the identification of quality difference when both muscles can be used for pH value measurement or only *m. semimebranosus* which is better accessible in the side of pork.

The very fast increase in lactic acid was documented during the first twelve hours after slaughter. The highest increase was measured between the first and the sixth hour after slaughter, i.e. 3.49 and 2.2 mmol per hour in MLLT, and 1.912 and 1.844 in SM. A subsequent increase in lactic acid concentration was very slow (0.2–0.3 mmol per hour in both muscles). The amount of lactic acid increased within 24 hours after slaughter and then it gradually decreased (except for the right side of SM, where a significant increase was still found). Lactic acid concentration was higher than the published data. Maribo *et al.* (1999) reported 94.5 mmol/kg thirty minutes after slaughter. Differences between both sides were not significant, but statistically significant differences ($P < 0.01$) were demonstrated between the individual muscles again.

A decrease in the pH values is typical of beef muscles. The pH value decreased in the right side at a speed of 0.062 units per hour between the first and the sixth hour after slaughter. In the left side, the pH value decreased more slowly, at a speed of 0.034 units per hour. These documented values were lower than the published data – 0.09 units per hour, within the first to the second hour *post mortem* (Kim *et al.*, 2000). The following decrease continued equally in both sides. The ultimate pH value was reached 48 h after slaughter, which is in concordance with the published data of pH value about 5.5 (Van Laack *et al.*, 2000). According to Immonen *et al.* (2000), the ultimate pH value was higher 48 h after slaughter (5.87). On the other hand, according to Byrne *et al.* (2000), the value 5.48 was reached twenty-four hours after slaughter. There was an increase in pH value 48 h post mortem. Lactic acid concentration increased very quickly within 24 h after slaughter, with the peak ranging from 4.45 to 4.65 mmol/h between the first and the twelfth hour.

The pH value of meat is not influenced by the presence of lactic acid only. Therefore we computed correlation coefficients for pH and lactic acid content. The correlation coefficients were congruent with the individual muscles, for MLLT –0.87 ($P < 0.01$) and for SM –0.78 ($P < 0.01$). This implies that the pH value in MLLT was influenced to a larger extent by the presence of lactic acid than that in SM. This difference is probably caused by different buffering capacity of both muscles, and/or compounds with buffering capacity. The correlation coefficient of MLLT in bulls was –0.96 ($P < 0.01$).

In pigs as well in bulls, the pH_u value in MLLT was obtained 48 h after slaughter. This value was lower in bulls than in pigs. Rapidity of pH decrease was higher in bulls, particularly between the first and the twelfth hour. The increase in lactic acid concentration was higher in pigs during the first six hours after slaughter. This rapid increase occurred in bulls later. In pigs, a decrease in its concentration was detected 24 h after slaughter, in contrast with bulls, where the increase in lactic acid content continued within 72 h after slaughter. There were no significant differences between the individual muscles of pigs or bulls. The correlation coefficient of pH and lactic acid content was higher in bulls; in pigs it was higher in *m. longissimus lumborum et thoracis* than in *m. semimembranosus*. The results show that the differences are due to different buffering capacity and chemical composition of muscles.

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ABSTRAKT

Postmortální změny pH a obsahu kyseliny mléčné ve svalovině prasat a býků

Cílem práce bylo stanovit průběh pH a obsah kyseliny mléčné ve svalovině prasat a býků po poražení a míru ovlivnění hodnoty pH přítomností kyseliny mléčné. Průběh postmortálních změn byl hodnocen u dvou svalů u prasat (*m. longissimus lumborum et thoracis* a *m. semimembranosus*) a v jednom svalu u býků (*m. longissimus lumborum et thoracis*) a byly porovnány obě půlky jatečně opracovaného těla. Pokles pH v MLLT do 24 hodin *post mortem* byl intenzivnější v levé než v pravé vepřové půlce. Nejnižší hodnota pH byla zaznamenána 36 hodin po poražení (5,52) v pravé půlce a za 48 hodin v levé půlce (5,48). Maximální koncentrace kyseliny mléčné bylo dosaženo za 24 hodin *post mortem* (109,78 a 109,22 mmol/kg). Pokles obsahu kyseliny mléčné je patrný 48 hodin po poražení. Hodnoty pH v SM 30 minut a 1 hodinu po poražení byly podobné jako v MLLT. Pokles pH byl v SM pomalejší a nejnižší hodnoty (5,68 a 5,79) byly nalezeny za 48 hodin *post mortem* a byly vyšší než v MLLT. Zvyšování koncentrace kyseliny mléčné bylo obdobné jako v MLLT, ale množství vytvořené kyseliny bylo nižší. Rozdíly mezi pravou a levou půlkou jatečně opracovaného těla nebyly statisticky významné. Průkazné rozdíly byly nalezeny mezi svaly ($P < 0,01$). Nejnižší hodnoty pH v MLLT býků bylo dosaženo za 48 hodin po poražení (5,43 a 5,42). Maximální koncentrace kyseliny mléčné bylo dosaženo za 72 hodin po poražení (113,33 a 116,00 mmol/kg). Rozdíly mezi půlkami nebyly statisticky průkazné. Korelační koeficienty u prasat byly pro MLLT –0,87 ($P < 0,01$) a pro SM –0,78 ($P < 0,01$), v MLLT býků –0,96 ($P < 0,01$). Rozdíly jsou ovlivněny rozdílnou pufrovací schopností a chemickým složením svalů.

Klíčová slova: pufrovací schopnost; kvalita masa; pH; prasata; býci

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