MUSCLE METABOLISM AND MEAT QUALITY OF PIGS AND POULTRY

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Abstract. Structural and functional properties of the skeletal muscle determine the meat quality in agriculturally used animals. Post-mortem changes of these properties vary among individual animals and can eventually lead to occurrence of poor meat quality depending on environmental conditions at slaughter. In pigs, as well as in poultry species, the PSE meat condition [pale, soft, exudative meat] predominates among meat quality alterations. Pigs genetically predisposed for PSS (porcine stress syndrome) and suffering stress before slaughter are characterized by an accelerated post mortem glycolysis. The ryanodine receptor gene [RYR1] was shown to bear the causal mutation for the PSS. Research on structure and function of skeletal muscle in pigs with different RYR1 – genotypes demonstrated differences in the diameter of all three muscle fiber types. In stress susceptible animals an increased diameter of the fibers can be observed. Chicken and turkey underwent a comparably intense selection for high meat yield like pigs. As a result, the breast muscle consists of more than 90% of white [i.e., glycolytic fibers] with higher diameters in turkey than in M. longissimus of pigs. It is suspected that this provides the basis for the occurrence of PSE - like conditions in meat from chicken and turkey. Besides the described structural and biochemical alterations, the so-called extracellular matrix gains more attention in current research. The analysis of the genome and of its translation into messages and proteins will increase our knowledge about muscle biology and may finally lead to selection criteria for favourable meat quality.
Keywords: meat quality, muscle structure, muscle function, pig poultry.

RAUMENŲ MEDŽIAGŲ APYKAITA BEI KIAULIŲ IR PAUKŠČIŲ MĖSOS KOKYBĖ

Santrauka. Skeleto raumenų struktūrinės ir funkcinės savybės apsprendžia žemė sūkyje naudojamų gyvulių mėsos kokybę. Atskirų gyvulių šių savybių pakitimai po skerdimo yra skirtingi ir jie gali sąlygoti blogą mėsos kokybę priklausomai nuo aplinkos sąlygų skerdimo metu.Blyškios, minkštos, suskystėjusios mėsos būklė (BMS) yra dominuojanti tarp tiek kiaulienos, tiek paukštienos mėsos kokybės pakitimų. Kiaulės turi genetinį polinkį į KSS (kiaulių streso sindromą) ir prieš skerdimą patirtas stresas apibūdinamas suintensyvėjusia pomirtine glikolize. Rianodino receptoriaus genas (RYR1) yra atsakingas už KSS mutaciją.Kiaulių skeleto raumenų su skirtingais RYR1 genotipais struktūros ir funkcijų tyrimai parodė skirtingus visų trijų tipų raumenų skaidulų diametrus. Gyvūnams, kurie yra jautrūs stresui, būdingas padidėjęs skaidulų diametras. Viščiukai ir kalakutai taip pat patyrė intensyvią atranką, siekiant didesnės mėsos produkcijos. To pasėkoje krūtinės raumuo susideda iš daugiau kaip 90% baltų (t.y. glikolitinių skaidulų), kurių diametras kalakutų organizme yra didesnis, negu M. longissimus raumens skaidulų kiaulių organizme. Manoma, kad tai ir yra KSS priežastis – kaip ir viščiukų ir kalakutų mėsos būklė. Be jau apibūdintų struktūrinių ir funkcinių mėsos pakitimų, taip vadinamai ekstraląstelinei terpei šiame darbe skiriamas didelis dėmesys. Genomo ir jo pavertimo genetinio kodo vienetais bei proteinais analizė pagilins mūsų žinias apie raumenų biologiją ir net gali nurodyti geros mėsos kokybės atrankos kriterijus.
Raktažodžiai: mėsos kokybė, raumenų struktūra, raumenų funkcijos, kiaulės, paukščiai.

Introduction. The conversion of skeletal muscle to meat is the result of complex biochemical pathways. These processes are influenced by the metabolic situation immediately before slaughter but also by genetically determined factors like muscle composition and stress susceptibility. Variability in one or more of these traits subsequently leads to variability in meat quality. Beyond a normal variability meat quality alterations may occur. In swine the most frequently observed deviation from normal meat quality is the so-called PSE meat condition (Bendall & Wismer-Pedersen 1962). It is characterized by decreased water holding capacity, pale colour and firmness. A rapid decrease of the pH is observed immediately after slaughter that indicates an accelerated glycolysis at still high muscle temperature (Mitchell & Heffron, 1982). There is a close relationship between the development of PSE meat and the Porcine Stress Syndrome (PSS) however, it can not completely explain the occurrence of PSE. The genetic basis for this syndrome was found to be a mutation in a gene coding for a sarcoplasmic calcium release channel (ryanodine receptor, RYR1; Fujii et al., 1990). Recent research revealed problems with meat quality in turkey and chicken that resemble the PSE condition in pig (Barbut, 1997, Owens et al., 2000, Woelfel et al., 2002). In contrast to pigs, the genetic basis of meat quality alterations in poultry is still not fully understood. Some authors, however, assume the existence of a so-called Avian Stress Syndrome (ASS; Stephan, 1993).

Furthermore, DFD meat (dark, firm, dry) can be found in pig, cattle and probably in poultry (Mallia et al., 2000a, b), whereas RSE meat (red, soft, exudative) and acid meat are conditions observed exclusively in pigs. Our paper summarizes current research on function and structure of the skeletal muscle in pigs and poultry from literature as well as from our own investigations.

Results and Discussion

Meat quality alterations in pigs and poultry

The biochemical reactions in skeletal muscle during its conversion to meat result among others in changes in the muscle pH. Since pH values are easy to measure, the course of pH changes is widely used for the characterization of meat quality in different species. The typical development of pH values resulting in different meat quality conditions in swine is shown in Figure 1.

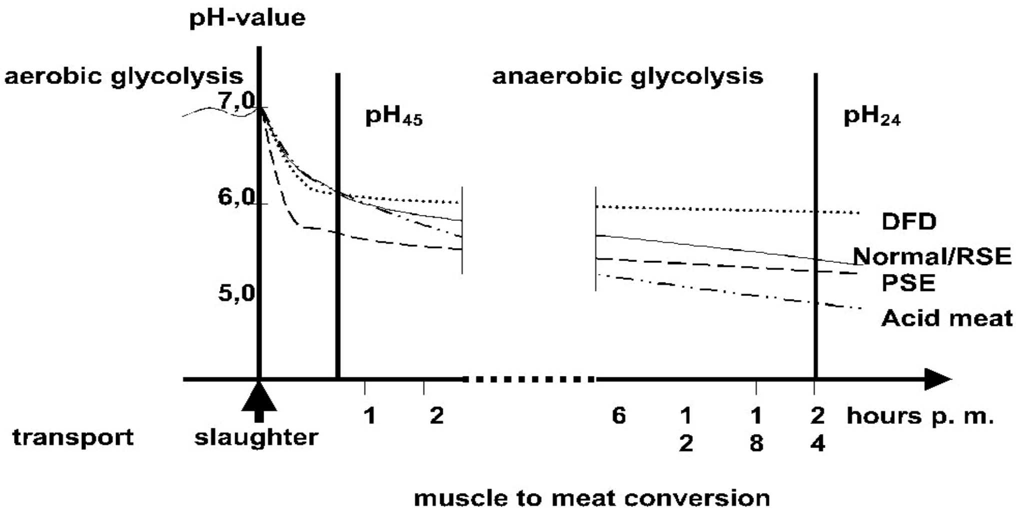

Figure 1. **Typical development of the muscle pH values resulting in different meat quality in pigs**

Due to the curve characteristics measurement of pH at 45 minutes post mortem and 24 hours post mortem, respectively can be used to differentiate between normal and poor meat quality, whereas pH values below 5.8 at 45 minutes post morten indicate the development of PSE meat, DFD and Acid meat can only be differentiated from normal meat on the basis of ultimate pH values (DFD: > 6.2; Acid meat: < 5.4). Red, soft, exudative meat (RSE) however, is indistinguishable from normal meat by means of either early or ultimate pH values. The relationships between pH and meat quality in swine are well established and are reviewed by Lengerken et al. (1998). This relation can also be simulated in vitro. A small muscle sample obtained by shot biopsy is incubated at 37°C for 45 minutes, and the pH of the fluid and the sample itself are measured. The **in-vitro** pH values are closely related to the meat quality observed after slaughter and thus, can be used as a predictor for it (Lengerken et al., 1994). The differences in pH courses finally lead to differences in meat colour and technological properties of the meat. PSE meat is the most frequent meat quality alteration in pig with estimates of 10 – 15 % among all slaughtered pigs in Germany (Wicke, unpublished data). Estimates of the frequencies of other meat quality alterations are hardly obtainable, because routine measurements of pH at 24 hours post mortem are not possible under practical conditions. The introduction of a simple molecular test for stress susceptibility (Foerster, 1992) opened the opportunity to select indirectly against PSE meat by eliminating stress susceptible pigs (allele “n”) from breeding. However, the negative genetic relationship between stress susceptibility and lean meat percentage lead to the phenomenon that the percentage of heterozygotes remained almost unchanged over the last 10 years despite the elimination of homozygous stress susceptible pigs (genotype nn; Figure 2). Pigs heterozygous at the RYR1 locus (genotype Nn) take an intermediate position between the both homozygous genotypes in lean meat percentage as well meat quality (Table 1).

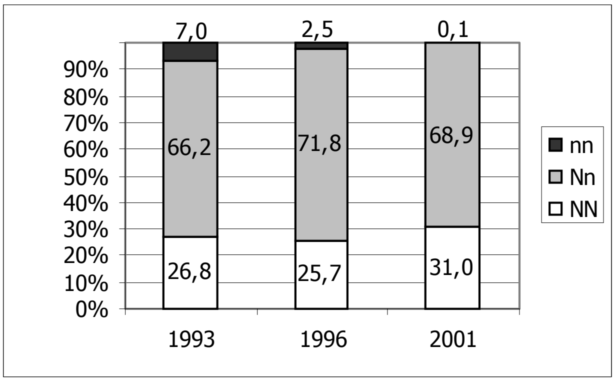

Figure 2. **Development of the genotype frequencies at the RYR1 locus in German slaughter pigs**

Although, a close relationship between the genotype at the RYR1 locus and the frequency of PSE is well established, it must be noted that PSE meat can also sometimes be observed in homozygous stress resistant pigs. This fact demonstrates that the RYR1 locus is indeed a major gene affecting meat quality, but additional genetic and environmental factors are involved.

Table 1. **Carcass and meat quality in pigs with different genotypes at the RYR1 locus (LSQ Means; SE)**

Trait	RYR1-genotype		
	NN	Nn	nn
pH (M. long.; 120 min p.m.)	$6.43^{a}\pm0.09$	$5.91^{b}\pm0.06$	$5.58^{c}\pm0.08$
Electric Conductivity (M. long.; 120 min p.m.)	$2.99^{a}\pm0.10$	$4.29^{b}\pm0.25$	$8.49^{c}\pm0.68$
Lean Meat Percentage (%)	$48.8^{a}\pm1.70$	$51.4^{b}\pm0.49$	$58.2^{c}\pm1.70$

Different superscripts: significantly different between genotypes ($p < 0.05$)

Acid meat is a meat condition that is restricted to Hampshire breed. The very low ultimate pH of the meat is due to increased glycolytic capacity of the muscle, and it has technological disadvantages (reduced yield of cooked ham; Monin & Sellier, 1985). LeRoy et al. (1990), postulated a monogenic heredity, and finally, the responsible gene could be identified and characterized (Milan et al., 2000). Acid meat is the only meat quality alteration that can be attributed to the effect of a single gene.

In contrast to swine, meat quality alterations in poultry gained attention only in the last decade (Barbut, 1993; Fletcher, 1999). The authors described the occurrence of a PSE like condition in breast meat of chicken and turkey. Meat of affected animals appeared pale and was characterized by a rapid pH decline immediately after slaughter. Investigations on the frequency of PSE like meat, revealed the variation from 0 to 37 % in broiler flocks in North America. It was suggested that the genetic basis underlying the PSE condition in poultry is similar to that in swine. Consequently, a halothane test was developed for turkeys to detect stress susceptible animals (Wheeler et al., 1999; Owens et al., 2000). However, the relationship between the response of the birds to the anesthetic halothane and the occurrence of PSE like meat was not as close as observed in pigs. Thus, Fletcher (2002) concludes that halothane susceptibility is only a limited predictor of meat quality in turkey. These results indicate potential differences in muscle metabolism between pigs and poultry and, therefore, point to a different genetic background of PSE in both species. More recently, a DFD like condition was reported in breast meat from turkey as well as from broiler (Mallia et al., 2000; Woelfel et al., 2002). The occurrence of this meat quality alteration is assumed to be related to stress [e.g. hypoxia due to overcrowded crates] that the birds experience prior to slaughter. However, also for DFD like meat in poultry contradictory observations were made and again indicate a difference to other species like pig and cattle (Mallia et al., 2000).

Wicke et al. (2000) and Opalka et al. (2000) investigated **in vitro** function of the muscle mitochondria in pigs and turkeys with different meat quality. The results indicate a reduced mitochondrial respiratory activity for some substrates in PSE developing animals. However it is likely, that mitochondrial dysfunction is a secondary process rather than the cause for PSE development.

Meat quality alterations are observed in pigs as well as in poultry at relatively high frequencies. Whereas PSE meat is a problem of comparable importance for pig and poultry, DFD like meat seems to occur more frequently in poultry than in pig. It is well established that alterations in velocity and intensity of glycolytic pathways lead to the described poor meat quality. As far as PSE meat in pig is concerned a major genetic factor for its development is known. In contrast, a genetic basis is known neither for DFD meat in both species nor for PSE in poultry. The structure of the skeletal muscle (e.g. fiber type composition) influences its function. Therefore, some results on respective investigations are discussed in the following chapter.

Muscle structure in relation to meat quality in pig and poultry.

Muscle fibers are commonly classified into three groups according to their biochemical and functional properties (Table 2). The M. longissimus of pigs consists of approximately 13% STO [slow twitch oxidative; red] fibers, 17% FTO (fast twitch oxidative; intermediate) fibers, and about 70% FTG (fast twitch glycolytic; white fibers). In contrast, M pectoralis of chicken and turkey is almost exclusively composed of white (TG) fibers. In several investigations on pigs clear differences in muscle structure were found between pigs of different meat quality and different stress susceptibility (Wicke et al., 1993; Fiedler et al., 1999). The percentage of the fiber fractions was similar in both pigs with normal and PSE meat condition (Figure 3).

Table 2. **Properties of skeletal muscle fiber types**

Property	Fiber type		
	slow twitch oxidative (STO, red)	fast twitch oxydative (FTO, intermediate)	fast twitch glycolytic (FTG, white)
Muscle colour	red	pale red	white
Diameter	small	medium	large
Contraction	slow	fast	fast
Endurance	high	medium	low
Myoglobin content	high	medium	low
Number of myofibrils	few	medium	many
Number of mitochondria	many	medium	few
Enzyme pattern	oxydative	oxydative/anearobic	anaerobic

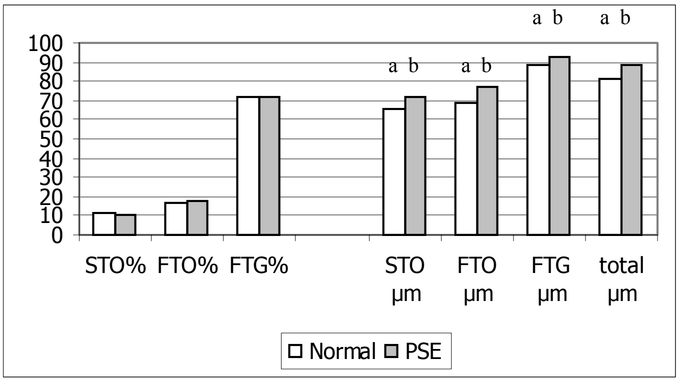

Figure 3. **Fiber type composition and mean diameter of the fiber types of the M. longissimus in pigs with normal and PSE meat (Different letters indicate significant differences between the meat quality groups).**

Table 3. **Comparison of structural parameters of M. longissimus in pigs and M. pectoralis in broilers and turkeys**

Species/Trait	Percentage of fiber types (%)			Pathological fibers (%)	Mean area of fiber types (µm²)		
	STO	FTO	FTG		STO	FTO	FTG
Broiler	0	0	99,5	0.5	-	-	2.373
Turkey	0	0	99.8	0.2	-	-	7.042
Pig	11.6	15.5	72.0	0.9	3.473	3.318	7.375

However, the mean fiber diameter of all types was significantly increased in pigs developing PSE meat after slaughter compared to pigs with normal meat quality. This fact indicates that the breeding selection for high lean meat yield resulted in hypertrophy of the muscle fibers. That is probably related to alterations in muscle metabolism and finally leads to the development of poor meat quality. Comparable data for poultry are relatively rare. First investigations on muscle structure in broiler and turkey demonstrate a similar development in these species (Wicke, unpublished data). Fiber type composition and mean fiber area of the fiber types are shown in Table 3 for turkeys, broilers and pigs. Besides the mentioned differences in compositions it is obvious that the fiber area of white fibers in poultry species is very high. So, in turkey breast muscle white fibers with an area of more than 7,000 µm² are observed - that is comparable to those in pigs (7.375 µm² in M. longissimus). The comparison of the mean fiber areas between turkeys with normal meat quality and those with PSE like meat reveals the same relationship as observed in pigs: PSE prone muscle is characterized by higher diameters (7.081 µm² vs. 5.651µm²; $p < 0.05$). The percentage of pathological fibers (giant fibers, dark angulated fibers) was 0.2 % in turkey and 0.5% in broilers. These values are lower than those reported for the pigs 1% (Wicke et al., 1993).

The intensive selection on lean meat yield in pigs and breast muscle yield in broilers and turkeys, respectively lead to an increase in the diameter of the muscle fibers. The metabolic changes following this increase are still not fully understood.

Future trends in research on meat quality

Besides the analysis of factors well described to be involved in meat development (e.g. glycolytic enzymes, myogenic factors) future research may be directed towards additional aspects of skeletal muscle structure and function. The so-called extracellular matrix may be a typical example. This matrix consists of glycoproteins, collagen and proteoglycans and provides the structural basis for the spatial distribution of muscle cells (Velleman, 2000). The author pronounces the potential importance of the extracellular matrix for meat quality, since proteoglycans are negatively charged and probably determine the water binding capacity of skeletal muscle.

The progress in molecular genetics opens new fields for research on meat quality. Methods for investigations on gene expression are available and allow to monitor the function of genes potentially involved in biochemical pathways responsible for muscle to meat conversion. So, very recently, Mott & Ivarie (2002) could exclude differences in the expression of myogenin as a cause for fiber hypertrophy in broilers. New techniques like DNA chips and quantitative analysis of mRNAs make it possible to investigate complex biochemical pathways on molecular level and thus, are expected to contribute to a rapid expansion of our knowledge about muscle biology.

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