

Historical perspectives and current aspects of pork meat quality in the USA

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Abstract

The condition of pale, soft and exudative (PSE) pork meat was recognized and documented by 1960, and the condition of porcine stress syndrome (PSS) was understood within the decade of the 1960s. The two are associated, with PSS animals having a high probability of producing PSE meat. Both are economically important with potential death losses, especially during transport, due to PSS, and PSE meat being viewed as of inferior quality by consumers and also having less value for further processing. An enormous amount of research has been directed at the problem and is presented in the manuscript as a time-line approaching a half-century of effort. Surveys of incidence showed, in pork produced in the USA, that 18% was PSE in 1963 and 16% was PSE in 1992. Fortunately, molecular/genetic understanding and tools are now available to attack the problem, but solving it may require further impetus — such as strong and unified resolution by producers, industry associations and governmental agencies. © 2000 Elsevier Science Ltd. All rights reserved.

1. Introduction

Quantity and quality are descriptive terms of great importance in the meat industry. Producers of meat animals have always striven for quantity. As the live animal is converted to meat and the meat moves along the line of distribution, from slaughters and processors to retailers and finally to consumers, the factor of quality becomes increasingly more important. Obviously, economic considerations influence the concerns for quantity and quality. In the present global economy, meat quality takes on considerable importance for all segments of the industry from producer to consumer. Consumers are becoming more discriminating and will no longer accept meat of inferior quality. Furthermore, there is a potential danger that consumers may begin to associate poor quality of meat with food safety issues.

This commentary about quality of meat focus specifically on pork and more narrowly yet on the USA. It must not be overlooked, however, that considerable effort has been directed at solving pork quality problems in Great Britain, the Scandinavian countries, especially Denmark, and the Central European

countries of Germany and France and especially The Netherlands.

Pork quality has assumed even greater significance in the past quarter century because of the availability of alternatives. Not only are there substitutes for pork available from poultry but also from plant sources. Protein from plants and poultry is generally less expensive, and the poultry industry has been highly successful in marketing and also in adopting existing technology for incorporating poultry meat into processed meat. Interestingly, the National Pork Producers Council launched a highly successful marketing concept based on the motto “The Other White Meat”. The idea imparted is that pork is a “light”, low-fat meat similar to poultry. But we must wonder about the “white” connotation in regard to the information to be presented in the next section about a “pale” color in pork being an indicator of poor quality.

The following body of this manuscript is a time-line of findings and events about pork quality. It is a most interesting topic for analysis — being on one hand a success story for research but on the other hand a failure of the industry and governmental agencies to grasp and utilize the research to solve the problem. The definition of the quality problem and the research which followed to describe and understand the basis for the

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problem is an incredible record of accomplishments by scientists.

2. Events and results

Pork quality is essentially synonymous with the condition known as pale, soft and exudative and identified by the term PSE. The other extreme, but without much importance to the matter of pork quality, is dark, firm and dry and identified by the term DFD. The terms reflect the appearance and physical condition of the meat. Pork which is a pale color, exuding drip into the package, and of a loose texture being unable to maintain its proper shape is not appealing to the eye of the consumer and the result is a loss in sales. Moreover, there is a clear economic loss in the 2–3% drip, which is not merely water but contains soluble nutrients. Of a more hidden nature, but of considerable monetary value, is the fact that PSE pork has limited value for further processing due to the poor binding properties. Most recently (see Kauffman, Cassens, Scherer & Meeker, 1992) another term (RSE for red, soft and exudative) has been introduced to classify pork of a “questionable” quality.

The following time-line of events and results should be considered as a series of highlights along the way from discovery and description of pork quality problems to the present time. Emphasis is placed on early and significant findings, especially during the 1960s. As the title indicates, the work cited is limited to the USA, but reference to work in other countries creeps in as it is impossible to isolate some findings. Even though there is an enormous body of literature citations, I have attempted to cite only a few important and original examples to illustrate each point. I have selected them as having historical impact, and they will lead easily to a vast and detailed literature. Also, explanation of each point is meager, as the purpose of the manuscript is not to concentrate on scientific detail but rather to document scientific progress over time so that an assessment of utilization of findings can be made.

2.1. Identification and description of the problem

PSE in pork was recognized and described during the 1950s. Therefore, an informed way to view the situation is that a problem in meat quality was identified nearly one-half Century ago, and, as we shall learn, the problem continues to exist today to approximately the same extent as when it was discovered. The earliest reports came from Denmark (Ludvigsen, 1954), France (Henry, Billon & Haouza, 1955) and the USA (Briskey, Bray, Hoekstra, Phillips & Grummer, 1959a). Early on, it was thought to be a degenerative or myopathic condition in the muscle, but it was learned quickly that the quality problem developed as a result of the very early

post-mortem changes as muscle was converted to meat. The early 1960s witnessed a great deal of research activity on pork quality, and an enormous amount of research information from numerous Institutes and Centers was recorded in the literature. An early review by Briskey (1964) ran to 88 printed pages and included more than 225 literature citations.

2.2. Effect of exercise and diet

Already by 1960 it was recognized that exercise and diet exert an important influence on the post-mortem conversion of muscle to meat and therefore on the ultimate quality characteristics of the meat (Briskey et al., 1959a–c). Varying the dietary content of protein, fat and sucrose led to the discovery that higher sucrose resulted in more PSE. This was related to higher glycogen stores in the muscle and the resulting higher acidity post-mortem from metabolism of the glycogen. Likewise, exercise of the animal immediately prior to slaughter resulted in darker, higher pH meat being produced. The conclusion was that exercise depleted muscle glycogen. So, a foundation was laid for subsequent and detailed studies of post-mortem biochemistry in the muscle.

2.3. Relationship of post-mortem acidity and temperature to PSE

This relationship was recognized and described by 1961 (Wisner-Pedersen & Briskey, 1961). Since then and still continuing today are efforts to use pH as a measure of pork quality and to regulate post-mortem chilling temperature as a means to control pork quality. The conclusion in 1961 was that PSE resulted when pH decreased to about 5.4 (lactic acid content of about 1%) while muscle temperature was above 25°C. Meat quality (color and water-binding) could be improved by rapidly chilling the pork carcass.

2.4. Classification and standards for pork quality

Researchers recognized early on (early 1960s) that in order to work with the pork quality problem a standardized description and nomenclature was necessary. The desire was for a easy, rapid and repeatable procedure, based on visual inspection, but which indeed was closely related to pH, water-binding and objectively measured color. Briskey, Hoekstra, Bray and Grummer (1960) examined a number of muscles and concluded that *M. biceps femoris* and *M. longissimus dorsi* were good indicator muscles for appearance and water-binding, as well as being two of the largest single muscles in the carcass. Subsequently (Anon., 1963) a Pork Quality Standards bulletin was developed at the University of Wisconsin. It used color photographs, of the two muscles described above, to illustrate five standards of color, structure and

firmness. 1 was extremely pale, soft and watery, 3 was normal, uniformly greyish-pink, moderately firm and moderately dry, and 5 was dark, very firm and very dry. These standards were used extensively to assess not only the results of research trials on pork quality but also in the industry to determine the extent and pattern of the problem. Numerous other standards and revisions have appeared in subsequent years.

2.5. *Post-mortem changes*

Researchers quickly comprehended the importance of the kind and rate of post-mortem changes in muscle on quality of the resulting pork, and these were well-described in the literature by the mid-1960s. Briskey et al. (1966), in reviewing the ongoing work, described the various patterns of pH decline which resulted in various meat qualities—these graphs of pH decline have been cited uncountable times in the literature. It was also established by then that the rapid glycolytic rate (resulting in PSE) was associated with high levels of G-6-P and glucose, accompanied by low levels of fructose diphosphate, ATP and phosphocreatine. It was also well-established by then that certain pigs were pre-disposed to rapid post-mortem glycolysis and were in an oxygen-deficient state at the time of slaughter.

2.6. *Rigor mortis*

Also, by the mid-1960s it was understood that the physical changes of rigor mortis were determined by post-mortem glycolysis, and measurements of rigor mortis were associated with ultimate meat quality. An instrument was developed to study rigor mortis (Briskey, Sayre & Cassens, 1962) and it was subsequently established (Sayre, Kiernat & Briskey, 1964) that when rigor mortis onset occurred at pH values below 5.9 and temperature above 35°C the resulting meat became pale, soft and exudative.

2.7. *Post-mortem changes in chicken muscle*

A series of experiments during the 1960s (DeFremery, 1966) established that the biochemical and biophysical changes occurring post-mortem in chicken muscle were quite similar to those in pig. While these studies were undertaken primarily to understand mechanisms for meat toughening, it is noted that there was little subsequent investigation or concern in poultry, until a quality concern surfaced in turkey muscle—and which will be described subsequently on this time line.

2.8. *Muscle structure*

Another aspect of meat quality under intensive investigation by the mid-1960s was muscle ultrastructure

(Cassens, Briskey & Hoekstra, 1963). It was becoming apparent that the disruption of sarcoplasmic components was a function of the rate of post-mortem glycolysis, and that the protein filaments in muscle were being disrupted more in PSE compared to normal muscle. The latter is probably associated with the poor water-binding properties of PSE meat.

2.9. *Water-holding-capacity*

Any description of work on meat quality during the 1960s must include a statement about water-holding-capacity (for review, see Hamm, 1994). Loss of water from PSE meat was an important factor since it could be related directly to an economic loss, as contrasted to color/appearance, which was more difficult to quantify in terms of economic loss. Several methods were developed to measure water-holding-capacity, but the fundamental work to explain the phenomenon was conducted in Germany as a part to the studies on post-mortem biochemistry and resulted finally in the suggestion water-holding-capacity is related primarily to the charges on the proteins of the myofibrils.

2.10. *Rapid chilling*

While a good deal has been heard in recent years about the importance of rapid chilling of carcasses post-mortem, the precedent was established already in 1963 (Borchert & Briskey, 1963). They used liquid nitrogen chilling over a wide range of conditions and found the treatment was extremely effective in preventing the development of PSE.

2.11. *Survey of incidence*

The first survey of incidence of PSE in the USA was completed in 1963 (Forrest, Gundlach & Briskey, 1963). They found that 18% of hams were PSE, and the daily incidence ranged from 0 to 75%. A total of 15,000 hams was observed over a period of 1 year, and it was found that a greater incidence occurred those times of year having greater temperature fluctuations — we now know this is more stressful to the animals. With that incidence of poor quality it is obvious that the problem was of considerable importance. Later on this time line, we will find that a similar survey in the USA in 1992, 30 years later, revealed that the incidence had, in fact, changed little.

2.12. *Effect of breed (genetics)*

In the search for experimental animals having a high predisposition for PSE, it was recognized during the 1960s that certain breeds or strains had a much higher

incidence of PSE. In the USA the Poland China breed, as well as the Hampshire were identified, and in Europe the Landrace and Pietrain were singled out. It must be pointed out that a very high incidence (breed related) often occurred in more restricted breeding plans such as experimental herds at Universities or Institutes. Most importantly it was also recognized that pigs most predisposed to PSE were very frequently highly muscled. This set up an important conflict — namely if selection was made against PSE then the most highly muscled animals would be the first to be culled from the breeding program.

2.13. Stress-susceptible animals

This is an appropriate point to introduce another key issue of importance. Just as breed or strain differences were recognized in the 1960s, as described above, researchers began to recognize so-called “stress-susceptible” pigs (also known as PSS or porcine stress syndrome). These pigs were very excitable to environmental, social and transportation situations and were sought out by researchers because the meat from them had a very high incidence of PSE. Sometimes, the animals succumbed to stress, a fact of direct monetary importance to breeders and producers. Some confusion existed early as DFD meat resulted on occasion from stress-susceptible animals — a circumstance explained by depletion of glycogen so that a high pH resulted post-mortem.

2.14. Processing yield

While most interest about PSE focused on fresh meat there was an underlying concern that if PSE meat was further processed the quality problem would be carried over. Merkel (1971) studied the effect of PSE on two of the typical and important products manufactured from pork — canned ham and as a component of emulsified products such as bologna. PSE muscle had lower emulsifying capacity. Greater weight loss during processing was observed for PSE meat, but the difficulties could be improved with the use of phosphates.

2.15. Fiber type characteristics

As an understanding of the situation that muscle is a mixture of different fiber types (primarily red and white), that the fibers have different characteristics such as post-mortem metabolism and that the nervous system exerts some control on fiber types, researchers began extensive studies to determine if fiber characteristics were related to stress-susceptibility and/or PSE. For the most part, a definitive answer was not found although a great deal of work was undertaken and some interesting suggestions surfaced. Cooper, Cassens and

Briskey (1969), for example, reported no difference in capillary to fiber ratio in muscle from normal and stress-susceptible animals, but did find more “intermediate” type fibers in muscle from stress-susceptible animals and suggested a possible link to PSE.

2.16. Sarcoplasmic reticulum and calcium accumulation

An observation in the late 1960s (Greaser et al., 1969) laid the basis for subsequent work that led to an understanding of Porcine Stress Syndrome and eventually to development of a clinical diagnostic method in the 1990s. The calcium accumulating properties of the sarcoplasmic reticulum functions in coupling excitation of the muscle cell with contraction of the myofibrils. The Greaser observation was that calcium accumulating ability of sarcoplasmic reticulum fractions from normal muscle was significantly higher than similar preparations from PSE muscle.

2.17. Physiology and endocrinology

With the background information about post-mortem biochemistry together with information about structural and physical changes in the muscle, and because of the increasing importance of the “stress syndrome”, the interest of researchers turned in the late 1960s and early 1970s to physiology of the animal. For example, Forrest, Will, Schmidt, Judge and Briskey (1968) studied homeostasis in pigs and found stress-susceptible animals had a poor tolerance to heat (venous blood P_{CO_2} increased significantly while P_{O_2} and pH dropped sharply). Marple and Cassens (1973) studied metabolic clearance of cortisol in stress-susceptible pigs and reported an increased rate of cortisol utilization and production.

2.18. Malignant hyperthermia and halothane sensitivity

The physiological studies led eventually to the realization that stress-susceptible pigs had a condition very similar to malignant hyperthermia in humans, and that the extreme sensitivity to halothane sensitivity could be used to identify the carrier pigs. Eikelenboom (1972) explained that the reaction of stress-susceptible pigs to inhalation-anesthesia with halothane is similar to the symptoms observed in transport deaths — that is hyperpyrexia, metabolic acidosis and an increase in muscle rigidity. He also reported from such stress-susceptible pigs, compared to normal, the mitochondria have a lower respiratory control (but a well-coupled oxidative phosphorylation).

The final stages of research in the area, which will bring us to the present, deals with selection possibilities and breeding plans based on molecular biology and specific detection methods. Before proceeding to that,

however, two more points will be inserted into the time line.

2.19. *Symposia*

One means of tracking and reviewing the history of an area of research is to establish the pattern of Symposia organized so that the involved researchers came together for a few days to assess the situation and plot future direction. In this regard, several important symposia about pork quality were organized during the early research activity.

Sybesma, van der Wal and Walstra (1968) organized a symposium under the title “Recent points of view on the condition and meat quality of pigs for slaughter”. They concluded the term “degeneration” should not be used in relation to abnormal meat quality. They agreed also that PSE was a good descriptive term, and called for collection of more data regarding consumer reactions.

The same group of workers (Anon., 1971) called a second symposium in 1971 under the same title. They considered the topics of muscle metabolism, stunning, transport and fresh contrasted to processed pork. In final conclusion, the participants believed that even if meat quality were not a problem, the difficulties associated with rearing, fattening and transport of stress-susceptible pigs justified continuing efforts to seek its elimination.

A somewhat different approach was taken in 1972 in a symposium organized by Cassens, Girsler and Kolb (1972) — pork quality was addressed by some speakers but the main feature of the symposium was a series of hands-on teaching demonstrations in which factors such as transportation stress, detection methods and effect of processing were pursued in a live setting.

While not in an actual symposium format, an assessment of pig meat quality was undertaken by Jul and Zeuthen in 1980 — it was an effort to bring up-to-date information into a report. For one thing, they pointed out the benefits of quality must be weighed against the cost of obtaining it. They acknowledged that perhaps a “code of practice” could be instituted having specific criteria and extending from breeding all the way to final packaging of the product.

Finally and more recently a workshop on pork quality was organized by Puolanne, Demeyer, Ruusunen and Ellis in 1992. Discussed at some length was the availability of the new molecular/genetic tools to geneticists and breeders. An important recommendation regarding pork quality was that efforts must be directed towards quality optimization by organizing integrated quality systems.

2.20. *Turkey quality*

Quality problems exist in turkey muscle. The most important of these is a loss of processing yield. To date

the cause is not totally elaborated, but the work of Sosnicki, Cassens, McIntyre, Vimini and Greaser (1989) has recorded a degenerative phenomenon, and whether this has some similarities to the problems of quality in pork remains to be determined.

2.21. *Molecular genetics*

This is the final research area on the time-line, and it is ongoing. New techniques have led to gene identification and diagnostic tools. The early work on calcium binding by the sarcoplasmic reticulum, porcine stress syndrome, malignant hyperthermia and finally halothane sensitivity testing brought us to this point. It became apparent that it was difficult or impossible to identify the heterozygote for PSS with halothane testing. More recently, the responsible gene was identified and has been referred to as the PSS or stress gene, the halogen or hal gene and the ryanodine receptor gene; molecular test have been developed and should allow detection of the heterozygote (see, for example: Houde & Pommier, 1993; Hughes & Lowden, 1998; Louis, Rempel & Mickelson, 1993; MacLennon & Phillips, 1992). de Vries (1999) presented a complete account about the use of gene technology for developing optimal pork quality.

2.22. *Recent survey of pork quality problems*

We can more or less complete the time-line with a 1992 survey of variations in pork quality (Kauffman et al., 1992) which revealed the pork supply in the USA contains about 16% PSE. The easy and obvious conclusion, then, is that the incidence of poor quality is almost identical to what it was in 1963. However, the situation is in fact much more serious. Another 10% of the pork was dark, firm and dry, which is likewise an undesirable quality. Only 16% of the pork was found to be of ideal quality. The remainder of the pork was of somewhat questionable quality — that is of acceptable reddish color but of soft and exudative texture and now identified as RSE.

3. Discussion and conclusions

Unfortunately, this discussion must begin by facing the facts — and therefore on a negative note. It is clear from the time-line that an enormous amount of research has been undertaken and completed on PSE and PSS, and that the basis for and understanding of the syndrome is in hand. However, on the basis of extensive surveys at the beginning and end of the time-line, very little progress in eliminating or minimizing the problem is recorded.

The problem of PSE in pork meat was recognized already in the mid-1950s. It was thought, at first, to be a

muscle degenerative disease. Frantic research efforts as the 1960s began established quickly the facts that it was due to early post-mortem changes in the muscle, and that these changes were influenced by diet, exercise (stress) and breed or strain of the pig. Subsequently, more was learned about post-mortem biochemistry — about glycogen, pH, temperature and rigor mortis and how these factors influence rigor mortis, water-holding capacity and color. The more difficult aspects of animal physiology and endocrinology were encountered and dealt with, and the discovery of animal stress was made. Subsequently, the importance of animal stress susceptibility was recognized, and the associations were extended to malignant hyperthermia and halothane sensitivity. More research about fiber type properties, ultrastructural changes post-mortem and calcium binding by the sarcoplasmic reticulum was completed and extended eventually to genetic/molecular techniques of today which promise excellent diagnostic tools. Along the way, note was also made of the importance of pH as a measuring tool, chilling as a control method and ways to improve processing yield.

Poultry meat has become a significant competitor of pork. Investigations during the 1960 revealed that poultry also had a very rapid post-mortem change, similar to pork. But, the quality of chicken meat has not been brought into question. Some reports have noted a quality/texture problem in turkey which may be similar to PSE in pork.

As somewhat of an aside, it is interesting that a recently published book (Horwitz, 1998) addresses, from a more sociological viewpoint, many of the problems associated with present-day production of quality pork meat.

It must be mentioned that during the Fall of 1998 the price of hogs in the USA went to as low as \$10 per hundred weight. This meant that farmers were losing about \$60 per head of hogs sold. The USDA announced purchase plans to assist.

The National Pork Producers Council has supported work on quality and safety and issued recently (Berg, 1998) a fact sheet about critical points affecting pork quality within the packing plant. Issues such as pre-transport handling, transport, lairage, stunning, post-mortem temperature, pH and chilling are addressed as means to improve pork quality. Rather interestingly, the earliest reference cited was 1973.

I must conclude that little progress has been made in improving pork quality. Why? What must be done? There has been a conflict for the producer — the more muscular, faster growing pigs have poorer quality. The marketing system in the USA does not reward quality with a premium, but rather pays for quantity. A positive feature is that commercial pig breeding companies stand poised to provide breeding stock which will produce known quality pork. While the packing plants can make

efforts to control quality, for example with rapid chilling, they are facing throughput problems. It is apparent that little progress will be made until firm resolution is taken by all involved — producers, industry associations and governmental agencies.

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