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Pork quality: a technical review

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Pork quality: a technical review

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La qualité du porc: revue technique

cover

The dots on the map represent Agriculture Canada research establishments.

CONTENTS

INTRODUCTION

Canadian pork production has shown a substantial increase during the last decade and in 1986 approximately 15 million market pigs will have been produced in Canada. Approximately 30% of the pork produced in Canada is exported mainly to the USA and Japan and this trade has an annual value in excess of $800 million. In all the major pork producing countries of the world there have been reports which indicate that pork quality appears to have declined. The major problem is the apparent increased frequency of pale, soft exudative pork (PSE) and to a lesser degree dark, firm and dry (DFD) pork. In 1981, a Work Planning Meeting on PSE and DFD pork organized by Agriculture Canada was held in Ottawa on April 27-28. One of the non-research recommendations resulting from this meeting was the preparation of a technical literature review on PSE/DFD pork. At that time the amount of Canadian information was extremely limited and during the last 5 years a considerable amount of applied work has been completed. In 1986, the Lacombe Research Station at the request of the Industry/Government Committee on PSE/DFD pork agreed to complete a technical review.

Chapter 1 examines the identification of PSE/DFD pork. National subjective pork quality standards have been developed in Canada and their use and relationship with objective measurements of muscle quality is explained. New methods which have the potential to measure PSE/DFD at different times post-mortem are also reviewed. Chapter 2 considers the processing problems which arise when pork from different quality groups is processed. The yield figures presented can be used by industry to estimate the financial implications of processing PSE and DFD pork. The retail case life of PSE/DFD pork is reviewed in Chapter 3 and its palatability in Chapter 4. The remainder of the bulletin reviews the current knowledge on the main factors responsible for causing increased frequences of poor quality pork. Chapter 5 deals with the genetics of stress susceptibility which is an area of intensive research particularly in Europe. The reader may find some of the information difficult to understand but further simplification would lead to losses in content. The methods that have been used to identify stress susceptible pigs other than halothane testing are covered in Chapter 6 and special reference is made to the identification of the stress susceptibility gene (halothane) in carrier pigs. Chapter 7 deals with the factors between the farm gate and the abattoir prior to slaughter which have been shown to influence pork quality. Post-mortem factors which have a bearing on muscle quality are covered in Chapter 8.

This bulletin was not intended as a complete documentation of all the scientific reports in the literature. We have attempted to highlight the most important studies and the references should be consulted for further information, since their interpretation in most cases is our own and we would be the first to acknowledge that the events leading to aberrant pork quality are far from understood.

In Canada the frequency of PSE and DFD pork is variable but for both conditions is estimated to range between 10-30% (Murray 1986) depending on the season of the year, and to cost the industry in excess of $20 million per annum. The objective of this review was to highlight the problems of aberrant muscle quality and to consider the main causal factors leading to a high frequency of PSE/DFD pork.

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1. IDENTIFICATION OF PSE/DFD PORK

A.C. Murray and S.D.M. Jones

A. Definition of pork muscle quality

The characteristics of fresh uncooked pork muscle which are considered to be major determinants of quality include: color, textural appearance and water holding capacity.

Quality may have different meanings to different people. Color, textural appearance and water holding capacity (drip) are obviously of importance to the consumer. Color and textural appearance are of importance for the export market. Water holding capacity is of importance to the processor because of its great influence on the curing yield. Water holding capacity is also of importance to the pork producer and the processor because of its relationship to carcass weight losses. Color is of importance to the retailer, not only as it relates to consumer acceptance, but also because of the relationship of color to retail shelf life. Textural appearance is highly related to water holding capacity. Therefore measures of color and textural appearance and/or water holding capacity are the minimum requirements to characterize lean pork quality.

B. Subjective quality standards for pork

The simplest method for the characterization of lean pork quality is that of subjective evaluation. The first system for the subjective scoring of pork lean quality was developed at the University of Wisconsin in 1963. It made use of a 5 point scoring system, with scores ranging from 1 - extremely Pale, Soft, Exudative (PSE) to 5 - extremely Dark, Firm, Dry (DFD) with 3 being normal pork. Agriculture Canada Pork Quality Standards released in 1984 have improved considerably upon the Wisconsin system. The Agriculture Canada bulletin is illustrated in color and describes a two part subjective scoring system, one part for color and one part for structure, as indicated below:

Agriculture Canada Pork Quality Standards†

Subjective Color	Subjective Structure
1 - Extremely Pale	1 - Extremely Soft, Exudative
2 - Pale	2 - Soft, Exudative
3 - Normal	3 - Normal
4 - Dark	4 - Firm, Dry
5 - Extremely Dark	5 - Extremely Firm, Dry

† Agriculture Canada 1984a.

Soft, exudative pork is not always pale. Conversely pale pork is not always soft and exudative. These standards allow color to vary independently from softness and exudativeness and have been particularly useful in identifying a commonly occurring quality type with essentially normal color but soft and exudative structure. Quality of this type has also been identified by other researchers (Monin and Sellier, 1985).

C. Objective measures of pork muscle quality.

Pork lean muscle quality has also been measured objectively or instrumentally. Such methods/devices have been most commonly used within about 1 hour or at about 24 hour after slaughter to estimate or predict the ultimate quality. A number of these are listed below:

1. Color/Reflectance. Two basic configurations of reflectance meters have been developed. One measures at the meat surface, the other at the interior of the muscle. Reflectance meters have been shown to be of value for the measure of muscle color at times equal to and exceeding 24 hr post slaughter. Table 1.1 shows the relationship between subjective Agriculture Canada pork quality scores and the readings of one surface-measuring reflectance meter (Minolta Chroma Meter II) for the longissimus dorsi muscle.

Table 1.1. The relationship of subjective pork quality to Minolta reflectance meter L, a and b values (C.I.E.) for the longissimus dorsi muscle.

Subjective Color/Structure	L		a		b	
Score†	Mean	SD	Mean	SD	Mean	SD
1/1	59.5	2.7	11.4	1.9	8.4	1.3
2/2	56.1	2.5	11.3	1.6	7.5	1.3
3/3	48.6	3.5	9.8	1.9	4.9	1.9
4/4	38.6	2.6	7.5	1.7	1.5	1.3

† Color/Structure Score 1-4,
Agriculture Canada Pork Quality Standards.
Murray and Nemeth 1986

Although deep muscle reflectance meters (Fat-O-Meater, Fiber Optic Probe [MRI, Bristol], Destron and Hennessy) show some promise for the prediction of ultimate quality from measurements within one hour after slaughter, these instruments have not yet been shown to be accurate enough for prediction of final color from measurements soon after slaughter (Jones et al, 1984; Somers et al. 1985). Fortin and Raymond (1987) recently concluded that electronic grading probes were unsatisfactory for detecting PSE/DFD pork at any stage post-mortem.

Because of the potential utility of such meters, their development and testing should continue. However, Swatland (1986a) found that internal reflectance of ham muscles measured with a portable fibre optic spectrophotometer (Colormet, Instrumar Ltd, St. John's, Newfoundland) at 24 h post-mortem could distinguish between normal and PSE pork.

2. pH. Table 1.2 indicates the expected pH values for various quality types of loin eye (longissimus dorsi muscle) at two times post-slaughter. The pH at 1 h has some potential to distinguish PSE pork from the other quality types while the pH at 24 h has the potential to distinguish DFD from other quality types. Because pH is difficult to measure in a reproducible fashion, and at 1 hour is markedly influenced by amount of available energy in the muscle, this method is not always a good predictor of ultimate muscle quality. Additionally, Table 1.2 shows there is considerable overlap in pH at 1 h for the different pork muscle quality groups. However, this method has been adopted in one country (Switzerland) for the estimation of pork quality on the slaughter floor and is a factor in settlement of carcass value.

Table 1.2. The relationship between time post-slaughter and pH for longissimus dorsi muscles of different quality.

Color/ Structure Score†	Time Post-Slaughter		
	1 hr	24 hr	
	Range	Mean	SD
1/1	5.5 - 6.4	5.41	0.13
2/2	5.5 - 6.4	5.47	0.14
3/3	5.7 - 6.8	5.58	0.12
4/4	6.4 - 7.0	6.23	0.24

† Color/Structure Score 1-4, Agriculture Canada Pork Quality Standards.
Murray and Nemeth 1986

3. Drip/water holding capacity. PSE pork has a lower and DFD has a higher water holding capacity than does pork of normal quality. Essentially, all techniques for indirectly determining water holding capacity have been reviewed by Kauffman et al. (1986). These methods included, among others, measurement of: 1. The amount of drip from a standard sized muscle sample, 2. The weight of liquid expressed during centrifugation, 3. The amount of swelling of a ground meat sample, 4. The amount of liquid expressed onto filter paper by pressure causing devices, 5. The amount of moisture absorbed by a piece of filter paper from a meat surface. All methods proved useful, although methods 1, 3, and 5 proved to be most precise in distinguishing all quality types. Table 1.3 presents an example of data from two commonly used methods for estimating water holding capacity. These procedures are used at times equal to or greater than 24 hr post-slaughter.

Table 1.3. The relationship between pork quality and measures of water holding capacity for the longissimus dorsi muscle.

Color/Structure Score †	Expressible Juice (g/100g) (Centrifuge Method)		Drip (g/100g)	
	Mean	SD	Mean	SD
1/1	35.2	3.0	4.6	1.3
2/2	33.1	2.9	4.6	1.2
3/3	27.2	5.1	1.9	1.0
4/4	9.9	6.4	0.7	0.4

† Color/Structure Scores 1-4,
Agriculture Canada Pork Quality Standards.
Murray and Nemeth 1986
Murray et al. 1987

4. Protein Solubility. The denaturation of muscle proteins is at the heart of the PSE pork quality problem. Two commonly used methods (Table 1.4) which indirectly assess the processing value of meat are based on protein solubility: % transmission (Hart 1962) and salt-soluble protein (Barton-Gade 1981). The % transmission method measures the turbidity of muscle sarcoplasmic proteins at a standard pH (Table 1.4). The salt-soluble protein method measures the extent of solubility of muscle proteins in a standard salt solution. Both are very acceptable indicators of pork muscle quality and are used at times equal to or exceeding 24 hr post-slaughter.

Table 1.4. The relationship between pork quality and measures of protein solubility transmission for the longissimus dorsi muscle.

Color/Structure Score †	% Transmission		Protein Solubility (g/100 g wet wt)	
	Mean	SD	Mean	SD
1/1	97.8	3.1	11.0	1.0
2/2	92.9	9.8	12.9	2.3
3/3	52.0	26.2	18.8	1.8
4/4	9.9	7.2	20.6	0.7

† Color/Structure Scores 1-4,
Agriculture Canada Pork Quality Standards.
Murray and Nemeth 1986

5. Electrical Properties of Muscle. The electrical capacitance or ability of a muscle to store electricity declines post-slaughter, the rate of decline being faster in muscle destined to become PSE than in normal meat. This phenomenon has been utilized for the prediction of pork quality (Swatland, 1982). Although the capacitance of the adductor has been shown to be a better predictor of ultimate quality than is the pH at 1.5 hr post mortem, it has yet to be proven accurate enough for predictive purposes. Other meters based on changes in the dielectric properties of muscle (MS Tester (Testron), QM Meter) have been developed in Europe, but have not been completely evaluated for use in Canada.

6. ATP Breakdown. This method is based on the change in the optical properties of ATP (adenosine triphosphate) as it is broken down to provide energy in the muscle post-slaughter (Honikel and Fischer 1977). Although the method was designed to be used in combination with pH measurement at 1 hour after slaughter, it is technically very cumbersome since it requires the removal, homogenization and filtering of a meat sample, followed by measurement of absorbance on a spectrophotometer. Therefore it is unlikely to find a use in industry.

7. Onset of Rigor. When the muscle ATP concentration reaches a certain low level after slaughter, rigor mortis ensues. Muscle destined to become PSE is much more active immediately after slaughter, and, as a result, it goes into rigor sooner than normal muscle. For example, in stress susceptible pigs rigor can be attained on the slaughter floor, whereas in normal pigs the onset of rigor is usually between 4 and 6 hours post-mortem. The stiffness/flexibility and orientation of the front limb (Davis et al. 1978) have been used as indicators of rigor. Attempts to use this phenomenon to predict ultimate pork quality have not been entirely successful, primarily because of lack of a practical

on-carcass method to obtain a meaningful monitoring of the rigor process. This limitation may be overcome by extension of methodology such as that described by Swatland (1987). However, the rate of onset of rigor has not yet been shown to be intimately related with ultimate pork quality.

8. Nuclear Magnetic Resonance (NMR). The nuclear magnetic resonance technique allows a more direct measure of the water binding status of muscle tissue. NMR parameters have been found to be correlated with a number of meat quality measures (Renou et al, 1985). This application of NMR measurements to the prediction of pork quality is very new and further evaluation is required.

D. Prospects for the industrial identification of PSE/DFD pork.

Instruments with the capability of recording deep muscle reflectance/light scatter (Fibre optic probe - Bristol, Colormet - Newfoundland) appear to have good potential for the measurement of pork quality in intact carcasses 24 hours post-mortem. These instruments could be used in coolers by industry to sort carcasses into different quality groups. The industrial prediction of pork muscle quality by measurements made on the warm carcass soon after slaughter is not possible with current methodology. Some of the technical problems have been discussed by Swatland (1986b). Further development of existing technology (fibre optic spectrophotometry, electrical properties of muscle) is recommended as a high research priority. However, at least 95% accuracy would be needed for the early detection of PSE meat for such a measurement to be used in the classification or grading of carcasses.

2. PROCESSING CONSIDERATIONS REGARDING PSE/DFD PORK QUALITY

L.E. Jeremiah

Many factors influence the transformation of muscle to meat and thereby, the functional properties of muscle proteins. Scheper (1971) observed that PSE pork cuts had limited moisture absorption, low water binding capacity and excessive weight loss (shrinkage), while DFD cuts possessed elevated moisture absorption and normal water binding capacity and weight loss (shrinkage). A detailed description of the properties of these conditions and the factors contributing to their formation has been provided by Briskey (1964).

A. Processing Problems and Meat Quality

Many processing problems have been shown to be associated with aberrations (PSE or DFD) in meat quality including: fat separation (breakdown of stable muscle protein/fat emulsions); water separation in processed foods made from meat; variable cured color intensity and stability; and textural problems, such as mushiness in finely comminuted products. It is widely recognized that low pH meat in comminuted sausages results in inferior quality and the use of extremely high pH meat produces sausage emulsions with only low viscosity.

Water binding properties of muscle are a function of protein solubility, and pH and are also influenced by microbiological growth, salt concentration and temperature. Reductions in water binding capacity lead to excessive juice separation in canned hams and similar products. Therefore, DFD muscle generally is considered superior to normal muscle for use in sausage products due to its superior binding and emulsifying properties, while PSE muscle generally is not considered desirable as a component in comminuted meat products because of its inferior binding and emulsifying properties.

In general, PSE muscle results in processed meat products that are paler than normal, while DFD muscle results in processed meat products that are darker than normal. In some cases, there is a two-toning effect in certain cuts, (e.g. hams) where certain muscles or portions of muscle became PSE while other muscles or portions of muscles remain normal or became DFD. These off-colors have been observed to be aesthetically less attractive to the consumer, particularly when they exist within the same cut (Kramlich et al. 1975).

B. Muscle Quality and Processing Yields

Although PSE primals have been reported to have only 3 to 5% higher smokehouse shrinks than normal primals, Kauffman et al. (1978) found that PSE hams lost substantially more weight during transit and processing than either normal or DFD hams, and estimated that this excess shrinkage may amount to as much as 1,000,000 kg per year in the United States. Other workers have also observed that PSE muscle produced lower yields (Cassens et al. 1975) and that DFD muscle produced higher yields (Kauffman et al. 1964, 1978) after curing and smoking. Cassens et al. (1975) reported that PSE muscle consistently had 2 to 8% higher gelatinous cookout when processed into canned hams, and Leest et al. (1971) observed similar gelatinous cook out from PSE muscle processed into luncheon meats. It was also shown that such gelatinous cookout increased dramatically when processing temperatures exceeded 77°C.

Such results have promoted the following conclusions:

1. That the primary importance of high pH or DFD meat to the industry is less shrinkage during processing, thereby, resulting in higher yields.

2. That PSE hams represented high potential economic losses to the processor through excessive shrinkage and lower quality products.

3. That PSE muscle was less suitable for certain processed products than normal muscle.

Recent research conducted by Lacombe Research Station staff in cooperation with industry personnel evaluated differences in shrinkage and yield among pork muscle quality (Agriculture Canada 1984a) groups when processed fresh and following frozen storage and thawing under commercial conditions (Jeremiah and Wilson 1986). This research demonstrated that the use of frozen and thawed cuts for processing substantially reduced total processing yields (1.7 to 5.2% in hams, 4.4 to 14.3% in backs, 1.3 to 2.0% in picnics, and 2.2 to 2.7% in bellies) when compared with fresh cuts, depending upon the inherent muscle quality; and that differences in inherent muscle quality substantially affected the total processing yields of various fresh (up to 7.7% in hams, 10.7% in backs, 4.8% in picnics, and 0.5% in bellies) and frozen and thawed (up to 13.5% in hams, 20.5% in backs, 4.6% in picnics, and 0.9% in bellies) cuts (Figure 2.1.). It is also of interest that freezing and thawing resulted in greater processing yields from normal and DFD hams. Therefore, it is clear that both the inherent muscle quality of pork cuts and the decision to process frozen and thawed cuts can exert substantial influences on the profitability of pork processing operations.

The research findings compiled to date show that aberrations in meat quality are associated with factors that produce inferior processed meat products, and may also have detrimental effects on the profitability of meat processing operations through reductions in yield.

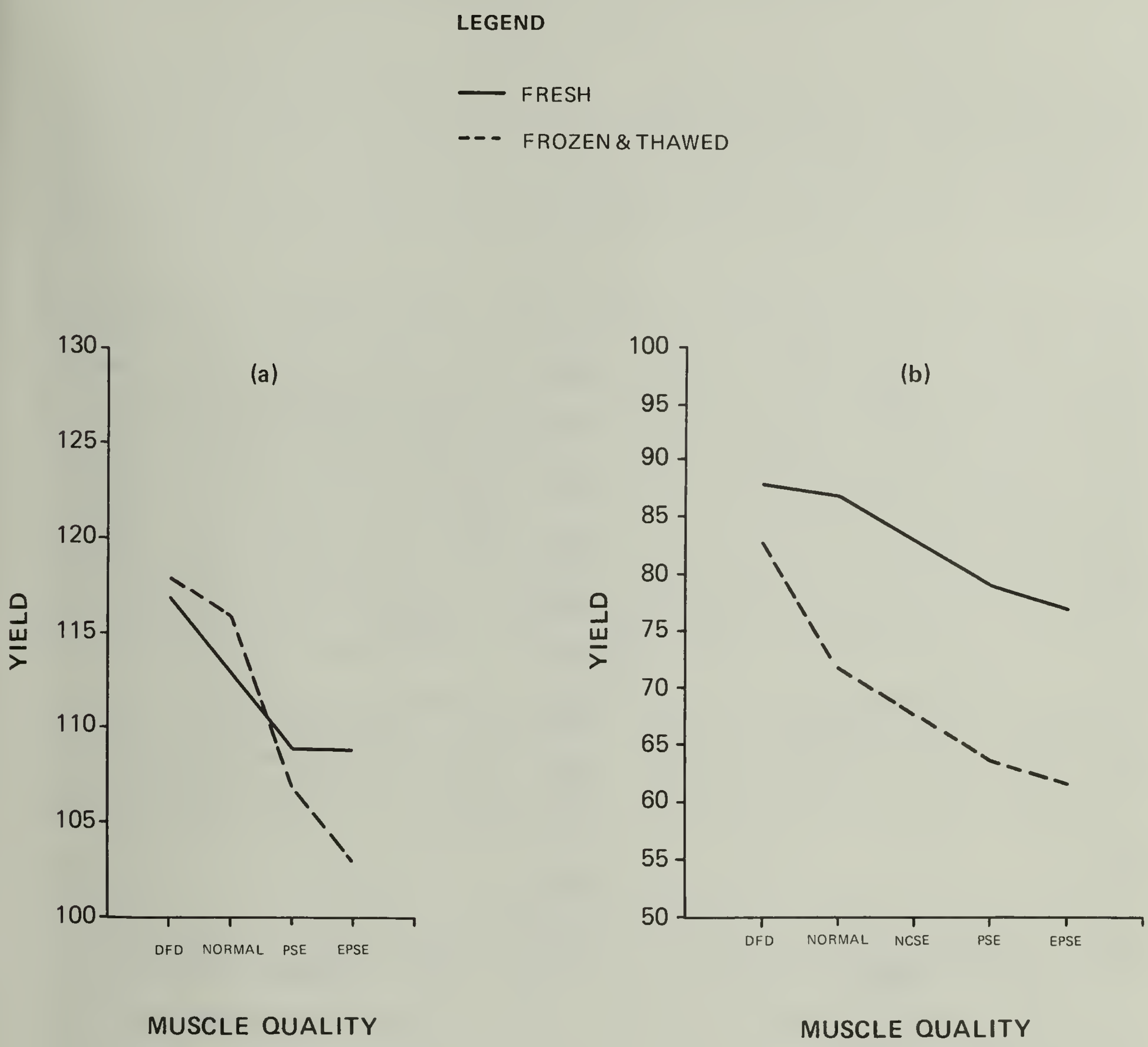
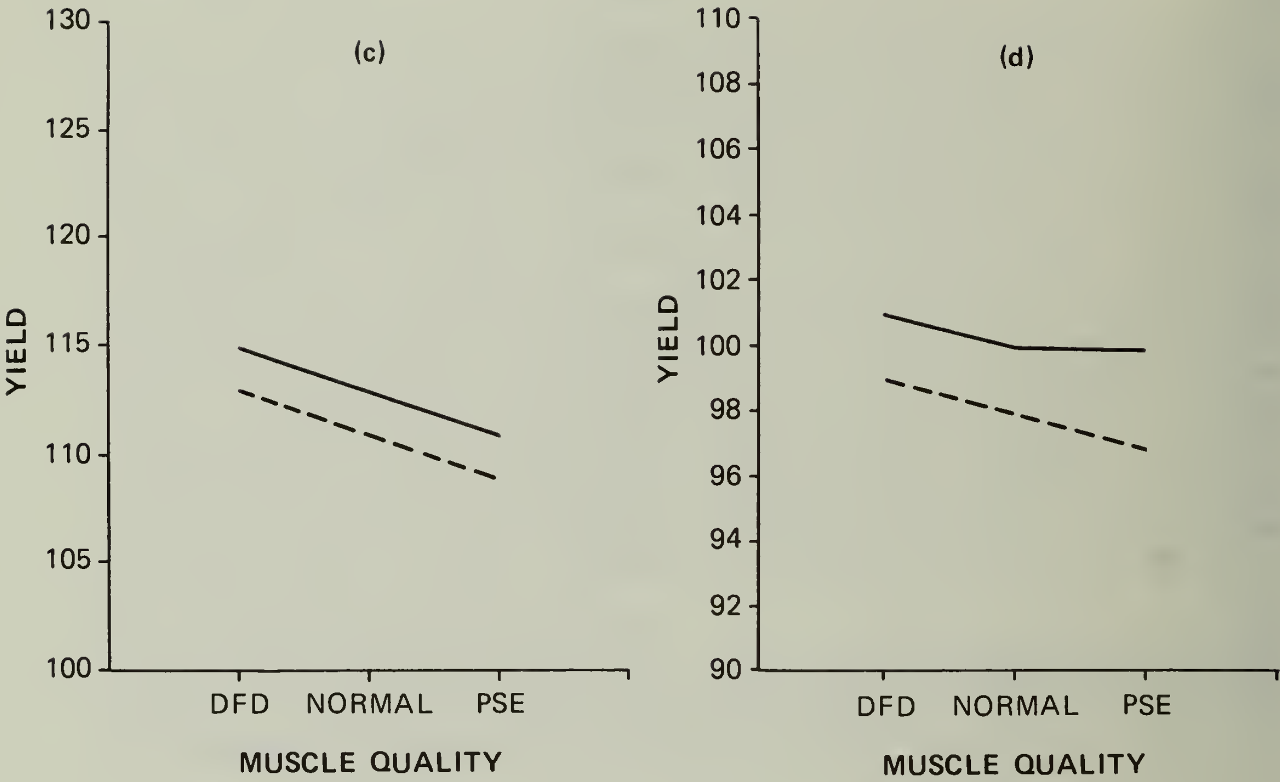


Figure 2.1. The relationship between total processing yields resulting from curing and smoking operations and inherent muscle quality in (a) hams, (b) backs, (c) picnics, and (d) bellies

DFD = Dark, firm, dry
N = Normal
NCSE = Normal color, soft, exudative
PSE = Pale, soft, exudative
EPSE = Extremely pale, soft, exudative


(c)
YIELD
130
125
120
115
110
105
100
DFD
NORMAL
PSE
MUSCLE QUALITY
(d)
YIELD
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108
106
104
102
100
98
96
94
92
90
DFD
NORMAL
PSE
MUSCLE QUALITY

3. PSE/DFD PORK AND RETAIL CASE LIFE

G.G. Greer

It is conceivable that the biochemical, physical and structural differences associated with pork of different muscle quality may exert a pronounced effect upon the quantity and quality of the bacterial flora. In view of the potential effect on storage life, export to distant markets and the retail case life of fresh pork, any differences in spoilage rates attributable to variation in muscle quality become important considerations.

Although most researchers would concur that muscle of darker quality is more susceptible to spoilage than normal muscle, existing data is limited and contradictory (Newton and Gill, 1980). In this regard, some workers have proposed that qualitative and quantitative differences in bacterial populations developing on DFD, PSE and normal muscle can be attributed, solely to pH. Thus, the higher pH inherent in DFD muscle was considered to be more conducive to bacterial proliferation. This speculation, however, has been contested by others who reported the growth of meat spoilage bacteria to be unaffected by pH within the range of 5.5 to 7.0. These latter investigators contend that muscle of darker quality has very low sugar reserves. Consequently, contaminating bacteria are forced to use amino acids as growth substrates with the generation of malodorous volatiles. It would then follow that these offensive off-odors should not arise in PSE or meat of normal muscle quality until the abundant supply of glucose is depleted.

Since the physiology of bacterial growth and spoilage in muscle of different quality is far from being resolved, studies at Lacombe were designed to provide more comprehensive data. The objectives of the research were to assess differences in the growth of the aerobic spoilage flora on pork of different muscle quality as classified by the Canadian Pork Quality Standards.

Results of a preliminary study are presented in Figure 3.1. The data compare the growth of cold tolerant spoilage bacteria on loin chops of quality groups 1 to 5 for up to 4 days of simulated retail display. These results extend the observations of previous researchers (Rey et al. 1976) by demonstrating that as one proceeds sequentially from quality groups 1 through 5 there is a corresponding increase in the levels of contaminating bacteria. That is, during display, muscle of the darker quality groups sustained significantly greater populations of bacteria. This increase can be attributed to a decrease in the length of the lag phase prior to the onset of bacterial growth.

In light of the implications for storage quality, subsequent studies are in progress to collect more extensive data on bacterial growth, odor case life and subjective and objective measures of the deterioration in acceptable muscle color. Only when these data become available can relevant conclusions be made concerning the effects of pork muscle quality on spoilage potential.

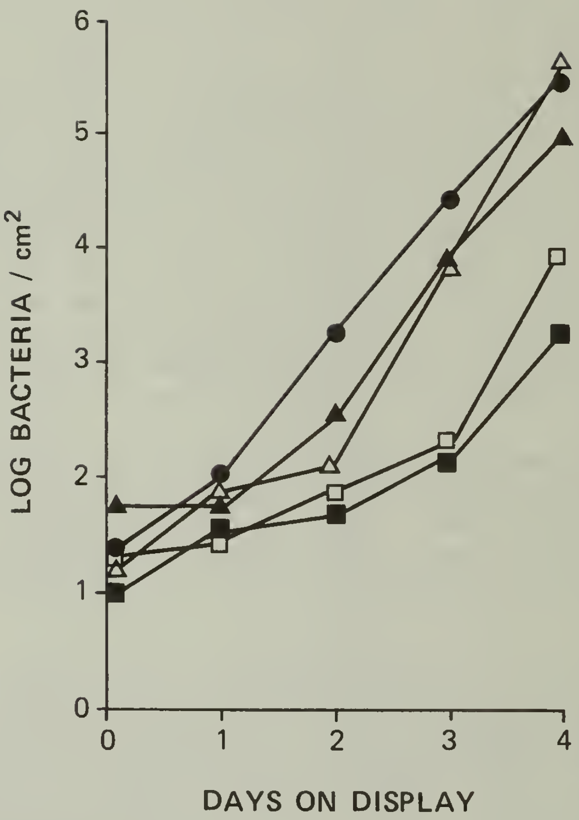


Figure 1. Effect of pork muscle quality on the growth of bacteria on chops during retail display. Data represents the mean of 6 determinations for each quality group. Canadian Pork Standard Quality groups 1(■), 2(□), 3(▲), 4(△) and 5(●) are compared.

4. PALATABILITY AND PSE/DFD PORK

L.E. Jeremiah

In general, research results within the literature are inconclusive and contradictory regarding the influence that inherent muscle quality exerts on palatability. Therefore, as a result Cassens et al. (1975), concluded that it was difficult to draw general conclusions regarding relative palatability differences among different levels of muscle quality; and Krol (1971) expressed a need for additional research to establish relationships of muscle quality with organoleptic attributes and consumer acceptance.

A. Pork quality and palatability

Recent research at Lacombe (Figure 4.1) has found that a range of pork products (ham steaks, loin chops, bacon slices, shoulder roasts and sausage patties) prepared from PSE, normal and DFD pork were all within the acceptable range for palatability (Jeremiah, 1986). However, important differences were identified in some products. For example, PSE hams were less juicy and had less desirable flavor than normal and DFD hams and PSE loin chops had less acceptable flavor and overall palatability than normal loin chops. In addition, meaningful differences in cooking losses were also observed in PSE loin chops and bacon compared to their normal counterparts. These findings are in agreement with other published studies (Kauffman et al. 1964; Merkel 1971; Cassens et al. 1975)

Although, it should be noted conflicting reports exist in the literature and some authors have found no differences in cooking losses that could be attributed to muscle quality (Topel et al. 1976; Jeremiah 1984), the studies conducted to date suggest that pork quality exerts a relatively important effect on cooking losses, but has a relatively minor influence on palatability.

B. Texture profiles

In recent years, sensory evaluation of food products has become more sophisticated. With the use of trained and specialized panels, profiles which contain a large number of variables to fully describe the components of meat texture and flavour have been developed at Lacombe. Evaluation of the texture profiles of pork loins with different levels of inherent muscle quality, indicated that pork with normal, as opposed to aberrent muscle quality, has a firmer, more elastic and cohesive texture, which is stringier, more fibrous and harder to compress, thereby, resulting in a slower rate of breakdown to particles which tend to be fibrous, grainy and mealy. Such findings aid in explaining that PSE loins were more tender than their normal counterparts (Fox et al. 1980; Kemp et al. 1976), but fail to support other reports that:

1. There was a lack of difference in the tenderness of loins from different quality groups (Merkel 1971; Searcy et al. 1969; Jeremiah 1984)

2. PSE loins were the most tender and DFD loins were the least tender (Judge et al. 1960; Deethardt and Tuma 1971)

3. PSE loins were less tender than their normal counterparts when evaluated by a taste panel (Buchter and Zeuthen 1971) and consumers (Topel et al. 1976).

4. PSE loins were the least tender and DFD loins were the most tender (Huffman and Adams 1972).

The PSE condition appears to result in a drier texture with less moisture and fat released during mastication and a greater amount of moisture being absorbed from the mouth. These findings aid in explaining previous reports that:

1. PSE loins were the least juicy (Bennett et al. 1973).

2. PSE loins were less juicy than normal loins (Buchter and Zeuthen 1971, Merkel 1971, Fox et al. 1980, Kemp et al. 1976).

3. PSE loins were less juicy than DFD loins (Kauffman et al. 1964; Jeremiah, 1984).

DFD muscle has a juicier texture than normal with greater amounts of fat and moisture being released into the mouth and a softer texture which was less cohesive, fiberous, and stringy; and easier to chew. Such findings may aid in explaining why some consumer surveys have shown preferences for DFD and discrimination against PSE pork.

C. Flavour Profiles

Evaluation of the flavour profiles recently formulated at Lacombe revealed that cooked PSE meat was associated with a predominance of sour character notes which detracted from the flavor amplitude of samples possessing PSE properties and resulted in extremely PSE samples receiving low flavor ratings. This predominance of sour character notes in samples with PSE properties may well be associated with the rapid postmortem glycolysis and more extensive build-up of lactic acid. Further evaluation revealed that DFD samples were associated with a predominance of porky, sweet, and fatty character notes, which may explain why they received the highest flavor amplitude ratings and aid in explaining why consumers in a previous study (Jeremiah 1985) showed a preference for DFD chops and discriminated against PSE chops. However, as the DFD condition became extreme more character notes contributing to off-flavors were detected.

Therefore, evaluation of the research conducted to date, relating inherent muscle quality differences to the cooking and palatability traits of pork indicate that:

1. In general, all pork cuts are well within the acceptable range in palatability, but that meaningful differences in cooking losses from bacon slices and loin chops occur among muscle quality groups

2. The PSE condition is associated with a predominance of sour character notes, which reduces the flavor amplitude and the desirability of the flavor and overall palatability of pork cuts

3. The PSE condition also is associated with a drier texture that reduces the texture amplitude and contributes to lower juiciness and overall palatability ratings

4. The DFD condition is associated with a predominance of porky, sweet and fatty character notes which enhance the flavor amplitude and the desirability of the flavor and overall palatability of pork cuts

5. The DFD condition is also associated with a juicier and softer texture, which is less cohesive, fiberous, and stringy and is easier to chew, thereby, enhancing juiciness, tenderness, and overall palatability ratings

6. As the DFD condition becomes extreme, the texture becomes excessively soft, crumbly and mushy which reduces the texture amplitude, while enhancing tenderness ratings and reducing the desirability of the overall palatability

7. As the DFD condition becomes extreme a predominance of character notes, contributing to off-flavors, is also noted, thereby, reducing the flavor amplitude and the desirability of the flavor and overall palatability of pork.

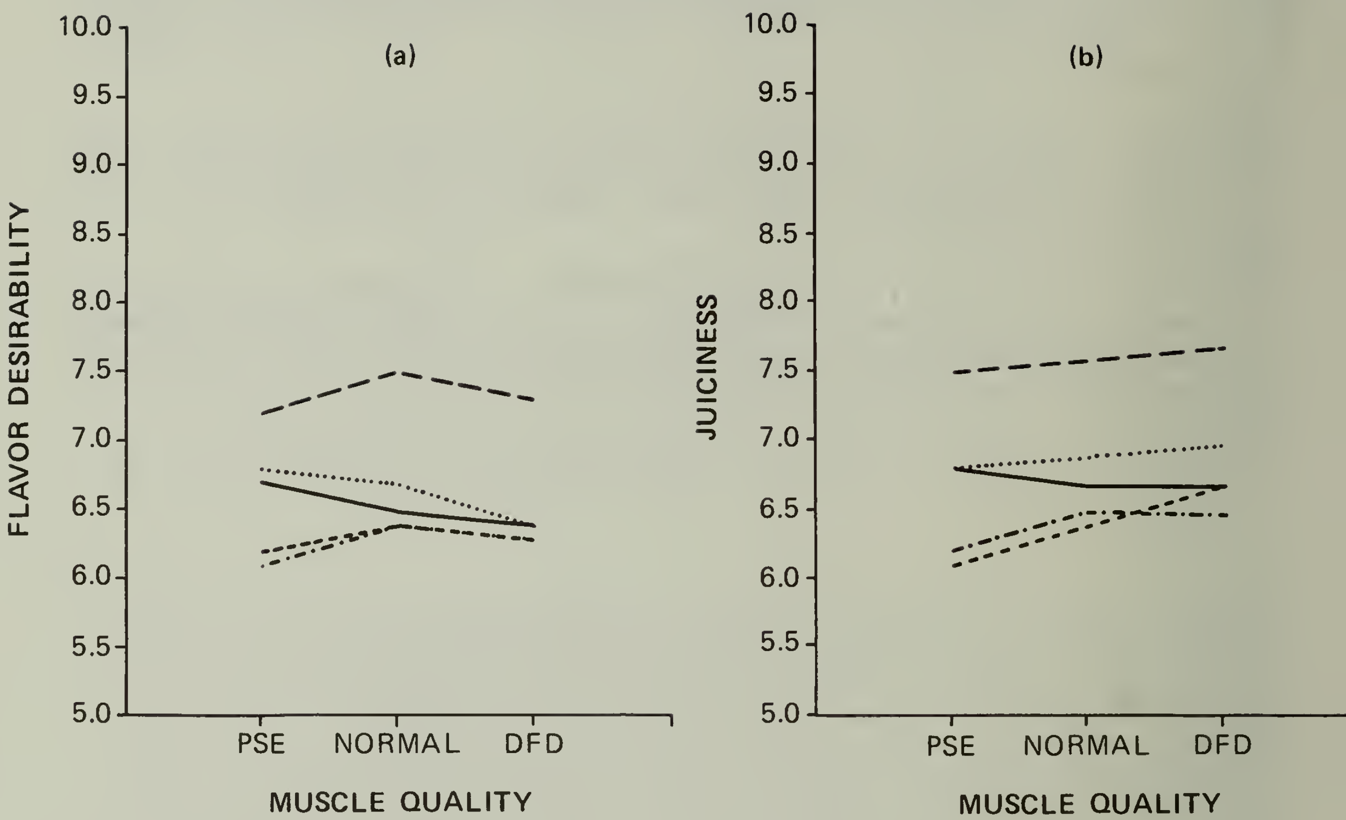
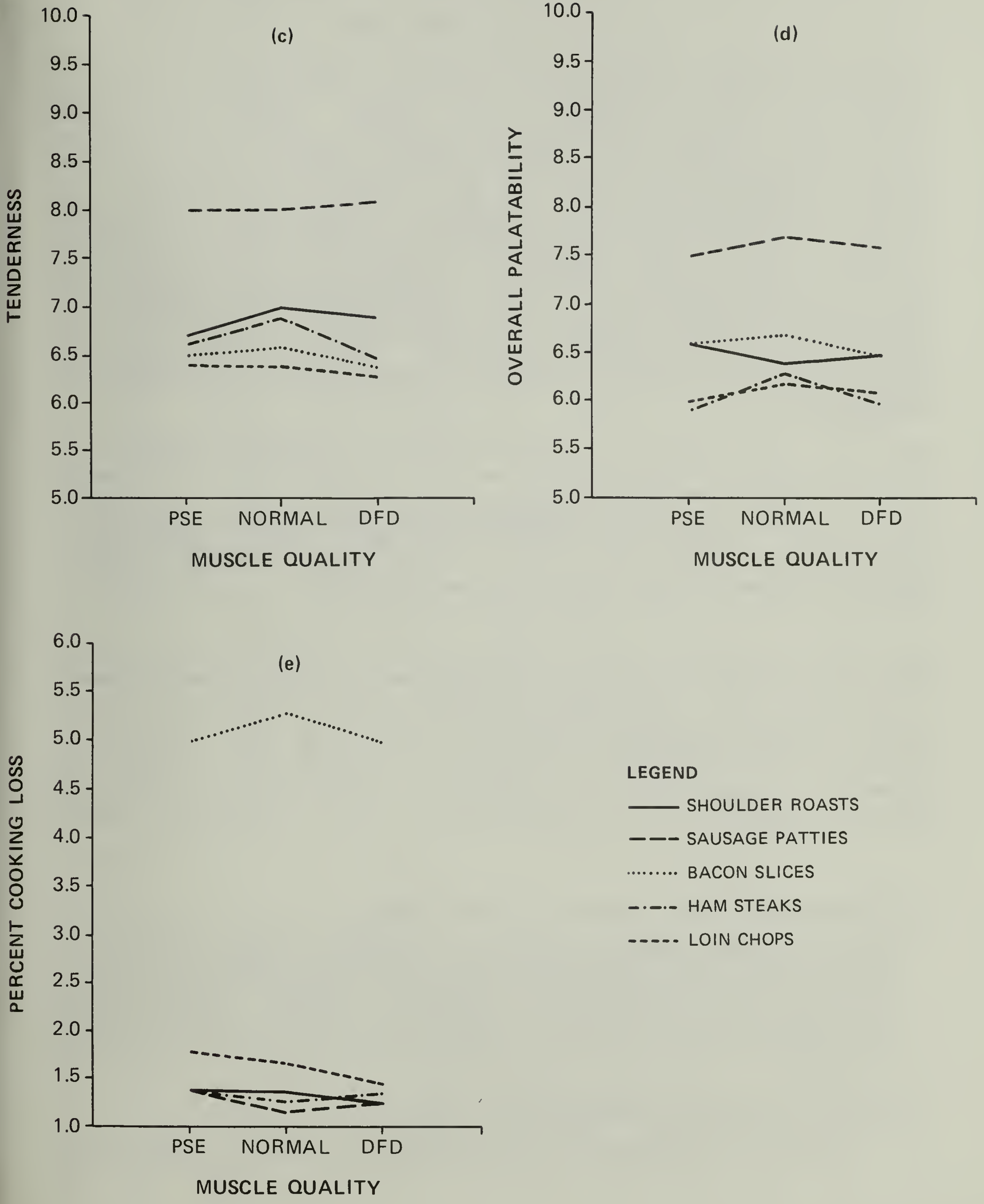


Figure 4.1. The relationship between palatability and cooking properties and inherent muscle quality: a) flavor desirability, b) juiciness, c) tenderness, d) overall palatability, and e) percent cooking loss.

PSE = Pale, soft, exudative
N = Normal
DFD = Dark, firm, dry


(c)
TENDERNESS
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
PSE
NORMAL
DFD
MUSCLE QUALITY
(d)
OVERALL PALATABILITY
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
PSE
NORMAL
DFD
MUSCLE QUALITY
(e)
PERCENT COOKING LOSS
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
PSE
NORMAL
DFD
MUSCLE QUALITY
LEGEND
SHOULDER ROASTS
SAUSAGE PATTIES
BACON SLICES
HAM STEAKS
LOIN CHOPS

5. THE GENETICS OF PORCINE STRESS SUSCEPTIBILITY

A. Sather and S.D.M. Jones

It has been recognized for many years that a small number of pigs die suddenly, often during transportation, but also on the farm as a result of normal, but stressful experiences (e.g. fighting, exercise, high ambient temperature). The cause of this sudden death was collectively named the Porcine Stress Syndrome (PSS). About 20 years ago certain pigs were found to exhibit an uncontrolled elevation in body temperature when exposed to the anesthetic halothane or by a muscle relaxant such as succinylcholine. This reaction is generally referred to as Malignant Hyperthermia (MH). In addition to the deviation of body temperature other clinical signs included muscle rigidity in the rear limbs, increased respiration rate, increased heart rate and cyanosis or blotchiness of the skin. Further work revealed that MH was an inherited condition and could be transmitted to successive generations. Pigs carrying MH are generally termed stress susceptible. In this bulletin stress susceptibility and halothane reactivity are considered to be synonynous. There may be other forms of stress susceptibility which are not related to the halothane gene.

There is a close association between MH and PSS. Autopsies conducted on a large proportion of pigs diagnosed as PSS have shown similar biochemical changes in their muscle tissue as those pigs exhibiting MH. It seems clear that quite a high proportion of deaths from PSS can be directly attributed to MH. However, it should be recognized that while stress susceptible or halothane positive pigs (characterized by the MH reaction) are the most likely animals to succumb to PSS, normal pigs (no MH reaction) can also exhibit PSS depending of the amount and duration of stressful events.

MH is closely related to aberrant muscle quality or pale, soft and exudative (PSE) pork in pigs. The stress susceptible line of pigs developed at Lacombe is 100% MH and about 85% of the pork from these pigs is classified as PSE. On the other hand the Lacombe breed under Research Station conditions is 0% MH and with minimal pre-slaughter stress has less than 10% PSE. Therefore, the frequency of PSE pork found in abattoirs is dependent on both genetic and environmental factors and their interaction. The following chapter will review the genetics of stress susceptibility, whereas environmental factors will be covered in Chapters 7 and 8.

A. Stress susceptibility in man and other animals

Malignant hyperthermia was first identified in man by Denborough and Lovell (1960) when several members of a family had adverse reactions to halothane. MH has been reported in many other species, including the dog (Bagshaw et al. 1978), the cat (De Jong et al. 1974), the horse (Klein 1975) the fallow deer (Pertz and Sunberg 1978) and in poultry (Korczyn et al. 1980).

B. The genetics of stress susceptibility in the pig

1. History. The association of the halothane anesthetic with death in the pig was first reported by Hall et al. (1966) after the

administration of a halothane/suxamethonium anesthetic to 3 pigs, and then by Harrison et al. (1968) who reported MH in pigs given halothane alone. Research into the inheritance of the condition was initiated by the Dutch researchers, Eikelenboom and Minkema (1974) who proposed a single recessive gene model (Table 5.1) with reduced penetrance (i.e. the proportion of animals that genetically should react to halothane which actually produce a positive test) and variable expressivity (i.e. variation in the degree of reaction to halothane). The model proposes 3 genotypes (nn, Nn and NN) which relate to 3 phenotypes (halothane positive, carrier, halothane negative). This model, but with high to complete penetrance has generally been accepted today (Smith and Bampton 1977, Eikelenboom et al. 1977, Andresen 1979, Webb 1981, Sather and Murray, 1986) as being most useful in detecting MH in pigs. Ollivier et al. (1975) however, proposed a model of incomplete penetrance. The Eikelenboom model has demonstrated the greatest potential for field testing and has resulted in the use of halothane testing of breeding stock in Canadian swine improvement programs. However, because the inheritance of stress susceptibility is generally considered to be a recessive trait, considerable effort continues to be expended to develop techniques that identify the heterozygous (i.e. carrier) pig which produces a negative halothane test (Table 5.1).

Table 5.1. Genotype and associated phenotypes of the Halothane Gene assuming a single recessive Mendelian gene model with complete penetrance

Genotype	Phenotype
nn	Halothane positive
Nn	Halothane negative (carrier)
NN	Halothane negative (normal)

2. Single vs Multiple genes. When the halothane test (Eikelenboom and Minkema, 1974) is defined as a simple (halothane only), short term exposure (up to but not exceeding 5 minutes) to a high concentration of halothane anesthetic (4-5%), a trait that follows single gene Mendelian inheritance is observed. With longer test periods, of up to 20 minutes, this condition appears "...to be a complex dominant with a modified single dominant gene or two dominant genes in concert to produce a graded series of phenotypes..." (Williams et al. 1977). The same authors also recommended a succinylcholine test in addition to the halothane test for a pig to be considered normal, but then they reported difficulty with pigs producing successive negative tests. The

work of Hall et al. (1972) also suggested that when the standard Eikelenboom halothane test is augmented with succinylcholine the inheritance of the gene appears to be under the control of a dominant gene. Britt et al. (1977) using both the caffeine contracture test on muscle biopsies with a halothane challenge of up to 100 minutes suggested that the inheritance of this trait was under the control of more than one gene. Thus, only when attempts are made to make the gene appear dominant or to identify the carrier pig does the inheritance fail to follow classical Mendelian patterns.

3. Dominant vs Recessive gene model. Webb et al. (1986) administered a standard 3 minute halothane challenge to 6-7 weeks old pigs followed by an injection of succinylcholine. However, while this test did produce differences among the genotypes, it was not sufficiently precise to identify heterozygotes (carriers). This testing procedure also requires a high degree of sophistication to administer making it unsuitable for field testing of pigs. While it is well established that the pharmacological aspects of PSS are recessive, meat quality aspects may be additive (Jensen and Barton-Gade 1985, Murray and Sather, 1986). That is the meat quality traits (PSE) of the carrier are intermediate to stress susceptible and normal pigs.

4. Penetrance. The standard test (3-5 min, 4-5% halothane) has generally produced a highly penetrant trait. Eikelenboom and Minkema (1974) first reported the gene to have reduced penetrance but later (Eikelenboom et al, 1977) found the trait to be fully penetrant, assuming a single recessive gene. Sather and Murray (1986), concur with this model and reported the gene to be essentially fully penetrant in their populations. Ollivier et al. (1975) suggested incomplete penetrance. It should also be noted that false positive reactions to halothane are essentially unknown. Variation in penetrance reported by these workers may be a function of the populations (eg breeds) tested.

   Carden and Webb (1984) reported that the penetrance of the halothane positive reaction increased with age. Penetrance was low (<0.75) for pigs less that 35 days of age and high (>0.85) for pigs greater than 56 days of age. Since expression of the halothane positive genotype is dependent upon age, this factor must be considered when testing pigs. In the Lacombe halothane testing program, pigs are routinely tested between 49 and 56 days of age.

5. Variable Expressivity. The separate expression of two distinct phenotypes, halothane positive and halothane negative, is not absolute. Webb (1980) described a third, infrequent phenotype, "doubtful", which fits neither of the two major classifications. Sather and Murray (1986), as well as other researchers, have reported variation in the degree of reaction. Pigs with an nn genotype can produce a range of reactions including those so mild to be called doubtful to those pigs that succumb to halothane challenge. No researchers have been able to provide a completely satisfactory explanation of the variation in terms of degree of reaction or time of onset except to state that modifier genes exist. It is also

probable that the physiological state of the pig prior to testing may also influence the degree of intensity of reaction.

6. Pleiotrophy. Genetic stress susceptibility has also been associated with a wide range of other traits that are directly connected with the strict pharmacological definition of MH. Most notably halothane positive pigs are more prone to stress than halothane negative pigs and they have reduced meat quality (PSE) (e.g. color, drip loss, water holding capacity). In addition, the condition is often associated with a heavy muscled conformation, reduced carcass fat, increased carcass lean, changes in growth rate and food conversion, reduced female reproductive potential including both reduced litter size and losses in life time sow productivity as well as changes in semen characteristics. Thus, the(se) gene(s) has a wide range of effects that go beyond the original concerns of reduced meat quality and sudden death of the PSS/PSE syndrome complex.

C. Relationship of genetic stress susceptibility with reproductive traits.

Genetic stress susceptibility has a significant effect upon reproductive performance of the sow in terms of litter size birth and at weaning. Webb and Jordan (1978) reported a reduction of 1.6 and 1.1 pigs at birth and at weaning from halothane positive sows. Webb et al. (1982) reported a 24% reduction in conception rate of halothane positive females. Carden et al. (1985) found 1.07 and 1.56 fewer pigs, born and weaned in their stress susceptible line (SS) when compared to their to stress resistant line (SR). Litters of carrier pigs, based on the assumption of a single recessive gene model, were produced by mating SR to SS females. The resulting litters were 1.27 and 1.88 pigs smaller when compared to similar litters produced from SR dams. This may suggest that the halothane gene can also increase perinatal and postnatal mortality of apparently stress resistant pigs. Lampo et al. (1985) reported that there were no differences in prolificacy among halothane negative and positive gilts, but second litter halothane negative sows had 0.4 more piglets born alive than did similar halothane positive sows. This difference increased to a full pig in subsequent litters. Willeke (1986) also reported not only smaller litters at birth of the halothane positive sow of nearly 0.2 pig, but a decrease in litter size weaned of over 0.5 pigs. Halothane positive sows also produced 1.1 few litters that did their halothane negative counterpart.

Schlenker et al. (1984) reported reduced ejaculate volume, forward motility, normal spermatozoa and total sperm per ejaculate from halothane positive compared to halothane negative boars. 72.0% of the halothane negative boars produced semen of satisfactory quality compared to only 64.5% for halothane positive boars.

D. Relationship of the genetic stress susceptibility with performance traits.

It is generally accepted that genetic stress susceptibility depresses growth rate (Carlson et al. 1980; De Wilde 1984), but this effect has not always been reported. While Webb and Jordan (1978) reported a nonsignificant reduction of 15 g per day in growth rate, Vogeli et al.

(1983) found significant reductions in growth rate. Hanset et al. (1982) demonstrated that while both males and females had a depressed growth rate associated with a positive halothane test, the differences were significant only for females. Webb (1980) summarizing 12 studies, reported a range in the difference between halothane positive and halothane negative pigs from -47 to 28 g per day, with a mean of -2 g per day. Daily food consumption and food conversion ratios are closely associated with growth rate. Webb and Jordan (1978) found no differences in average backfat for halothane positive and negative animals. De Wilde (1984) however, reported less backfat on halothane positive pigs, while Hanset et al. (1982) could only demonstrate a significant difference in female pigs on the shoulder and back, but both sexes of halothane positive pigs had less backfat on the loin. Jones et al. (1987a) suggested that the distribution of subcutaneous fat in carcasses from halothane positive pigs may differ from that of halothane negative pigs. This in turn has important implications for the carcass grading system as these pigs may have greater backfat at different sites along the loin but a 4-5% increase in carcass lean yield.

E. Relationship of the genetic stress susceptibility with carcass yield and meat quality.

The association of halothane sensitivity with increased lean tissue content has been well established (Carlson et al. 1980, Webb and Jordan 1978, De Wilde 1984, Vogeli et al. 1983). Based on 14 studies, Webb et al. (1982) reported a decrease of 1 mm in average carcass backfat. He also reported that the meat color from halothane positive pigs was "paler" and meat quality was "worse" than that observed for halothane negative pigs. Webb and Jordan (1978) reported an incidence of 31.7% PSE meat from carcasses of halothane positive pigs, but only 10.2% from halothane negative pigs. Murray and Sather (1986), found their halothane positive line of pigs produced a frequency in excess of 80% PSE meat, while the same laboratory reported less than 10% PSE from a 100% halothane negative Lacombe line. The halothane gene however may not necessarily produce similar effects on meat quality in all breeds. Barton-Gade and Olsen (1987) reported a lower incidence of PSE pork in halothane positive Danish Large White pigs than they observed in halothane positive Danish Landrace pigs. They also reported that these Large White pigs had more dark, firm and dry pork than did the Landrace pigs. These results suggest the possibility that either different halothane positive alleles or modifying genes exist among different breeds.

F. Distribution of pig populations

Webb et al. (1982) reviewed the distribution of the genetic stress susceptibility in British and other pigs. He reported a very low incidence in Large White or Yorkshire pigs at close to 0% and up to 100% in the Dutch Pietrain (Table 5.2).

Table 5.2. Incidences of halothane positive pigs (HP) in breeds from different countries

Breed	Number of Studies	Number of Pigs	% HP
Yorkshire/Large White:			
American	1	225	0
Australian	1	140	0
Irish	1	58	0
British	1	1758	1
Canadian	1	5342	1
Norwegian	1	169	1
Dutch	2	1394	3
Swiss	1	1130	6
Landrace:			
Canadian	1	3724	2
Australian	1	1206	5
Irish	1	168	5
Norwegian	3	2146	5
Danish	2	1990	7
German (GDR)	1	300	10
British	1	1646	11
Finnish	1	2003	12
Swiss	1	7480	13
Swedish	1	1668	15
French	1	127	17
Dutch	3	4073	22
German (GFR)	2	1251	68
Belgian	5	1260	86
Pietrain:			
French	1	335	31
Belgian	3	795	88
White Meat:			
Slovak	1	112	9
Lacombe:			
Canadian	1	412	3
Hampshire:			
American	2	232	2
Duroc:			
American	3	248	0

updated from Webb et al, 1982

Since halothane testing was not being carried out in Canada at that time, no Canadian data was reported in his study. In 1983, the overall incidence in Canada was 1.82%, averaged over the 3 White breeds (Yorkshire, Landrace and Lacombe) reporting reactor pigs. As in other world populations, the incidence is higher in the Canadian Landrace than in the Yorkshire (Table 5.3). The incidence of halothane positive pigs in Canada is one of the lowest found in the world. It is interesting to note that in the Lacombe breed halothane genes have been identified, while the Lacombe Research Station with an extensive halothane testing program has yet to detect a halothane positive Lacombe pig (Sather and Murray 1986). The colored Canadian pigs have reported no halothane positive reactions since halothane testing began in Canada, although only relatively small numbers have been tested.

Table 5.3. Number of herds station testing boars in the Canadian Swine ROP Program and percentage those herds reporting at least 1 halothane positive boar

		Number of Herds			% Halothane Positive Herds		
Breed	Prov†	1983	1984	1985	1983	1984	1985
Yorkshire	NS	10	11	5	10.0	9.1	0.0
	PQ	21	19	27	0.0	9.5	14.8
	ON	70	61	58	4.3	9.8	0.0
	MN	16	16	10	0.0	0.0	10.0
	SA	11	11	11	0.0	9.1	0.0
	AB	25	25	21	0.0	4.0	19.0
Landrace	NS	15	15	8	14.0	33.3	25.0
	PQ	28	24	27	25.0	20.8	14.8
	ON	44	46	39	13.6	4.3	0.0
	MN	3	6	4	33.3	16.7	0.0
	SA	5	5	4	20.0	0.0	0.0
	AB	10	7	9	10.0	42.9	11.1
Lacombe	NS	1	1	0	0.0	0.0	-
	PQ	1	2	3	0.0	0.0	33.3
	ON	2	0	2	0.0	-	0.0
	MN	1	1	0	0.0	0.0	-
	SA	5	2	2	20.0	0.0	0.0
	AB	4	4	3	25.0	0.0	33.3
Yorkshire		153	143	132	2.6	7.7	6.8
Landrace		105	103	91	20.9	15.5	7.7
Lacombe		14	10	10	14.2	0.0	20.0
Grand Total		282	256	233	9.9	10.5	7.7

Agriculture Canada 1986 †NS = Nova Scotia, PQ = Quebec, ON = Ontario, MN = Manitoba, SA = Saskatchewan, AB = Alberta

Although Table 5.3 tends to present a somewhat biased picture on the frequency of halothane positive animals since herds are identified rather than individuals, it can be seen that genetic stress susceptibility is well established in all Canadian white breeds throughout all regions across Canada. The initial incidence of the halothane gene was greatest in the Landrace and somewhat less in the Yorkshire. However, it appears that the Landrace breeders have been successful in reducing the number of herds reporting the gene compared to that of the Yorkshire breed. There are too few Lacombe herds to make a consistent estimate of the frequency of halothane positive reporting herds. However, these results indicate that the while the gene frequency is low compared to that in other countries, it is nevertheless well distributed across the Canadian national herd.

Clearly, because of low gene frequency of the halothane gene and uniform distribution of halothane sensitive pigs across Canada, halothane testing alone will not be very effective tool in reducing the frequency of the halothane gene. However, if the halothane test is used in conjunction with other genetic tools that can assist in the identification of the heterozygous pig (Nn), such as genetic markers (e.g. the Pgd, Phi loci), it may be possible to identify carrier pigs, and in that way more effectively reduce the incidence of animals carrying stress susceptibility.

G. Effects of halothane testing

The frequency of genetic stress susceptibility in 1983 varied from 0.069 for Yorkshire to 0.238 for Lacombes with a national average gene frequency over all breeds of 0.135 (Table 5.4). If this is accepted as an appropriate gene frequency for the national herd, and assuming that the populations are in genetic equilibrium, then the calculations shown in Table 5.5 consider the changes in gene frequency that can be expected through different selection intensities.

Table 5.4. Frequency of halothane positive (H+) pigs and estimated gene frequency (Q) in pigs tested for the halothane reaction in test stations

Breed	1983				1984				1985			
	number of pigs	H^+†	%H^+	Q‡	number of pigs	H^+	%H^+	Q	number of pigs	H^+	%H^+	Q
Yorkshire	1851	9	0.49	0.069	1887	22	1.17	0.108	1604	11	0.68	0.083
Landrace	1268	43	3.39	0.184	1334	25	1.87	0.137	1122	9	0.80	0.090
Lacombe	124	7	5.65	0.238	142	0	0.00	0.0	146	4	2.74	0.166
Total	3243	59	1.82	0.135	3363	47	1.40	0.118	2872	24	0.84	0.091

† H+ - halothane positive, ‡ Q = gene frequencies.

Table 5.5. Expected changes in gene frequency (Q) with different levels of selection intensity(s)

	Gene Frequency		
	1983	1984	1985
Selection intensity			
1.0	0.135	0.119	0.106
0.5	0.135	0.127	0.120
0.1	0.135	0.133	0.132
0.05	0.135	0.134	0.133
Observed	0.135	0.118	0.091

The selection intensity (s) is the proportion of halothane positive pigs culled. If all pigs (boars and gilts) were tested and only negative pigs used for breeding, then s=1. Since only boars are presently tested s can have a maximum value of only 0.5. It has been estimated that only 10% of the boars used by seed stock producers are station tested and thus halothane tested. Therefore, for present Canadian conditions s cannot be greater than 0.05 per generation. The generation interval was assumed to be one year. In a typical pig herd, this ranges from 2.5 to 3 years. Thus, the estimated gene frequency should decrease by approximately .001 per generation or 0.0004 per year, a rate that could not be detected under our present testing conditions and sampling procedures. However, from Table 5.4 the apparent frequency of halothane positive pigs is decreasing at a rate greater than that possible under the most ideal conditions of selection (s=1.0). Thus, it is evident that the assumed equilibrium conditions have not been met. The most important deviation from equilibrium probably arises from non-random mating with respect to the halothane gene. This would result in an underestimation of the frequency of the halothane gene, since the nn genotype would be found less frequently than that expected under equilibrium conditions. This breeding strategy while reducing the number of reactor pigs (nn) in the test station, may do little to reduce the overall incidence of PSE arising from carrier pigs (Nn).

To further illustrate this point, the Large White was considered to be free of the halothane gene in the U.K. (Webb et al, 1982), from survey testing procedures similar to that found in Canada. When Southwood (1985) progeny tested the British Large White with reactor pigs, a gene frequency of 0.11 was detected. Thus, while halothane testing may be an effective monitoring procedure, unless it is also accompanied with proper sampling procedures supported by progeny testing or estimated from within designed experiments, it should not be used for gene frequency estimation.

H. Selection strategies

Reduction (or removal) of genetic stress susceptibility from the Canadian swine population will be difficult (or nearly impossible). The gene is well entrenched in all white breeds, in all regions in Canada. However, the frequency of halothane positive pigs can only account for a small proportion of the PSE pork seen in Canada. A number of reports (Jensen and Barton-Gade 1985; Webb et al. 1986, Murray 1987) have suggested that carrier (Nn) pigs may also have reduced meat quality. If these reports can be demonstrated to be applicable to Canadian breeds, then this additive genetic model could account for a substantial proportion of the meat quality problems seen in Canada. If a gene frequency of 0.135 is accepted, then, while only 1.8% of pigs would be halothane positive (nn), 23.3% would be carrier pigs (Nn) and at greater risk of producing PSE than normal pigs (NN). This genetic model then implies that the halothane gene would be much more important in determining meat quality for Canadian pigs than previously thought under the assumptions of the recessive gene model, and be responsible for up to half of the current incidence of PSE meat found in commercial abbatoirs. There are a number of areas where our knowledge of the halothane gene is limited. In Canada, the Lacombe work on the meat quality of carrier pigs has shown the frequency of PSE meat to be intermediate to halothane positive and halothane negative pigs. The halothane positive line at Lacombe was based on crosses between purebred Pietrain and Lacombe breeding stock. The same results may not have been obtained with other white breeds such as the Yorkshire or Landrace. Thus, we would suggest that there is some urgency to evaluate the meat quality of carrier pigs (halothane positive x normal and their reciprocal crosses) for the major breeds used in Canada. If the same model was found to be generally applicable to the breeds commonly used in Canada, efforts would then be needed to estimate the frequency of carriers in the national herd. Methodology to accomplish this is discussed in the next chapter. In the mean time, we would recommend that all imported breeding stock and A.I. boars be progeny tested for stress susceptibility. This would entail maintaining halothane positive lines of pigs. However recent work has suggested that some carriers do react to the halothane test and this could result in false positives being identified.

Since the frequency of PSE meat has increased in most countries we would conclude this chapter by presenting several hypothesis to explain these findings:

1. That there is a general relationship of carcass lean meat content with muscle quality (color, water holding capacity) and that selection for increased lean growth rate will also increase the incidence of PSE meat.

2. That certain types of lean, heavily muscled pigs produce meat with inferior quality.

3. That the more intensive nature of the industry (large production units and central abattoirs) has imposed greater degrees of stress on the modern pig resulting in an increased incidence of PSE meat.

Hypothesis 1., if true, presents very serious problems to the swine industry, since breeding programs place very high emphasis upon efficient production of lean tissue. While long term selection experiments for increased lean growth rate have generally not reported any substantial decline of meat quality as a correlated genetic response, they have not in general considered the genetically lean pig (e.g. less than 12 mm fat at the last-rib at 100 kg live weight). However, the available evidence (Sather et al, 1981) suggests that certain types of pigs (e.g. heavy muscled conformation) may be responsible for a substantial proportion, although not all, of the meat quality problems. Long term genetic studies, using lines that are free of genetic stress susceptibility (halothane gene) are still required to verify hypothesis 1.

The development of halothane positive lines of pigs (e.g. Webb 1981, Jensen and Barton-Gade 1985, Murray and Sather, 1986) has confirmed hypothesis 2. Halothane positive (nn genotype) and carrier (Nn genotype) pigs have a higher lean carcass yield than normal pigs (NN genotype) and under certain breeding programs may be considered superior animals in terms of carcass yield traits.

However, recent evidence (Jensen and Barton-Gade 1985, Murray and Sather, 1986) now suggests that carrier pigs (Nn) may have intermediate meat quality relative to either homozygote (i.e. NN vs nn). These results imply that even if the frequency of halothane positive pigs are low (say, approximately 1.8%), the incidence of halothane carrier pigs can be substantial (23.3%) and contribute significantly to the amount of PSE meat found in Canadian pork. However, it is becoming increasingly clear that environment (hypothesis 3) has a vital bearing on the overall incidence of PSE pork. Canadian pork production has not only expanded but also become more intensive in the last 25 years. Large abattoirs now routinely slaughter up to 30,000 pigs a week. There is little doubt that the modern pig is subjected to a greater degree of stress during marketing (farm gate to slaughter) than in the past.

6. THE DETECTION OF AND TESTING FOR STRESS SUSCEPTIBILITY

A. Sather and A.C. Murray

A. Genetic markers.

Halothane testing has proven to be very useful for the indentification of homozygous stress susceptible pigs (genotype nn - Table 6.1) but is ineffective as a tool to identify the heterozygote (genotype Nn). In addition, halothane testing at the field level in Canada because of its expense is usually confined to pigs housed in test stations. For these reasons, considerable work has been underway in Europe to evaluate genetic markers which require a blood sample to determine the presence of absence of certain blood group loci, Archibald and Imlah (1985) pointed out that the halothane gene was a member of a linkage group consisting of 5 other linked gene loci:

1. S(A-O) blood group locus which suppresses the expression of the A-O blood group. The S^s allele suppresses the expression of the A-O blood groups and is recessive to the dominant S^S allele allowing expression of the A-O blood antigens.

2. H blood group locus is a multiallelic system of 6 alleles (alternatative form of the same gene) that controls a series of erythrocyte antigens. The alleles of this system have been usually classified as the H^a allele (presence of the "a" antigen) and the compound H^- "allele" (absence of the "a" antigen).

3. Pig erythrocyte 6-phosphogluconate dehydrogenase (Pgd) locus has two codominant alleles Pgd^A and Pgd^B.

4. Pig blood serum protein postalbumin-2 (Po-2) locus has two codominant alleles $Po2^F$ and $Po2^S$.

5. Pig erythrocyte phosphohexose isomerase (Phi) locus has two codominant alleles Phi^A and Phi^B.

Codominant loci, in which both genes at a single gene locus are simultaneously expressed, are particularly useful since the complete genotype at that locus can be readily established.

The use of genetic markers as a predictive tool to assign a probability that a pig is a carrier of stress susceptibility is dependent upon linkage disequilibrium. That is, certain haplotypes (combinations of specific alleles at different loci on a single chromosome) have greater probability of existing than that expected if a population were in equilibrium. While the mathematics of this topic is beyond the scope of this review several points can be discussed in general that pertains to the use of genetic markers as a tool for locating the carrier pig.

1. Linkage disequilibrium means that specific alleles (variants of a gene) from two gene loci are associated or correlated with each other. The implication is that a marker gene can only provide a probability statement as to whether or not a pig is a carrier. The presence or

absence of the marker gene is not proof, but rather a good indication, that the pig is a carrier. Greater certainty of identifying a carrier pig can be achieved by using two or more marker loci.

2. Since two or more gene loci are involved, recombination events can occur between these loci. Thus, the phase of a marker gene can change. Crossing over between two gene loci leads to a degeneration of linkage disequilibrium. Thus, linkage disequilibrium will be more stable with closely linked loci. If there is no linkage between two loci, then all "linkage disequilibrium" will be lost in one generation of random mating.

3. The linkage disequilibrium that exists between any two loci is population dependent and subject to genetic drift (i.e. variation is linkage disequilibrium from one population to the next) and sampling errors. The parameters and thus the usefulness of a marker must be determined for each specific population.

While genetic markers may be of value in determining whether or not a pig is a carrier, considerable ground work must be done prior to the general application and adoption of such techniques. The effectiveness of the use of genetic markers are dependent upon two genetic parameters that can vary from population to population:

1. gene frequency of both the marker and the primary gene, and

2. linkage disequilibrium between the marker and the primary gene.

If genetic techniques are to be used to improve meat quality in Canada, then the first priority should be to make stress resistance pigs available at A.I. centers. This could be done with a progeny test to a known line of halothane positive sows, and halothane testing the resulting progeny. After blood typing procedures have been adapted for use as genetic markers, these should be used to replace the costly and time consuming progeny tests.

B. Physiological Markers

1. Blood enzymes. A number of blood enzymes have been tested for their ability to predict stress susceptibility as indicated by a positive halothane test (Sybesma and Eikelenboom 1978). For example, levels of serum lactate hydrogenase (LDH) and glutamate oxalate transferase (GOT) and plasma aldolase have been found to be higher in halothane-positive (H^+) pigs than in halothane-negative (H^-) pigs although enzyme levels were not highly correlated highly with halothane reactivity. Since these enzymes are found in most tissues of the body, many varied causes can contribute to increase their blood levels.

   Creatine phosphokinase (CPK) has shown promise as an indicator of stress susceptibility (Mitchell and Heffron 1982). This enzyme is concentrated in muscle and brain tissues. Serum CPK usually emanates from the muscle and is a useful indicator of muscle deterioration through disease or injury. Although serum levels vary greatly due to factors not related to stress susceptibility such as other muscle disorders, diurnal variation, muscle activity such as exercise, and age, they are consistently higher for H^+ than for H^- pigs. CPK measurements may have some potential if all confounding sources of variation can be understood and controlled.

2. Erythrocyte osmotic fragility. Red blood cells from H^+ pigs have a different resistance to hemolysis by salts than do those from H^- pigs. The measurement of erythrocyte osmotic fragility is a simple test which has shown limited potential to detect heterozygous carriers of the halothane gene (Harrison and Verburn 1973). However the technique appears to show breed differences which are not related to stress susceptibility. It requires further examination and refinement to maximize differences between halothane genotypes and to minimize variability.

3. Mitochondrial calcium efflux. The rate of efflux of calcium from muscle mitochondria has been found to be higher in H^+ pigs than in H^- pigs (Cheah and Cheah 1979). This finding is unlikely to be incorporated into a diagnostic test for stress susceptibility since it would require the use of a biopsy technique, and a sophisticated procedure for the isolation of mitochondria.

4. Blood platelet morphology and membrane bound calcium. The electron microscopic examination of blood platelets has found to be useful to distinguish between H^+ and H^- pigs (Basrur et al. 1983). The area of the platelet open canalicular system is greater for the H^+ than for the H^- pigs. However, this approach is far too costly and and time consuming to offer potential as a routine test for stress susceptibility.

5. Blood hormone levels. The stress hormones (cortisol, catecholamines, thyroid hormones) are in general higher in H^+ than in H^- pigs, although the levels are far too variable to be of any predictive value.

6. Heat production. Observations show that H^+ pigs, but not H^- pigs, exhibit a considerable increase in muscle temperature as measured by a rectal thermometer during the administration of the anesthetic, halothane. The fact that this temperature increase is quite erratic, and by the time it is great enough to measure the recovery of the pig is unlikely, makes single muscle temperature measurements an unlikely candidate as a predictive tool. The evaluation of infrared thermography techniques for the detection of temperature changes in stressed and unstressed pigs differing with respect to their reaction to halothane is currently in progress.

7. Microscopic examination of muscle tissue. Microscopic examination of muscle tissue using both light and electron microscopes can detect structural anomalies related to stress susceptibility, but these techniques have been found to detect only a small percentage of H^+ pigs.

8. Muscle contracture test. The usual test to predict susceptibility to malignant hyperthermia (MH) in humans is the in vitro contracture test in which strips of muscle are exposed to drugs such as halothane, caffeine and succinylcholine which may cause contraction. This test has shown a great degree of variability in pigs and it is very demanding technically, but because of the fact that it appears to identify a greater number of carriers than even the halothane test, further research into its use as a predictor of stress susceptibility is warranted.

9. Muscle metabolism. The changes in glycolytic rate and pH, which occur in muscle post-slaughter, also occur in a muscle sample removed from a live pig. Increase in muscle glucose-6-phosphate (G-6-P) and halothane-induced decrease in adenosine triphosphate (ATP) have been shown to be related to stress susceptibility (Sybesma and Eikelenboom 1978). These methods are not only deficient in accuracy but are somewhat technically demanding to be of general use.

Considerable research efforts are being expanded particularly in Europe on tests that will accurately identify pigs carrying genetic stress susceptibility. The most promising research area concerns the use of genetic markers such as blood groups, although there is no work underway in this field in Canada.

7. ANTE-MORTEM INFLUENCES ON PORK QUALITY

A.C. Murray and S.D.M. Jones

The treatment of pigs during the period up to 48 hours prior to slaughter has a major influence on the economic losses due to transit deaths, loss in carcass yield (shrink and/or bruising) and inferior lean meat quality. To a great degree these losses relate to the ability of a pig to cope with stressors. Certain pigs, including those which react in a unique way to the anesthetic, halothane, are particularly susceptible to stressors.

A. Swine Deaths

Within Canada death losses during transit over the last few years has averaged about 1.2 pigs/1000 pigs transported. On a Canada wide basis the economic loss to the industry through transportation deaths is estimated to be over $2 million per annum. Transportation deaths based on pigs found dead on arrival at abattoirs are shown in Table 8.1 by region and season. In most regions, transportation deaths tend to be more frequent in the summer months when high temperature and humidity levels prevail, leading to increased stress. There are large regional differences with the Western Provinces (Saskatchewan and Alberta) recording the highest death losses due to transportation in most seasons. At the present time the reasons why transport deaths are almost three times higher in Alberta and Saskatchewan compared to other regions of Canada are not clear. Some of these regional differences may be accounted for deaths in assembly yards before the pigs reach the abattoir.

Table 7.1. Market pigs found dead (% of total slaughter in region) on arrival at the abattoir by region and season (1984-1985).

	Region						
Season	Atlantic	Quebec	Ontario	Manitoba	Sask.	Alberta	B.C.
Winter (Nov-Feb)	.09	.09	.07	.06	.18	.24	.17
Spring (March-May)	.11	.11	.08	.06	.19	.21	.11
Summer (June-Aug)	.17	.15	.09	.06	.27	.32	.16
Fall (Sept-Oct)	.14	.13	.09	.05	.15	.18	.13

Overall deaths 1984-1985 = 0.117 based on 13,138,237 pigs slaughtered.
Information supplied by Meat Hygiene Division of Agriculture Canada.

Stress susceptible pigs are more prone to transit death. Immediately prior to death these pigs usually exhibit at least some of the symptoms of classical "porcine stress syndrome" (PSS). The symptoms include: labored breathing, blotchiness of the skin, hyperthermia and rigidity of the limbs.

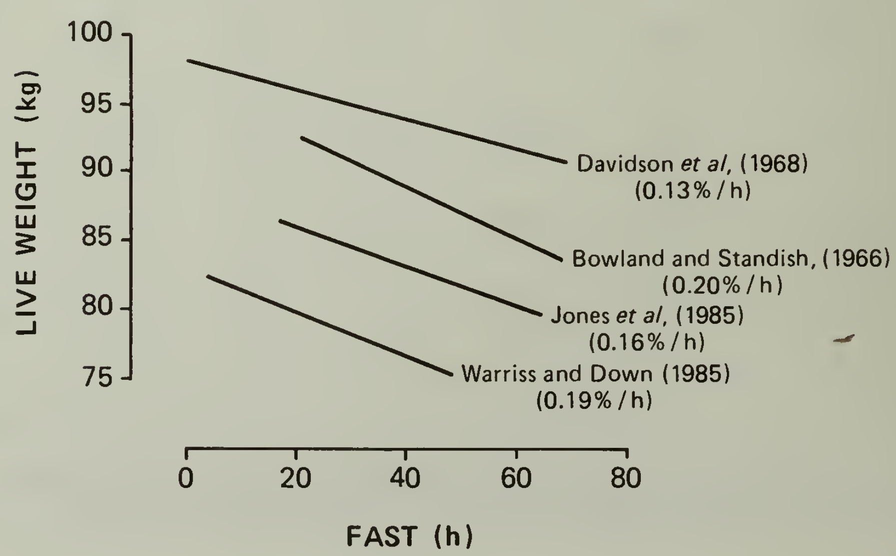
B. Carcass Bruising

The extent of the losses through bruising has been reviewed by Warriss (1986) for Britain. In the UK between 1969 and 1975 about 2.6 pigs per thousand were condemned either partially or wholly because of bruising. Of particular concern was the skin damage caused mostly through fighting, as these carcasses were often unsuitable for the production of rind-on bacon. This fighting problem may be somewhat more prevalent in the UK because of the extensive slaughter of young boars for meat production. A brochure by Grandin, describing the situation for the U.S.A., placed annual losses to the livestock industry due to bruising at $46 million. Approximately two thirds of all bruises in pigs were found to occur in the very valuable ham area. Both hams were often ruined in the case of a spreader injury, which might result from slippery flooring. Grandin suggested that a substantial proportion of all bruises was due to careless or abusive handling. The movement of pigs more at their own pace with canvass slappers (which are not frozen) or boards instead of canes, clubs, electric prods, kicking, etc will greatly reduce bruising. The design of facilities to permit good footing and to avoid steeply inclined ramps is also crucial.

C. Carcass Weight Loss

If pigs do not eat for extended periods of time they will inevitably lose weight. Figure 7.1 shows the extent to which duration of feed restriction will affect the live pig weight (Warriss, 1986). Live weight losses occur at the rate of approximately 0.2% per hour.

Figure 7.1 The effect of length of feed restriction on live pig weight



Carcass weight losses probably begin between 9 and 18 hours after the last feeding and occur at the rate of about 0.1% per hour thereafter (Warriss, 1986). Although transit distance and time have been used to explain weight losses, probably the major factor influencing losses is the duration of feed and water restriction. Of course stress situations, such as handling, mixing, transit and elevated temperatures would be expected to exacerbate any effects of feed and water restriction. The feeding of sucrose solutions to pigs immediately prior to slaughter has been shown to increase carcass yields by up to 3% (Fernandes et al, 1979). However, the concomitant decrease in meat quality, as evidenced by a decreased in muscle pH at 45 minutes post-slaughter, may offset any potential weight gains.

D. Marketing

Many of the PSE/DFD-related losses have been attributed to treatment during the period immediately prior to slaughter, and are thought to be due to exposure of the pig to stress situations which it has not previously encountered to any great degree. The following stressors are among the most common and may be considered to have both a physical and emotional component.

1. Interaction among pigs. Pigs usually exist in a very well defined social structure and they are very possessive of their territory. The mixing of unfamiliar pigs usually results in a great deal of fighting during the social regrouping process. This situation is one of extreme stress. In addition, fighting causes losses due to bruising and it can have an effect on the quality of certain muscles (Warriss and Brown, 1985; Warriss, 1986). The effects of mixing can be minimized by using adequate partitioning during transit and proper pen design at the packing plant. Since pigs prefer to stand at the perimeter of the pen along the fences, long narrow pens are preferred at assembly points and in lairage areas of packing plants.

2. Climate/Micro-environment. Pigs are particularly sensitive to both high temperatures and extreme fluctuations in temperature. The incidence of PSE pork and the incidence of transit deaths are known to be at their highest during the hottest periods of the year. Since pigs do not have a great ability to compensate for temperature changes, every effort must be made to assure proper temperature and humidity control. Because of the extreme cold temperatures in most parts of Canada during the winter months, pigs must also be protected against frostbite.

   Control of temperature during the transportation of pigs to market is critical. This is accomplished by assuring that trucks have adequate levels of ventilation. Overcrowding should be avoided. Loading densities ranging between 0.34 m^2 and 0.41 m^2 per hog, depending on the weather, have been recommended (Agriculture Canada 1984b). Very little work has been conducted in Canada relating to stocking density in a truck, its interaction with environmental conditions and the effects on pork quality. Recent work in Holland (Lambooy et al. 1985) examined long transportation periods (44 hrs) in conjunction with 3 stocking densities on a triple deck truck (0.66, 0.44 and 0.33 m^2/pig). Pigs stocked at 0.66 m^2/pig sat or lay down quietly within the first two hours of the journey. About 1/3 of the compartment was not occupied. The pigs stocked at 0.44 m^2/pig sat down or lay quietly, about 15-30 minutes later than the lowest stocking density. The area of the compartment was almost completely occupied. In the compartment with the highest density (0.33 m^2/pig), not all animals could lie down at the same time and as a result the pigs were continually changing their positions. The authors concluded that the highest stocking density should be 0.44 m^2/pig (for 100 kg pigs) for reasons of animal welfare and meat quality. Prolonged rest stops and prolonged waiting at time of unloading should be avoided. Transportation during the hottest part of the day in the summer months should also be avoided.

The problem of overheating has been addressed through the spraying of pigs in the lairage area. The spraying of pigs prior to stunning caused a decrease in the temperature of the longissimus dorsi muscle 35 minutes after slaughter and a reduction in the incidence of PSE meat (Smulders et al. 1983).

In addition to control of temperature, control of lighting is important. Hogs may experience bright sunlight for the first time during the loading for transport to market. Movement from low light intensity into bright sunlight, perhaps in combination with change in temperature from 18°C to -20°C, is undoubtedly stressful, and this tends to increase the liklihood for physical abuse during loading and unloading. Uniform lighting in the abattoir holding area must also be considered.

3. Handling. Physical abuse not only dramatically increases the incidence of bruising, but is also a contributor to the overall stress level of the hog (Grandin). Rough handling including kicking and beating should be avoided. Canvass slappers, which are not frozen, should be used instead of canes and clubs. The use of electric prods is discouraged. Van der Waal (1970) after measuring epinephrine levels concluded that pigs may be considerably stressed by electric prods. Lewis et al. (1961) found that stress through the application of 18 electric shocks per hour for a period of 5 or more hours caused the depletion of muscle glycogen reserves and ultimately resulted in DFD meat. On the other hand much briefer treatments of this type would be expected to result in PSE meat. Driving boards can decrease the degree of stress during the moving of pigs, and where possible hogs should be permitted to move at their own pace.

4. Handling facilities and facility design. Lack of proper design of handling and holding facilities is a major contributor to bruising and to stress levels which ultimately result in PSE pork. Elimination of slippery walkways, steep ramps, sharp corners, sharp protruding surfaces, noise and vibrations, etc at all points from farm to slaughter will undoubtedly result in improved pork quality. Extensive reviews on this subject have been completed by Grandin (1980) and Braathen (1981).

5. Water and feed restriction. Numerous research reports describe the effects of feed and water restriction on pork quality. These are typified by the data of Neilsen (1981) which are presented in Table

7.2. Increasing the duration of feed restriction and resting time prior to slaughter resulted in a decrease in the incidence of PSE meat and an increase in the incidence of DFD meat.

Table 7.2. Frequency of PSE and DFD pork in relation to feeding and holding periods.

Fed on Delivery Day	Holding Time (hr)	No. of Pigs	% PSE	%DFD
No	0	204	7.8	2.9
	2	206	5.8	17.0
	4	205	2.9	12.2
	24	104	1.9	20.2
Yes	0	175	13.1	3.4
	2	174	7.5	10.3
	4	177	4.0	6.2
	24	81	2.5	7.4

Neilson 1981

Table 7.3. Scores (%) for pork muscle color (differences from base-line) in pigs transported and rested for different periods of time prior to slaughter†.

Transport Duration	Resting Period (hr)	‡Color Score			
		1	2	3	4
Less than 1 hour	0	0	0	0	0
	3	+2.3	-20.8	+21.1	
	6	+1.0	-29.8	+27.8	+1.2
Greater than 2 hours	0	-0.4	-19.2	+18.6	
	3	-5.5	-27.3	+32.1	+0.8
	6	-4.7	-31.9	+36.2	

‡ Study conducted during the summer months.
† Color Score 1-4, Agriculture Canada Pork Quality Standards.
Fortin 1986

6. Transportation and resting period. European work with pigs has indicated that short transportation periods combined with no resting period at the abattoir results in an increased incidence of PSE pork. A recent study conducted in Quebec (Fortin, 1986) has confirmed these findings under Canadian conditions. The frequency of pork colour scores for transport duration of less than 1 hour and 0 hours resting were set at 0 (baseline value) and all other frequencies were reported against the base-line values (Table 7.3). During the summer, pigs were either transported for less than 1 hour or greater than 2 hours and slaughtered on arrival at the packing plant or rested for 3 or 6 hours. The baseline values where PSE incidence would be expected to be highest are shown as 0 in Table 7.3 and the other treatments are measured against these values in terms of percentage differences. Short term transportation with no rest prior to slaughter produced a much higher incidence of color scores of 2 (pale) than pigs transported for over 2 hours. Short transportation would be expected to be more stressful than longer transportation, since there is a very short period of time between loading and unloading. Also, pigs are often mixed prior to transportation with the result that social regrouping will continue on the truck. A longer resting period was associated with improved pork color scores. For example, 6 hour resting decreased the frequency of pale loins by about 30%. The incidence of dark pork (color score 4) did not show a major increase with an increased resting period. Therefore, short resting periods (3 hour or more), particularly following a short truck journey, would appear to offer considerable benefit in reducing the frequency of PSE pork. These short rest periods are not likely to have a major influence on carcass weight shrinkage, but do require the plant to invest in modern animal handling facilities, and to have deliveries of pigs extremely well coordinated.

7. Interaction of environment with genetic susceptibility to stress. Certain pigs, including those that give a positive halothane test, are particularly susceptible to stressors. As such, little or no stress is required to trigger the PSE condition. An example of the effect of stress susceptibility (as determined through halothane testing) and length of feed restriction on the final lean meat quality (Murray, 1986) is shown in Table 7.4.

Table 7.4. The effect of duration of feed restriction on the incidence of soft exudative (SE) structure† in the longissimus dorsi muscle of pigs from three lines.

Duration of Feed Restriction (hr)	Line of Pigs‡		
	NN	Nn	nn
0	0	60.7	87.0
24	0	53.6	60.9
48	3.2	14.3	47.8

Murray 1986
† Structure Score, Agriculture Canada Pork Quality Standards.
‡ Line of pigs: NN = Lacombe, Nn = Lacombe x Halothane positive, nn = halothane positive.

For this trial feed restriction was carried out in the barn in which the pigs were raised with no mixing, but with water available, and slaughter occurred within one hour of arrival at the Lacombe abattoir. Table 8.4 shows a major effect of line on pork quality. At 0 hour off feed the incidence of pork with soft exudative structure varied from 0% for the Lacombe breed (probably non-carriers of the halothane gene) to 87% for the nn line (all of which were halothane-positive), while the cross line was intermediate. At 48 hour off feed both the nn line and the cross line showed considerable improvements in quality, the cross line giving greater response to the 48 hour feed restriction than the nn line. Had this experiment been carried out in a commercial packing plant, the increased stress of commercial marketing would probably have resulted in even more obvious interactions between line and time off feed.

Environmental conditions have been shown to be a major contributing factor in the development of PSE/DFD pork. Although some sound general principles have been established e.g. handling, facility design, resting periods prior to slaughter, etc., the area is still poorly researched in Canada. For example, the average transportation distances to processing plants and times spent in transportation in the marketing process have not been defined. A major effort is required to collect this information before cause and effect can be established, and the incidence of poor meat quality reduced.

Research findings have resulted in recommendations concerning the handling of pigs at the farm, during transit, and at the abattoir. Information, written in a non technical style, is available from Canadian sources (Thompson, 1980; Canadian Pork Council, Canadian Meat Council 1980). The most comprehensive treatment of the subject is found in the "Recommended code of practice for care and handling of pigs" (Agriculture Canada 1984b).

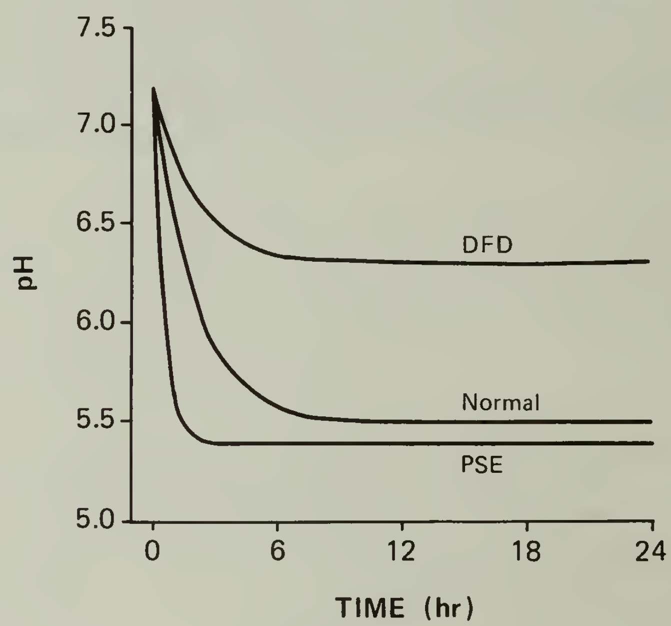
8. POST-MORTEM INFLUENCES ON PORK QUALITY

A.C. Murray and S.D.M. Jones

Muscle of the living pig has a pH of near 7.2, that is, it is neither acidic nor basic. The blood, in addition to supplying the muscle nutrient requirements, serves to remove metabolic end products, such as lactic acid, which are produced as a result of muscle activity.

Biochemical reactions within the muscle continue for considerable time after slaughter, making use of the energy supplies stored mostly in the form of the carbohydrate, glycogen. The rate of reaction is controlled to a large extent by the levels of free calcium. However since blood circulation has ceased at death, lactic acid accumulates. Rigor mortis sets in within about the first 6 hours post-slaughter. The accumulation of lactic acid is evidenced by a decrease in the pH value to approximately 5.5 within about 12 hours after slaughter (Figure 8.1). This process constitutes the normal conversion of muscle to meat.

Figure 8.1. The effect of length of time after slaughter on the pH of PSE, normal and DFD meat.



A. PSE Pork

The timing of the above events is somewhat different in muscles destined to become PSE. These muscles are well endowed with energy (glycogen), and because of an apparent inability to control levels of calcium, are biochemically very active immediately after slaughter, so that lactic acid is produced much more rapidly than normal and the pH may fall to below 5.6

within one hour post-slaughter while the carcass is still at or near body temperature (Figure 8.1). This combination of low pH and warm temperature causes structural changes in the muscle proteins which markedly decrease their ability to bind water while also influencing the texture and color of the meat surface. Thus pale, soft, exudative pork results.

Muscles such as the longissimus dorsi (loin eye), the biceps femoris (outside ham) and the gluteus medius (ham face) are particularly susceptible to the PSE condition.

B. DFD Pork

Muscles use energy for the pH decline which is required for normal conversion to meat. Muscles which have been depleted of their energy supply (glycogen) through long term stress (eg. long exposure to extreme cold with mixing and holding without feed) are incapable of the producing much lactic acid and thus remain at a high pH (> 6) (Figure 8.1). Because of the higher pH, the water holding capacity remains high and the texture is dark, sticky or dry and much firmer than normal.

A number of practices occurring at or immediately after slaughter can have an influence on the rate of pH decline and thus the incidence of PSE pork.

C. Stunning

Three common methods have been used for the stunning of hogs - captive bolt, electrical and carbon dioxide stunning. These have been described and compared in detail (Eikelenboom, 1983). During captive bolt stunning, a bolt is driven either into or against a pig's head by air pressure or a blank cartridge.

Electrical stunning is performed by passing an electric current through the brain so as to render the pig unconscious. The current is applied at 60-70 volts (low voltage) for up to 20 sec (5 - 7 seconds is effective - Gregory 1987) or at 240-1000 volts (high voltage) for 1-5 sec. This is usually accomplished through electrodes placed either 1. on both sides of the head midway between the eyes and the ears, 2. on both sides of the head immediately behind the ears or 3. between the forehead and the nape of the neck or back (front or head to back stunning).

Carbon dioxide stunning is accomplished by exposing pigs to approximately 70% carbon dioxide in a gas chamber. This technique appears to be more stressful to the pig, since there is a period of 20-30 sec between entering the gas and unconsciousness (Hoenderken, 1983), whereas the other two stunning methods produce instant unconsciousness.

Choice of stunning technique can have a major impact on meat quality. Captive bolt stunning causes a higher incidence of PSE meat than either of the other methods (Yang et al. 1983). Agriculture Canada research data (Murray, 1987) indicates that captive bolt stunning may cause four fold higher incidence of PSE pork than does electrical stunning (Table 8.1).

Table 8.1. The effect of stunning method on the PSE score of porcine longissimus dorsi muscle (loin eye).

Stun Method	No. of pigs	Frequency with PSE† Score 1/2	3	4/5
Electrical	100	11	85	4
Captive bolt	100	43	55	2

† PSE score 1/2, Extremely pale/soft structure, 3 = normal, 4/5 dark/firm structure.

The carcass and meat quality defects which can be influenced by stunning include: bone fractures, blood splash, bruising, inadequate bleeding and PSE meat (Gregory 1987). Bone fractures can occur in the shoulder blade, thoracic, and lumbar vertebrae and the pelvis. Shoulder blade fractures can largely be avoided by the use of a restraining conveyer or by restricting the duration of current application to a short period (2 sec when using 320 volt, Brathen and Johansen 1984). Gregory (1987) concluded that the incidence of bone fractures probably depended on the voltage used. Blood splash appears as small dots of blood and can be observed in the muscles of the shoulder, loin and ham. No slaughter method can completely eliminate blood splash since it has also been recorded in the muscles of animals subject to ritual slaughter. The evidence in the literature suggests that high voltage head and back stunning results in less blood splash than low voltage stunning since head to back stunning would result in a greater frequency of cardiac arrests. Shorter electrical stunning times (< = 2 sec) have been shown to give less blood splash, fewer broken bones and improved pork quality (less PSE) than longer stunning times (Hoenderken 1978; Van der Waal 1978; Braathen and Johansen 1984).

Detailed research by Hoenderken (1978, 1983) has lead to the conclusion that for effective electrical stunning:

1. A current of at least 1.25 amperes must be attained within 1 sec. In practice this requires a voltage in excess of 240 volts (preferably >300 volts).

2. The electrodes must be placed on the head to assure that the current passes through the brain.

3. Pigs must be stuck as soon as possible and definitely within 30 sec after stunning in order to prevent a return to consciousness.

The controversy concerning the relative merits of electrical and carbon dioxide stunning continues. Prior to 1980, the consensus of research data indicated that electrical stunning was superior to CO_2 for both meat quality and humaneness reasons (eg. Van der Waal, 1978). As of 1983, CO_2 stunning was not permitted in the Netherlands because of the apparent additional stress imposed during the period of 20-30 sec between entering the gas and unconsciousness (Hoenderken, 1983). However, Mosfeldt Laursen (1983) concluded that electrical stunning with at least 300V and anesthesia with 70% CO2 were both acceptable procedures, and differences in the humaneness of the procedures was insignificant when the general background state of stress was considered. Also, low voltage stunning was considered less humane than the other procedures. In an experiment involving several thousand pigs (Table 8.2), carbon dioxide stunning with a Compact Stunner was shown to yield a lower incidence of PSE pork than electrical stunning at either 300V or 700V (Larsen 1983). In addition, the former method resulted in less blood splash and fewer bone fractures. Further comparative testing of these two techniques is required in Canada to arrive at a recommendation on choice of CO_2 versus electrical stunning.

Table 8.2. Comparison of the effect of electrical and carbon dioxide stunning on quality of the longissimus dorsi muscle.

Stun Method	% PSE	% DFD
Elect. 300V	18.5	5.7
Elect. 700V	15.1	8.3
Carbon dioxide	4.0	6.1

Larsen 1983

D. Side of Shackling

The effect of shackling side on meat quality has been a concern. Fisher and Augustini (1981) showed that for the semimembranosus muscle (inside ham), the pH at 45 min post-slaughter and a number of other meat quality measures were dependent upon whether the pig was hung from the left or right leg during the period between stunning and scalding. The quality was poorer (more PSE) in the ham of the side that was shackled. This observation has also been supported by Swatland (1986). Jones and Murray (1987) however, have shown that the side of shackling had no effect on the lean meat quality of the longissimus dorsi (loin-eye) muscle. Lundstrom and Henningson (1986) found that shackling pigs by two legs did not result in a great enough improvement in the quality of the loin muscle to be recommended for commercial practices (one to two leg shackling). The concencus in the literature is the shackled side (usually the left side) may produce a higher incidence of PSE muscle in the ham, but has minor influence on the quality of the loin muscle.

E. Scalding

The practice of scalding pigs after stunning and sticking to permit dehairing adds heat to the carcass and would therefore be expected to exacerbate PSE quality problems. The skinning of carcasses is an obvious alternative to the scalding process. Skinning can result in faster carcass chilling and therefore better color and higher quality (Voogd, 1983). In addition, it has been shown to be more economical than scalding where markets are available for pig-skin.

F. Rate of carcass cooling

Carcass cooling systems have been developed with an overall objective to reduce deep muscle temperatures so as to minimize the growth of spoilage bacteria. Conventional cooling systems for hog carcasses usually employ air temperatures of close to 1 C and air speed of 0.5 meters/sec. Very few coolers are designed with sufficient refrigeration capacity to overcome the initial high heat load. Consequently, air temperature rises, leading to an extended cooling cycle. Increasing the rate of carcass cooling will lower the rate of biochemical reactions and pH decline, and in theory improve meat quality in carcasses susceptible to PSE. Multiple stage chilling was developed in Denmark and is now finding acceptance in the Canadian meat industry. Although these newer systems differ in specifications, the pork carcass is chilled for about 1 hr at very low temperatures (-20° to -40° C) at varying air speeds (1-3 meters/sec) followed by conventional cooling. Only limited research has been conducted in Canada on the effects of two stage chilling on pork muscle quality. The results to date (Table 8.3) show that a blast-chill cycle of 1 hr does result in improved subjective scores for pork quality compared to conventional chilling (Jones et al. 1987b).

Table 8.3. The effect of chilling treatment on loin color and structure scores†.

	Frequency of Scores				
Chilling Treatment	1	2	3	4	5
			Lean Color		
Conventional	0	11	611	141	10
Blast-Chill	0	13	518	225	17
			Lean Structure		
Conventional	2	16	599	144	12
Blast-Chill	1	16	545	180	31

Jones et al. 1987b

† Color/Structure Score 1-5, Agriculture Canada Pork Quality Standards.

However, it should be noted that there was a very low incidence of PSE pork (color and structure scores of 1 and 2) encountered in this study for both chilling treatments. The net effect of blast-chilling was a shift of subjective scores from 3 to 4, thus producing pork of a darker color and firmer structure than conventional chilling. Whether the same general results would apply when a high frequency of PSE pork was encountered is a matter of speculation. In addition, rapid chilling of pork under certain conditions may lead to muscle toughening (Dransfield and Lockyer 1985) and this problem is likely to be of greater importance in leaner pigs. Clearly more research is still needed under Canadian conditions to establish optimum chilling rates for pork carcasses.

Spray chilling has been adopted by several pork processing plants in Canada. Although there has been little research conducted, it appears that spray chilling for up to 8 hrs can substantially reduce carcass shrink (2.5% to 0.6%), while having no effect on meat quality (Jones et al. 1987) Spray chilling has a slight benefit to carcass cooling rate by reducing deep ham temperature 6 hrs after commencement of chilling by 2-4° C.

G. Electrical Stimulation

The electrical stimulation of beef carcasses has been shown to increase the meat tenderness. It also speeds the rate of muscle pH decline and rigor development, negating any effect of cold toughening which might be associated with hot boning and/or very rapid chilling. However, application of the technique to pork carcasses has in some cases adversely affected pork quality (Crenwelge et al, 1984). This is not surprising since increasing the rate of pH decline while the muscle is still near body temperature would be expected to increase the incidence of PSE meat. Electrical stimulation of pork may however offer some potential if used in conjunction with very rapid chilling.

EXECUTIVE SUMMARY†

1. The current frequency of pale soft and exudative (PSE) pork in Canada is regarded as an important commercial problem by the Canadian meat industry and influences the competitive position of Canadian pork in international markets.

2. PSE muscle results increased drip in fresh pork. Losses amount to 4% for PSE compared to 2% for normal pork. Processed yields for PSE pork are reduced by about 10% in fresh and 20% in frozen backs compared to normal pork.

3. Limited research shows that the shelf life of PSE pork may be longer than that of normal and dark pork.

4. Although PSE meat is not rated as high in palatability as normal meat, it is still generally regarded as acceptable. However, cooking losses are generally significantly higher in PSE compared to normal and dark pork. Detailed results obtained by flavor and texture panels show PSE pork has a sour taste which reduces flavour ratings, and a drier texture that contributes to lower juiceness.

5. A very high incidence of PSE pork is produced from homozygous stress susceptible pigs. Stress susceptibility is a genetic disorder and is probably inherited as a recessive gene. However, after several years of halothane testing, homozygous stress susceptible pigs only make up 1-2% of the national swine population. Therefore homozygous stress susceptible pigs are not a main contributor to the current commercial incidence of PSE meat.

6. Heterozygous pigs which carry the stress susceptibility gene (carriers) cannot be identified by halothane testing, yet the frequency of carriers could be up to 24% of the national swine population. Work at Lacombe has shown that carriers produce meat quality intermediate to stress susceptible and normal pigs. In simple terms up to 12% of all pigs slaughtered could produce PSE pork through carrying the stress susceptibility gene.

7. Transportation, time of last feeding, environmental temperature, stocking density and the handling of pigs have been shown to be the most important environmental factors influencing the frequency of PSE pork. Over the last 20 years the Canadian swine industry has increased in size along with the development of slaughter facilities which routinely handle up to 30,000 pigs per week. There is little doubt that increased intensification in the industry combined with larger throughputs at slaughter plants have resulted in more stress on the market pig. For example, in one study short transportation distances (< 1 hour) and no resting prior to slaughter was associated with a 20% increase in PSE pork compared to pigs rested for 3 hours prior to slaughter. In another experiment, pigs carrying the stress susceptibility gene had only a 14% incidence of PSE after 48 hours without feed, but a 60% incidence at 0

† The executive summary highlights the main findings of the technical review and represent the views of the authors.

hours off feed. Knowledge of marketing conditions across Canada is limited, but it is clear that environmental factors play an important causal role in the current frequency of PSE pork. Capital will have to be expended to improve transportation conditions and animal handling facilites in assembly yards and abattoirs, to reduce the frequency of PSE pork.

9. The two most important post-mortem factors influencing muscle quality are stunning and the rate of carcass cooling. High voltage stunning (> 300 volts) has generally been adopted by the Canadian industry. However, recent work with a compact CO_2 stunner has shown a much lower incidence of PSE meat than that obtained by electrical stunning (4% vs 16.5%). Blast-chilling of pork carcasses increases the cooling rate compared to conventional chilling and results in a slightly darker, coloured pork with a firmer structure. However, it is doubtful if blast-chilling alone can control the production of PSE meat.

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