S. Afr. J. Anim. Sci. 3, 183–192 (1973)

THE SIGNIFICANCE OF PALE, SOFT, EXUDATIVE (PSE) PORK IN THE SOUTH AFRICAN MEAT INDUSTRY

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Consumers' preference

The production of the maximum quantity and optimal quality of lean meat is an integrated process in which many factors, which are interdependant and inseparable, are involved. The different links in this production chain are dependant upon the following factors determining the quantity and quality of the product being produced:

Ante mortem	*Post mortem*
1. Heredity	5. Storage and transport
2. Physiology	6. Processing
3. Environment	7. Marketing and distribution
4. Slaughter process *(Mortem)*	8. Consumption

During the slaughter process *ante* and *post mortem* factors overlap in the death reaction of the animal. The entire life span of the animal and the product must therefore be considered and all factors must be included which may influence the production and acceptibility of meat – from conception to consumption. The latter link very often dictates to the preceding seven links in the production chain. This trend can be illustrated by figures obtained from a recent consumers' survey on pork and bacon characteristics in South Africa, including 500 informants (Market Research Africa, 1970). When pork chops with the same size of *M. longissimus dorsi* with varying degrees of fat thickness were presented to the panel, 40% preferred one millimeter of fat only, 33% 5 mm and 16% 10 mm. When different chops with the same fat to lean ratio were offered, 41% preferred small chops and 47% large chops. Bacon rashers with the same muscle size but with different degrees of fat cover were also presented. Sixty one per cent of the panel preferred rashers with a 5 mm fat layer, 22% with 15 mm and 10% with 30 mm. It may therefore be deduced from these figures that large sized lean portions are presently preferred by the consumers of South Africa. Similar trends have been reported on in many parts of the world during the past decade or two (Krol, 1971).

Breeding, selection and stress

As a result of this preference, Danish Landrace pigs have for instance been selected and bred for improved leanness. This is illustrated by figures obtained from their progeny testing stations for the period 1926 to 1963 (Lister, 1970). The test period, in which pigs are being fed to gain from 20 to 90 kg in live mass, has been shortened by eight days over this 37 year period, muscle content in the carcasses increased by 20% and fat content decreased by 20%. The increased protein deposition was responsible for 77% of the improved efficiency of food utilisation resulting from the selection for rate, efficiency and composition of growth. The consequence of this selection is an increased secretion of growth hormones by the pituitary most probably at the cost of the adrenocorticotrophic hormone secretion of this gland (Lawrie, 1966a). This change in the hormonal balance of the animal seems to lead to increased stress susceptibility causing a more severe physiological reaction resulting from certain unusual environmental factors, than would be the case with animals which are more stress resistant. In the Netherlands particular attention is being paid to deaths of perfectly healthy pigs when transported to abattoirs or of pigs subjected to other forms of stress such as extreme environmental temperatures, excessive excercise or fighting pre slaughter (Lendfers, 1968, 1969). A condition of stress created in the animal directly prior to or during the death or slaughter of the animal causes excessive muscle contraction while the animal is in a state of anoxia (McLoughlin, 1971). In view of the fact that stunning and the slaughter process as such can act as stressors it is evident that severe muscle contraction can be stimulated even in the most stress resistant pigs (Ratcliff, 1971).

Post mortem muscle changes

Active contraction of muscles shortly prior to or during the death of the animal results in an increased rate of *post mortem* glycolysis. As a result of this rapid biochemical reaction, the rate of lactate production, measured by the muscle pH change from 7,0 to 5,5, usually occurring within 12 hr (Briskey, 1964), is now increased to the extent that it takes place in 30 to 90 min. and sometimes even within 10 min. Muscles have then already passed into *rigor mortis.* In practice it normally takes approximately one hour before warm carcasses are placed in cold storage. At this stage muscle temperature is still in excess of 35°C and if the muscle pH has then already decreased to a level of 6,0 or lower, it causes muscle protein denaturation to such an extent that the normal firm, dry texture and bright red colour is changed to the typical pale, soft, exudative (PSE) condition of pork muscle. The pH of muscles which were relaxed prior to or during slaughter, decreases to only 6,4 by the time the carcass has cooled down to 35°C and less (McLoughlin, 1969). Therefore preventing the typical occurrence of protein denaturation. In 1953 Ludvigsen (Briskey, 1964) called this condition "muscle degeneration", but it has since been ascertained that it is not a disease of the musculature of the live animal but that PSE muscles in the carcass result from a rapid *post mortem* glycolysis and consequent protein denaturation (Van Gils & Van Logtestijn, 1969).

The pale, soft, exudative condition

Pork muscle is lighter in colour and has a lower myoglobin content than beef or mutton (Lawrie, 1966a). PSE muscle however has a typical very light and dull grey colour. This is not due to a lower content of myoglobin in the muscle (McLoughlin, 1965a, 1969), but the result of the coagulation of sarcoplasmic proteins at a low pH and high muscle temperature, which masks the true inherent colour of the muscle. These proteins are also precipitated on the myofibrillar proteins causing a greater degree of light reflection (McLoughlin & Goldspink, 1963). The rapid rate of *post mortem* glycolysis also causes hydrolysis of the muscle fibre endomysium which accumulates along with the sarcoplasmic fluid in the intercellular spaces of the muscle as a gelatenous oedema (Briskey, 1964; Carrol, 1971). As a result of the above changes the muscle loses its firm texture and becomes soft and flabby.

Water binding capacity of muscle is undoubtedly the most important quality phenomenon to the manufacturer. The poor quality of this characteristic in Danish bacon carcasses exported to England since the beginning of the twentieth century, has been a matter of concern to the processors and exporters in Denmark (Jonsson, 1968). Manufacturers of Wiltshire bacon, smoked and canned hams, sausages and prepackaged fresh pork all set very high standards to the muscle in meat cuts to retain its 75% water during processing, in a form bound to the structural proteins. PSE muscles have a poor water binding capacity because of the protein damage which has occurred during the rapid lactate formation at a high muscle temperature. Cutting such muscles therefore results in a serious exudation of cellular fluid containing cell plasm and hydrolysed collagen (McLoughlin, 1965a; Lawrie 1966a, b; Lister, 1970).

Physiology, biochemistry, environment and stress

Stress prior to or during slaughter causes muscle contraction resulting in the breakdown of adenosine triphosphate (ATP). Resynthesis during the *post mortem* anaerobic condition of the muscle is very inefficient, therefore a rapid drop occurs in the ATP level followed by the onset of *rigor mortis* within two hours after stunning as compared to the normal six hours in relaxed muscles (Briskey, 1964). All these abnormal changes in the muscle occur more readily in "white" muscle fibres, which tend to accumulate lactic acid more easily, in comparison to "red" muscle fibres. Certain muscles eg. *M. longissimus dorsi* and *M. semimembranosus* have a larger proportion of "white" than "red" fibres and are therefore more susceptible to the above detrimental changes (Carroll, 1971).

Sybesma & van Logtestijn (1969) ascertained that an excited condition in pigs pre slaughter causes an impaired blood circulation resulting in an oxygen deficit in the muscle concurrent with a hyperthermic condition of the muscle as a result of the active ATP-hydrolysis. A more rapid onset of rigor mortis consequently occurs.

Certain breeds of pigs as well as certain individuals within a breed are more prone to stress conditions resulting in the above physiological and biochemical changes as well as the PSE phenomenon, once *rigor mortis* has set in. Examples of stress susceptible breeds are the Poland China breed of America and the Piétrain breed of Belgium. One of the early signs of stress susceptibility in pigs is the occurrence of tremors in the young pig (Sink, Judge, Cassens, Hoekstra, Grummer & Briskey, 1966). This has already been noticed in some South African herds (Naudé, 1972). In contrast to the above two breeds, Large White pigs are particularly stress resistant and have a slow rate of *post mortem* glycolysis in the muscles. Danish, Dutch and German Landrace pigs are intermediate between the above extremes (Briskey, 1964; Lister, 1970).

Lawrie (1966a) describes metabolic stress conditions in the muscle. An imbalance between the catabolic and anabolic processes caused by certain unfavourable conditions is being referred to as stress. Many stressors can have an influence on the organism. These are excercise, environmental temperature, humidity, nutrition, pathological conditions, anaesthesia, toxins, electric shock and physiological factors such as fear, light, temperament and noise. In practice pigs are subjected to a wide range of stressors. Industry is affected most seriously by those factors influencing the pigs shortly before slaughter (Briskey, 1964; Lawrie, 1966b; Sybesma & Van Logtestijn, 1969; Wismer-Pedersen, 1969; Lister, 1970). Fighting and conditions of high environmental temperatures during transport cause animals to become hyperthermic and anoxic, and this may result in the death of the animal. It has been a matter of concern in the Netherlands during the last decade (Lendfers, 1968, 1969) and is at present economically the most serious aspect of the live animal to be considered. Topel (1968) refers to the condition where death of the animal occurs prior to slaughter and the *post mortem* appearance of the meat is PSE, as the "porcine stress syndrome" (PSS). Shock, fear and tension directly prior to slaughter and struggling directly after slaughter cause a marked increase in the rate of glycolysis and lactate production *post mortem*. Stress susceptible pigs react more seriously under these circumstances, but even less susceptible pigs reveal a rapid pH fall in their muscles when they experience shock before or during slaughter resulting in severe struggling after stunning. Rough handling in holding pens and chasing to stunning pens often using electric prodders, invariably act as stressors. In Ireland (McLoughlin, 1965a) and in England (Bendall, Cuthbertson & Gatherum, 1966) it was found that stunning *per sé* can also have a detrimental effect on meat quality. This applies to electric as well as carbon dioxide stunning (Ratcliff, 1971). Vigorous struggling occurs after captive bolt pistol stunning of a pig in the brain (McLoughlin, 1965b) resulting almost without exception in PSE muscle (McLoughlin, 1963). After all types of stunning, blood pressure rises sharply and it is therefore most important to stick and bleed all animals immediately after stunning in order to prevent blood splash in the muscles (Ratcliff, 1971; Sybesma, 1972a). Unnecessary delay during the slaughter and evisceration process can also result in a high rate of lactate formation in muscles at high temperatures (Briskey, 1964).

To determine the incidence of PSE in practice, a number of parameters are being used. These are pH, reflectance and rigor development. When the pH_1 (45 minutes *post mortem*) value is 6,0 or less while the muscle temperature is still 35°C or higher, the development of PSE symptoms can usually be predicted with reasonable certainty. In many surveys pH_1 values of 6,0 and lower have been used as a criterion of PSE. At Danish progeny testing stations a figure of 35 to 40% has been reported (Briskey, 1964; Lister, 1970). In England PIDA reported an increase from one to four and a half percent (McLoughlin, 1965a). Bendall *et al* (1966) in the United Kingdom found 6,6% of the progeny tested pigs to have pH_1 values of 6,0 and lower in comparison with 1,8% in commercial pigs at the same abattoir. They found the figure to be 10,5% in Landrace and 3,9% in Large White pigs. In the U.S.A. a figure of 18% (Briskey, 1964) has been reported and in Ireland it varied between 6 and 22% (McLoughlin, 1965b). Steinhauf mentioned that the figure in Germany was between 17 and 20% (Van Gils & Van Logtestijn, 1969).

The death of animals prior to slaughter and the PSE characteristics of the muscle are financially the most important characteristics to be considered and can be grouped as follows:

1. *Negative factors*

   1.1 Soft and exudative muscle (Briskey, 1964)

   1.1.1 Curing loss – 5% more
   1.1.2 Cooking loss – 20% more
   1.1.3 Jelly in cans – 4 - 8% more
   *1.1.4 Drip loss – 6 - 10%

   1.2 Pale loins and two toned hams (Krol, 1971)

   1.2.1 Consumers' surveys yield variable results; but 51% select first on leanness
   1.2.2 27% select secondly on colour.

   1.3 *Mortality, eg. during transport (Lendfers, 1968) Increased in the Netherlands from 1,5 per thousand in 1960 to 6,0 in 1969.

   (*Factors with serious economic implications).

2. *Positive factors*

   2.1 Meat quantity (Sybesma, 1972a)

Breed	*Meat %*	pH_1
Large White	54,7	6,7
Dutch Landrace	54,6	6,4
Piétrain	59,4	6,2

   2.2 Increased growth rate (Lister, 1971)
   This factor is correlated with higher feed efficiency and leaner carcasses.

   2.3 Meat quality (Sybesma, 1972b)
   A lower pH attained in a shorter time (cf. meat quantity – 1) yields an enhanced keeping quality in the meat.

The negative characteristic mentioned under 1.1.2 can be improved in processing by addition of polyphoshates (Sybesma, 1972b) rendering the poor water binding capacity in PSE muscles of less economic importance or by tumbling of hams improving the canning quality (cf 1.1.3). Excessive drip loss in the fresh product, whether packaged or open, can however not be curbed in the same manner. This can presently be regarded as economically the most important quality characteristic of PSE meat. A second factor which is undoubtedly of financial importance is death loss prior to slaughter of stress susceptible pigs experiencing stress of some kind. These pigs often have a higher lean content in the carcass which is an aspect sought for by the present day consumer (Lister, 1971; Sybesma, 1972b). These leaner pigs within a breed also grow more rapidly and efficiently. Lister (1971) summarizes: "There is an almost complete lack of published information on the economic consequences of handling meat of varying quality and the lack is, perhaps, even greater so far as the organoleptic characteristics of pork of varying quality are concerned".

Measurement of PSE

Lister (1971) classified the physiological and biochemical characteristics of the animal in relation to its potential meat quality into "causal", "effect" and "associated" factors. Endocrine reactions triggering physiological and biochemical changes in the animal can be classified as "causal". "Effect" characteristics, most commonly measured to assess quality of the pork, are:

(a) pH measurements *post mortem* of muscles at standard times after slaughter – this factor is closely associated with water binding capacity of muscle proteins.
(b) *Rigor*-value of ham muscles to measure the rate of onset of *rigor mortis*.
(c) Reflectance value of the cut surface of muscles to measure colour.
(d) Drip loss of fresh meat to measure the loss prior to cooking.
(e) Direct measurement of water binding capacity using the press or centrifuge method.
(f) Cooking loss to measure the weight yield of cooked meat.
(g) Toughness of meat using taste panel assessments or shear force values.

The above measurements have been extensively used overseas and in South Africa.

"Associated" factors of the living animal used to predict potential meat quality are for example the relative levels of certain serum and muscle enzymes.

Research in South Africa

No research on the "causal" factors in pigs has been published in this country. Berman, Conradie & Kensch (1972) have published some work regarding the "associated" factors on the relationship between certain serum enzymes and the potential development of PSE in porcine muscles.

Regarding the "effect" characteristics, extensive surveys have been undertaken in South Africa as well as certain experiments under controlled conditions.

Controlled experiments

The main factors involved in causing a muscle to become PSE *post mortem* is a low muscle pH_1 of 6,0 or lower while the temperature of that particular muscle is still 35°C or more (usually 45 minutes *post mortem*). It therefore seems that the logical thing to do would be to attempt cooling carcasses as rapidly as possible in order to prevent the above combination of factors in the muscle. Several workers have noted that it was commercially impossible to cool carcasses to achieve this object (Lister 1970; Carroll, 1971; Ratcliff, 1971). In Table 1 data from four pigs are presented. They were stunned with a captive bolt pistol, immediately split and within 20 min after stunning one side of each carcass was placed in a deep freeze at -20°C. From the figures in this table it is evident that no difference was found in the muscle temperature or pH values 45 min and 24 hr *post mortem*.

In Table 2 it is illustrated that weaner pig carcasses normally cool down more rapidly than bacon carcasses. Therefore even though the pH had dropped to below 6,0 within 45 min *post mortem*, the temperature had already decreased sufficiently in these small carcasses, perhaps, preventing protein damage to have occurred.

In an experiment comparing four methods of slaughter (Table 3) it was found that electrical stunning yielded higher pH_1 values than carbon dioxide stunning which is in agreement with the results of Bendall *et al* (1966) but in contrast with that of McLoughlin (1965b). The fact that exsanguination without stunning did not yield pH_1-values which were relatively as high as those of McLoughlin (1965b), might be ascribed to the experimental technique used when sticking the pigs. However there is general agreement that captive bolt pistol stunning almost invariably caused pH_1-values to be lower than 6,0. McLoughlin (1971) explains the effect of the penetration of the forebrain by the captive bolt as violent struggling because of the damage of the motor centres and subsequent neural discharges passing down the spinal column in the intact motor tracts finally activating the voluntary muscles. He then points to the lack of information on the effect of percussion of a non penetrating bolt on *post mortem* glycolysis. Ratcliff (1971) poses the question whether more effective stunning would be obtained by avoiding penetration of the brain by using something similar to the American knocker used for stunning cattle, or a hammer. Results of a small trial to test these suggestions are given in Table 4. Muscles of pigs stunned by a blow of a 2 kg hammer on the forehead exhibited a much slower fall in pH than pigs stunned by a captive bolt pistol. It has often been observed in practice that pigs are being handled without the necessary care prior to slaughter. Shouting, prodding and beating are some of the factors which excite pigs at abattoirs when driven to the stunning pens. Klingbiel & Naudé (1973) found that a much higher rate of *post mortem* glycolysis and onset of *rigor mortis* occurred in the muscles of a group of pigs which were excited experimentally before stunning (90 Volt) in comparison to pigs which were calm prior to slaughter. These figures clearly illustrate the stress effect of *pre mortem* stressors on the *post mortem* muscle glycolysis of stressed pigs. In all the experiments thus far described measurements were done on the *M. longissimus dorsi* as well as on the *M. semimembranosus*. In each case the former muscle revealed a slightly higher rate of glycolysis than the latter

Table 1

Muscle characteristics of rapidly cooled vs normally cooled bacon sides

	Cooled (-20°C)	Not cooled
Number	4	4
M. longissimus dorsi		
Temp (45 min) °C	38,1	37,4
pH_1 (45 min)	6,12	6,15
pH_f (24 h)	5,32	5,30
M. semimembranosus		
Temp (45 min) °C	37,4	36,6
pH_1 (45 min)	6,35	6,37
pH_f (24 h)	5,40	5,43

Table 2

Muscle characteristics of captive bolt stunned pigs (Landrace and Landrace x Large White).

	Weaners	Baconers
Number	22	32
Age (months)	2,0	6,0
Carcass mass (kg)	15,6	68,1
M. longissimus dorsi		
Temperature (45 min. p.m.)°C	30,6	39,6
pH_1 (45 min. p.m.)	5,8	5,5
pH_f (24 h. p.m.)	5,6	5,3
M. semimembranosus		
Temperature (45 min. p.m.)°C	34,5	40,2
pH_1 (45 min. p.m.)	5,8	5,6
pH_f (24 h. p.m.)	5,7	5,4

Table 3

The influence of stunning on post mortem *pH values of porcine muscles*

1	2	3	4	5	6	7	8
Stunning	n	*M. longissimus dorsi*			*M. semimembranosus*		
		pH_1	pH_f	$\%pH_1 \lessapprox 6,0$	pH_1	pH_f	$\%pH_1 \lessapprox 6,0$
Captive bolt pistol	10	5,79	5,50	80	6,10	5,49	60
CO_2 (65%)	10	6,31	5,57	20	6,47	5,59	0
Electrical stunning	10	6,48	5,57	0	6,48	5,56	0
Exsanguination	10	6,24	5,45	30	6,47	5,62	0

3. pH_1 = 45 minutes *post mortem*
4. pH_f = 24 h *post mortem*
5. $\%pH_1 \lessapprox 6,0$ = %PSE muscles

Table 4

The influence of stunning technique on the pH_1 value and colour of porcine muscles

		Stunning technique	
		Hammer	Captive bolt pistol
Number		2	2
Carcass mass	kg	80	85
M. longissimus dorsi			
pH_1		6,2	5,4
$Temperature_1$	°C	38,5	39,0
pH_f		5,4	5,5
$Temperature_f$	°C	4,0	4,0
Reflectance		49	67
M. semimembranosus			
pH_1		6,4	5,8
$Temperature_1$	°C	38,5	38,0
pH_f		5,4	5,4
$Temperature_f$	°C	4,0	4,0

which illustrates the phenomenon of different muscle types within the same carcass. These differences can be ascribed to the different proportions of red muscle fibres – of the aerobic type readily oxidizing lactic acid – and white muscle fibres – of the anaerobic type which accumulate lactic acid (Briskey, 1964; McLoughlin, 1969; Carroll, 1971). These differences between the two muscles were however relatively small and McLoughlin (1965a) pointed out that both are usually classified as muscles readily affected by stress conditions in the pig.

The microstructure of PSE and normal *M. longissimus dorsi* was also studied by Dreyer, Naudé & Gouws (1972) in a histological study in which the muscles of captive bolt stunned versus exsanguinated pigs were compared (Table 5). The mean diameter of unfixed fibres which were homogenized prior to measuring (59,66μm) was greater than the size of fibres obtained following processing in different ways. This demonstrated the shrinkage effect of fixing and embedding and of freezing muscle fibres. The most significant finding of this investigation however was the shrink-

Table 5

Muscle fibre diameter of low pH_1 and normal pig M. longissimus dorsi (μm)

	pH_1	Carcass Mass kg	No.	Carnoy's	10% Formalin	Zenker's	Cryostat	Homogen-izer	Mean	"Giant Fibre" Mean
Exsanguinated	6,70	64,9	4	1 44,27	2 39,01	3 41,56	4 47,23	5 64,39	6 47,29	65,87 (n =89)
Captive bolt	5,50	64,4	4	7 38,08	8 35,05	9 39,95	10 40,08	11 54,93	12 41,62	71,93 (n =63)
Mean				13 41,17	14 37,03	15 40,76	16 43,66	17 59,66		

P<0,01 6: 12; 17: 13, 14, 15, 16; 5: 1, 2, 3, 4; 11: 7, 8, 9, 10; 5: 11; 4: 10
P<0,05 1: 7; 14: 15

age observed in the low pH_1 muscles of the captive bolt stunned pigs. This shrinkage was ascribed to the transudation of moisture from the intracellular to the extracellular spaces. "Giant fibres" were identified morphologically by their round appearance in transverse sections as well as by their more intense staining ability. The much greater size of these fibres may be ascribed to a lack of *post mortem* shrinkage (Naudé & Hegarty, 1970; Dreyer *et al*, 1972) or it may be the result of a state of supercontraction of these fibres (Hessel-de Heer, Sybesma & Van der Wal, 1971) which could be related to their very short sarcomeres (Naudé, 1972).

Surveys

In Table 6 the results of several surveys are summarized regarding pH_1 values of muscles of baconer carcasses. These were obtained at three of each of the largest bacon factories and largest municipal abattoirs in the Republic (Klingbiel & Naudé, 1971, 1972; Naudé, 1972). The factory procedures at A and B were very efficient and very similar. Because of the high rate of flow in B, pH_1 values had to be taken earlier (30 min pm) than the anticipated 45 min *post mortem*. It was however found in a sample of carcasses that the decrease in the pH of muscles during the period 30 to 45 min *post mortem* was such that the mean calculated pH_1 values (45 min pm) and percentage of these values being 6,0 or less were nearly identical. In comparison to overseas figures these results reveal a fairly favourable picture regarding the relatively low incidence of PSE in bacon pigs in South Africa. These belong mainly to the Landrace and Large White breeds or their crossbred combinations. At both factories electrical stunning (90V) was applied with sufficient care and pre slaughter handling was also performed most efficiently. Several other factors which could be associated with PSE were also measured and observed at A and B. Results at these two factories were very similar therefore only the figures obtained at factory A are illustrated in Table 7. Carcass mass did not influence the incidence of low pH_1 values which is in contrast with the findings of Briskey (1964) and Taylor (1966). The effect of fat thickness was also not statistically significant which agrees with results of Briskey (1964), Bendall *et al* (1966) and Taylor (1966). A factor associated with pH_1 values – used in Danish factories to detect PSE (Briskey, (1964) – and which is being used in Dutch factories Sybesma, 1966), is the *rigor*-value. Results on this characteristic indicate a good relationship between high *rigor* measurements and low pH_1 values. Higher than average *rigor* values yielded 24,0% carcasses with pH_1 values equal to or lower than 6,0 and lower than average values only 4,5%. A correlation of -0,63 (P< 0,01) was calculated between *rigor* values in the *M. semimembranosus* – indicating the rate of onset of *rigor mortis* – and the pH_1 value of the *M. longissimus dorsi* indicating the rate of *post mortem* glycolysis in this muscle of the same carcass. In factory C (Table 6) a very high incidence of low pH_1 values (28,6% $pH_1 \leq 6{,}0$) was recorded in the *M. semimembranosus* of baconer carcasses – this is the muscle with a somewhat lower rate of glycolysis than the *M. longissimus dorsi* which were measured at A and B. In these two factories carcasses were all split and the spinal column removed before the sides entered the cold rooms at a time between 30 and 60 min *post mortem*. This was however not the case at factory C, nor was it normal procedure at abattoirs D, E and F. Consequently the pH_1 measurements were taken in the *M. semimembranosus*. Vosloo (*vide* Weiss, 1971), using reflectance values as a criterion of paleness of muscle colour, found at the same factory that 33% of the muscle surfaces measured gave evidence of the condition "to a serious degree". This figure agrees fairly well with the 28,6% excessively low pH_1 values observed at that factory. Vosloo did however also mention that only 23% of the carcasses measured could be regarded as "free of the condition". Further analysis of the figures

Table 6

The pH_1-values of muscles in bacon pig carcasses at bacon factories and abattoirs

1 Centre	2 n	3 $\bar{x}$ pH_1	4 % $pH_1 \leqslant 6,0$	5 Min. p.m.	6 Muscle	7 Stunning
Factory A	580	6,43	8,6	45	LD	E
Factory B	1019	6,51	5,0	30	LD	E
Factory C	626	6,24	28,6	45	SM	E
Abattoir D	285	6,41	17,5	45	SM	E
Abattoir E	235	5,88	71,9	45	SM	P
Abattoir F	342	6,41	12,9	45	SM	E

1. Factory = Bacon factory
   Abattoir = Municipal abattoir – controlled area
2. Total number of baconers = 3087
4. % $pH_1 \leqslant 6,0$ = % PSE-Carcasses (Temp. $\geqslant$ 35°C)
5. Min. p.m. = minutes *post mortem*
6. LD = *M. longissimus dorsi*
   SM = *M. semimembranosus*
7. E = Electrical stunning
   P = Captive bolt pistol stunning

Table 7

The influence of carcass mass, fat thickness and rigor *on the pH_1 values in the muscles of baconer carcasses*

Mean carcass mass	Group	n	$\bar{x}$ pH_1	% $pH_1 \leqslant 6,0$
67,1 kg	> 67,1 kg	264	6,43	7,4
	< 67,1 kg	311	6,46	8,3
Mean fat thickness				
27 mm	> 27 mm	257	6,45	7,8
	< 27 mm	278	6,42	8,6
Mean *rigor* value				
8 mm	> 8 mm	96	6,30	24,0
	< 8 mm	289	6,47	4,5

of this factory revealed that of the carcasses which were not eviscerated by 45 min *post mortem* when muscle pH measurements were taken, 41,4% had pH_1 values of 6,0 and lower compared to 22,9% of the eviscerated carcasses. Bendall & Lawrie (1964) and Wismer-Pedersen (1969) found similar results. It was also noticed at Factory C as well as at abattoir D that pigs were handled with much less care than at factories A and B and abattoir F. At all these centres pigs are being stunned electrically. Factory C and abattoir D are both in the same area and have the highest incidence of low pH_1 values. Vosloo (1971) suggested that stress susceptibility in these pigs could also add to the high incidence of pale muscles and Berman *et al* (1972) found certain serum enzyme patterns to be associated with low pH_1 values for *post mortem* muscles of pigs slaughtered at factory C. It is therefore possible that, in addition to the unfavourable handling and slaughtering conditions prevailing at these two centres, pigs from this area could be more susceptible to factors causing a rapid rate of *post mortem* glycolysis in their muscles. Pigs at abattoirs E and F were handled fairly favourably for large sized abattoirs. The main and dramatic difference between these two centres however was the difference in the method of stunning. At E electrical stunning was applied with a 12,9% incidence of pH_1 values equal to or less than 6,0. At F where captive bolt stunning was applied the figure was 71,9%. This is in agreement with the work of McLoughlin (1965b) and with the controlled experiment previously mentioned in this review.

In Table 8 pH_1 values measured at 30 and 45 min *post mortem* at abattoirs E and F are given to illustrate how both these pH_1 values may be used to indicate potential PSE in porcine muscles, provided that a different critical level, accounting for the difference in stage of glycolytic development at the two periods, is incorporated in the recalculation. At both stages muscle temperature was still higher than 35°C.

Not only bacon pigs develop PSE muscles but it was found that all categories of pigs may be affected and consequently develop poor muscle quality. The figures in Table 9 illustrate that the incidence of low pH_1 values was found also to be very high in porkers (78,7%) and in sausage and fat pigs (63,93%) when these pigs are stunned with a captive bolt pistol – abattoir E. At abattoir F where electrical stunning is applied, figures for these groups of pigs were 16,36 and 15,31% respectively.

In a final attempt to estimate the national incidence of low pH_1 values of porcine muscles in South Africa a questionnaire was sent to all abattoirs and bacon factories (approximately 750) in the Republic. The figures in Table 10 illustrate the extensive use of the captive bolt pistol at the smaller abattoirs. Only 23 of the 449 centres use the electrical stunner, but 72,1% of the total number of pigs is being slaughtered in this manner. In an attempt to determine the incidence of PSE in South Africa the calculation as set out at the bottom of the table was made using figures given in Table 6. A figure of 29,6% was calculated.

Conclusions

In view of the findings of many overseas and local investigations it can be stated with a great deal of confidence that the PSE phenomenon in pig carcasses as well as the porcine stress syndrome in live pigs may have serious financial implications for the pig industry of South Africa. Certain fairly reliable parameters of "associated" factors are available and can be applied in detecting certain strains of stress susceptible pigs participating in our pig improvement schemes – with particular reference to boar performance testing. In the progeny testing scheme the reliability of these parameters may be verified by comparing them with the *post mortem* "effect" factors observed in PSE muscles. In this way selection against PSE susceptible pigs, which have already been noticed in certain herds and breeds in South Africa, can be effectively applied. By

Table 8

The pH values (30 and 45 min. post mortem) *in the* M. semimembranosus *of baconer carcasses at two abattoirs*

	30 min. *post mortem*			45 min. *post mortem*		
	n	$\bar{x}$ pH	%PSE*	n	$\bar{x}$ pH	%PSE**
Abattoir A	475	$6{,}48^1 \pm 0{,}30$	$14{,}52^5$	345	$6{,}41^2 \pm 0{,}33$	$12{,}87^6$
Abattoir B	235	$6{,}08^3 \pm 0{,}29$	$71{,}06^7$	235	$5{,}88^4 \pm 0{,}30$	$71{,}92^8$

* Percentage pH values $\leqslant 6{,}1$ at Abattoir A and $\leqslant 6{,}2$ at Abattoir B
** Percentage pH values $\leqslant 6{,}0$ at both abattoirs
$P < 0{,}01$: 1:2, 3:4, 1:3, 2:4, 5:7, 6:8
NS : 5:6, 7:8

Table 9

A survey of pH_1 values in the M. semimembranosus of various types of carcasses at two abattoirs

Type of carcass	Abattoir E				Abattoir F			
	n	$\bar{x}$ pH_1	n$\leqslant$6,0	%$\leqslant$6,0	n	$\bar{x}$ pH_1	n$\leqslant$6,0	%$\leqslant$6,0
Porker	202	5,82	159	78,71	110	6,43	18	16,36
Baconer	235	5,88	169	71,92	342	6,41	44	12,87
Sausage & Fat	61	5,94	39	63,93	98	6,34	15	15,31
Total	498	5,87	367	73,69	550	6,40	77	14,00

Table 10

Survey of method of stunning and number of pigs slaughtered in South Africa

Stunning technique	Abattoirs		Pigs slaughtered per week	
	Number	%	Number	%
Captive bolt pistol	316	70,4	7 992	26,3
Electric stunning	19	4,2	20 803	68,6
Electric and pistol stunning	4	0,9	1 058	3,5
Rifle stunning	63	14,0	309	1,0
No stunning	47	10,5	170	0,6
Total	449	100,0	30 332	100,0

Estimate of Percentage pH_1 values $\leqq 6{,}0$

72% of	7 992	=	5 754
10% of	20 803	=	2 803
20% of	1 058	=	211
72% of	309	=	222
Total			8 990

$$\therefore \frac{8\,990}{30\,332} \times 100 = 29{,}6\%$$

utilizing the knowledge that has been gained through surveys and other studies it is clear that the present estimated incidence can be decreased appreciably by improving the efficiency of certain environmental factors influencing the pig or its carcass. These factors are: the way of handling pigs immediately prior to slaughter; the method and efficiency of stunning and the efficiency and speed of handling and processing pig carcasses prior to cooling. The consequences of stress susceptibility in pigs such as death during transport must be prevented by breeding stress resistant pigs and by transporting pigs under the most favourable conditions possible (Van Putten, 1971). The consequences of a rapid fall in muscle pH *post mortem* should also be curbed by breeding pigs exhibiting a retarded rate of *post mortem* glycolysis as well as providing the most favourable *pre* and *post mortem* conditions for slaughter pigs.

Acknowledgements

We wish to acknowledge the spontaneous co-operation experienced at all bacon factories and municipal abattoirs, as well as the technical assistance given by Koot and Attie Venter, Leon Laubscher and the abattoir staff at Onderstepoort.

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