How pig pre-slaughter welfare affects pork quality and the pig industry

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Abstract
Most of the consumers in developed countries are increasingly becoming concerned about pig rearing conditions and pork eating quality. Knowledge of animal welfare and its impact on pork production in many developing countries is still lacking. The objective of this review is to open a discussion among stakeholders in the South African pig industry on improving pre-slaughter handling of pigs and its application to improve pork eating quality, income to the farmer and the viability of the pig industry in general. Pig handling at the farm, during transportation and at the abattoir influences physic-chemical and sensory properties of pork. These welfare issues also affect consumer acceptability of pork and the health of pork consumers. Furthermore, the review identifies pig welfare, use of molecular techniques, traceability and disease control, effect of pork products on consumer health, pork processing and value adding, pork safety, and pork acceptability as possible areas in the South African pig industry which need further research.
Keywords: consumer acceptability, consumer health, developing countries, ethics, meat quality, PSE, ultimate pH, welfare practices
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Outline of Presentation

1. Introduction

The pre-slaughter welfare of a pig refers to the influence of the various internal challenges or *ante-mortem* conditions on the physiological or biochemical state of the pig at the time of observation during the growth phase and handling pre-slaughter (Broom, 2000; Gregory, 2007; Grandin, 2007). Centuries ago, pigs were brought to the slaughterhouse in town because of town immigration by people (Lambooij, 2000). Nowadays, most pigs are transported to markets and/or slaughterhouses by different forms of vehicles. As pigs are transported, several human-animal interactions and environmental factors that have effects on pig welfare are at play. These factors include handling, genotype, nutrition, feed withdrawal, loading, transportation to the slaughterhouse, off-loading, lairage waiting, and finally slaughtering (Barton-Gade and Christensen, 1998; Velarde *et al*., 2000; Maria *et al*., 2005). These conditions influence pig behaviour, welfare, productivity and subsequently pork quality (Eikelenboom *et al*., 1991; Ekkel *et al*., 1997).

The important pork characteristics affected by pre-slaughter stress include ultimate pH (pHu), colour, water-holding capacity (WHC), shelf life, cooking loss and tenderness, and all these are important in the meat science and technology industry (Hoffman *et al.*, 2003; Muchenje *et al.,* 2009a). The influence of handling conditions on the process of conversion of pig to pork is inconclusive in the South African context (Hoffman *et al.*, 2003). Poor welfare procedures that stress the pigs may not only influence the conversion of muscle to pork (Van der Wal *et al*., 1997), but may also compromise the health of the pig (D'Souza *et al.,* 1998a, b), change muscle glycogen concentration, acidity and temperature immediately *post mortem* (Maria *et al*., 2005), eventually leading to aberrant pork eating quality. Major pork defects faced by producers are the dark firms dry (DFD) and the pale soft exudative (PSE). The PSE pork is characterized by its paleness, softness and low water binding capacity. The DFD and PSE are undesirable as they influence the consumer's purchasing decisions, preferences and, thus, negatively affect the pork industry.

Concerns of pig welfare are major issues in most developed countries and are based on the fact that animals can suffer, eventually leading to aberrant pork eating quality, especially when the five familiar freedoms that define the animal's fundamental needs and freedoms are not met. These are freedom from thirst; hunger and malnutrition; discomfort; pain, injury and disease; fear and distress. In most developing countries, including South Africa, such issues receive low priority mainly due to lack of education and funding with regard to animal welfare related issues. Pigs slaughtered at abattoirs, with limited resources, infrastructure and poor operating environments, are supplied by producers, who are located far away from the abattoirs and with limited infrastructure (Aklilu, 2002). Poor handling facilities and infrastructure, harsh climates, poor operational techniques, bullying by others and fearful pigs are common in most production systems of South Africa (Neethling, 2009b). These may not only impose detrimental effects on the transformation process of pig into pork, but may also cause frustration to the stockman (Hemsworth, 2000), increase individual healthy risks, influence pig well-being and impart negatively on the ecological sustainability of food systems.

In South Africa, research on the halothane genotype and pork quality (Fisher *et al*., 2000a,b,c) and sensory characteristics (Moleich *et al*., 2003) has been conducted. However, studies on perception of pork by farmers, butcheries and consumers on pig handling, transportation and slaughterhouse practices and their effects on pig injuries, bruising and meat quality in both small scale and large scale abattoirs, are limited. Moreover, information on the perceptions of producers and consumers on the animal welfare legislation is scarce or not available at all. Improvement of practices on farm animals destined for slaughter can be of assistance in reducing mortalities on the farm and during transportation, reducing skin, and carcass damage due to bruise and injury, and avoiding pH variation thereby reducing the economic losses to the pork industry. The farmers, slaughterhouses, butcheries and the consumers can all, thus, be rewarded by improvement on the quality of pork produced. Most of the research on pig welfare and pork quality has been conducted in the developed world (Rosenvold and Andersen, 2003a; Broom, 2000; Gregory, 2007).

This review focuses on the behavioural, biochemical, physiological and ethical issues that pertain to pre-slaughter pig welfare and their effects on pork physic-chemical and eating quality. These issues are reviewed in relation to how they are likely to affect the South African pig industry in this era of globalization. The review also identifies possible areas which need further research to develop the pig industry of South Africa.

2. Pig pre-slaughter welfare issues

Animal welfare issues are a major consideration in most developed countries; and this has led to government interventions and formation of non-profit organizations which are responsible for raising animal welfare awareness issues. Developing countries, such as South Africa, are beginning to be conscious about animal welfare issues and some regulations such as, the "Code of practice for the handling and transport of livestock," are being implemented (Tomlinson, 2000). Poor handling facilities, lack of education on animal handling and welfare awareness issues, to some extent, social customs and beliefs are major impediments to proper animal welfare amongst most farmers in the developing world (Gregory, 2008). Pigs respond or cope with handling procedures through specific features and previous experiences. When animals are restricted from behaving naturally, this may lead to behavioural problems and aggression. Therefore, it is important for stockpersons to understand the behaviour of pigs so that stress can be reduced from the farm to the abattoir. Although effects of slaughterhouse conditions have been extensively studied (Ekkel *et al*., 1997; Barton-Gade and Christensen, 1998; Maria *et al*., 2005), their relationship with pork eating quality in South Africa has not been investigated.
Assessment of the welfare status of pigs during the pre-slaughter period is of paramount importance if pork of high quality is to be produced while maintaining the well-being of the animals and reducing the spread of health risks (Gregory, 2008). Assessment records by the farmer, transporter and the abattoir owner should accompany traceability records from the farm up to the point of consumption. Some of the pig welfare assessment methods that can be easily used include pig behaviour, bruises, injuries and deaths. Welfare audits have remarkably improved animal handling in USA and Canada (Grandin, 2007). If the same is done in South

Africa the handling of commercial pigs can be improved, therefore, there is need to assess the impact of these audits locally. At research and more technical level the easily used methods can be used in conjunction with biological components, such as heart rate, temperature, hormonal levels and other blood metabolites. These methods can be used to assess pig welfare from rearing at the farm until the time of slaughter at the abattoir.

2.1. Pig handling at the farm

On-farm handling procedures begin from the time of birth up to the time of loading into vehicles or driving them on hoof to the slaughterhouse. On-farm handling practices and their impact on pig welfare status during the pre-slaughter period are influenced by factors such as loading, use of sticks or electrical goads, breeds, appropriateness of handling facilities, previous experience and the skill of the handler. Prior to transportation to the slaughterhouse, pigs are gathered to a handling point, if there is any, or are just driven to the slaughterhouse.

Poor handling may lead to serious injuries and bruising, especially to pigs that are not familiar with a particular confinement because they may react badly (Gregory, 2008). The situation can be exacerbated if stockpersons are not familiar with the principles of animal behaviour, such as flight zones and visual fields (Grandin, 2000a) and social instincts. Such principles may protect stress-susceptible animals to physical disturbances from forceful contacts such as hitting, rough handling or during re-grouping for social order during confinement (Grandin, 2000b) as these may lead to carcass devaluation. Carcass devaluation leads to huge losses to farmers and the pig industry.

Any occurrence of bruises indicates that some aspect of the welfare status was aversive because skin damage from an injury is inevitably painful to the animal. On the other hand, age and position of the bruises indicates when and where the welfare is suboptimal. Age and position of the bruises can be used to identify animal welfare problem areas that need to be improved between the farmer, the transporter and the abattoir owner. Since free-range pigs are not used to handling they have more skin damage than the pigs raised indoors during handling (Lambooij *et al*., 2004). This loss from bruised and injured pigs may result in additional expenses for labour to do the trimming of the bruised or injured muscle part. The use of conventional ways of driving pigs with electrical goads has been associated with the increase in the incidences of major pork defects, such as PSE and DFD (Lambooij, 2000). Such incidences can be reduced through modern ways such as the use of opaque passages, shades, uniform colours of handling facilities and flipping flags (Grandin, 2000a, b, Gregory, 2007). Figure 1 illustrates a pig refusing to move due to fear of change of the floor setup.

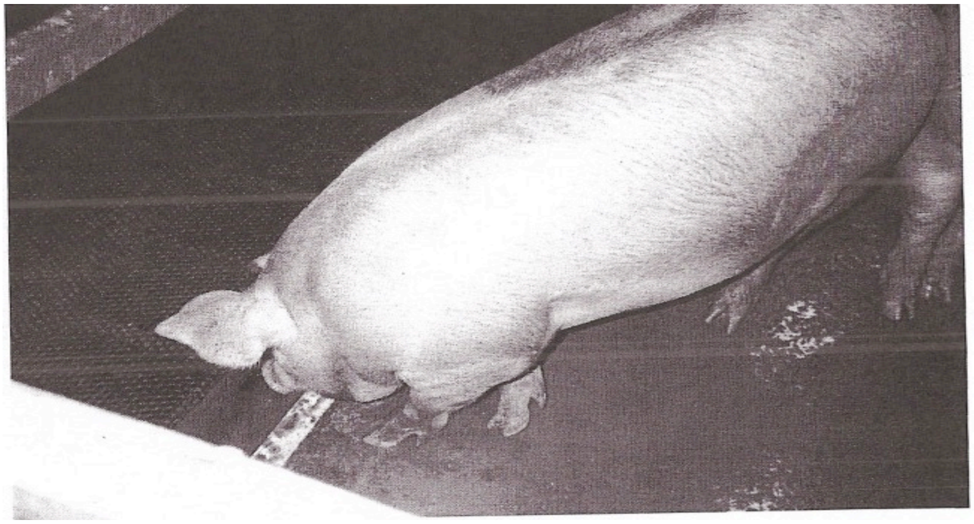

Fig 1. A pig refusing to move over a white plastic strip and on the drains on the floor (Gregory, 2007).

Furthermore, pork defects can also be reduced by formulating pig groups according to uniqueness of age, sex, size or herd and using proper loading facilities with required inclination at the same time providing opaque sides which prevent visual field of the ground for height stress pigs (Lambooij, 2000). Good animal welfare practices at the farm should be friendly from time of rearing because susceptibility of pigs to stress factors is partly influenced by the animal's previous experience. For example, high stocking densities during rearing have been linked to a reduced risk of DFD and paler meat (Hamilton *et al*., 2003; Guardia *et al*., 2005). In PSE –prone pigs, high stocking densities have been associated with reduced drip loss (Gregory, 2007). This may be ascribed to the fact that the pigs reared in high densities get used to stressful conditions such that they will be able to cope with pre-slaughter stress.

2.2. Pig transportation

Pig transportation to slaughterhouses is inevitable, but can be potentially harmful. It is characterized by threatening and novelty events that can negatively affect animals, either physically or physiologically depending on the mode of transportation used. The common mode of transport for pigs are by vehicle of which most of these vehicles are unsuitable for the job and in many cases the vehicles are over-loaded (Gous, Personal communication). Unfamiliarity of pigs to the novelty of the transport conditions, mixing of different social species, weather conditions, loading density, duration of trip and loading or unloading (Lammens *et al*., 2007) and associated handling during transportation influence the welfare status of pigs (Lambooij, 2000).

Long journeys can also result in huge economic losses to the pig industry, especially when the pigs are loaded at high stocking densities (Gregory, 2007). According to the Council Directive 91/628/EC (1991), OJEU (1986) and Council Regulation 98/411/EC (1998) on the protection of animals during transport, all pigs should at least be able to stand or lie down in their natural position, requiring a stocking density of 236 kg/m^2 and a duration of transport period of up to 8 hours (Gregory, 2007). Moreover, laws and ordinances governing animal transport in the developing world are either not enforced, lax or absent. There are some transport regulations in effect in South Africa; these are obtained from the Red Meat Abattoir Association and Department of Agriculture (Neethling, 2009a). Some of the risk assessment guidelines at various control points have been revealed by Neethling (2009b) to reduce or completely eliminate risks associated with animal handling, meat processing and distribution. However, the scientific information or surveys to confirm the fully implementation of these guidelines in the local meat industry are scarce or not effectively implemented at all.

The magnitude of stress associated with road transportation of these animals under the year-round inclement weather of South Africa has not been previously assessed. Research had been carried out to assess transport slaughter animals around Gauteng province in South Africa and the current vehicles used are undesirable (Gous, Personal communication). However, information pertaining to actual situation is not easily accessible to all stakeholders in the industry. A rough guide to the space required for animals during transportation can be based on the formula:

$A=0.021W^{0.67}$ were A is Area in m^2 and W is the live weight in kg (Broom, 2000).

According to the code of practice for handling and transporting animals in South Africa, the recommended floor space per animal are 0,3 m^2 per porker; 0,4 m^2 per baconer; and 0,8 m^2 per adult pig (Tomlinson, 2000). Considering that pigs are transported for slaughter at different weights, it is difficult in practice for handlers to compromise welfare and meat quality with economic factors. Therefore, there is need to investigate the effect of loading densities on pork quality so that handling of slaughter animals can be improved in South Africa. When these estimates are exceeded, there will be cause for concern among stock handlers and chances of obtaining poor quality pork will be increased. There is need to investigate the influence of these stocking density on pork quality, as well as the perceptions of handlers and consumers on the current transport regulations and its implementation.

Normally, pigs do not lie down and rest two to four hours after the start of the journey so on short journeys pigs can be highly stocked (Gregory, 2007). In South Africa vehicles which transport pigs are usually overcrowded. Although this may not significantly affect meat quality, this may cause more physical exertion (Warris *et al*., 1998b). Pigs that are easily agitated by nature may result in high economic losses due to high deaths on arrival rates, skin lesions and bruises. There is need for welfare audits around all South African abattoirs so that animals are handled humanely. Implementation of welfare audits year round also opens an opportunity for the local abattoirs to imitate first world countries at the same time welfare organizations can also restructure regulations which are currently in effect. When assessing the welfare status of the pigs during transportation mortality rates exceeding 1% indicate that the transport conditions were harsh (Gregory, 2007). Death during transportation signifies that the pigs have failed to cope with the welfare procedures. Suitability of regulations, such as those applied in

Europe, under the local less benign conditions should be investigated especially during this global era of climatic change.

According to Gregory (2007), much of the stress associated with short journeys occurs during loading and at the start of the journey. The behavioural responses of pigs, such as vocalizations or aggressiveness, are the obvious indicators of the animal welfare status (Broom, 2000; Gregory, 2007). The behavioural response of pigs during transportation and their effect on pork eating quality, however, have not been extensively investigated not only in developing countries but through out the whole world. During transportation, pig coping behaviours, such as mounting, lying, vomiting, aggressiveness, vocalizations and fighting of pigs can be recorded through video recording and consequently assessed in relation to the meat quality *post mortem*. Such studies have not been done extensively due to the difficulties associated with recording behaviours when the vehicle is in motion.

It can be postulated that mounting and fighting between different social groups result in detrimental effects such as skin blemishes and subsequent increase in ultimate pH (Grandin, 1990; Warris *et al*., 1998a). This is due to the fact that *ante-mortem* stress associated with transportation accelerates depletion of muscle ATP, eventually leading to an increased AMP/ATP ratio and this activates glycolysis, lactic acid build-up (Muchenje *et al*., 2009a), and subsequent increase in PSE and DFD incidences especially during hot weather. The situation is further aggravated by lengthy journeys with food and water withdrawal which may cause dehydration and mobilization of fat and muscle glycogen reserves (Warrris *et al*., 1998a, b) thus resulting in less lactic acid and consequently high pork pH *post-mortem* (Muchenje *et al*., 2009a;b) which is detrimental to pork eating quality.

Research has also shown that during transportation, discomfort can result due to long food and water deprivation, unkind or strange weather, fright or physical conditions, such as muscle ischemia (Mounier *et al*., 2006). The coping status of the pigs is likely to be altered considering that the whether conditions of the Southern region are generally harsh. Therefore, the coping status of pigs being transported in South Africa should be investigated in both gravel and tarred roads. Lengthy journeys place a greater demand for energy metabolism on the animal and are the reason of depleted muscle glycogen concentration. However, in South Africa, the current code of practice for handling and transporting slaughter animals does not specify the time limit for animals in transit as well as resting times during transportation (Tomlinson, 2000).

Considering that the roads in South Africa are not uniform, there is need also for adjustment of these regulations with regard to the condition of the road. World-over, studies on the influence of duration of transportation in relation to the welfare status and pork quality are lacking but may be useful if the regulations in effect are to be reviewed. Occurrences of high PSE and DFD in pork can be prevented by supplementing the pigs with sucrose during lairage period (Rosenvold and Andersen, 2003b). Poor transport conditions and/or prolonged transportation of stress-susceptible pigs result in stressful events, especially when environmental conditions are not conducive, and this can result in high mortalities before slaughter. During transportation, mortalities can also occur due to the accretion of exhausts fumes and road dust with subsequent poisoning. This poisoning combined with inadequate escape of gaseous exchange, particularly on stationary vehicles, can then be large enough to cause the animal to faint or to die from suffocation before getting to the slaughterhouse (Berg, 2001). The effects of these exhaust fumes and road dust have not been extensively researched but are potentially harmful because gas residues in meat may result in brain damages especially in children.

During transportation, pigs can be depressed due to bruising or injuries and these can lead to release of cortisol, vasopressin, epinephrine, creatinine kinase, lactate dehydrogenase and norepinephrine into the blood stream (Broom, 2000). These hormones cause the breakdown of stored glycogen which is further utilised by animals' muscles to counteract for survival (Grandin, 2000b). Hormonal fluctuations from normal basal levels can be used in conjunction with other indicators, such as behavioural measurements, to ascertain the welfare status of the pigs during transportation, such scientific information is lacking in South Africa. Besides the use of hormones as stress indicators when pigs are handled or transported, blood cells are released from the spleen (Parrott *et al*., 1998), thus haematocrit can also be used to assess the aversiveness of the welfare procedures.

2.3. Pig handling at the abattoir

Welfare procedures associated with pre-slaughter conditions at the abattoir begin during unloading of animals up to the time when the animals are stunned in the slaughterhouse. During unloading, proper handling facilities and knowledge of behavioural aspects, such as flight zones and visual fields prevent detrimental effects which may occur. These include bruises, injuries and broken limbs for these impose negative impact on animal well-being and carcass grading or classification.

Some animals may refuse to walk resulting in the use of sticks or electrical goads to drive animals in a required direction. According to Hemsworth (2000), the use of solid panels as shown in Fig. 2 will prevent the pigs from turning back. The use of electrical goads when moving the pigs to the slaughter point have been proven to be sufficient in increasing the expression of PSE meat (D'Souza *et al*., 1998a, b; Van der Wal *et al*., 1999). From the lairage to the slaughterhouse, the method of bringing the pigs to the stunning device affects the frequency of PSE-zones in pig hams. For example, Franck *et al*. (2003) reported that the frequency of occurrence of PSE using the automated driving of groups of animals to the stunning machine, combined with the back loading of a nacelle, compared to a traditional system of driving pigs in a single file, using electrical goads and a restrainer, were 13 and 50 %, respectively. The modern system is, therefore, beneficial with respect to both meat quality and animal welfare.

Fig. 2. A solid panel being used by stockman to move the pigs forward without turning back (Hemsworth, 2000).

At the abattoir, handling methods which result in high carcass temperatures and low pH values early *post-mortem* lead to inferior pork quality (Hambrecht *et al*., 2005). However, hyper temperatures are reduced by showering the pigs (Long and Tarrant, 1990) such that they are slaughtered when their body temperature is within the normal range of 38.7 to 39.8 ^{o}C (Cunningham, 1997). It is, therefore, important for the farmer to be familiar with the differences in climatic conditions, particularly temperature, because by nature, pigs are heat susceptible. Management should, therefore, aim to reduce pork defects associated with thermoregulation. Use of weather forecasting information as a guide to when pigs can be transported to the slaughterhouse is encouraged.

Social groups should be maintained during this period up to the time of stunning for these may result in stress due to fights, mounting or general fear of other unfamiliar pigs. Investigators of factors related to pork defects in slaughterhouses face problems of sub-standardizing pre-processing factors, such as genetic background, duration of transport and lairage conditions (Gispert *et al*., 2000; Velarde *et al*., 2000) and failure to reliably identify carcasses on the day after slaughter when ultimate meat quality is assessed (Warris *et al*., 1994). This is likely to be a major problem in the developing world where online measurement of carcasses is one of the major challenges. Introducing pigs in groups as they enter the slaughterhouse and familiarizing stockman with the principles of animal behavior can alleviate these problems. Aversiveness of animal welfare at the abattoir and slaughter handling systems can be assessed through behavioural, biochemical and physiological measurements of stress indicators, such as hormonal concentrations, body temperature (Weeding *et al*., 1993), blood pH and vocalizations (Gregory, 2007).

2.4. Lairage duration and conditions

Handling in the lairage is important to allow recovery and acclimation from trauma and novelty of the transport, and to produce pork of high quality, the lairage should not be a stress factor (Hambrecht *et al*., 2005). The welfare status of the animal in the lairage is influenced by conditions of the lairage, such as duration of resting (Hambrecht *et al*., 2004), previous pre-slaughter treatment (transport, unloading, mixing) (Aaslyng and Barton-Gade, 2001), social classes, stress susceptibility, age difference, air temperature (Lammens *et al*., 2007), stocking density, climatic conditions, and ventilation. Pigs which are easily agitated by nature are at a greater risk of developing PSE conditions compared to those which are not carriers of stress susceptible genes. However, due to the prolonged waiting period, differences in social groups and high stocking densities usually encountered at the place, a fight for social order between the pigs may be promoted thus causing pork defects such as PSE condition. In the lairage, stress-susceptible pigs can be easily agitated due to social pressure and overcrowding, a situation which can be chaotic, especially in large groups and in hot climates which are common in South Africa in summer. In temperate climates, lying area requirements are based on the following equation:

$$\text{Lying area} = 0.033 \times \text{body weight}^{0.66}$$ (Ekkel *et al*., 2003).

Pork quality is negatively affected by forcing pigs to move over a period of 1 min through the stunning pen as opposed to slaughtering pigs immediately without exposing them to stress (Van der Wal *et al*., 1999). Aaslyng and Barton-Gade (2001) reported that holding pigs less than 1 h before slaughter improves meat colour, reduces incidences of the PSE occurrence while a prolonged resting time increases DFD while skin damage occurrences increases (Grandin, 1994; Warriss *et al*., 1998c). Overnight lairage leads to a depletion of glycogen thus inducing a decrease of pH, colour co-ordinates, and drip loss values and an increase of ultimate pH (Costa *et al*., 2002). Compared with shorter lairage, overnight lairage tended to reduce backfat thickness, the weight of the *Longissimus thoracis* (LT) muscle and increased the proportion of pigs with severe skin damage in all areas of the carcasses (Costa *et al*., 2002). In heavy pigs, prolonging holding time before slaughter from 2 to 22 hours reduces the incidence of PSE meat without increasing DFD occurrence (Costa *et al*., 2002).

There is need to ascertain or quantify actual optimum resting time in relation to specific physiological or biochemical threshold levels which are necessary for optimization of desired pork quality. Poor handling in lairage immediately prior to stunning gives a higher temperature in muscle and a faster pH fall early *post mortem*, as well as a higher drip loss and a greater PSE-incidence than a careful handling (D'Souza *et al*., 1998a).

2.5. Stunning of pigs

Prior to slaughter, the first step in the transformation of pig into edible pork involves stunning. Stunning makes the animal unconsciousness such that there is enough loss of blood to cause death from lack of oxygen to the brain and with high insensitiveness to pain before humane slaughtering or slitting (Anon, 2001). Stunning depends on the religious structures of slaughterhouse operations and ethical concerns of clients and legislation (Gregory, 2007).

Mechanical stunning involves the use of CO_2 inoculations or the captive bolt method which does not only result in concussion, but can also penetrate the skull and injure some portion of the brain. On the other hand, electrical stunning can be achieved by passing a current (1.25 amps) across the brain and this requires correct placement of stunning tongs as illustrated in Fig. 3. The head tongs must not be placed on the neck.

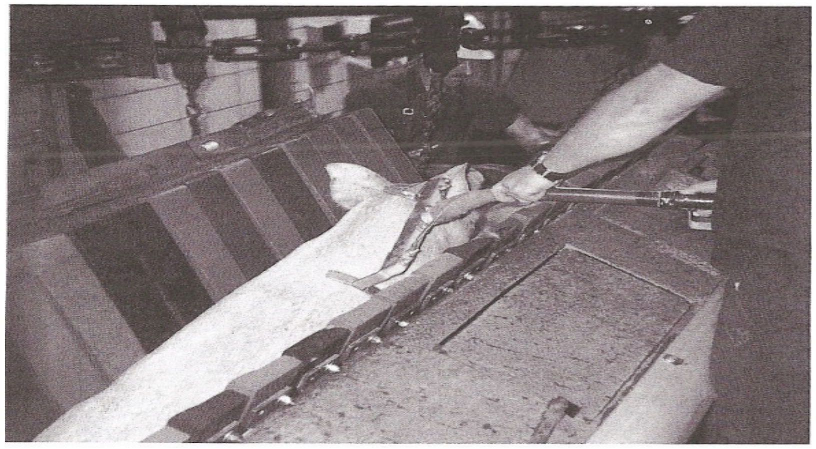

Fig. 3. The correct positioning of the head electrode is right behind the ear or on the forehead when using the head-to-back cardiac arrest (Gregory, 2007).

Although the method of stunning affects pork eating quality (Channon *et al*., 2002), stress immediately before slaughter has severe, negative consequences on pork quality attributes, such as drip loss and pork color, both after electrical and CO_2 stunning (Hambrecht *et al*., 2004). Channon *et al*. (2000), however, reported that CO_2 stunning systems improve carcass and meat quality attributes of pork to a greater extent than electrical stunning. In Denmark, researchers developed excellent CO_2 stunning chambers and handling systems (Fig. 4) which allow pigs to be stunned in a group of four or five without the use of electrical goads in moving the animals. Stunning pigs with CO_2 can reduce the incidence of ecchymosis and bone fractures, improve meat quality and improve worker safety compared with electrical stunning (Channon 1997a,b; Channon *et al*., 2002). The use of gases during stunning impose economic advantages as well as reduce animal welfare concerns but it has not been introduced in South Africa.

On the other hand, poor handling immediately prior to stunning or inappropriate stunning techniques has been shown to give a higher temperature in muscle and a faster pH fall early *post mortem*, as well as a higher drip loss and a greater PSE-incidence than a careful handling (D'Souza *et al*., 1998a, b). The negative effects of stress may be aggravated by high muscle energy levels present at slaughter (Hambrecht *et al*., 2004). Missed or improper stunning may lead pigs to kick violently following concussion, and this can increase the rate of *post mortem* muscle glycolysis (Gregory, 2007). Muscular contractions during and after stunning had a negative effect on pork quality, causing a more rapid drop in pH, a faster development of *rigor* *mortis* and a reduced water holding capacity (van der Wal *et al*., 1997). Muscle contractions may be worsened further if the stunning procedure is imperfect.

Fig. 4. Danish group handling system for moving groups of five pigs into a CO_2 chamber (Grandin, 2007).

3. Linking pig pre-slaughter welfare, stress hormones to pork quality

Pigs respond or cope with various welfare conditions which they perceive as dangerous through specific features and, subsequently, react with physiological and biochemical changes. Physiological parameters demonstrate aversiveness of welfare because impulses result in the activation of the hypothalamo-adenohypophyseal-adrenocortical axis due to stimulation of the parasympathetic or sympathetic nervous system, which leads to changes in hormonal levels (Lambooij, 2000) and subsequently the quality of meat. Stress or physical exertion stimulates release of hormones, such as cortisol, adrenaline, noradrenaline, creatinine kinase, dehydrogenase, prolactin, beta-endorphin and glucocorticoids and are often used in assessing welfare during handling (Muchenje *et al*., 2009b). The release of glucocorticoids and cathecholamines triggers the depletion of muscle glycogen causing increased meat pH and pork eating defects (Lambooij, 2000).

Fluctuations of biochemical components following deviation from normal function, below or above normal critical threshold levels, may impose detrimental effects on the process of transformation of muscle to pork. Monitoring stress levels by blood lactate measurement in combination with strategies to control muscle energy present at slaughter aid in improving pork quality (Hambrecht *et al*., 2004). In pigs, most meat quality traits are largely affected by the stress sensitivity status (Claeys *et al*., 2001; Gregory, 2007). In other words, the halothane genotype of the pig has great influence on meat quality than pre-slaughter management (Costa *et al*., 1999). However, the relationship between animal characteristics, stress sensitivity or fresh pork quality, on one hand, and muscle enzyme activities, on the other hand, has not been extensively investigated (Gil *et al.*, 1998; 1999).

4. Pig pre-slaughter welfare and physical meat attributes

As pigs are handled from the farm up to the time of stunning, stockpersons are faced with challenges of improving physical *post mortem* pork attributes which are concerned with both consumer acceptance and technological aspects. The main physical pork attributes associated with pre-slaughter stress are acidity, PSE, DFD, boar taint, bruising, toughness, sogginess, cooking loss, meat dryness, two-toning such as colour, water holding capacity and texture and rancidity in stored products (Van der Wal *et al*., 1997; Gregory, 2007). Hambrecht *et al*. (2004) reported that pigs which were severely stressed, as compared to those handled under standard conditions, resulted in inferior pork quality attributes, including electrical conductivity, filter paper moisture, drip loss and lightness. Stress responsiveness is partially influenced by genotype. Table 1 illustrates that acceptability of pork was low for palatable attributes of pork produced from stress-susceptible genotypes. On the other hand, Klont *et al*. (1993) revealed that slaughter pigs of different genotypes handled under identical conditions showed different values of meat quality parameters.

Table 1. Percentage of unacceptable chops from different porcine stress syndrome (PSS) genotype.

Trait	Non-carrier	Carrier
Initial tenderness	21.11	30.11
Overall tenderness	21.78	32.13
Juiciness	30.17	39.13
Flavour desirability	28.80	30.19
Overall palatability	32.48	37.92

Source: Hambrecht *et al*. (2004)

4.1. Pre-slaughter stress and pork pH

During the *ante-mortem* period, handling procedures involving severe welfare procedures are associated with stress and, subsequently, influence the acidity of pork. Warriss *et al*. (1989) demonstrated that characteristics of *post mortem* pH decline are determined by the physiological state of the animal at the time of stunning. Physical activity or any source of stress that lasts for hours before an animal is slaughtered will deplete muscle glycogen. Once muscle glycogen concentration is reduced below the lower critical threshold level (53 mmol/kg) at the time of stunning, the pH of the meat will be raised (Henckel *et al*., 2002). Acidity of the meat affects most meat quality parameters such as colour, water holding capacity, tenderness and flavour (Muchenje *et al*., 2008a).

Rosenvold *et al*. (2001; 2003a) reported that muscle glycogen stores at the time of slaughter can be manipulated through feeding and, thus, influence the rate of pH decline and possibly the technological pork quality. Figure 5 illustrates the relationship of pH values occurring *post mortem* and associated pork quality characteristics.

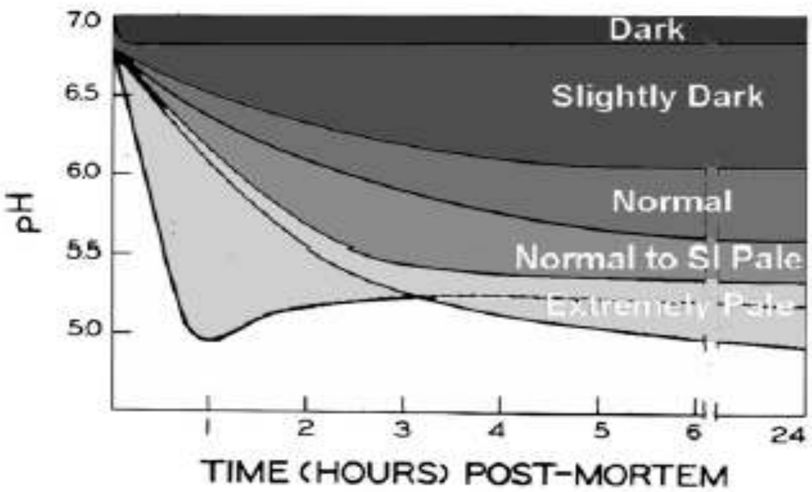

Fig. 5. Various pH declines occurring postmortem and associated pork quality characteristics (Scheffler and Gerrard, 2007).

Normally, pH declines gradually from 7.4 in living muscle to roughly 5.6–5.7 within 6–8 h *post mortem* and then has an ultimate pH at 24 h (pHu) of about 5.3–5.7 (Muchenje *et al*., 2009a). Muscles with a hastened pH decline, however, exhibit rapid glycolysis and produce large amounts of heat, which slows carcass chilling and the chances of developing PSE are high.

4.2. Pre-slaughter stress and PSE

When pigs are stressed during the *ante-mortem* conditions, an increased rate of glycolysis results, leading to rapid acidification and increased *post mortem* muscle temperature and may subsequently lead to PSE (Lambooij, 2000; Swatland, 2004). PSE is a meat quality defect which is caused by a combination of factors, such as stress-susceptible genes, rough handling shortly after slaughter and poor carcass chilling (Grandin 2000a). Increased temperatures above upper levels of normal range of 37.0-39.6 (Hannon *et al*., 1990) result in increased chances of PSE pork, especially with stress-susceptible pig breeds (Klont *et al*., 1993). The PSE conditions results in reduced shelf life due to increased chances of growth of microorganism (Lambooij, 2000) and subsequently imposes negative economic implications to the pork industry.

A 50-min transportation period before slaughter was associated with a higher occurrence of PSE pork loins (Fortin, 2002). This implies that towards slaughter, any handling procedures which stress the animals should be followed with resting so that animals may acclimate and restore the normal basal physiological and biochemical levels. PSE is common in November and December when abattoirs have high numbers of pigs in preparation for Christmas (O'Neill *et al*., 2003a). During slicing in the processing plant, meat PSE zones produce ham which crumbles easily, making holes and splits which may affect the appearance of the meat during slicing (Gregory, 2007).

Although factors leading to PSE pork and to prevent its occurrence have been identified, molecular mechanism underlying these phenomena remains largely undefined (Shen *et al*., 2006). Showering and resting pigs can be the answer to reduction of the incidences of PSE meat under harsh weather of South Africa especially during winter. Some breeds are stress-susceptible by nature and this offers an opportunity for genetic improvement of pig welfare by selecting against stress sensitive genes.

The incidence of PSE can be reduced by feeding a ration containing carbohydrate that has a low digestibility in the foregut but fermented in the hind gut (Rosenvold *et al*., 2001). PSE conditions can also be reduced by reducing stocking densities during long journeys (Gregory, 2007) and resting the pigs for 1 to 22 h in the lairage (Santos *et al*., 1997; Owen *et al*., 2000; Fortin, 2002) depending on the duration of the journey. The actual time required to rest pigs and its relationship with PSE has not been investigated due to a number of reasons. These include the fact that animals are subjected to different pre-slaughter treatments, and lack of reports on the actual mechanisms which counter for the recovery phenomenon. According to Barbut *et al*. (2008), the use of genetic markers to remove stress susceptible pigs have been more successful in reducing the incidences of PSE compared to management at the farm.

4.3. Pre-slaughter stress and pork colour

Stress during the pre-slaughter period influences the rate and extent of postmortem muscle pH decline and subsequently pork colour. In addition, the colour is related to the level of the protein pigment, myoglobin, present in the muscle (Muchenje *et al*., 2009a) and sarcoplasmic proteins. Rapid post mortem glycolysis results in accumulation of lactate and hydrogen ions, while muscle temperature is relatively high (Allison *et al*., 2003). The combination of low pH and high temperature causes denaturation and reduced solubility of proteins (Joo *et al*., 1999) and will consequently influence pork colour. Pale colours have been attributed to denaturation of sarcoplasmic and myofibrillar proteins (Warner *et al*., 1997; Joo *et al*., 1999). Pork with a high pHu due to restricted formation of lactate in muscles with low levels of glycogen and creatine phosphate at the time of slaughter, characterized by high calpain and capalstatin activity, is prone to being dark in colour (Perez *et al*., 2002). The DFD pork has a dark, unattractive appearance and a firm, dry, and sticky texture due to enhanced water binding capability (Scheffler and Gerrard, 2007). Conversely, PSE pork is characterized by pale colour, soft texture, and low water-holding capacity, and has limited functionality in further processing (Scheffler and Gerrard, 2007). In other words, pork that is aberrant in colour represents a major problem to the pork industry due to its poor processing characteristics and appearance which makes it unacceptable to both processors and consumers (Scheffler and Gerrard, 2007).

Nutritional manipulation of pork colour may reduce the incidences of DFD, but the incidence of PSE meat is likely to increase, especially for carriers of the halothane gene, even when pigs are supplemented with sucrose (Pethick *et al*., 1997). During rearing, high stocking densities have been linked to reduced risks of DFD and paler meat (Hamilton *et al*., 2003; Guardia *et al*., 2005). Lengthy journeys (>3 hours) can increase the risk of DFD meat through physical exhaustation (Perez *et al*., 2002). The rapid acidification of PSE results in rapid metmyoglobin formation which can subsequently contribute to the brown-grey colour of meat (Gregory, 2007). However, paleness of meat from *nn* pigs does not persist with cooking or roasting, although the pork is less juicy (Moelich *et al*., 2003).

4.4. Pre-slaughter stress and pork tenderness

Meat tenderness refers to the toughness or the ability of meat to resist fragmentation when being chewed. In general, breed and sex have relatively little effect on tenderness, but pre-slaughter treatments, such as Vitamin D injections, quiet handling and good transport conditions on the way to the killing plant, stunning method, and freezing then thawing and aging significantly improved tenderness (Gregory, 2007). Although cartilage and connective tissue content of meat influence meat tenderness, prolonged stress during the *ante mortem* period may result in biochemical processes taking place in *post mortem* skeletal muscle (Sentandreu *et al*., 2002). These, eventually, influence pork aging and impart tenderness at consumption. The best pork cuts can be toughened by stress, and an older animal can have relatively tender meat if it is docile, handled and slaughtered without being stressed, and the meat aged correctly.

As meat ages, high meat pH influences tenderization because it enhances muscle catabolism through elevated calpain or reduced calpastatin activities. The greater toughness of PSE meat might be partly due to its lower µ- and m-calpain activities (Claeys *et al*., 2001) and associated muscle enzymatic activities. According to Sentandreu *et al*. (2002) and Sensky *et al*. (1998), proteolysis of both sarcoplasmic and myofibrillar proteins by the action of endogenous muscle enzymes has a major role in the development of an adequate meat texture.

Although stress before slaughter and lack of aging of meat influence pork toughness, intramuscular fat (IMF) content also enhances pork tenderness (Aaslyng and Stoier, 2004). Restricted growth during the last days of slaughter followed by compensatory growth can increase tenderness (Therkildsen *et al*., 2002a, b; Kristensen *et al*., 2003). Furthermore, ham made from PSE meat tends to be tougher when cooked and those dry-cured hams have poorer cohesion between muscles (Gregory, 2007).

4.5. Pre-slaughter stress and water holding capacity

Water-holding capacity is a factor that also determines the juiciness of meat. It is defined as the ability of meat to retain its water during application of external forces, such as cutting, heating, grinding or pressing (Lawrie & Ledward, 2006). Muscle energy and the rate and extent with which postmortem muscle pH declines is associated with the water-holding capacity of meat (Van der Wal *et al*., 1999; Barbut *et al*., 2008). Within a normal range of glycolytic potential values, muscle energy had a clear impact on drip loss, with low muscle energy levels being associated with lower drip losses (Hambrecht *et al*., 2004). When pigs are stressed at the time of stunning, rapid postmortem glycolysis results in accumulation of lactate and hydrogen ions while muscle temperature is relatively high. The reduced water-binding capacity is attributed to a combination of low pH and high temperature which causes denaturation and reduced solubility of myosin (Offer *et al*., 1989) eventually leading to denaturation of myofibrillar proteins (Warner *et al*., 1997; Joo *et al*., 1999).

Although drip loss is of economic importance, the mechanism behind this phenomenon has not been extensively studied (Otto *et al*., 2007). In PSE- prone pigs, high stocking densities have been associated with less drip loss from their meat (Gregory, 2007). Such observations have been explained by various reports (Sutton *et al*., 1997, Fisher *et al*., 2000c; Hamilton *et al*., 2000; Costa *et al*., 2002; Otto *et al*., 2007) which revealed that genotypes Nn and NN were significantly associated with drip loss regardless of the method of handling or measurement used, with heterozygote (Nn) pigs showing higher drip loss than the homozygous stress resistant animals (NN). The quantitative trait loci (QTL) and major genes affecting drip loss or water-holding capacity were located on SSC1, SSC2, SSC4, SSC6, SSC11, SSC13, SSC14, SSC15 and SSC18 (http://www.animalgenome.org/QTLdb/). In addition, Thomsen *et al*. (2004) described evidence for further QTL for drip loss and water-holding capacity on SSC5 and SSC9, respectively. These results confirm that stress susceptibility of breeds to pork defects occur even under optimum management conditions. Locating such genes and selecting against such traits can be of great importance for pig breeds in most developing countries because little has been done on characterization of pigs reared in the local environments.

Short-term (1 min) acute stress experienced immediately before stunning involving excitement or forcing pigs from the resting facility to the stunning pen resulted in reduced water holding capacity 24 h *post mortem* (Van der Wal *et al*., 1999). Walking the pigs 125 m to the abattoir instead of transporting them in a vehicle resulted in substantial increase in drip loss from the loin after slaughter (De Smet *et al*., 1998). Although walking pigs to the abattoir is gradually being replaced by vehicle transportation and is cheap, distance as short as 125 m can still persist between the lairage and slaughterhouse. Therefore, driving pigs into the slaughterhouse should be done as gently as possible if quality pork of normal drip loss is to be obtained. In the Netherlands, Italy and Spain, pigs grown under free-range conditions produce meat with less drip loss than those raised intensively (Lambooij *et al*., 2004; Pugliese *et al*., 2005).

4.6. Transportation and sogginess

Pork produced from stressed animals is characterized by reduced water holding capacity. Sogginess is a quality or a state of being wet which is uncommon to normal meat. Losses of water are further exacerbated during transportation of pork from the abattoirs to butcheries due to shaking and vibrations, consequently leading to sogginess. Loss of water from meat has negative economic implications to the pig industry because it substantially reduces the weight of meat (Otto *et al*., 2007) and may also reduce water soluble nutrients which are vital for human consumption. In addition, sogginess reduces the consumer acceptability of pork because it is commonly associated with toughness, reduced pork flavour and exhibits more off-flavour and darker pork colour. Although meat sogginess may impose great economic losses to the pork industry, its relationship with transportation and other pre-slaughter conditions with which the animals are subjected to have not been investigated.

4.7. Pre-slaughter stress and cooking loss

Cooking loss is the percent weight difference between fresh and cooked samples relative to the weight of fresh meat samples (Honikel, 1998; Torley *et al*., 2000; Moelich *et al*., 2003). During cooking the meat undergoes changes in its physical properties, such as colour and texture, and it is subjected to chemical reactions, such as protein denaturation and Maillard reaction, that influence its final quality and acceptability (Chiavaro *et al*., 2009). The major components of cooking losses are thawing, dripping and evaporation (Jama *et al*., 2008). Thawing loss refers to the loss of fluid in pork resulting from the formation of exudates following freezing and thawing. Dripping is the loss of fluid from pork cuts and water evaporation from the shrinkage of muscle proteins (actin and myosin) in the form of drip. Evaporation refers to the loss of fluid from the pork surface through its conversion to gaseous form. It changes the shape of pork through shrinkage and causes firmness and poor juiciness in pork.

An increase in cooking loss has a large financial impact in the pork industry. It results in the loss of several essential minerals and vitamins, thereby deteriorating pork nutritional quality. Despite the influence of cooking temperature, cooking loss is negatively correlated to *post mortem* pH (Torley *et al*., 2000; Muchenje, 2007). It can be postulated that cooking meat with a high pH requires a low temperature to minimize the cooking loss. During cooking meat, losses of 20 to 40 % occur (Jonsall *et al*., 2001; Aaslyng *et al*., 2003; Muchenje, 2007). These losses are ascribed to water holding capacity and acidity of the meat (Aaslyng *et al*., 2003). Structural shrinkage (Aaslyng *et al*., 2003) and structure as reflected in sarcomere length are known to affect cooking loss (Bertram *et al*., 2004). Since pre-slaughter stress influences pork pH, its water holding capacity, acidity, structural linkage and sarcomere length it may consequently affects cooking loss.

Severe pre-slaughter stress results in a high cooking loss and consequently pork is given an expectation of a less optimal eating quality and imposes a great economic loss to the meat and catering industry (Aaslyng *et al*., 2003). Low water holding capacity (WHC) and low pH result in high cooking loss (Aaslyng *et al*., 2003; Muchenje, 2007). Porcine meat from RN-gene carriers is associated with high cooking loss (>25%) (Lundstrom *et al*., 1996; 1998; Jonsall *et al*., 2001). The reduced water binding capacity during processing has been ascribed to a combination of lower protein and higher glycogen content in meat from RN-carriers, as it is assumed that the ability of protein to bind water during cooking is higher than for glycogen (Fernandez *et al*., 1991). Less cooking loss is common in pigs which are kept under free-range conditions (Pugliese *et al*., 2005). It can be postulated that feed deprivation and exercise which is severe may reduce the water binding capability of proteins even when the glycogen concentrations have been restored to normal during the post-mortem period.

Mixing pigs from different batches results in pork with more drip and cooking loss (Beattie *et al*., 2002). These defects can be linked to the stress which is imposed by the new social group giving them less time to acclimatize. Juncher *et al*. (2003) and O'Neill *et al*. (2003b) suggested that severe pre-slaughter stress could enhance warm-over flavours (WOFs) in PSE meat as well as more drip and cooking loss.

5. Pig pre-slaughter welfare and muscle histological attributes

As pigs attempt to respond or cope with external and internal challenges which they face during the pre-slaughter period, biochemical changes occur and these influence enzymatic action of exogenous enzymes on the protein building blocks of meat, including the properties and structure of muscle and meat physiology. As a result, the muscle histological attributes are also influenced by changes in protein structure such that the more severe are the welfare procedures, the poor the pork eating quality.

5.1. Sarcomere length

Sarcomeres are structural and functional units of striated muscles where actin and myosin filaments overlap to produce the movements that are required for muscle contraction. Sarcomere length is used to determine the effectiveness of electrical stimulation as a way of preventing cold-shortening in beef (Muchenje *et al*., 2009a). The shorter the sarcomere the tougher is the meat (Swatland, 2004). Electrical stimulation reduces the pH of the muscle rapidly and hastens the onset of *rigor mortis,* and is not applied to pork because it enhances PSE.

When animals are handled towards slaughter, transitions between rest and exercise requires the muscle to be a dynamic tissue with the ability to adapt to dramatic changes in energy expenditure (Scheffler and Gerrard, 2007). If stress conditions persist resulting in the breakdown of ATP exceeding its synthesis by glycolysis, less ATP is available and the formation of actomyosin bonds shortens sarcomeres and increases muscle tension, signaling the onset of *rigor mortis* (Scheffler and Gerrard, 2007). *Rigor mortis* is complete when the ATP supply is exhausted; thus, actomyosin cross bridges cannot be broken and the muscle is relatively inextensible and as a result the pork becomes tough when chewed. However, muscle tension will eventually decrease with *post mortem* storage as a result of degradation of myofibrillar proteins and loss of structural integrity.

5.2. Myofibrillar fragmentation length, ageing and tenderness

Myofibrils are structural units of striated muscle fibres consisting of one long multinucleate cell. Ageing involves holding meat after slaughter under refrigeration at temperatures ranging from 0 to 4 ^{o}C, to enhance tenderness and the development of flavor (Muchenje *et al*., 2009a). During ageing, an enzyme collagenase, produced by bacteria within the meat, breaks down the myofibrillar protein structure and connective tissue protein (Zhang *et al*., 2005). Since myofibrils make up nearly 80 % of the volume of the muscle cell, their disruption greatly influences meat tenderness (Zhang *et al*., 2005). The pH of the meat at slaughter influences the fragility and fragmentation of the myofibrils.

When *rigor mortis* sets at high temperature and low pH it results in denaturation of approximately 20 % of the sarcoplasmic and myofibrillar proteins (Honikel and Kim, 1986). During this period, reduction in myosin head length is sufficient to draw thick and thin filaments closer together, leading to increased expulsion of water (Offer *et al*., 1989). Greater precipitation of sarcoplasmic proteins is largely responsible for paler pork color, while denaturation of myofibrillar proteins explains the reduced water holding capacity in PSE muscle (Joo *et al*., 1999). Moreover, sarcoplasmic protein solubility declines with decreasing pHu and contributes to paler pork colour (Joo *et al*., 1999) and the rate and extent of *post mortem* pH decline influence protein characteristics and thus critically affect pork quality development (Scheffler and Gerrard, 2007).

6. Pork consumer health issues

Most meat consumers are increasingly becoming concerned about production of quality and safe meat with no undesirable effects on their health (Andersen *et al*., 2005; Okrouhlá *et al*., 2008; Muchenje *et al*., 2009a). Biochemical processes occurring during the transportation of pigs to the abattoir, the immediate pre-slaughter period, the slaughtering process and meat handling after slaughter affect pork eating quality. A variety of factors affect such processes, the chemical composition and the physico-chemical characteristics of pork, including fatty acid profiles. In addition to influencing pork sensory characteristics, the fatty composition of pork is important to the consumer's health.

There has been an increased interest in recent years in ways to manipulate pork chemical compositions, especially fatty acid profiles. This is because meat fat is seen to be a major source of fat in the diet, particularly of saturated fatty acids, which have been implicated in diseases associated with modern life, especially in developed countries (Wood *et al.,* 2003, Okrouhlá *et al*., 2008). In developing countries, such as South Africa, however, knowledge of consumer acceptability of pork and the implication of pork consumption on the consumers' health have not been well-documented.

6.1. Fatty acid profiles and consumer health

Breed of pig and the way pigs are managed from rearing up the time of slaughter affect fatty acid composition, which is closely related to intramuscular fat levels in meat (Hansen *et al*., 2000; Nilzen *et al*., 2001). Meat healthiness is largely related to its fat content and its fatty acid composition (Fisher *et al.*, 2000). The meat from free-range pigs, including organic pig production systems, has been reported to be leaner (Sather *et al*., 1997; Danielsen *et al*., 2000; Sundrum *et al*., 2000) and has more unsaturated fatty acids (Hansen *et al*., 2000; Nilzen *et al*., 2001). The differences in fatty acid composition between breeds subjected to various pre-slaughter conditions can be explained by differences in the proportion of intramuscular fat as the ratio of polyunsaturated fatty acid to saturated fatty acid (PUFA/SFA) (Muchenje *et al*., 2009c). This ratio decreases with the increasing fat level of pork.

Increased health-consciousness among consumers has led to demands for lean muscle with less fat (Moelich *et al*., 2003). Pig producers have improved carcass merit by inclusion of the halothane gene resulting in increased lean growth (Fernandez *et al*., 1999a; Moelich *et al*., 2003) and higher yielding carcasses (Scheffler and Gerrard, 2007). Besides its health benefits, progressive production of lean pork has been accompanied by complaints from the food industry that pork quality has been deteriorating (Wood, 2001). However, extreme variation in pork quality due to the presence of the halothane gene, DFD and PSE pork, has also become more prevalent (Scheffler and Gerrard, 2007).

In the United Kingdom, for example, the Department of Health (1994) recommended that fat intake be reduced to 30 % of total energy intake (from about 40 %) with a figure of 10 % of energy intake for saturated fatty acids (from 15 %). At the same time, the recommended ratio of polyunsaturated fatty acids (PUFA) to saturated fatty acids (P:S) should be above 0.4 (Wood *et al*., 2003). Although fatty acid profiles may impose possible health effects (Aharoni *et al*., 1995; Padre *et al*., 2007), they also affect the sensory characteristics of meat (Wood *et al*., 2003).

The pre-slaughter diet influences the fatty acid profile of the pork produced from pigs in different production systems. For example, traditional breeds raised under pasture produce pork with relatively low SFA (Estevez *et al*., 2004). The negative influence of the intramuscular fat (IMF) content of meat on health aspects, therefore, competes with its positive influence on meat juiciness and flavour (Issanchou, 1996). Assessment of fatty acid profiles of pigs in particular production systems is, therefore, needed. Control of lipid composition in pork might be useful in the production of high quality fresh pork, but there is need for investigating critical threshold values of specific fatty acids to specific flavor attributes in relation to pre-slaughter conditions which pigs are subjected to before any general conclusions can be drawn.

7. Pork acceptance

Consumer acceptance refers to the willingness and preference of consumers to pay for and consume meat cuts based on their appearance at the time of purchasing and consumption. Knowledge of the consumers' preferences, acceptance and choice behaviour is, therefore, crucial to the meat industry in its aim to produce meat of high quality (Aaslyng *et al*., 2007). According to Krige (2000), the perceptions of consumers in South Africa affect purchasing behaviour more than the attributes. This may be due to fact that meat attributes can be made uniform characteristics country-wide but consumer perceptions can be influenced by various attributes such as gender, culture and religion within various ethical groups. Pork acceptance is influenced by sensory attributes, knowledge of method of rearing, health-related issues and some other ethical issues which are linked to religion, customs and social beliefs (Verbeke *et al*., 1999). Sensory evaluation trials are helpful to assess the consumer acceptance of pork from pigs reared and slaughtered in different production systems. There are noticeable correlations between specific fatty acids and explicit sensory attributes but the relationship have not been explicitly investigated in the South African context.

7.1. Sensory evaluation

Sensory evaluation of pork refers to a scientific discipline that deals with the application of principles of experimental design and statistical analysis to the use of human senses (sight, smell, taste, touch and hearing) for the purposes of assessing compositional quality and palatability of pig meat. Components of the palatability of meat include tenderness, juiciness and flavour (Muchenje *et al*., 2008b,c; 2009b). Aroma, the impression that is formed on the first bite of meat, and the amount of connective tissue in meat, is also important sensory characteristics.

7.1.1. Sensory evaluation variables

The quality aspects of pork considered as the main sensory evaluation variables are tenderness, flavour and juiciness. These sensory variables are all influenced by intramuscular fat (IMF). The PSE meat is prone to build up of microorganisms because its chemical background of a high pH and high temperature creates a conducive environment for their growth leading to spoilage. Such meat has a short shelf life and biochemical processes and products following microbial activity may cause rancidity in pork products (Gregory, 2007), thereby imparting sensory attributes such as taste, flavour and aroma. Warmed-over flavours (WOFs) can develop following severe pre-slaughter stress (Juncher *et al*., 2003), but they may be masked up by the mild acidic flavours associated with PSE meat (Gregory, 2007). However, cooked hams processed from PSE meat are susceptible to development of WOFs, high drip and cooking loss (Fisher *et al.,* 2000a; O'Neill *et al*., 2003b; Hoffman *et al.,* 2003).

Since water holding capacity determines the juiciness of meat when pigs are stressed the pork becomes less juicy and this is not desirable. Although pork obtained from the RN pigs does not exhibit high-drip-high-tenderness combination (Gregory, 2007), greater drip in PSE condition is usually associated with tough fresh meat (Stalder *et al*., 1998). Some sensory attributes, such as lower water holding capacity, juiciness and tenderness have been reported to occur hand in hand (Olsson *et al*., 2003).

7.1.2 Intramuscular fat and sensory evaluation

Also known as marbling, intramuscular fat (IMF) refers to the fat layers embedded within meat muscle fibres. IMF content is one of the optimum traits which influence quality characteristics, such as meat tenderness, juiciness, and taste (Verbeke *et al*., 1999; Okrouhlá *et al*., 2008). IMF is related to most welfare issues which are governed by nutrition and exercise mostly during the rearing period or in the fattening period towards slaughter.

IMF content below the recommended optimum of 3 % diminishes pork quality (Okrouhlá *et al*., 2008). A higher IMF content will, however, not further improve this parameter but will instead have adverse effects on the consumer acceptability due to the increased visibility of fat in the meat. According to Gregory (2007), pork leanness is associated with low levels of marbling within the muscle as well as small amounts of subcutaneous and intermuscular fat. Marbling enhances the flavour and juiciness of meat (Calkins and Hodgen, 2007; Muchenje *et al*., 2008b, c). However, high levels of marbling based on the appearance of pork chops in the retail display cabinet increase the reluctance of consumers to purchase but the behaviours are likely to change with familiarity of the benefits that marbling has for eating quality (Fernandez *et al*., 1999b). The Duroc breed has been recorded to have the highest IMF content of 2.9 % (Oliver *et* *al*., 2003; Okrouhlá *et al*. 2008). This has lead to the incorporation of Duroc sire lines, as a way of imparting superior marbling and succulence, and at the same time producing acceptable lean carcasses (Gregory, 2007). The heritability of marbling IMF ranges on average between 0.5 – 0.6 (Visser, 2003). However, the heritability of IMF in the local less benign weather conditions of South Africa have not been done.

7.2. Consumer acceptability and preference tests

The ultimate success of any product in the market-place depends on its acceptability to consumers. Consumer acceptability of pork is dependent upon the appearance of the product at the point of purchase and the satisfaction derived at the point of consumption. Previously, emphasis over the past decades has been placed on producing the most pork at the lowest cost with little regard for the quality of the product. Nowadays, the challenge facing producers and processors of pork products in South Africa is ensuring that the end product meets high quality expectations as well as consumers' experienced quality demands (Oyewumi and Jooste, 2001, SAPPO, 2009). SAPPO (2009) describes the South Africa pork which is available on line to consumers. Consequently, preference tests can be used to ascertain the pork's market position with considerable emphasis on eating quality in relation to consumer acceptance (Jeremiah *et al*., 1999). This can be done by formulating preference tests to determine views of the consumers on particular pork products produced in different production systems.

Despite the substantial amount of research conducted over the past three decades, considerable controversy remains on the effects of breed, gender, and the halothane genotype on meat quality, cooking, and palatability attributes (Torley *et al*., 2000). World-over, such controversy presents a dilemma for pork producers and it is further exacerbated by the majority of previous studies which involve relatively small numbers of animals or meat samples, often from uncontrolled or unknown environments (Torley *et al*., 2000). In South Africa, there is need for research on the relationship between the acceptances of pork in relation to the conditions with which they are kept. Furthermore, due to the diversity of people as you move from place to place such research should be done to ascertain consumer preferences in different provinces. In addition, scientific information on the knowledge of consumers and producers on legislation with regard to how they perceive meat produced under the current animal welfare conditions is lacking.

7.2.1. Boar taint

Sensory boar taint is the off-odour or off-flavour of pork perceived more easily upon cooking and eating (O'Neill *et al*., 2003a). It is primarily caused by androstenone and skatole (O'Neill *et al*., 2003a) and indole. Skatole is mostly associated with sensory descriptors, such as manure whilst androstenone is mostly related to urine (Dijksterhuis *et al.,* 2000). The majority of the South African consumers hesitate to consume pork that exhibits detectable levels of Boar taint (De Kock *et al.*, 2001b; Visser, 2004). Generally, detection of these sensory descriptors on consumption depends partially on the gender and/or ethnic group of consumer as well as how the meat is prepared. It was reported by de Kock *et al.* (2001a) that the ability by white, black and coloured consumers to detect these sensory descriptors depend on gender with more females detecting androstenone than males do. This might be due to the fact that most women spend their time in kitchen so they are used to distinguish various aromas.

Fluctuations in these hormonal concentrations depend on diet, rearing condition, handling of pigs, sex, age, and genetics (Claus *et al*., 1994; Aldal *et al*., 2005). The results reported by De Kock *et al*. (2001b), suggested that future research involving factors influencing volatilization of skatole and androstenone should also be considered when predicting sensory responses of boar odour. In South Africa pork can be prepared using different methods, such as boiling, steaming, frying, grilling and braaing (Hoffman *et al.*, 2003, Fisher *et al.,* 2000a,b; SAPPO, 2009), but little research is done to compare consumer perspective on their sensory responses of boar taint. As a result, there is also need to further investigate the influence of different methods of preparation and temperatures of meat at consumption on sensory responses of boar taint.

Although boar taint can be corrected through surgical castration with anaesthesia (Gregory, 2007), Thun *et al*. (2006) suggested that immunological castration is the best alternative to surgical castration as it is more welfare-friendly. Boar taint affects the acceptability of pork by consumers (De Kock *et al.,* 2004a,b). Although studies were carried out in Pretoria and Stellenbosch to assess the perceptions of black, white and coloured groups respectively on only boar taint precursors (androstenone and skatole), studies on consumer perceptions on another precursor (andole) are lacking. However, the expressions of these off-flavours and odours depend on the method of preparing the meat (Banon *et al*., 2003). This is illustrated in the detection threshold listed in Table 2. Dry-cured ham is comprised of oxidized fats and these help in masking the boar taint (Gregory, 2007), especially when the ham is consumed cold (Banon *et al*., 2003). Furthermore, there is need to investigate the perceptions of consumers of South Africa on how they react to prepared pork samples.

Table 2. Threshold values for the organoleptic detection of androstenone and skatole in pigs meats.

	Threshold concentration (µg/g)	
Pig meat product	Androstenone	Skatole
Cooked meat	0.5	0.10
Cooked ham	1.5	0.75
Dry-cured ham	2.0	0.12

Source: Gregory (2007)

Some major genes for intramuscular fat (Janss *et al*., 1997) and androstenone (Fouillaux *et al*., 1997) have been identified. The latter causes boar taint in meat from entire males thus its identification offers an opportunity for reducing its intensity through genetic programmes. Few, if any, studies on the sensory acceptability of meat from immunocastrated pigs in South Africa are available. Furthermore, there is need to investigate the influence of rearing conditions on boar taint in a South African context. Research on the expression of boar taint odours can be carried out in link with welfare features, such as skin lesions (hock burns), ammonia poisoning, foot pad lesions and microbial infestation. There is also need to investigate whether carcasses or chops with boar taint influence those without so that possible ways of identifying carcasses with boar taint can be introduced on slaughter line.

8. Areas needing further research in South Africa

The South African pork eating population is comprised of a heterogeneous composition in which various black ethnic groups (75%), whites (14%) and coloureds (9%) have different meat eating habits and attitudes towards pork in general (South African Pork Producers Organisation, 1993; Viljoen, 1996; De Kock *et al.*, 2001). Most of the available literature on the relationship between welfare of pigs and pork consumption and quality is based on studies conducted on exotic breeds in the developed countries. There is need to investigate the influence of pig pre-slaughter welfare on pork quality and subsequently its acceptance by South African consumers.

Further research should also focus investigation in consumers' willingness to pay for specific non-economic attributes of pork and pork products and the geographical characteristics associated with this. In addition, pre-slaughter behavior of animals from the time of loading up to the time of stunning are indicators of poor welfare, with vocalizations been the most obvious indicators (Gregory, 2007). However, studies on the relationships between behaviour of animals just before slaughter and meat traits of economic importance at post mortem are lacking not only in South Africa but globally.

8.1. Use of local breeds

Commercial pig farmers and breeders in South Africa have been routinely selecting for reproductive traits such as litter size, litter birth weight for a long time. While considerable research effort has been spent optimising mean values of these reproductive traits within production systems, relatively less has been dedicated to investigate the influence local genotype on meat traits of economic importance. There is need for research on the performance of local breeds under conditions which are common in most developing countries, including South Africa. The use of local breeds is advisable because especially during this era of global warming if sustainable pork production is to be met. This is so because animal welfare is improved especially when animal are kept in their environment of genetic origin.

In practice, development of these breeds though breeding programmes may impose serious economic constraints to the commercial meat industry because it is time consuming, requires construction of more pens, thereby increasing the cost of housing, cleaning needs and general management up to the time of slaughter and determining meat attributes. Very little, if any, information of the impact of behaviours on welfare status and meat traits is available in the pig commercial sector in South Africa. The lack of appreciation of the role of behaviour at slaughter largely explains why most commercial farmers are reluctant to record individual pig pre-slaughter behaviours. Understanding the genetic determination of pig pre-slaughter behaviours will also help in development of a selection scheme for breeding pigs that consider influence of behaviours on handling and meat quality. This will help commercial farmers to improve reduce production costs and, hence, improve pig production efficiency.

In South Africa, the relationship of meat attributes with porcine stress syndrome genotypes, NN and Nn, (Fisher *et al.,* 2000a, b; Moelich *et al.,* (2003). However these have not been linked to pre-slaughter behavioural scorings such as crush scores, pen scores, vocalization scorings, stunning scores, fighting and mounting during transportation or handling. World-over research on the relationship between pre-slaughter behaviour of different pig breeds and the subsequent pork quality is limited or not done at all. Such information can be made available when behavioural measurements are scored through video camera recording in relation to meat attributes. For example, vocalization scorings for each animal can be assessed in conjunction with meat traits of economic importance, such as colour, tenderness, water holding capacity, pH and temperature drop. Behavioural scores are easy and cheap to compile implying that they impose less economic cost to the commercial sector.

8.2. Pig welfare and pork quality

Countries such as France have managed to reduce the halothane gene to levels below 2 % through controlled breeding programmes. Most of the surveys done at abattoirs in developed countries reveal occurrence of major defects, such as PSE and DFD. However, the specificity within these results on the actual production systems used in raising animals or during particular pre-slaughter conditions is not always available. The use of pig groups when introducing animals in the slaughterhouse needs to be investigated, as a way of controlling welfare issues which are linked to failure of proper record compilation.

In small-scale abattoirs, however, such information can be easily compiled because animals arriving at abattoirs are usually in small numbers. In commercial setup such as in South Africa, the information can be extracted more effectively on farm than at the slaughterhouse in order not to interfere with the welfare of the animals during the pre-slaughter period. Most of the studies reveal that the conditions of rearing influence the pork eating quality, but the mechanisms of interaction between environmental conditions and meat attributes especially in this global era of climatic change have not been extensively studied in South Africa. In some systems, especially in developing countries, animals awaiting slaughter are exposed to the site of other animals being bled or walked over a floor covered with blood (Gregory, 2007). Research is, therefore, needed to investigate how such practices affect voluntary behaviour of the pigs and subsequent pork quality *post mortem*. Numerical scores are also lacking or not done at all, but they are useful in validating whether animal welfare practices are improving or deteriorating the pork quality. The se numerical scores are more effective especially when they are linked to research on how pork changes quality at *post mortem*.

8.3. Use of molecular techniques

Application of biotechnological methods in trying to improve welfare can be useful if pork of high quality is to be produced. The use of techniques, such as marker assisted selection (MAS) can be used for improving meat quality traits of animals subjected to various pre-slaughter conditions. This is important, especially for production systems such as those in South Africa, because improvement of meat quality is difficult using conventional selection methods since most traits of interest can only be measured after slaughter (de Dekkers *et al*., 2001).

Therefore, only information on relatives can be used for selection, but breeding records are not kept and the ones available are not easily accessible.

Furthermore, high costs are involved in genetically improving meat quality in terms of the number of animals required in sib slaughter schemes (Otto *et al*., 2007), and the sophisticated measurement techniques (e.g. tenderness, colour, drip loss), and logistics within the slaughter plant (Knap *et al*., 2002). In applying molecular techniques, genetic selection may be extended to other meat quality traits, but possible downstream effects are expected so overall benefits and disadvantages need to be assessed also in Sub-Saharan Africa (Gregory, 2007).

8.4. Traceability and disease control

Traceability can be defined as the ability to maintain the identity of an individual pig from the farm, through slaughter and distribution, to the consumer (Jensen and Hayes, 2006). Pigs can be identified through paper records, electronic records, brands, tattoos, tags and transponders (Smith *et al*., 2005). It is imperative that livestock and meat should be identifiable and should be accompanied by proper records that guarantee traceability through all or parts of the life-cycle and such information should be authentic, visible and should be verified (Smith *et al.,* 2008).

Such records can be helpful to prevent or control the spread of diseases, especially in the light of outbreaks, such as the Classical Swine Fever that was reported in the Eastern Cape, South Africa in 2005. The current regulations on traceability of livestock products only specifies the need for traceability at the abattoir level solely on the animal by-products that are used for feeding such as blood (DOA, 2009). However, it would be more effective if guidelines are reviewed such that they extent up to the time of consumption. There is need for investigating the traceability system of South Africa by circulation of questionnaires at farm, abattoir and household level so that possible interventions can be done to improve the safety of livestock products.

Currently, there is speculation that South African large abattoirs are selling meat which is supplied from small scale abattoirs but little is done to prevent or trace such fraudulent behaviour. Authentication of the origin of livestock products can be done by making sure that written information should accompany the product from the place of origin up to the time of slaughter. Biotechnology can be linked with modern information technology and coding to enhance traceability in South Africa through the entire supply chain-from the farm up to the time of consumption (Visser, 2004). Developed countries have involved consumers in implementation of traceability of meat products. According to Dickinson *et al.* (2003) some of the Canadian and American consumers are willing to pay for red-meat traceability, transparency, and enhanced quality assurances in red-meat products. However, such research has not been conducted to ascertain South African consumer preferences.

In serious disease outbreaks farmers should apply biosecurity measures so that they may reduce the risk of cross-contamination between farms. In tracing disease infection or checking the health status of the animals acute phase protein biosensors may be of great use because these increase in concentration in the blood in the event of any infection or tissue damage. Polymerase reactions can also be used in tracing diseases. However, some stress mechanisms involving Salmonella excretion during transportation and pre-slaughter handling are not fully understood (Gregory, 2007).

Besides its use in preventing health risk and ascertaining animal welfare, traceability is also important in preventing stock theft and identifying animals which are suspected to have been stolen (Smith *et al*., 2008). Brook (2008) reported that EU countries have proposed legislation that information on the animal and farm-of-origin should be carried all the way to the point of sale. Such regulations if practiced in developing countries may be useful not only to the pork industry, but also to the health sector in South Africa. With efforts to optimize safety of meat products in South Africa, traceability can be combined with Hazard Analysis Critical Control Points (HACCP).

8.5. Pork products and consumer health

Pork products have been found to impose human health risk, especially when processed from meat with high fat content. This has led to developed countries proposing levels of fats which are suitable to prevent health risks, but such measures have not been proposed in most developing countries. Knowledge of fatty acid profiles of pork for most breeds in the developed world might have assisted health practitioners in drawing out such proposals considering that amounts of meat consumed in these countries is high. In South Africa, the consumption of pork is aggregated between high and low income groups and these are also correlated with racial compositions (Mcguigan and Nieuwoudt, 2002). However, regarding visible pork fat, appearance and health at retail level are major dimensions of quality affecting purchase motives of consumers (Resurreccion, 2002).

The guide to South African pork only generalizes the meat contents on average but does not link up these levels with healthy eating (SAPPO, 2009). Moreover, knowledge of fatty acid profiles of pork produced from indigenous or even exotic breeds reared in local conditions is unavailable, making it difficult to develop appropriate recommendation. Reporting and epidemiological investigation of food borne illnesses leaves a lot to be desired not only in South Africa but throughout the world. For example, the 2005 and 2008 outbreaks of Swine flu and Foot and mouth disease respectively in South Africa and Europe concurrently indicates that networking on disease control and awareness is not up to standard. These diseases led to remarkable decrease in the consumption of pork in South Africa (Maunder *et al.,* 2001). Moreover, in South Africa, food poisoning outbreaks are not recognized, reported and reacted on in the same way as in other first world countries (Neethling, 2009a). There is also need to assimilate developed countries, such as USA in raising food safety awareness programmes and animal welfare campaigns/ workshops through non-profit organizations.

8.6. Pork processing and value adding

Handling and processing in slaughter plants is well-known to have a great influence on stress immediately prior to slaughter and on the pork eating quality (Warris *et al*., 1998a, b; Van der Wal *et al*., 1999). Stunning method affects quality of processing pork products. Although most studies reveal effects of pre-slaughter conditions on the easiness of processing pork, future work should aim at unraveling those factors causing variations in meat quality at commercial processing plants. According to Oyewumi and Jooste (2004), more pork consuming households show a preference for value added products than non-pork consuming households but these patterns are not scientifically explained. For example, the cooked ham industry processing is experiencing a fast and sustained development of the slicing-packing process, but development is seriously handicapped by the frequent occurrence of PSE-zones in the hams (Franck *et al*., 2003).

In South Africa, the effects of genotypes (nn, Nn, and NN) on processing and quality of hams and back bacon have been investigated (Fisher *et al.,* 2000a, b). Although the results suggest halothane carriers should be eliminated by producers and processors when preparing value added pork products (Fisher *et al.,* 2000b,c), not all meat attributes of economic importance were evaluated. However, the presence of the halothane gene may have advantages for producers because carcasses produced have higher lean yield which suits well in the current South Africa carcass classification system were producers are paid for the predicted lean yield (Fisher *et al.,* 2000). The PSE-zones crumble easily, making holes or splits in the slices which are detrimental to the presentation of the product, often making it unsalable pre-packed (Franck *et al.,* 1999). However the mechanisms responsible for such observations are not well understood.

8.7. Pork safety

To ensure production of pork within a quality management system some developed countries in Europe established non-profit organizations, such as Belpork, which support stakeholders in the pig production sector in various management aspects such as feed, accommodation of the pigs, animal welfare and health, identification of the pigs, transport and slaughterhouse practices and meat processing (Lammens *et al*., 2007). Such organizations shares the same objective with SAPPO in ensuring that pork of high quality is always available to the consumers with minimum healthy risks. However, workshops and awareness programmes to improve pork safety are still not fully implemented in South Africa.

In South Africa, the Meat Safety Act and Consumer Protection Act requires abattoirs to send meat samples for lab testing so that safe products are available to consumers (DOA, 2004; Red Meat Abattoir Association, undated; Neethling, 2009a). However, the regulation should also govern the butcheries because they are also involved in meat dispersal. There is no scientific information on the perceptions of animal handlers and pork consumers on the present safety measures regarding pork distribution. According to Neethling (2009b), meat quality and safety issues are more often referred back to the abattoir owner due to the increased awareness among consumers on health related matters. As a result, there is need for introducing some basis of the application of hygiene management systems such as HACCP plans for fresh meat

(Parsons and Neethling, 2009; Neethling, 2007; NSF, 2009). However, the genuine application of HACCP principles can be difficult in the design of HACCP plans for raw food commodities, especially in the case with fresh meat which implies that its introduction warrants further investigations in the South African context.

Regulations require information on the production systems used in rearing pigs, especially when meat is being exported. Most European countries have banned the use of antibiotics in animals, especially towards slaughter because these have adverse effects on the human immune system. The impact of this has been receiving low priority in most developing countries but in South Africa the Consumer Protection Act (Act 68 of 2008) which was promulgated in April 2009 promotes a fair, accessible, safe and sustainable market place for consumer products (Neethling, 2009a, b). To increase pork safety in terms of the fat content, involvement of the Duroc sire lines in breeding programs has been found to be of great use with other exotic breeds. However, it is imperative to investigate the impact of including the Duroc breed in mating programmes to improve meat quality in South Africa. Such programmes should also include indigenous pig breeds in the farming sector.

8.8. Religion and pork acceptability

Besides the sensory quality of pork, which is an important quality criterion for the consumer, one should also be aware of other consumer values, such as ethical aspects including religion. Consumers' choice of meat could be for emotional reasons rather than for traditional reasons, such as nutritional and sensory quality (Jonsall *et al*., 2001). According to Scholtz *et al*. (2001) and Oyewumi and Jooste (2005), availability, affordability, culture, tradition and religion influence the consumption of pork by many South Africans.

Some religions are more concerned about the rearing systems in which pigs are raised while at the same time the natural behaviour and needs of the animal will also influence consumer acceptability of pork (Torley *et al*., 2000). Controversy arises especially when the ethical needs of different social groups clash with the safety meat requirements as stipulated by the Meat Safety Act (Act 40 of 2000) especially during ritual slaughter. Oberholzer (2003) reported on a media release that the industry have allowed for informal slaughtering in a manner that ensures the safety of consumers as well as the welfare of animals prior to and during the slaughter process. However, there is need to investigate whether the meat is not being commercial dispensed because such meat products could have a severely detrimental impact on South Africa’s meat safety standards and general public health.

According to a survey which was done in the Free state province, it was reported that whites consumed most pork products, followed by blacks and the least were the Asians and the reasons for this was assumed to be linked to religious beliefs (Oyewumi and Jooste, 2004). These results agree with report by Scholtz *et al.* (2001) that most white and coloured South Africans have no cultural, religious or traditional patterns that influence consumption. However, these population groups make up a minor portion of the population of South Africa and this implies that there needs to be further investigation of the perceptions of blacks. In

South Africa, such research is lacking mainly due to lack of adequate funding. The influence of religion on pork acceptability should be considered given that some societies shun consumption of pork due to its “uncleanliness”. As a result, if guides to South African pork quality are made available to consumers they may provide more information about the ‘pork goodness’ and override some ethical issues leading to pork unacceptability.

9. Conclusions

Pre-slaughter welfare procedures which are stressful will subsequently impart the process of transformation of pig to pork. Pre-slaughter pig handling management is important in improving pork quality. Since failure to improve pre-slaughter management of pigs will affect the consumers’ decisions to buy pork and pork products this signifies a major problem for the pig industry. There is need, therefore, to conduct comprehensive research on pig welfare, from farm to fork, and its relationship to pork eating quality in South Africa. Hot research topics for the pork industry include the possible use of biotechnology, traceability and disease control, welfare and ethical considerations, consumer health, processing and value adding, safety and how pig production systems affects the environment. This is more important in this era of globalization because South Africa is part of the global village.

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References

Aaslyng, M.D. and Barton-Gade P. (2001). Low stress pre-slaughter handling: effect of lairage time on meat quality of pork. Meat Science, 57: 87–92.

Aaslyng M.D. and Støier S., 2004. The effect of intramuscular fat on eating quality of pork depending on end point temperature, Proceedings for the 50th. International Congress of Meat Science and Technology, Helsinki, Finland (2004), pp. 548–550.

Aaslyng, M. D., Bejerholm, C., Ertbjerg, P., Bertram, H. C. and Andersen, H. J. (2003). Cooking loss and juiciness of pork in relation to raw meat quality and cooking procedure. Food Quality and Preferences, 14: 277–288.

Aaslyng M. D., Oksama M., Olsen E. V., Bejerholm C., Baltzer M., Andersen G., Bredie W. L.P., Byrne D. V. and Gabrielsen G.(2007). The impact of sensory quality of pork on consumer preference. Meat Science, 76: 61-73.

Aharoni, Y., Nachtomi, E., Holstein, P., Brosh, A., Holzer, Z. and Nitsan, Z. (1995). Dietary effects on fat deposition and fatty acid profiles in muscle and fat depots of Friesian bull calves. Journal of Animal Science, 73: 2712–2720.

Aklilu, Y. (2002). An audit of the livestock marketing status in Kenya, Ethiopia and Sudan. Volume 1. Nairobi, Kenya: Community-Based Animal Health and Participatory Epidemiology Unit, Pan African Programme for the Control of Epizootics, and the Organization of Africa Union/Inter-Africa Bureau for Animal Resources. Available onlineat:http://www.unsudanig.org/darfurjam/trackII/data/cluster/development/An

%20Audit%20of%20the%20Livestock%20Marketing%20Status%20in%20Kenya,%20Ethiopi.pdf.

Aldal I., Andresen O., Egeli A.K., Haugen J.E., Grodum A.and Fjetland O. (2005). Levels of androstenone and skatole and the occurrence of boar taint in fat from young boars. Livestock Production Science, 95: 121–129.

Allison C.P., Bates R.O., Booren A.M., Johnson R.C., Doumit M.E. (2003). Pork quality variation is not explained by glycolytic enzyme capacity. Meat Science, 63:17–22.

Andersen, H. A., Oksbjerg, N., Young, J. F. and Therkildsen, M. (2005). Feeding and meat quality – a future approach. Meat Science, 70: 543–554.

Anonymous. (2001). Australian code of practice for the welfare of animals. Livestock (including poultry) at slaughter establishments (abattoirs, slaughter-houses and knackeries). Melbourne, Australia: CSIRO Publishing.

Banon, S., Costa, E., Gil, M. D. and Garrido, M. D. (2003). A comparative study of boar taint in cooked and dry-cured meat. Meat Science, 63: 381–388.

Barbut, S., Sosnicki A.A., Lonergan, S.M., Knapp T., Ciobanu D.C., Gatcliffe L.J., Huff-Lonergan E. and Wilson E.W. (2008). Progress in reducing the pale, soft and exudative (PSE) problem in pork and poultry meat. Meat Science,79:46-63.

Barton-Gade, P. and Christensen, L. (1998). Effect of different stocking densities during transport on welfare and meat quality in Danish slaughter pigs. Meat Science, 48: 237–247.

Beattie, V.R., Burrows, M.S., Moss, B.W. and Weatherup, R,N. (2002). The effect of food deprivation priour to slaughter on performance, behavior and meat quality. Meat Science, 62:413-418.

Berg, E. P. (2001). Running Head: Effect of stress on meat yield and quality. Influence of stress on composition and quality of meat, poultry, and meat products. Available online: http://www.fass.org/fass01/pdfs/Berg.pdf. Columbia: Animal Science Research Centre. Accessed July 13, 2009.

Bertram, H. C., Engelsen, S.B., Busk, H., Karlsson, A.H. and Andersen, H.J. (2004). Water properties during cooking of pork studied by low-field NMR relaxation: effects of curing and the RNA-gene Meat Science, 66: 437–446.

Brook, J. (2008). Global consumer demand panel – Europe/Middle East. In Proc. 2008 International Livestock Congress (pp. 9–10). Denver, CO: ILC-USA.

Broom, D.M. (2000). Welfare assessment and welfare problem areas during handling and transport. In: Grandin T (Ed) Livestock Handling and Transport Livestock, Second edition. CABI Publishing, New York, pp 43-61.

Calkins, C.R. and Hodgen, J.M. (2007). A fresh look at meat flavour. Meat Science, 77: 63–80.

Channon, H.A., Payne, A. M. and Warner, R. D. (2000). Halothane genotype, pre-slaughter handling and stunning method all influence pork quality. Meat Science, 56:291-299.

Channon, H. A., Payne, A. M., and Warner, R. D. (2002). Comparison of CO2 stunning with manual electrical stunning (50 Hz) of pigs on carcass and meat quality. Meat Science, 60: 63-68

Channon, H.A., Pengelly, A. M. and Warner, R. D. (1997b). Effect of halothane genotype, pre-slaughter handling and stunning method on meat quality of pigs. In: P.D. Cranwell, Editor, *Manipulating Pig Production VI*, Australasian Pig Science Association, Werribee, VA, Australia p. 126.

Channon, H. A., Trout, G. R., Pengelly, A. M. and Warner, R. D. (1997a). Stunning of pigs: effect of method, current level and duration on carcass and meat quality of pigs. In: P.D. Cranwell, Editor, *Manipulating Pig Production VI*, Australasian Pig Science Association, Werribee, VA, Australia.

Chiavaro, E., Rinaldi, M., Vittadini, E. and Barbanti, D. (2009). Cooking of pork Longissimus dorsi at different temperature and relative humidity values: Effects on selected physico-chemical properties . Journal of Food Engineering, 93: 158–165.

Claeys, E., De Smet, S., Demeyer, D., Geers ,R. and Buys, N. (2001). Effect of rate of pH decline on muscle enzyme activities in two pig lines. Meat Science, 57:257-263.

Claus, R., Weiler, U. and Herzog A. (1994). Physiological aspects of androstenone and skatole formation in the boar: A review with experimental data, Meat Science, 38:239–305.

Costa, E. C., Restle, J. and Brondani, I. V. (2002). Composição física da carcaça, qualidade da carne e conteúdo de colesterol no músculo longissimus dorsi de novilhos red angus surper precoces, terminados em confinamento e abatidos com diferentes pesos. Brazilian Journal of Animal Science, 31: 417–428.

Costa, L.N., Fiego, D.P.L., Dall'Olio, S., Davoli, R. and Russo, V. (1999). Influence of loading method and stocking density during transport on meat and dry-cured ham quality in pigs with different halothane genotypes. Meat Science, 51:391-399.

Cunningham, J. G. (1997). Textbook of Veterinary Physiology. Phila-delphia: W.B. Saunders.

Danielsen, V., Hansen, L. L., Møller F., Bejerholm, C. and Nielsen, S. (2000). Production results and sensory meat quality of pigs feed different amounts of concentrate and ad lib. Clover-grass or clover grass silage. In J. E. Hermansen, V. Lund & E. Thuen Ecological animal husbandry in the Nordic countries. DARCOF Report 2, 79–86.

De Dekkers, J. C. M., Rothschild, M. F. and Malek, M. M. (2001). Potential and application of marker assisted selection for meat quality. In: Second International Virtual Conference on Pork Quality, November, 05 to December, 06, via internet (http://www.conferencia.uncnet.br/ pork/seg/pal/anais01p2_deckkers_en.pdf).

De Kock H.L., Van Heerden S.M., Heinze P.H., Dijksterhuis G.B., Minnaar A. (2001a). Reaction to boar odour by different South African consumer groups. Meat Science 59:353–362.

De Kock H.L., Heinze P.H., Potgieter C.M., Dijksterhuis G.B., and Minnaar A. (2001b). Temporal aspects related to the perception of skatole and androstenone, the major boar odour compounds. Meat Science 57:61-70.

Department of Agriculture, Forestry and Fisheries. (2009). Guidelines for an effective trace traceability system for the use of mammalian blood products from South African sterilization plants that is destined for feeding of non-ruminant animals. Notice No. VPN/…/2009/02. Available on: http://www.rvav.co.za/2009/Mammalian_Blood.pdf. Accessed on 21 june 2010.

Department of Health (1994). Nutritional aspects of cardiovascular disease. Report on Health and Social Subject No. 46., Her Majesty's stationery, London (1994).

De Smet, S., Bloemen H., van de Voorde G., Spincemaille G., and Berckmans D. (1998). Meat and carcass quality in two pig lines of different stress-susceptibility genotype and their crosses. Animal Science, 66: 441-447.

Dickinson, D.L., Hobbs, J.E. and Bailey, D. (2003). A comparison of US and Canadian consumers' willingness to pay for red-meat traceability. Paper prepared for presentation at the American Agricultural Economics Association Annual Meetings, Montreal, Canada, July 27-30, 2003.

Dijksterhuis, G. B., Engel, B., Walstra, P., Font-i-Furnolls, M., Agerhem, H., Fischer, K., Oliver, M. A., Claudi-Magnussen, C., Siret, F., Beague, M. P., Homer, D. B. and Bonneau, M. (2000). An international study on the importance of androstenone and skatole for boar taint. II. Sensory evaluation by trained panels in seven European countries. Meat Science, 54: 261–269.

DOA. (2004). Meat Safety Act, 2000 (Act No. 40 of 2000). Red Meat Regelations. Extract from Government Gazette No. 26779, 2004 09 17.

D'Souza, D.N., Dunshea, F.R., Warner, F.R. and Leury, B.J. (1998a). The effects of handling pre-salughter and carcass processing rate post-slaughter on pork quality. Meat Science ,50:429-437.

D'Souza, D.N., Dunshea, F.R., Warner, F.R. and Leury, B.J. (1998b). Effects of on farm and pre-salughter handling of pigs on meat quality. Australian Journal of Agricultural research, 49:1021-1025.

Eikelenboom, G., Bolink, A. H. and Sybesma, W. (1991). Effects of feed withdrawal before delivery on pork quality and carcass yield. Meat Science, 29: 25 -33.

Ekkel, E. D., Savenije, B., Schouten, W. G., Wiegant, V. M. and Tielsen, M. J. (1997). The effects of mixing on behaviour and circadian parameters of salivary cortisol in pigs. Physiology and Behavior, 62: 181–184.

Ekkel E.D., Spoolder H.A.M., Hulsegge I. and Hopster H. (2003). Lying characteristics as determinants for space requirements in pigs. Applied Animal Behaviour Science, 80:19-30.

Estevez, M., Morcuende, D., and Cava, R.C. (2004). Oxidative and colour changes in meat from thress lines of free range reared Iberian pigs slaughtered at 90kg live weight and from industrial pigs during refrigerated storage. Meat Science, 65:1139-1146.

Fernandez, X., Lefaucheur, L., Gueblez, R., & Monin, G. (1991). Paris ham processing: technological yield as affected by residual glycogen content of muscle. Meat Science, 29: 121–128.

Fernandez, X., Mourot J., Lebret B., Gilbert B. and Monin, G. (1999a). Influence of intramuscular fat content on the quality of pig meat-1. Composition of lipid fraction and sensory characteristics of m.longissimus lumbrorum. Meat Science, 53:59-65.

Fernandez, X., Mourot J., Lebret B., Gilbert B. and Monin, G. (1999b). Influence of intramuscular fat content on the quality of pig meat-2. Composition of lipid fraction and sensory characteristics of m.longissimus lumbrorum. Meat Science, 53:67-72.

Fisher, P., Mellett, F. D. and Hoffman, L. C. (2000a). Halothane genotype and pork quality. 1. Carcass and meat quality characteristics of three halothane genotypes. Meat Science, 54: 97–105.

Fisher, P., Mellett, F. D. and Hoffman, L. C. (2000b). Halothane genotype and pork quality. 2. Cured meat products of three halothane genotypes. Meat Science, 54: 107–111.

Fisher, P., Mellett, F. D. and Hoffman, L. C. (2000c). Halothane genotype and pork quality. 3. Comminuted meat products derived from the three halothane genotypes. Meat Science, 54: 113–117.

Fortin, A. (2002). The effect of transport time from the assembly yard to the abattoir and resting time at the abattoir on pork quality. Canadian Journal of Animal Science, 82: 141–150.

Fouillaux, M. N., Le Roy, P., Grusand, J., Renard, C., Sellier, P. and Bonneau, M. (1997). Support for single major genes influencing fat androstenone level and development of bulbo-urethral glands in young boars. Genetics Selection Evolution, 29: 357–366.

Franck, M., Svensson, M., von Seth, G., Josell, A., Figwer, P.H., Poirel, M.T., Monin, G. (2003). Effect of stunning conditions on occurrence of PSE defects in hams of rn+/RN_ pigs. Meat Science, 64:351–355.

Franck, M., Be´nard, G., Fernandez, X., Barbry, S., Durand, P., Lagant, H., Monin, G. and Legault, C. (1999). Observations pre´ - liminaires sur le jambon de´structure´ , description du phe´nome`ne et e´tude de quelques facteurs de variation. Journe´es Recherche Porcine en France, 31: 331–338.

Gil, M., Guerrero, L. and Sarraga, C. (1999). The effect of meat quality, salt and ageing time on biochemical parameters of dry cured Long- issimus dorsi muscle. Meat Science, 51: 329-337.

Gil, M., Hortos, M. and Sarraga, C. (1998). Calpain and cathepsin activities, and protein extractability during ageing of longissimus porcine muscle from normal and PSE meat. Food Chemistry, 63: 385-390.

Gispert,M., Faucitano, L.,Oliver, M. A.,Gua` rdia, M. D., Coll, C., Siggens,K., Harvey, K. and Diestre, A. (2000). A survey of pre-slaughter conditions, halothane gene frequency, ad carcass and meat quality in five Spanish pig commercial abattoirs. Meat Science, 55: 97–106.

Gous, R. Personal communication with the author through mail. University of Kwa-Zulu Natal.

Grandin T. (1990). Design of loading facilities and holding pens. Applied Animal Behavior Science, 28:187-201.

Grandin, T. (1994). Methods to reduce PSE and blood splash. In Proceedings Allen D. Leman Swine Conference, College of Veterinary Medicine, University of Minnesota, 21, 206–209.

Grandin, T. (2000a). Handling and Welfare of livestock in slaughter plants. In: T Grandin (Ed) Livestock Handling and Transport, CABI Publishing, New York, pp 409-439.

Grandin, T. (2000b). Livestock Handling and Transport. Second Edition. CIBI Publishing. Colorado State University, United States of America, pp. 51-153.

Grandin, T. (2007). Livestock Handling and Transport, Third Edition. CABI Publishing, New York, pp 340-341.

Gregory, N.G. (2007). Animal Welfare and Meat Production, second ed. CAB International, Wallingford, UK.

Gregory, N.G. (2008). Animal welfare at markets and during transport and slaughter. Meat Science, 80 2-11.

Guadia, M.D., Estany, J., Balasch, L., Oliver, M.A., Gispert, M., and Diestre, A. (2005). Risk assessment of DFD meat due to pre-slaughter conditions in pigs. Meat Science 70:709-716.

Hambrecht, E., Eissen, J. J., Newman, D. J., Smits, C. H. M., Verstegen, M. W. A. and den Hartog, L. A. (2005). Pre-slaughter handling effects on pork quality and glycolytic potential in two muscles differing in fibre type composition. Journal of Animal Science, 83: 900-907.

Hambrecht E., Eissen, J. J., Nooijen, R. I. J., Ducro, B. J., Smits, C. H. M., den Hartog, L. A. and Verstegen, M. W. A. (2004). Preslaughter stress and muscle energy largely determine pork quality at two commercial processing plants. Journal of Animal Science, 82:1401-1409.

Hamilton, D. N., Ellis, M., Miller, K. D., McKeith, F. K. and Parrett, D.F. (2000). The effect of the Halothane and Rendement Napole genes on carcass and meat quality characteristics of pigs. Journal of Animal Science, 78: 2862–2867.

Hamilton, D.H., Ellis, M., Wolter, B.F., McKeith, F.K. and Wilson, E.R. (2003). Carcass and meat quality characteristics of the progeny of two swine sire lines reared under different environmental conditions. Meat Science, 63: 257-263.

Hannon, J.P., Bossone, C.A., and Wade, C.E. (1990).Normal physiological values for conscious pigs used in biomedical research. Laboratory Animal Science, 40:293-298.

Hansen, L. L., Bejerholm, C., Claudi-Magnussen, C. and Andersen, H. J. (2000). Effects of organic feeding including roughage on pig performance, technological meat quality and the eating quality of the pork. In: T. Alfo¨ ldig, W. Lockeretz, & U. Niggli Proceeding 13th International IFOAM Scientific Conference (p 288). 28–31 August 2000. IFOAM 2000—The World grows Organic. Session Number 2.1. Quality of organic products.

Hemsworth, P.H. (2000). Behavioural Principles of Pig handling. In: Grandin T (ed) Livestock Handling and Transport Livestock, Second edition, CABI Publishing, New York, pp 255–270.

Henckel, M.S., Karlsson, A., Jensen, M.T. and Winfield, C.G.,(2002). Metabolic conditions in porcine longissimus muscle immediately pre-slaughter and its influence on peri and post mortem energy metabolism. Meat science, 62: 145-155.

Hoffman L.C., Styger E., Muller M. and Brand T.S. (2003) The growth and carcass and meat characteristics of pigs raised in a free-range or conventional housing system. South African Journal of Animal Science, 33.

Honikel, K. O. (1998). Reference methods for the assessment of physical characteristics of meat. Meat Science, 49: 447–457.

Honikel, K. O. and Kim, C. J. (1986). Causes of the development of PSE pork. Fleischwirtsch, 66: 349–353.

Issanchou, S. (1996). Consumer expectations and perceptions of meat and meat product quality. Meat Science, 43: S5–S19.

Jama, N., Muchenje, V., Chimonyo, M., Strydom, P. E. and Dzama, K. (2008).Cooking loss components of beef. In the Proceedings of the 54th International Congress of Meat

Science and Technology (ICOMST) to be held in Cape Town, South Africa from the 10^{th} to the 15^{th} August 2008.

Janss, L. L., van Arendonk, J. A. and Brascamp, E. W. (1997). Bayesian statistical analyses for presence of single genes affecting meat quality traits in a crossed pig population. Genetics, 145: 395–408.

Jensen, H. H. and Hayes, D. J. (2006). Private sector approaches to secure traceability, transparency, and quality assurance in food chains (pp. 1–14). Paper prepared for the IATRC Summer Symposium, Bonn, Germany.

Jeremiah, L.E., Gibson, J. P., Gibson, L.L., Ball, R. O., Aker, C. and Fortin, A. (1999). The influence of breed, gender, and PSS (Halothane) genotype on meat quality, cooking loss, and palatability of pork. Food Research International, 32:59-71

Jonsall, A., Johannsson, L. and Lundstrom, K. (2001). Sensory quality and cooking loss of ham muscle (M. biceps femoris) from pigs reared indoors and outdoors. Meat Science, 57: 245–250.

Joo, S. T., Kauffman, R. G., Kim, B. C. and Park, G. B. (1999). The relationship of sarcoplasmic and myofibrillar protein solubility to colour and water-holding capacity in porcine longissimus muscle. Meat Science, 52: 291–297.

Juncher D., Ronn B., Hansen B., Henckel P., Karlsson A., Skibsted L.H. and Beratelsen G. (2003). Effect of pre-slaughter physiological conditions on the oxidative stability of colour and lipid during chill storage of pork. Meat Science, 63:151-159.

Klont R.E. Lambooij E. and van Logtestijn J.G. (1993). Effects of pre-slaughter anaesthesia on muscle metabolism and meat quality of pigs of different halothane genotypes. Journal of Animal Science, 71:1477-1485.

Knap, P. W., Sosnicki, A. A., Klont, R. E. and Lacoste, A. (2002). Simultaneous improvement of meat quality and growth-and-carcass traits in pigs. In: Proceedings of the 7th World Congress on Genetics Applied to Livestock Production, vol. 31 (pp. 339–346), 19–23 August, Montpellier, France

Krige, G. (2000). Guest speaker. South African Pig Producers Organization's National Congress. Petermaritzburg. South Africa. 06 September 2000.

Kristensen, L., Therkildsen M., Riis, B., Sørensen, M.T., Oksbjerg, N.and Purslow, P.P. (2003). Dietary-induced changes of muscle growth rate in pigs: effects on in vivo and post mortem muscle proteolysis and meat quality. Journal of Animal Science, 80: 2862–2871.

Lambooij, E. (2000). Transport of Pigs. In: T Grandin (Ed) Livestock Handling and Transport, CABI Publishing, New York, pp 275-296.

Lambooij, E., Hulsegge, B., Klont, R.E., Wilnkelmen-Goedhart, H.A., Reimert H.G.M. and Kranen, R.W. (2004). Effects of housing conditions of slaughter pigs on some post mortem muscle metabolites and pork quality characteristics. Meat Science, 66:855-862.

Lammens, V., Peeters, E., De Maere, H., De Mey, E., Paelinck, H., Leyten, J. and Geers R. (2007). A survey of pork quality in relation to pre-slaughter conditions, slaughterhouse facilities, and quality assurance. Meat Science, 74:381-387.

Lawrie, R. A. and Ledward, D. A. (2006). Lawrie's meat science (7th ed.). Cambridge, England: Woodhead Publishing.

Long, V. P. and Tarrant, P. V. (1990). The effect of pre-slaughter showering and post-slaughter rapid chilling on meat quality in intact pork slides. Meat Science, 27: 181-195.

Lundstrom, K., Andersson, A. and Hansson, I. (1996). Effect of the RN gene on technological and sensory meat quality in crossbred pigs with Hampshire as terminal sire. Meat Science, 20: 145–153.

Lundstrom, K., Enfalt, A. C., Tornberg, E. and Agerhem, H. (1998). Sensory and technological meat quality in carriers and non-carriers of the RN allele in Hampshire Crosses and in purebred Yorkshire Pigs. Meat Science, 48: 115–124.

Maria, A., Buil, T., Liste, G., Villarroel, M., Sanudo, C. and Olleta, J. L. (2005). Effects of transport time and season on aspects of rabbit meat quality. Meat Science, 72: 773- 777

Maunder, E.M.W., Matji, J., Hlatshwayo-Molea T. (2001). Enjoy a variety of foods — difficult but necessary in developing countries. South African Journal of Clinical Nutrition 14 (3): Supplement, S1-S80.

McGuigan, S.M., and Nieuwoudt, W.L. (2002). The expected consumption of protein feed in South Africa by 2020". *Agrekon*, Vol 41(1):1-23.

Moelich, E.I. Hoffman, L.C. and Conradie, P.J. (2003). Sensory and functional meat quality characteristics of pork derived from three halothane genotypes. Meat Science, 63:333-338.

Mounier, L., Dubroeucq, H., Andanson, S. and Veissier, I. (2006). Variations in meat pH of beef bulls in relation to conditions of transfer to slaughter and previous history of the animals. Journal of Animal Science, 84: 1567-1576.

Muchenje, V. (2007). Growth performance, carcass characteristics and meat quality of Nguni, Bonsmara and Angus steers raised on natural pasture. Unpublished PhD Thesis. University of Fort Hare, Alice, RSA.

Muchenje, V., Dzama, K., Chimonyo, M., Raats, J.G., Strydom, P.E. (2008a). Meat quality of Nguni, Bonsmara and Angus steers raised on natural pasture in the Eastern Cape, South Africa. Meat Science, 79: 20-28.

Muchenje, V., Dzama, K., Chimonyo, M., Strydom, P.E., Hugo, A., Raats, J. G. (2008b). Sensory evaluation and its relationship with physical meat characteristics of beef from Nguni and Bonsmara steers raised on natural pasture. Animal, 2: 1700-1706.

Muchenje, V., Chimonyo, M., Dzama, K., Strydom, P. E., Ndlovu, T. and Raats, J. G. (2008c). Relationships between off-flavour descriptors and flavour scores in beef. In the Proceedings of the 54th International Congress of Meat Science and Technology (ICOMST) to be held in Cape Town, South Africa from the 10th to the 15th August 2008.

Muchenje, V., Dzama, K., Chimonyo, M., Strydom, P.E., Hugo, A., Raats, J.G. (2009a). Some biochemical aspects pertaining to beef eating quality and consumer health: a review. Food Chemistry, 112: 279-289.

Muchenje, V., Dzama, K., Chimonyo, M., Strydom, P. E., Raats, J.G. (2009b). Relationship between pre-slaughter stress responsiveness and beef quality in three cattle breeds. Meat Science, 81: 653-657.

Muchenje, V., Hugo A., Dzama K., Chimonyo M., Raats J. G., Strydom, P. E. (2009c). Cholesterol levels and fatty acid profiles of beef from three cattle breeds raised on natural pasture. Journal of Food Composition and Analysis, 22: 354-358.

Neethling, G. (2007). Red Meat Abattoir Association. New letter: Issue 17. November to December 2007. Available on: http://www.rvav.co.za/newsletter/issue17.pdf. Accessed on: 22 June 2010.

Neethling, G. (2009a). Consumer Protection Act and the abattoir. Red Meat Abattoir Association Press release. Available on: http://www.rvav.co.za/2010/Consumer%20Protection%20Act.pdf. Accessed on: 21 June 2010.

Neethling, G. (2009b). The abattoir's view of the material received from the producer. Red Meat Abattoir Association. Available on: http://www.rvav.co.za/ Accessed on: 21 June 2010

Nilzen, V., Babol, J., Dutta, P. C., Lundeheim, N., Enfa¨ lt, A. C. and Lundstro, M, K. (2001). Free range rearing of pigs with access to pasture grazing—effect on fatty acid composition and lipid oxidation products. Meat Science, 58: 267–275.

NSF. (2009). NSF-CMi Africa Press release. Accreditation for HACCP in South Africa by South African National Accreditation Sysytem (SANAS). Available on: http://www.nsf-cmi.com/pressreleases/Accreditation%20for%20HACCP%20in%20South%20Africa.pdf. Accessed on: 22 June 2010.

Oberholzer, G., (2003). Ceremonial/religious slaughtering and public health: Finding a balance between rights and responsibilities. Red Meat Abattoir association. Available on: http://www.rvav.co.za/media21july2003.html. Accessed on 21 June 2010.

Offer, G., Knight, P. K., Jeacocke, R., Almond, R., Cousins, T. and Elsey, J. (1989). The structural basis of the water-holding, appearance and toughness of meat and meat products. Food Microstructure, 8: 151–170.

Okrouhlá M., Stupka R., Čítek J., Šprysl M., Trnka M. and Kluzáková E. (2008): Effect of lean meat proportion on the chemical composition of pork. Czech Journal of Food Science, 26: 464–469.

Oliver M.A., Gispert M. and Diestre A. (2003): The effect of breed and halothane sensitivity on pig meat quality. Meat Science, 35: 105–118.

Olsson V., Andersson K., Hansson I. and Lundstrom K. (2003). Difference in meat quality between organically and conventionally produced pigs. Meat Science, 64:287-297.

O'Neill, D.J., Lynch, P.B., Troy, D.J., Buckley, D.J. and Kerry, J.P. (2003a). Influence of the time of the year on the incidence of PSE and DFD in Irish pig meat. Meat Science, 64:105-111.

O'Neill, D.J., Lynch, P.B., Troy, D.J., Buckley, D.J. and Kerry, J.P. (2003b). Effects of PSE on the quality of cooked ham. Meat Science, 64:113-118.

Otto G., Roehe R., Looft H., Thoelking L., Knap P.W., Rothschild M.F., Plastow G.S. and Kalm E. (2007). Associations of DNA markers with meat quality traits in pigs with emphasis on drip loss. Meat Science, 77:185-195.

Owen, B. L., Montgomery, J. L., Ramsey, C. B. and Miller, M. F. (2000). Preslaughter resting and hot-fat trimming effects on the incidence of pale, soft and exudative (PSE) pork and ham processing characteristics. Meat Science, 54: 221–229.

Oyewumi O.A. and Jooste A. (2004). Accepted for a poster-paper presentation at the World Food and Agribusiness Symposium on 25-26 of June 2005, Chicago, USA.
Padre, R. G., Aricetti, J. A., Gomes, S. T. M., de Goes, R. H. T. B., Moreira, F. B. and Prado, I. N. (2007). Analysis of fatty acids in Longissimus muscle of steers of different genetic breeds finished in pasture systems. Livestock Science, 110: 57–63.
Parrott, R.F., Hall, S.G., Lloyd, D.M., Goode, J., A., and Broom, D.M. (1998). Effects of maximum permissible journey time (31 h) on physical responses of fleeced and shorn sheep to transport, with observations of behaviour during short (1h) rest –stop. Animal science 66, 197-207.
Parsons T. and Neethling G.(2009). HACCP in the abattoir - Meat safety aspects during the slaughtering of livestock. In: Neethling, G. (2009b). The abattoir's view of the material received from the producer. Red Meat Abattoir Association. Available on: http://www.rvav.co.za/ Accessed on: 21 June 2010.
Perez, M.P., Palacio, J., Santoralaria, M.P., Acena, M.C., Chacon, G., Gascon, M., Calvo, M., Zaragoza, P., Beltran, J.A. and Garcia-Belenguer, S. (2002). Effects of transport time on welfare and meat quality in pigs. Meat Science, 61:425-433.
Pethic, D., Warner, R.D., D'Souza, D.N., Dunshea, F.R. (1997). Nutritional manipulations of meat quality. In P.D. Cranwell (Ed), Manipulating pig production VI (pp. 91-99, 117-123(ref))Melbourne: SR Frankland.
Pugliese, C., Bozzi, R., Campodoni, G., Acciaioli, A., Franci, O. and Grandinin G. (2005). Perfomance of cinta senese pigs reared out doors and indoors: 1. Meat and subcutaneous characteristics. Meat Science, 69:459-464.
Red Meat abattoir association. (undated). Do you evaluate the safety of the meat provided at your abattoir ? Available on: http://www.rvav.co.za/newsflashenglish.htm. Accessed on:21 June 2010.
Resurreccion, A.V.A. (2002). Sensory aspects of consumer choices for meat and meat products. *Meat Science,* 66:11-20.
Rosenvold, K., Laerke, H.N., Jensen, S.K., Karlsson, A.H., Lundstrom, K., Andersen, H.J. (2001). Strategic finishing feeding as a tool in the control of pork quality. Meat Science, 59:397-406.
Rosenvold, K. and Andersen, H. J. (2003a). Factors of significance for pork quality—a review. Meat Science, 64:219-237.
Rosenvold, K. and Andersen, H. J. (2003b). The significance of pre-slaughter stress and diet on colour and colour stability of pork. Meat Science, 64:199-209.
Santos, C., Almeida, J. M., Matias, E. C., Fraqueza, M. J., Roseiro, C. and Sardina, L. (1997). Influence of lairage environmental conditions and resting time on meat quality in pigs. Meat Science, 45: 253–262.
SAPPO.(2009). The Complete Guide to South African Pork. Available on: http://www.google.com/search?q=The+complete+guide+to+south+African+pork&btnG=Search&hl=en&sa=2. Accessed on: 22 June 2010.
Sather, A. P., Jones, S. D. M., Schaefer, A. L., Colyn, J. and Robertson, W. M. (1997). Feedlot performance, carcass composition and meat quality of free-range reared pigs. Canadian Journal of Animal Science, 77: 225–232.

Scheffler, T.L. and Gerrard D.E. (2007). Mechanisms controlling pork quality development: The biochemistry controlling postmortem energy metabolism. Meat Science, 77:7–16.

Scholtz S.C., Vorster H. H.(Junior), Matshego L, Vorster H H (2001). Foods from animals can be eaten every day — not a conundrum! The South African Journal of Clinical nutrition, 14, (3).

Sensky, P. L., Parr, T., Scothern, G. P., Perry, A. Bardsley, R. G., Buttery, P. J., Wood, C. C. and Warkup, J. D. (1998). Difference in the calpain enzyme system in tough and tender samples of porcine longissimus dorsi. In Proceedings of the British Society of Animal Science (pp. 16).

Sentandreu, M. A., Coulis, G. and Ouali, A. (2002). Role of muscle endopeptidases and their inhibitors in meat tenderness. Trends in Food Science and Technology, 13: 400–421.

Shen, Q.W., Means, W.J., Thompson,S.A., Underwood, K.R., Zhu, M.J., McCormick, R.J., Ford, S.P. and Du, M. (2006). Pre-slaughter transport, AMP-activated protein kinase, glycolysis, and quality of pork loin, Meat Science, 74:388–395.

Smith, G. C., Tatum, J. D., Belk, K. E., Scanga, J. A., Grandin, T. and Sofos, J. N. (2005). Review. Traceability from a US perspective. Meat Science, 71: 174–193.

Smith, G. C., Pendell, D. L., Tatum, J. D., Belk, K. E. and Sofos, J. N. (2008). Post-slaughter traceability-review. Meat Science, 80: 66–74.

South African Pork Producers Organisation (1993). Project protein pork workshop. 30 September 1993.

Stalder, K. J., Maya, J., Christian, L.L., Moeller, S.J. and Prusa, K.J. (1998). Effects of pre-slaughter management on the carcasses from porcine stress syndrome heterozygous market hogs. Journal of Animal Science 76:2435-2443.

Sutton DS, Ellis M., lan Y., mcKeith FK. and Wilson ER. (1997). Influence of slaughter weight and stress genotype on the water-holding capacity and protein and protein gel characteristics of there porcine muscle. Meat Science 46; 173-180.

Sundrum, A., Dutfering, L., Henning, M. and Hoppenbrock, K. H. (2000). Effects of on-farm diets for organic pig production on performance and carcass quality. Journal of Animal Science, 78, 1199–1205.

Swatland, H. J. (2004). Progress in understanding the paleness of meat with a low pH. South African Journal of Animal Science, 34 (Supp 2)**:** 1-7.

Therkildsen, M., Riis, B., Karlsson, A., Kristensen, L., Ertbjerg, P. and Purslow, P.P. (2002a). Dietary induced changes in growth rate affect muscle proteolytic potential and meat texture. Effects of duration of compensatory growth. Animal Science, 80:2862-2862.

Therkildsen, M., Riis, B., Karlsson, A., Kristensen, L., Purslow, P.P. and Aaslyng, M.D. (2002b) Compensatory growth response in pigs, muscle protein turn-over and meat texture: effects of restriction/re-alimentation period. Animal Science, 75: 367–377.

Thun, R., Gajewski, Z. and Anett, J. (2006).Castration in male pigs: Techniques and animal welfare issues. Journal of Physiology and Pharmacology, 57 (Suppl. 8): 189–194.

Tomlinson, F. (2000). Code of practice for handling and transport of livestock. Drawn up by the Livestock Welafare coordinating Committee in furtherance of livestock welfare in South Africa.

Torley, P. J., D'Arcy, B. R. and Trout, G.R. (2000). The effect of ionic strength, polyphosphates type, pH, cooking temperature and pre-blending on the functional properties of normal and pale, soft, exudative (PSE) pork. Meat Science, 55:451-462.

Van der Wal, P. G., Engel, B. and Hulsegge, B. (1997). Causes for Variation in Pork Quality. Meat Science, 46:319-327.

Van der Wal, P.G., Engel, B. and Reimert, H.G.M. (1999). The effect of stress, applied immediately before stunning, on pork quality. Meat Science, 53:101:106.

Velarde, A., Gispert, M., Faucitano, L., Manteca, X. and Diestre, A. (2000). The effect of the stunning method on the incidence of PSE meat and haemorrhages in pork carcasses. Meat Science, 55: 309–315.

Verbeke, W., Van Oeckel, M.J., Warnants, N., Viaene, J. and Boucque C.V. (1999): Consumer perceptions, facts and possibilities to improve acceptability of health and sensory characteristics of pork. Meat Science, 53: 77–99.

Viljoen, A. T. 1996. Eetgewoontes en voedselvoorkeure van mans (16– 25 jaar) van die Suid-Afrikaanse bevolking. M.Dieetkunde. Universiteit van Pretoria, Pretoria. Suid Afrika.

Visser D. (2003). The effect of the Duroc breeds on the genetics of meat quality. ARC-AII, Nov. 2003. Accessed on the 18th June 2010. Available on: http://www.sapork.com/82duroc.html

Visser, D. (2004). The changing agricultural environment-extending the genotype a step further. University of Pretoria.

Warris, P. D., Bevis, E. A. and Ekins, P. J. (1989). The relationships between glycogen stores and muscle ultimate pH in commercially slaughtered pigs. The British Veterinary Journal, 145: 378–383.

Warner, R. D., Kauffman, R. G. and Greaser, M. L. (1997). Muscle protein changes *post mortem* in relation to pork quality traits. Meat Science, 45: 339–352.

Warris, P. D., Brown, S. N., Adams, S. J. M. and Corlett, I. K. (1994). Relationship between subjective and objective assessments of stress at slaughter and meat quality in pigs. Meat Science, 38: 329–340.

Warriss, P.D., Brown, S. N., Edwards J. E. and Knowles, T. G. (1998a). The welfare of slaughter pigs during transport. Animal welfare, 7: 365-381.

Warriss, P.D., Brown, S. N., Edwards J. E. and Knowles, T. G. (1998c). Effect of lairage time on levels of stress and meat quality in pigs. Animal Science, 66: 255–261.

Warris, P.D., Brown, S.N., Knowles, S.N., Edwards, T.G., Kettlewell, P.J. and Guise, H.J. (1998b). The effect of stocking density on transit on the carcass quality and welfare of pigs.2. results from the analysis of blood and meat samples. Meat Science, 50:447-456.a

Weeding, C.M., Hunter, E.J., Guise, H.J. and Penny, R.H.(1993). Effects of abattoir and slaughter handling systems on stress indicators in pig blood. The Veterinary Record,133:10-13.

Wood, J.D. (2001): Meat quality and the designer pig. In: Lyons T.P., Coles D.J.A. (eds): Concepts of Meat Science. Nottingham Nutrition International, Nottingham: 17–31.

Wood, J.D., Richardson, R.I., Nute, G.R., Fisher, A.V., Campo, M.M. and Kasapidou, P.R. (2003). Effects of fatty acids on meat quality: A review. Meat Science, 66:21–32.

Zhang, S. X., Farouk, M. M., Young, O. A., Wieliczko, K. J. and Podmore, C. (2005). Functional stability of frozen normal and high pH beef. Meat Science, 69: 765–772.