Effects of pre-slaughter handling on pork quality from a smallholder abattoir

By

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Declaration

I, Christian Sabelo Gajana, vow that this dissertation has not been submitted to any University and that it is my original work conducted under the supervision of Prof. V. Muchenje and Miss T.T. Nkukwana. All assistance towards the production of this work and all the references contained herein have been fully accredited.

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Abstract

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A total of 158 pork samples from Landrace and Large White pigs were collected from Nxuba Municipal abattoir to determine the effects of pre-slaughter handling on pork quality. Technological quality attributes of pork such as pHu, L*, a*, b*, WBSF values, TL%, CL% EL% were determined. Breed differences were observed in ultimate pH (pHu) and redness (a*) with meat from the Large White having higher pHu and lower a* values than meat from the Landrace. Meats from pigs slaughtered in spring season had the highest (P<0.05) shear force values (27.6±1.58) while the lowest shear force values (18.5±1.58) were found in meat from pigs that were slaughtered in the autumn season. The lowest pHu and highest a* values were found in meat from 9 month-old pigs (5.3±0.07). The 6, 9 and 10 months had highest (P<0.05) than 7 and 8 months old pigs. Cooking loss and evaporation loss increased with age groups. Only distance and transportation time had a positive relationship to TL% of pork whilst no significant relationship was reported between all the other pre-slaughter variables and technological quality attributes of pork. Highest risks of PSE occurrences were observed with more space allowance of 0.4 m² per 100 kg during transportation. Reduced risks of PSE occurrences were observed with space allowance of 0.35 m² per 100 kg. The pHu were positively correlated to WBSF values (P < 0.001). The L* values were positively correlated to b* (P < 0.001), and negatively correlated to a* while CL and EL were positively correlated to L*. In the current study, a* values were positively correlated to b* (P < 0.001) but negatively correlated to EL (P < 0.01). There were
positive correlations between CL and EL. Both CL and EL were positively correlated to WBSF values. The first four principal components (PCs) explained about 95% of the total variability for technological quality attributes of pork. It can be concluded that pig breeds vary in pHu and considerations should be made on different seasons of slaughter when assessing pork quality. Precautions should also be made on age categories of animal when improving the quality of pork. Transportation time, distance, stocking density, temperature and lairage time did not show significant relationship with technological quality attributes measured; except for transportation time and distance travelled which had a positive relationship with TL%. The risk of PSE increased with more space availability more than 0.4 m$^2$ per 100 kg pig, but stocking density of 0.35 m$^2$ per 100 kg was an ideal reduce the risk of PSE pork.

**Key words:** ultimate pH, pork colour, cooking loss components, principal component analysis, PSE, DFD, WBSF values
List of abbreviations

$L^*$ = Lightness
$a^*$ = redness
$b^*$ = Yellowness
$TL$ = Thawing loss
$CL$ = Cooking loss
$EL$ = Evaporation loss
$IMF$ = Intramuscular fat
$PSE$ = Pale soft exudatives
$DFD$ = Dark firm dry
$DOA$’s = death on arrivals
$WBSF$ = Warner Bratzler Shear Force
$PC$’s = Principal components
$pHu$ = Ultimate pH
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Chapter One

1.1. Introduction

Meat quality can be affected by the cumulative effects of chronic or continued environmental stressors (Miranda-de la Lama et al., 2009, 2010). Traditionally, producers’ focuses on the economic benefits of overloading pigs. Nowadays, however, pig production is no longer focused on just economically efficient pork production, but conditions during transportation and the welfare of transported animals are becoming important (Chai et al., 2010). The term stress was first used by an endocrinologist, Hans Selye who defined it as being a non-specific phenomenon representing the consequences of the behavioural, physiological and emotional status of a human or an animal to respond appropriately to a wide variety of environmental stimuli (Chai et al., 2010; Terlouw, 2005). The detrimental effects of pre-slaughter handling, stunning and transportation on meat quality have been reported by (Perez et al., 2002; Velarde et al., 2000; Gosalves et al, 2006; Muchenje et al., 2009a). Chai et al. (2010) reported that many stimuli such as ambient temperature, humidity, noise, stocking densities, transport or lairage duration and management can influence pig welfare during the pre-slaughter period and subsequently meat quality.

Other factors, besides transport time, that can induce stress on animals during road transportation and subsequent affect meat quality are loading and unloading, stocking density, weather conditions (temperature, air velocity and humidity), vehicle characteristics (poor vehicle design increases the incidences of bruised carcasses (Dalla Costa et al, 2007; Vimiso 2010), food and water deprivation or mixing animals from different groups (Perez et al, 2002; Gosalves et al, 2006), restraint, handling, and novelty of the pre-slaughter environment, adverse weather
Physiological responses of pigs as a consequence of transportation result in physiological stress and/or physical fatigue and can even lead to death (Mota-Rojas et al., 2006). On the other hand, poor handling can cause economic losses to farmers, transporters and slaughter houses (Mota-Rojas et al., 2006). In addition, injuries produced during the transportation or at lairage affect carcass temperature and pH (Gallo et al., 2003; Mota-Rojas et al., 2006) leading to alterations in carcass shelf-life. Meat quality depends on both animal-related and environmental factors (Lammens et al., 2007) and these factors can affect muscle metabolism, thus influencing the development of PSE-meat (pale, soft and exudative), a major problem in the pork industry. However, for the consumer the surface colour of meat is the most important quality attribute at the time of purchase (Juncher et al., 2001).

Furthermore, season of slaughter has been shown to influence the welfare of pigs (Gosalvez et al., 2006). Gregory, (2009) reported that extremes in summertime temperatures increase the risk of deaths on arrival (DOAs), the risk of pale soft exudative (PSE) (Dalla Costa et al., 2007) meat in pigs and turkeys, as well as dark cutting beef in cattle and increased concentrations of cortisol, adrenaline, nor-adrenaline and dopamine (Kadim et al., 2009). The rising environmental temperatures will pose a greater risk of meat spoilage and carcass contamination with E. coli in poultry and Salmonella in a range of species (Gregory, 2010). In addition, cold temperatures and
poor vehicle design increase the incidence of bruised carcasses (Dalla Costa et al., 2007). Therefore, time of year might be a medium stressor that acts independently from transport time (Maria et al., 2006). Hence, the seasonal temperatures are said to be the main reason for differences in meat quality (Kadim et al., 2008).

Most of the reported studies have been on large scale commercial slaughterhouses. There is lack of information concerning pork quality as influenced by transport characteristics, handling procedures and season of slaughter in smallholder and rural abattoirs. This is despite the fact that more than 50% of abattoirs in provinces such as the Eastern Cape in South Africa are classified as smallholder abattoirs (low throughputs). Therefore, this means that smallholder abattoirs supply more meat to the local butcheries and consumers. Therefore, consumers need more transparency and information about pre-slaughter handling on the farm, transportation and during slaughter because transportation is a stressful experience for animals (Miranda-de la Lama et al., 2010). On the other hand, farmers need to be well informed of the effects of handling on meat quality at different season of the year. For example, in summer high temperatures increase incidences of dead on arrivals (DOAs), pale soft exudatives (PSE) and dark cuts. Seasons have been shown to influence the welfare of pigs while transportation of animals for long times in open trucks at high ambient temperatures may cause significant negative physiological responses in animals. The determination of the effect of pre-slaughter handling on pork quality from smallholder abattoir is therefore necessary.

1.2. Justification

The Eastern Cape has many smallholder abattoirs, whose operations and effect on pre-slaughter handling are not clearly understood. This research created a better understanding of the effect of
pre-slaughter handling conditions that influence pork quality from smallholder abattoir in Eastern Cape. It is also crucial to improve the logistics of transport to reduce the stress on animals. Social mixing due to regrouping, high loading densities, inadequate ventilation, exposure to extreme temperatures, road conditions, driving experience, lack of food and water and delays before unloading are the critical points for consideration when monitoring the pre-slaughter handling, welfare and stress on animals. Pigs are loaded, unloaded, regrouped in several hours and placed in a novel environment, which may cause significant stress to the pigs. However, the extent to which the pre-slaughter handling and seasons of slaughter affects pork quality from smallholder abattoir needs to be explored. The objective of the current study was to determine the effects of pre-slaughter handling of pigs slaughtered at a smallholder abattoir on pork quality. The null hypothesis tested is that, under smallholder abattoir conditions, pre-slaughter handling does not affect pork quality.

The specific objectives of the study were:

- To determine the effects of breed, age, season of slaughter on technological quality attributes of pork from a small-holder
- To determine the effects of transportation time, distance, stocking density, temperature and lairage time on technological quality attributes of pork from a small-holder.

**Null hypothesis**

- Breeds, age, season of slaughter do not affect technological quality attributes of pork.
- Transportation time, distance, stocking density, temperature and lairage time do not affect technological quality attributes of pork
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Chapter 2: Literature Review

2.1. Background

In order to effectively limit animal exposure to stress, particular attention must be paid to the animal’s management during the pre-slaughter phase, and careful evaluation of the effects of different ante mortem treatments on productive parameters must be made (Lambertini et al., 2006). Transport (Perez et al., 2002; Mazzone et al., 2010), handling (Gregory, 2008), time spent in the lairage (Warris, 2003; Mach et al., 2008) and slaughter conditions (Mach et al., 2008) are of great importance for final meat quality since these ante mortem short-term or long-term stressors change the normal muscle metabolism and affect fresh meat colour, water-holding capacity, shelf-life, and technological yields (Gispert et al., 2000). However, there are variations in the emphasis that consumers put on the welfare of animals, when they buy meat (Barton-Gade, 2002). Some do not consider welfare at all, whereas others have certain requirements that vary according to their particular perception as to what is good welfare. Furthermore, environmental aspects, such as high stocking density, long transports and lairage periods, reduce the proportion of normal meat quality, independently of the presence of the halothane gene (Gispert et al., 2000). On-farm fasting periods between 12 and 18 h reduce pre-slaughter stress and increase meat quality. On-line skin damage evaluation is a good indicator of pre-slaughter stress and meat quality (Gispert et al., 2000). The risk of PSE condition also depends on the on-farm fasting time, the loading time, the transportation time and the lairage time (Guardia et al., 2004).

The abattoir, season, gender, floor surface of the lorry, loading system, and the stocking density during delivery, influence the occurrence of pale soft exudatives (PSE) and dark firm dry (DFD)
condition meats (Guardia et al., 2004). Thus, for the consumer the surface colour of the meat is the most important quality attribute at the time of purchase (Juncher et al., 2001). However, factors affecting the surface colour are related to differences between breeds and even individual animals, the age of the animal at slaughter, pre-slaughter handling, the chilling process and methods of packaging.

The whole pre-slaughter handling of the animals requires attention. When pigs are handled with care throughout the pre-slaughter period, the effects on meat quality of otherwise detrimental factors can be reduced (Martoccia et al., 1995). Minka et al. (2009) concluded that the risk of increase in morbidity and mortality often encountered during transportation of goats may be reduced considerably by adjusting transportation conditions or all together suspend the journey; and, if unavoidable, by the administration of ascorbic acid (AA) prior to transportation. The objective of this chapter is to review literature related to the effects of animal handling, loading and unloading, transportation and abattoir handling on meat quality.

2.2. Pre-slaughter handling on meat quality.

The way animals react to the environment or situation depends, among others factors, on prior experience. During the slaughter procedure, pigs are handled repeatedly by humans. Manipulation by humans may therefore, be a cause of stress at slaughter (Terlouw, 2005). Pre-slaughter handling includes mixing of unfamiliar animals, loading, transport and abattoir lairage (Rosenvold and Andersen, 2003). These handling practices can induce stress either psychologically or physically. Pre-slaughter stress is both an animal welfare issue and a quality
issue, as it has long been recognised that pre-slaughter stress can adversely affect the quality of pork (Rosenvold and Anderson, 2003).

Transportation of animals is defined by the European directive concerning road transportation of live animals (91/628/CEE) to include the process of handling, loading and unloading. Unfortunately, handling and loading of animals represent the most stressful period compared to the journey itself (Minka and Ayo, 2008a,b; Minka et al., 2009). Reducing stress, therefore, during handling and loading may improve the health of the animals and prevent physiological changes that may reduce productivity (Grandin, 2002).

Handling, unloading and bleeding procedure (Tadich et al., 2009) have been reported to increase cortisol concentration in the lambs after transport, more than to transport itself, especially considering that from the start of the unloading to the time of bleeding. Handling of the animals to obtain blood samples can produce an increase in the concentration of glucocorticoids (Tadich et al., 2009), masking the real effect of the stressor agent in the study; hence it is important that the blood sample should be taken as soon as possible, before unloading, because in most species the increase in corticoid concentration starts around two minutes after handling the animal.

Navarro et al. (2007) took blood samples from lambs submitted to an identical transport journey, but before unloading, and also found an increase in cortisol concentration after the prolonged transport. Zhang et al. (2010) reported that after 1h of transportation peak levels of all three enzymes (Hsp27, αB-crystallin and mRNA and protein) were regularly reached, confirming the stress in animals during loading and when the transport vehicle started to move. On the other hand, unloading procedure has been shown to be less stressful than handling or loading (Minka
et al., 2009). For the first time, this study objectively scored the stresses induced by handling, loading and unloading of transported goats, and showed that unloading is the least stressful of all the procedures. Therefore, the whole pre-slaughter handling of the animals requires attention. When pigs are handled with care throughout the pre-slaughter period, the effects on meat quality of otherwise detrimental factors can be reduced (Martoccia et al., 1995).

2.3. Pig transportation and meat quality

Transport is a complex stressor involving temperature fluctuations, stocking density, withdrawal from food and water, mixing with unfamiliar animals, and motion (Sutherland et al., 2009). Nowadays, modern pig production is no longer focused on just economically efficient pork production, but the conditions during transport and the welfare of transported animals have become the subject of discussion (Chai et al., 2010). Furthermore, transportation has been shown to negatively affect the meat quality (Perez et al., 2002), sensory (Villarroal et al., 2003) meat quality in terms of tenderness and overall liking. It also results in increased plasma concentrations of cortisol, adrenaline, nor-adrenaline, and dopamine, shrinkage loss and deterioration in meat quality (Kadim et al., 2006). It also alters serum concentrations of IL-2, IL-6 and IL-10 and the expression of IL-2, IL-6 and IL-10 mRNA and their receptors in the thymus of pigs (Lv et al., 2010).

Transporting weaned pigs for approximately 112 minutes resulted in elevated blood chemistry values and cortisol concentrations (Sutherland et al., 2009). After 1 h or 2 h of transportation creatine kinase (CK) activity was found to clearly increase in the plasma of F2 offspring pigs of Pietrain and Erhualian parents (Yu et al., 2009). Furthermore, greatest decline in pH, drip loss, and expressible moisture, and the greatest inductions were found in L* and b values, in the pigs
transported for 2 h, indicating that pigs subjected to 2 h of transportation show signs of a reduced meat quality compared to pigs subjected to either 1 h or 4 h transportation (Yu et al., 2009). However, Yu et al. (2009) found no detrimental effect at 4 h of pre-slaughter transportation on meat quality which seems to confirm the results of the study by Pérez et al. (2002) who suggested an adaptation of pigs when transported longer than 3 h. Perez et al. (2002) observed that pigs subjected to short transport (15 minutes) showed a more intense stress response and poorer meat quality than pigs subjected to moderately long transport (3 h), when they are immediately slaughtered on arrival at the slaughterhouse. These authors concluded that transport for 3 h may have allowed the animals to adapt to the transport conditions and then could act as a resting period like a lairage time. Therefore, pigs subjected to short transport would need longer lairage time as resting time.

2.4. Transportation factors that affect meat quality

2.4.1. Stocking density

Stocking density is one important aspect of transport, which could affect animal health and welfare, especially in pigs already experiencing weaning stress which has been shown to affect the immune response, performance, and behaviour in pigs. Higher stocking densities have been associated with higher mortality rates in market weight hogs (Warriss, 1998). However, Lambertini et al. (2006) reported no significant effects of animal density in the transport cages on weight losses and slaughter data, and there was also no significant interaction between transport time and stocking density. The results were in agreement with observations by De la Fuente et al. (2004) who worked with even lower densities (53.6 or 37.0 kg/m2).
In the pig particularly, the effects of stocking density on weight losses during transport are usually irrelevant (Lambertini et al., 2006). Mach et al. (2008) found no significant effects of stocking density at slaughterhouse on meat pH24. Instead, a statistically significant interaction between stocking density at slaughterhouse and gender was found, indicating that meat pH24 ≥ 5.8 of males increased, in contrast to females, as stocking density increased, reaching a maximum 2.79-fold incidence when stocking density at the slaughterhouse increased above 0.38 animals per m². Thus, reducing stocking density at slaughterhouse could have a greater impact on the incidence of meat with pH24 ≥ 5.8 in males than in females. However, Guise et al. (1998) successfully found an effect of stocking density with a significantly higher hot carcass weight in pigs loaded at a higher density. The risks of PSE pork meat according to stocking density (0.25–0.5 m²/100 kg pig) and transportation time (Alvarez et al., 2009) are shown in Figure 2.1.
Figure 2.1: Risk of PSE pork meat according to stocking density (0.25–0.5 m²/100 kg pig) and transportation time. (Adopted from Alvarez et al., 2009)
2.4.2. Distance from farm to abattoir

The slaughter period starts at the farm with the preparation of the animals for transport and ends at the moment of slaughtering the animals (Bourguet et al., 2010). However, animals are subjected to many potentially stress-inducing factors and it is difficult to determine which aspects of the procedure contribute significantly to the stress status of the animal (Bourguet et al., 2010). Stress-inducing factors may have a physical origin, such as food deprivation, fatigue or inappropriate ambient temperatures, but they may also have a psychological origin, such as disturbance of the social group, presence of humans or exposure to novel environments (Terlouw et al., 2008). Lambertini et al., (2006) showed that the duration of transport, from the farm to the slaughterhouse, is the main factor that negatively influences slaughter data. In fact, rabbits subjected to a longer transport time exhibit greater weight losses than others. Furthermore, this effect is not entirely ascribable to urine and fecal losses, but also to carcass weight losses that are already apparent after two hours of transport (Lambertini et al., 2006).

2.4.3. Transportation time

Pigs subjected to short journeys have a higher tendency to produce pale soft exudatives (PSE) meat than pigs transported for longer. Transporting animals for more hours could allow the animals to adapt to transport conditions and then could act as a resting period like a lairage time, which may be beneficial in reducing the level of PSE meat. Perez et al. (2002) found that pigs subjected to short transport (15 minutes) showed a more intense stress response and poorer meat quality than pigs subjected to moderately long transportation (3 h), when they are immediately slaughtered on arrival at the slaughterhouse. Transport for 3 h may have allowed the animals to adapt to the transport conditions and then could act as a resting period like a lairage time. Furthermore, Maria et al. (2006) concluded that transport time affected several measures of
rabbit meat quality and this effect depended on the time of year the rabbits were transported. The effect was higher in summer than in winter, therefore time of year might be a medium stressor that acts independently of transport time. Based on their results, the multifactor stressors involved in the transport process can affect rabbit meat quality even under optimal transport conditions.

2.4.4. Mixed loads

Gosalvez et al. (2006) reported negative influence of mixed loads in pigs a journey distance increased. When pigs from different farms were not mixed, mortality varied between 0.19% and 0.31%, but when mixed loading was made deaths in more than 100 km journeys almost tripled those found in less than 50 km journeys (0.23% vs. 0.68%). These results suggest that mixing animals from different farms can have a more marked effect on pig welfare than the distance they are transported (Gosalvez et al., 2006). However, mixing of unfamiliar animals, loading, transport and abattoir lairage (Rosenvold and Andersen, 2003) can all induce stress either psychologically or physically.

2.4.5 Environmental factors affecting meat quality

2.4.5.1. Loading and unloading

Mazzone et al. (2010) reported no negative effects on loading methods on carcass and meat quality traits. The rough loading method could be an additional stress for animals that may be negatively affected by, in particular, environmental transport conditions, such as high temperatures during the journey. These authors further explained that the analysed stress parameters were more influenced by transport and handling than by specific conditions related to different loading methods onto the truck. However, Van de Perre et al. (2010) concluded that
stress during transportation and or unloading had an important role in determining meat quality and can be measured by means of the number of decibels produced during unloading and the percentage of pigs that show panting behaviour. However, Minka et al. (2009) suggested that for the first time, a very safe, readily available and cheap antioxidant agent, ascorbic acid (AA) that may be used in ameliorating the stresses imposed by handling, loading and transportation of goats.

2.4.5.2. Weather conditions

Climate change could affect meat quality in one of two ways. There could be an effect through changing farming or abattoir practice to adapt to the climate change, and there could be a direct effect of the changing weather conditions on the animals (Gregory, 2010). The indirect effects of the changing weather conditions on the animals may include: changing the genotype of animals by introducing more heat tolerant breeds; holding animals outdoors instead of housing them during winter; feeding low protein-high fat finisher rations to combat heat induced growth suppression; pre-conditioning animals to hot conditions so they will be better adapted to survive heat stress during transport to a processing plant (Gregory, 2010). Summer conditions have been associated with paler meat colour compared with wintertime (Gregory 2010). However, Kadim et al. (2008) reported higher initial pH40 minutes in hot season than the cool season.

Transportation during summer conditions (15–35 °C) has been associated with less skin bruising compared to wintertime (0–31 °C) (Dalla Costa et al., 2007; Gregory, 2010). The meat was also darker, and this may be attributed to the fact that there was more huddling together in the truck as well as more activity. On the other hand, Gosalvez et al. (2006) also reported a higher incidence of carcass bruises and consequently carcass trimming in pigs transported in winter.
The effect of cold temperatures on the aggressiveness and climbing behaviour of pigs was confirmed by the higher number of density behaviour and fighting behaviour. Since pigs are usually raised indoors, it was observed that high humidities (85% RH) result in darker meat regardless of temperature, and have more effect (85% and 30% RH) in Landrace pigs (Gregory, 2010). Factors and their components to be taken into consideration when assessing the potential welfare risks to animals during road transport are summarised in Table 2.1. These include the effects of an animal, management prior to transport, loading, transport environment (social), transport environment (physical, climatic conditions, driving conditions and time of the year.
Table 2.1: Factors and their components to be taken into consideration when assessing the potential welfare risks to animals during road transport

<table>
<thead>
<tr>
<th>Factors</th>
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<tbody>
<tr>
<td>Animal</td>
<td>Species; sex; age; size; physiological state (e.g. lactating, pregnant); health; individual characteristics (e.g. horns, experience with transport)</td>
</tr>
<tr>
<td>Management prior to transport</td>
<td>Housing conditions; prior handling experience; time since last feeding, watering and milking; movement and mixing of animals; waiting time</td>
</tr>
<tr>
<td>Loading</td>
<td>Duration; animal handling; ramp design (e.g. footholds, angle, slipperiness); unloading or not during journey breaks</td>
</tr>
<tr>
<td>Transport environment (social)</td>
<td>Group size and composition (e.g. mixing; age, size or sex differences); isolation; stocking density</td>
</tr>
<tr>
<td>Transport environment (physical)</td>
<td>Individual and total space (m2 and m3); floor surface and bedding; height to ceiling; freedom of movement (e.g. tied up); water and feed access; ventilation; insulation; light; shock-absorption of vehicle suspension; surveillance (level of automation, alarms; frequency of human monitoring)</td>
</tr>
<tr>
<td>Climatic conditions</td>
<td>Temperature; humidity; draught; weather (e.g. snow, rain, sun)</td>
</tr>
<tr>
<td>Driving conditions</td>
<td>Driving quality (e.g. speed, braking, turning); road quality</td>
</tr>
<tr>
<td>Time</td>
<td>Duration of transport; journey breaks (frequency, duration, timing and quality); waiting time (e.g. at borders, on arrival)</td>
</tr>
</tbody>
</table>

Adopted from Nielsen et al. (2010)
2.4.6. Vehicle characteristics

Little has been done on the effects of vehicle design on pork quality (Dalla Costa et al., 2007). Such studies have only focused on some vehicle features, like loading devices, flooring, and number of decks, ventilation and deck height. The effects of vehicle type and animal location during transport on pork quality may vary depending on external environmental temperatures (Dalla Costa et al., 2007). These authors showed that cold temperatures and poor vehicle design increase the incidence of bruised carcasses. Increased paleness was found in pork at higher ambient temperatures. However, the type of vehicle plays an important role as well as the way the load area is equipped (Fischer, 1996). Flexible equipment with barriers reduces the risks of motion sickness and damage as they grant optimal loading density. In addition, dividing the load area in the interior of the vehicle serves to reduce social stress and avoids potential sources of danger in pigs. The style of driving and the conditions of the road surface determine that any start, acceleration, braking or turning exposes the animals to thrusting or centrifugal forces. There is some evidence from studies (Warriss, 1998) of pigs that vibration associated with transport is likely to have adverse effects. Vibrations during transport are an important cause of animal stress, provoking an increase of heart rate.

2.4.7. Other factors affecting meat quality

2.4.7.1. Breed and genetics

Pigs of similar genetic type (but of different genetic make-up) and the same rearing unit (but having different social and other experiences) shows different stress reactivity (Terlouw, 2005). The genetic influence on pork quality comprises differences among breeds as well as differences among animals within the same breed (Rosenvold and Andersen, 2005). These differences can
be caused by a large number of genes with small effects, known as polygenic effects, and in principle most traits of interest for meat quality have a multifactorial background (Anderson, 2001). However, pork quality attributes can also be associated with large monogenic effects. Such genes are known as major genes. A gene can be considered a major gene, when the difference between the mean value of the individuals homozygous for the gene and that of individuals not carrying this gene is equal to or greater than one phenotypic standard deviation of the trait of interest (Sellier and Monin, 1994). This therefore means that fresh pork colour is detrimentally affected by the presence of the halothane allele (Channon et al., 2000).

Breed and genetic effects on meat colour have been reported (Mancini and Hunt, 2005; Edwards et al., 2003). Brewer et al. (2004) evaluated several sire lines (Duroc, Synthetic, Duroc/Landrace, Pietrain, Duroc/Hampshire, and large white) and reported that genetic line affected loin chop two-toning, lightness, pinkness, and yellowness. Similarly, Edwards et al. (2003) suggested that Duroc progeny had more favourable visual colour, higher pH, and increased redness than Pietrain sired pigs. Although enhancement (10% injection of water plus 0.25% salt and 0.4% tripolyphosphate) tended to minimize the effects of genetic background on pork loin colour, variability in the effects of enhancement on pork loin colour were attributed to genetic background (Brewer et al., 2004).

2.4.7.2. Animal behaviour

The effects of slaughter conditions on behaviour, physiology and subsequent meat quality vary between animals for other reasons. The way animals react to slaughter conditions and effects of these reactions on their meat quality depend, amongst others, on the genetic background and prior history of the animal (Terlouw, 2005). Temperament which is the excitability or the
tendency of an animal to become agitated when it is handled has negative effects on meat quality (Voisinet et al., 1997), particularly meat tenderness (King et al., 2006). Temperament of cattle was shown to have significant impact on the incidence of borderline dark cutting in cattle. Animals that were more excitable had a greater tendency to exhibit borderline dark cutting at slaughter. Additionally, the temperament of cattle had a significant effect on subsequent carcass tenderness. Animals which were more excitable were also more likely to produce carcasses which exhibited shear force values of 3.9 kg or higher, which reduces the acceptability of the meat for use in food service establishments (Voisinet et al., 1997). As a result, it was recommended that selecting for cattle with calm temperament may result in benefits in meat quality by indirect selection against stress susceptible animals (Voisinet et al., 1997). On the contrary, King et al. (2006) reported that carcasses from cattle with calm temperaments had higher 0.5 h post-mortem pH values than those from intermediate and excitable cattle (0.1 and 0.2 units, respectively). However, these differences occurred after high-voltage electrical stimulation, which should have caused post-mortem metabolism to occur at its maximum rate.

The tougher the meat, more force is required to shear it, and higher values of Warner Bratzler shear Force are recorded and vice versa, that is known as the Warner–Bratzler shear force (WBSF) test. Higher Warner Bratzler Shear (WBS) values were also observed in excitable steers and none of the animals evaluated possessed dark cutting lean characteristics. Additionally, lean maturity, which depends largely on lean colour, was similar among temperament categories. However, Terlouw and Rybarczyk (2008) concluded that meat quality differences between Duroc (Ds) and Large Whites (LWs) were partly explained by breed differences in sensitivity of muscles to the effects of slaughter conditions. Furthermore, compared to Ds, LWs were less
active in their home pens and less responsive to humans during an exposure test, but despite this, their meat quality was more strongly influenced by slaughter conditions. For LWs, and to a lesser extent for Ds, variations in early post-mortem muscle metabolism were predicted by reactivity to humans, while reactivity to novelty predicted aggression during pre-slaughter mixing and variations in ultimate pH.

2.4.7.3. The abattoirs environment

Abattoir design is normally based on conventional architectural criteria, such as space optimization or how to facilitate human movement, and not on the behavioural characteristics of the animals (Miranda-de la Lama et al., 2010). This situation produces problems when moving animals after unloading and to slaughter. Lairage pen size is normally fixed, although they house a very variable number of animals. Velarde et al. (2000) observed an interaction between the abattoir and the stunning method on the incidence of haemorrhages. However, only the differences in the incidence of petechiae in the loin and the ham that can be attributed to the stunning type are of concern. Haemorrhages were higher in the abattoirs equipped with electrical stunning systems than in those equipped with carbon dioxide (Velarde et al., 2000). In addition, comparisons between three plants revealed that processing plant may cause variation in meat quality independent of pre-slaughter factors such as genetic background of the animals or transport and lairage (Hambrecht et al., 2003). However, since peri-slaughter factors such as stress level, stunning method and chilling rate were confounded, no causal relationships could be established.
2.4.7.4. Post-mortem pH changes and its effects on meat quality attributes

2.4.7.4.1. Ultimate pHu (pHu) and meat quality

Pork is considered better in health aspects because of comparably low levels of cholesterol and high levels of iron (Jaturasitha et al., 2008). Breed plays a major role in carcass fatness and the quality of pork meat (Jaturasitha et al., 2004). Water holding capacity, pH, colour and tenderness are important properties of pork meat (Apple et al., 2005). Meat quality is influenced, to a large extent, by the rate of pH decline in the muscles after slaughter and by the ultimate pH (Sales and Millet, 1996; Muchenje et al., 2009a). The pH of living animals is around pH 7, but after death the sugars in the muscles are converted to lactic acid, lowering the pH (Hambrecht et al., 2004). Studies of pH have shown that high pH meat is darker but less consistently tender than normal pH meat. The rate of decrease in pH early post-mortem and the final pH of the meat are shown to be key factors of pork meat quality (Sales and Millet, 1996). Understanding the effects of stress on final meat quality in different breeds is important to understand the relationship between muscle glycogen and lactic acid to pH decline in meat after slaughter.

An animal which has not been stressed will have normal levels of glycogen in its body but when the animal is slaughtered the metabolic process continues, however there is no longer circulating oxygen (Hambrecht et al., 2004). Without the presence of oxygen, the breakdown of glycogen/glucose results in a build-up of lactic acid which then causes a drop in pH of the meat. The final quality of meat is greatly affected by the rate of pH decline in the meat after slaughter (Hambrecht et al., 2004). The rate of pH decline depends on breed, nutrition and pre-slaughter stress levels (Muchenje et al., 2009a). These factors are controllable and do not account for all the variability between animals that occurs during post-mortem pH decline (McGeehin et al.,
Pork consumers desire meat that is lean and possesses desirable eating characteristics such as tenderness, juiciness, colour, texture and flavour. Several factors such as breed, feeds and age of pig can affect tenderness of meat. Therefore, it is critical for food industries and meat processors to consistently produce a tender meat product that meets or exceeds consumer expectations. In order to achieve uniformity in tenderness it is necessary to standardize the procedures of ante- and post-mortem handling of carcasses. In addition, injuries produced during the transportation or at lairage affect carcass temperature and pH (Gallo et al., 2003; Mota-Rojas et al., 2006) leading to changes in carcass shelf-life. Meat quality depends on both animal-related and environmental factors (Lammens et al., 2007) and these factors can affect muscle metabolism, thus lead to the two most well known inferior meat quality grades, namely dark, firm and dry (DFD), and pale, soft and exudative (PSE) meat.

2.4.7.4.2. Colour and meat quality

Meat purchasing decisions are influenced by colour more than any other quality factor because consumers use discoloration as an indicator of freshness and wholesomeness (Mancini and Hunt, 2005; Rosenvold and Anderson. 2003; Muchenje et al., 2008) of meat. Pre-slaughter conditions for the pigs have clearly shown their effect on both the initial colour of pork chops from longissimus dorsi muscle and their colour stability, lipid oxidation and drip loss during subsequent chill storage in light (Juncher et al., 2001). The colour of meat depends on the concentration of the meat pigments, essentially myoglobin, and the chemical state of myoglobin (Rosenvold and Anderson, 2003). Meat colour is determined by the relative amount of three myoglobin derivatives; (i) reduced myoglobin, deoxymyoglobin (Mb), which is the purple pigment of deep muscle and known from meat under vacuum, (ii) oxygenated myoglobin, oxymyoglobin (MbO2), which is bright cherry red and considered to signify fresh meat by the
consumer, and (iii) oxidised myoglobin, metmyoglobin (MetMb), which is grey-brown (Rosenvold and Anderson, 2003) (Figure 2.2).

Meat colour may be influenced by many factors, such as enzymes, diet and age of the animal and even the activity undertaken by the animal. For example, myoglobin, a protein, responsible for the majority of the red colour in meat, does not circulate in the blood but is fixed in the tissue cells and is purplish in colour (Muchenje et al., 2009b). The colour of meat can be measured by tricolorometric measurements e.g. the Lab systems, where L*, a* and b* are the colour coordinates reflecting lightness, redness and yellowness, respectively, in the defined colour room. The Lab-systems have been found to be appropriate to characterise meat colour and especially the a-value seems to correlate well to sensory properties of the meat (Rosenvold and Anderson, 2003).
Figure 2.2: Meat and Livestock Commission, British Nutrition Foundation 2004
2.4.7.4.3. Meat tenderness

Human perception of meat palatability is derived from a complex interaction of sensory and physical processes during chewing. Of the various subjective characteristics determining meat palatability, tenderness is the most important (Caine et al., 2003; King et al., 2006). According to Thompson (2002), meat tenderness is a function of production, processing, value adding and cooking method used to prepare the meat for consumption by the consumer. Failure of one or more links in the beef supply chain increases the risk of a poor eating experience for the consumer. Tenderness is also a highly variable characteristic, depending on many intrinsic and extrinsic factors of the animal and on their interaction. This wide variability is a limiting factor for consumer product acceptability (Destefanis et al., 2008), besides being a reason for consumer dissatisfaction and reduction in beef consumption. Therefore, tenderness inconsistency is a priority issue for the meat industry (Destefanis et al., 2008).

Accurately measuring and/or predicting beef tenderness has been a goal of meat scientists for the better part of a century (Yancey et al., 2010). The consumer would be willing to pay a higher price in the marketplace for beef as long as it is guaranteed tender (Destefanis et al., 2008; Yancey et al., 2010). Tenderness can be evaluated by objective methods, instrumental or sensorial with trained panels, or by subjective methods, with a consumer panel (AMSA, 1995). Predicting beef tenderness has become one of the most extensively researched areas in meat science. The Warner–Bratzler shear force (WBSF) method, which was developed in 1930, is still the most widely used objective measure of beef tenderness in research (Yancey et al., 2010). In spite of the success of WBSF, the protocol requires that a steak be cut from the carcass, aged,
cooked, and destroyed. Warner-Bratzler shear force (WBS) is an imprecise predictor of beef tenderness characteristics determined by trained panellists (Caine et al., 2003).

2.4.7.4.4. Conclusion

Transportation and pre-slaughter handling are very important, not only from a welfare point of view, but because they also have effects on pork quality thereby resulting in negative economic implications. When pigs are stressed, glycolysis rate increases which can result in poor meat quality after slaughter i.e. pale, soft and exudative (PSE) meat. DFD (dark, firm, dry) meat might be associated with a long period of stress. However, meat consumers, farmers as well as butcher owners needs to be well informed about the pre-slaughter conditions that might affect meat quality and income inputs. Furthermore, the different methods of improving meat eating quality pre-slaughter and consumer health also need to be evaluated in low throughput abattoirs since these abattoirs are supplying meat to the communities. In addition, it is necessary to determine consumer’s attitudes towards pork meat consumption from smallholder abattoirs to understand consumption patterns thereby enhancing human health.
8.5. References


Navarro, G., Gallo, C., Strappini, A., 2007. Efectos de la provisión de agua y disponibilidad de espacio sobre el comportamiento y variables sanguíneas durante el transporte prolongado de


Chapter 3: Technological quality attributes of pork from a small-holder abattoir as affected by breed, age and season of slaughter.

By

Christian Sabelo Gajana

Abstract

The objective of the current study was to determine the effect of breed, age group and season of slaughter on technological quality attributes of pork from a smallholder abattoir. Meat from the Large White had higher pHu and lower a* than values than meat from the Landrace. No breed differences were observed in lightness (L*), yellowness (b*), tenderness, thawing loss, cooking loss and evaporation loss values. Meat from pigs slaughtered in spring season had the highest (P<0.05) shear force values (27.6±1.58) while the lowest shear force values (18.5±1.58) were found in meat from pigs that were slaughtered in autumn season. The lowest pHu and highest a* values were found in meat from 9 months old pigs (5.3±0.07). The 6, 9 and 10 months had highest (P<0.05) than 7 and 8 months old pigs. Cooking loss and evaporation loss increased with age groups. The risks of PSE occurrences were more prevalent in autumn (37%) than other seasons of slaughter. WBSF, CL and EL values increased with age of an animal. It was concluded that pig breeds vary in pHu and considerations should be made on different seasons of slaughter when assessing pork quality. Precautions should also be made on age categories on animal, the younger the animal, the less force is needed to shear it, low CL and EL and therefore good quality meat.

Key words: ultimate pH, pork colour, tenderness, thawing loss, cooking loss, evaporation loss.
3.1. Introduction

The interaction of several ante-mortem and postmortem factors affect meat quality. Of all these factors the final end-point pHu and colour, WBSF values, thawing loss, cooking loss and evaporation loss are considered the most important in determining the quality of meat. Meat should have a desirable colour that is uniform throughout the entire cut and this can be influenced by pHu. The colour is related to the level of the protein pigment, myoglobin, present in the muscle. Meat should also have marbling (intramuscular fat) throughout the cut. Marbling increases juiciness, tenderness, and flavour of the meat. The major components of cooking losses are thawing loss (TL), dripping loss (DL) and evaporation loss (EL) (Barbantia and Pasquini, 2004; Obuz et al., 2004; Jama et al., 2008). Thawing losses are lower following a rapid freezing compared with slow freezing because of small crystallization formed by the rapid freezing (Hui, 2004). Evaporation loss changes the shape of meat through shrinkage and causes firmness and poor juiciness (Yu et al., 2005). Jeremiah et al. (1999) reported that cooking loss and WBSF were reasonable indicators of sensory panel palatability within a breed. However, there is limited information concerning the effect of animal age, breed and season on the major components of cooking loss.

Breed is one of the most important sources of variation in technological and sensory quality of pork. Breed and genetic effects on meat colour have been reported (Mancini and Hunt, 2005; Edwards et al., 2003). Brewer et al. (2004) evaluated several sire lines (Duroc, Synthetic, Duroc/Landrace, Pietrain, Duroc/Hampshire, and large white) and reported that genetic line affected loin chop two-toning, lightness, pinkness, and yellowness. Similarly, Edwards et al. (2003) suggested that Duroc progeny had more favourable visual colour, higher pH, and
increased redness than Pietrain sired pigs. Different breeds or lines may vary in their stress reactivity (Terlouw, 2005). Pigs of similar genetic type (but of different genetic make-up) and kept in the same rearing unit (but having different social and other experiences) show different stress reactivity (Terlouw, 2005). Therefore, the genetic influence on pork quality comprises differences among breeds as well as differences among animals within the same breed (Rosenvold and Andersen, 2005).

Season of slaughter has been shown to influence the welfare of pigs (Gosalvez et al., 2006). Extremes in summertime temperatures increased the risk of deaths on arrival (DOAs) and the risk of pale soft exudatives (PSE) (Gregory, 2010; Dalla Costa et al., 2007). Cold temperatures and poor vehicle design increase the incidence of bruised carcasses (dalla Costa et al., 2007). Therefore the time of year might be a medium stressor that acts independently from transport time (Maria et al., 2006). Hence, the seasonal temperatures are said to be the main reason for differences in meat quality (Kadim et al., 2008).

Increasing age of an animal at slaughter could result in an improvement of pork quality. Indeed, meat quality of older culled animals differs from that of hogs. For instance, sow meat is considered more appropriate for processing some dry cured products. However, little information is available on whether the variation in age and weight at slaughter, within usual commercial limits, may influence muscle characteristics and sensory quality of pork. Simultaneous increase in age and weight of pigs may result in a lower sensory quality of pork, in spite of elevated Intramuscular fat (IMF), possibly because of larger fibres and/or lower degree of post mortem proteolysis (Candek-Potokar, 1998).
Most studies on improving meat eating quality have been conducted in big commercial abattoirs (high throughputs) under high input large-scale production systems. However, the effect of different pig breeds, age and season of slaughter on improving meat eating quality and consumer health also need to be evaluated in smallholder abattoirs (low throughputs) where most of the delivered animals for slaughter are from low input production systems. With Eastern Cape having 88 red meat abattoirs, 48 of them are smallholder abattoirs (low throughputs) supplying more meat to the local butcheries and consumers. Therefore, information on how age, breed and season of slaughter affect pork quality in low input systems will help local butcheries, farmers and consumers better understand the effects of these variables; thereby improving their productions systems and financial returns (profit). Hence, the objective of this study was to determine the effects of breed, age, season of slaughter on technological quality attributes of pork.
3.2. Materials and methods

3.2.1. Description of study Site

The study was conducted at Adelaide Municipal Abattoir under Nxuba local municipality in the Amatole District Municipality. The small town of Adelaide lies on the R73 between Bedford and Fort Beaufort towns, and nestles in the foothills of the majestic Winterberg Mountain range in the heart of the Eastern Cape Midlands, South Africa. The slaughterhouse is located approximately 60 km west of the University of Fort Hare and the road is paved. It is approximately 740 m above sea level. It is located 33.30 °S latitude and 26.30 °E longitudes. It is situated in the False Thornveld of the Eastern Cape, and has a diversity of vegetation ranging from grasslands and thicket to forests and bushveld.

3.2.2. Carcass pH, temperature and colour determination

The pH and temperature measurements were performed 24 hours after slaughter on carcasses from Landrace and Large White using a pH meter (Crisson pH 25, Crison instruments, S.A., Alella, Spain). The pH meter was calibrated with pH 4 and pH 7 standard solutions. Carcasses with pH24 between 5.5 and 5.8 were classified into normal pork quality (i.e., red, firm and nonexudative (RFN)). Lower than 5.5 were classified into pale soft exudative pork (PSE). Higher than 5.8 were classified as dark firm dry (DFD) pork (Ninna Costa et al., 1999; Kortz, 2001). The carcasses were identified in slaughter sequence for temperature sampling (T24) and pH24. Both measurements were done on the Longissimus dorsi muscle (central area of the loin) on the right side of the carcass, at the level of the tenth and eleventh ribs.

Colour of the meat ($L^*$ = Lightness, $a^*$ = Redness and $b^*$ = Yellowness) was also determined 24 hours after slaughter using a Minolta colour-guide 45/0 BYK-Gardener GmbH machine, with a
20 mm diameter measurement area and illuminant D65-day light, 10° observation angle. Three readings were taken by rotating the Colour Guide 90° between each measurement, in order to obtain a representative average value of the colour. The guide was calibrated before each day’s measurements using the green standard.

### 3.2.3. Thawing loss, cooking loss and evaporation loss determination

Percentage thawing loss, cooking loss and evaporation loss were calculated as follows:

Immediately after slaughter before freezing, the samples from *Longissimus dorsi* were weighed. The samples were thawed over a period of 24 h at 0 - 4°C and weighed again.

- **Thawing loss** = \( \frac{\text{(weight before thaw - weight after thaw)}}{\text{weight before thaw}} \times 100 \).
- **Cooking loss** = \( \frac{\text{(weight of raw steak after thawing - weight of cooked steak)}}{\text{weight of raw steak after thawing}} \times 100 \).
- **Evaporation loss** = 100 - \( \frac{\text{(weight after cooking)}}{\text{raw weight}} \) × 100

### 3.2.4. Warner Bratzler Shear Force determination

The samples to be used for shear force resistance were vacuum packed and either frozen directly. A day before preparation, samples to be used were measured and vacuum packed and thawed over 24 h at 0–4 °C. The steaks were prepared in plastic bags and cooked using a water bath at 85°C for 45 minutes (Ding et al., 2010). Raw and cooked weights were recorded. The tenderness of pork was determined using Instron- Warner-Bratzler Shear Force (WBSF). Following cooking, sub samples of specified core diameter were cored parallel to the grain of the meat. The samples were sheared perpendicular to the fibre direction using a Warner Bratzler (WB) shear device mounted on an Instron 3344 Universal Testing (cross head speed at 400mm/min, one shear in the centre of each core. The mean maximum load (N) was recorded for the batch.
3.2.5. Statistical analysis

The PROC GLM procedure of statistical Analysis Systems (SAS) Institute (2003) was used to analyse the effect of breed, age and season on colour (L*, a*, b*), pHu, cooking loss (CL), thawing loss (TL) and evaporation loss (EL). The model used was as follows:

\[ Y_{ijkl} = \mu + B_i + A_j + S_k + E_{ijkl} \]

Where \( Y_{ijkl} \) = response variable (pHu, L*, a*, b*, CL, TL, EL)

- \( \mu \) = constant mean common to all observations
- \( B_i \) = effect of breed
- \( A_j \) = effect of age group (6, 7, 8, 9 and 10 month-old pigs)
- \( S_k \) = effect of season
- \( E_{ijkl} \) = random error

Comparisons of means were analyzed by least significance difference (LSD, SAS, 2003).
3.3. Results

3.3.1. Effect of breed on technological properties of pork

Table 3.1 shows the effects of breed on pHu, L*, a*, b* and technological properties. Meat from the Large White had higher pHu values than meat from the Landrace while meat from the Landrace had higher values for a* than meat from the Large White. No breed differences were observed in the L*, b*, WBSF values, thawing loss, cooking loss and evaporation loss.
Table 3.1: Effects of different breeds on technological meat quality attributes

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Landrace</th>
<th>Large white</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>pHu</td>
<td>5.5 ± 0.21</td>
<td>5.7 ± 0.78</td>
<td>**</td>
</tr>
<tr>
<td>L*</td>
<td>48.7 ± 0.46</td>
<td>50.1 ± 1.71</td>
<td>NS</td>
</tr>
<tr>
<td>a*</td>
<td>7.7 ± 0.19</td>
<td>6.03 ± 0.68</td>
<td>*</td>
</tr>
<tr>
<td>b*</td>
<td>10.4 ± 0.19</td>
<td>10.1 ± 0.74</td>
<td>NS</td>
</tr>
<tr>
<td>WBSF</td>
<td>24.3 ± 0.64</td>
<td>21.2 ± 2.37</td>
<td>NS</td>
</tr>
<tr>
<td>TL (%)</td>
<td>11.0 ± 0.56</td>
<td>8.1 ± 2.08</td>
<td>NS</td>
</tr>
<tr>
<td>CL (%)</td>
<td>30.1 ± 1.14</td>
<td>34.1 ± 4.25</td>
<td>NS</td>
</tr>
<tr>
<td>EL (%)</td>
<td>37.5 ± 1.14</td>
<td>39.4 ± 4.24</td>
<td>NS</td>
</tr>
</tbody>
</table>

* P < 0.05; ** P < 0.01; NS: not significant
3.3.2. Effect of Season on technological properties of pork

Table 3.2 shows the effects of season on pHu, L*, a*, b* and technological properties of pork. Meat from pigs slaughtered in spring had the highest pHu values and the lowest pHu values were observed in meat from pigs slaughtered during the autumn season. However, there were no significant seasonal differences in the L*, a*, b* values of pork. Meat from the pigs slaughtered in spring season had the highest (P<0.05) WBSF values and the lowest WBSF values were found in meat from the pigs that were slaughtered in autumn.
Table 3.2: Effects of different seasons on technological quality attributes

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Autumn</th>
<th>Spring</th>
<th>Summer</th>
<th>Winter</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pHu</td>
<td>5.4±0.05\textsuperscript{a}</td>
<td>5.8±0.05\textsuperscript{b}</td>
<td>5.6±0.06\textsuperscript{b}</td>
<td>5.6±0.05\textsuperscript{b}</td>
<td>0.0001</td>
</tr>
<tr>
<td>L\textsuperscript{*}</td>
<td>48.7±1.16\textsuperscript{a}</td>
<td>49.6±1.14\textsuperscript{a}</td>
<td>50.2±1.27\textsuperscript{a}</td>
<td>49.1±1.20\textsuperscript{a}</td>
<td>0.61</td>
</tr>
<tr>
<td>a\textsuperscript{*}</td>
<td>6.8±0.47\textsuperscript{a}</td>
<td>6.6±0.46\textsuperscript{a}</td>
<td>6.1±0.51\textsuperscript{a}</td>
<td>8.0±0.48\textsuperscript{b}</td>
<td>0.0310</td>
</tr>
<tr>
<td>b\textsuperscript{*}</td>
<td>9.8±0.50\textsuperscript{a}</td>
<td>10.5±0.49\textsuperscript{ab}</td>
<td>9.2±0.55\textsuperscript{a}</td>
<td>11.6±0.52\textsuperscript{b}</td>
<td>0.0038</td>
</tr>
<tr>
<td>WBSF</td>
<td>18.5±1.61\textsuperscript{a}</td>
<td>27.6±1.58\textsuperscript{c}</td>
<td>21.5±1.76\textsuperscript{a}</td>
<td>23.3±1.66\textsuperscript{b}</td>
<td>0.0001</td>
</tr>
<tr>
<td>TL (%)</td>
<td>13.7±1.41\textsuperscript{c}</td>
<td>9.5±1.39\textsuperscript{b}</td>
<td>9.6±1.55\textsuperscript{b}</td>
<td>6.1±1.46\textsuperscript{a}</td>
<td>0.0001</td>
</tr>
<tr>
<td>CL (%)</td>
<td>30.1±2.87\textsuperscript{a}</td>
<td>35.6±2.82\textsuperscript{b}</td>
<td>34.2±3.14\textsuperscript{b}</td>
<td>28.7±2.96\textsuperscript{a}</td>
<td>0.0704</td>
</tr>
<tr>
<td>EL (%)</td>
<td>38.6±2.87\textsuperscript{b}</td>
<td>42.2±2.83\textsuperscript{b}</td>
<td>40.2±3.15\textsuperscript{b}</td>
<td>32.9±2.97\textsuperscript{a}</td>
<td>0.0393</td>
</tr>
</tbody>
</table>

\textsuperscript{a,b,c} Differences between the means of treatment groups carrying various letters in the same row are significant (*\textit{P} < 0.05). Seasonal division is as follows:

Summer: November, December and January

Autumn: February, March and April

Winter: May, June and July

Spring: August, September and October
3.3.3. Effect of Age on technological properties of pork

Table 3.3 shows for the effects of age on pHu and meat colour. Meat from 9 month-old pigs had the lowest pHu values, whilst meat from 10 month-old pigs had the highest pH values. No significant differences were found in L* values of different age categories. Means for a* values for 6, 7, 8 and 10 months old pigs were not significantly different from each other. Meat from 9 month-old pigs had the highest a* values, while meat from 8 month-old pigs had the lowest values. 6, 9 and 10 months old pigs had the highest b* values than 7 and 8 months old pigs which showed the least b* values. The highest WBSF values were found in pigs slaughtered between 6, 9, and 10 months old then 7 and 8 months old pigs which shared the same superscript. There were no differences in shear force values between 7 and 8 months old pigs although lower shear force values were observed in 7 months old pigs. Lower (P<0.05) cooking loss and evaporation loss were observed in 6 months old pigs than 7, 8, 9 and 10 months old pigs.
Table 3.3: Effects of different age categories on technological quality attributes

<table>
<thead>
<tr>
<th>Parameters</th>
<th>6 months</th>
<th>7 months</th>
<th>8 months</th>
<th>9 months</th>
<th>10 months</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pHu</td>
<td>5.5±0.07a</td>
<td>5.7±0.05b</td>
<td>5.5±0.05a</td>
<td>5.3±0.07a</td>
<td>5.8±0.05b</td>
<td>0.0001</td>
</tr>
<tr>
<td>L*</td>
<td>50.1±1.58a</td>
<td>49.1±1.03a</td>
<td>49.8±1.18a</td>
<td>48.3±1.44a</td>
<td>49.7±1.13a</td>
<td>0.7872</td>
</tr>
<tr>
<td>a*</td>
<td>7.0±0.63a</td>
<td>6.6±0.41a</td>
<td>6.1±0.47a</td>
<td>8.0±0.58b</td>
<td>6.7±0.45a</td>
<td>0.0632</td>
</tr>
<tr>
<td>b*</td>
<td>10.7±0.68ab</td>
<td>9.4±0.44a</td>
<td>9.2±0.51a</td>
<td>11.0±0.63b</td>
<td>11.0±0.48b</td>
<td>0.0044</td>
</tr>
<tr>
<td>WBSF</td>
<td>17.8±2.18a</td>
<td>25.3±1.42b</td>
<td>21.3±1.63ab</td>
<td>24.4±1.99b</td>
<td>25.0±1.56b</td>
<td>0.0025</td>
</tr>
<tr>
<td>TL (%)</td>
<td>10.6±1.91a</td>
<td>9.9±1.28a</td>
<td>9.3±1.43a</td>
<td>10.1±1.75a</td>
<td>8.7±1.37a</td>
<td>0.8011</td>
</tr>
<tr>
<td>CL (%)</td>
<td>21.0±3.87a</td>
<td>35.3±2.53b</td>
<td>36.8±2.90b</td>
<td>34.9±3.55b</td>
<td>32.7±2.78b</td>
<td>0.0017</td>
</tr>
<tr>
<td>EL (%)</td>
<td>29.0±3.88a</td>
<td>41.7±2.54b</td>
<td>40.9±2.91b</td>
<td>41.4±3.57b</td>
<td>39.3±2.79b</td>
<td>0.0175</td>
</tr>
</tbody>
</table>

*a,b,c* Differences between the means of treatment groups carrying various letters in the same row are significant (*P < 0.05).
3.3.4: Chi square test for association between seasons and pHu classes

On a pHu classes of 5.5-5.8 (with pH >5.8 high representing occurrences of DFD cuts and pH <5.5 low representing occurrences of PSE meat), an association between seasons and pHu classes was observed (Table 3.4). Highest (P<0.001) incidences of PSE carcasses were associated with autumn season. The association for the spring, summer and winter seasons of slaughter and pHu classes was poor (P<0.01), more carcasses were associated with pH 5.5-5.8 normal meat cuts. In total, 70 carcasses were associated with PSE, 65 carcasses were associated normal meat cuts and 23 carcasses had DFD problems
Table 3.4: Chi square test for association between seasons and pHu classes

<table>
<thead>
<tr>
<th>Parameters</th>
<th>pH &gt;5.8 high (DFD)</th>
<th>pH 5.5-5.8 normal</th>
<th>pH &lt;5.5 low (PSE)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autumn</td>
<td>2</td>
<td>15</td>
<td>37</td>
<td>54</td>
</tr>
<tr>
<td>Spring</td>
<td>11</td>
<td>23</td>
<td>11</td>
<td>45</td>
</tr>
<tr>
<td>Summer</td>
<td>2</td>
<td>14</td>
<td>12</td>
<td>28</td>
</tr>
<tr>
<td>Winter</td>
<td>8</td>
<td>13</td>
<td>10</td>
<td>31</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>65</td>
<td>70</td>
<td>158</td>
</tr>
</tbody>
</table>

Seasonal divisions are as follows:

Summer: November, December and January

Autumn: February, March and April

Winter: May, June and July

Spring: August, September and October
3.4. Discussion

The pHu is determined by the extent of the pH decline at 24 hours after slaughter. The variation in pHu influences the factors such as meat colour and the ability of meat to retain water. In this study the lower ultimate pH (pHu) values were reported in Landrace than in Large White, even though they were within the normal pH range for pork. The differences in pH values between Large White and Landrace are most likely to be due genetic factors. Stress, prior to slaughter, is said to be one of the most important influences on pHu and ultimate meat tenderness (Muchenje et al., 2009). It may result from transportation, rough handling, inclement temperatures, or anything that causes the animal to draw on its glycogen reserves before slaughter (Muchenje et al., 2009). Differences in meat colour were reported to be associated with variations in intramuscular fat and moisture contents (Lambooij, 2000). Furthermore, increased \( a^* \) is attributed to genotype effects on increased drip loss and oxymyoglobin concentration (Fabrega et al., 2002). Redness differences between alleles at the PRKAG3 (RN) locus are due to myoglobin redox state, oxymyoglobin stability, and metmyoglobin reductase activity (Lindahl et al., 2004).

The absence of breed effects on L*, b*, WBSF, TL, CL and is most likely to be due to different genetic makeup on these two breeds. Rosenvold and Andersen (2005) found no significant effects on lightness or redness of meat from different breeds. Similarly Cassens (2006) found no breed effects on colour. The presence of the halothane allele (Nn or nn; Channon et al., 2000) detrimentally affects pork colour (increased paleness) and protein denaturation (increased transmittance; Piedrafita et al., 2001).

Season had a significant influence on pHu, with low pHu reported in autumn season than other seasons. The high incidence of pork with low pHu registered in this study indicates
environmental factors should be taken into account whenever the effects of seasonal conditions on pork quality are evaluated (dalla Costa et al., 2007). In the current study the Highest (P<0.001) number and carcass percentages with the incidence of PSE were reported on pigs slaughtered during autumn (37%) than other seasons. This can be attributed to the variations in environmental conditions with seasons. Temperature; humidity; draught; weather (e.g. snow, rain, sun) have been shown to be important to consider when assessing the potential welfare risks to animals during road transport (Nielsen et al., 2010). Although Guardia et al. (2004) stated that PSE prevalence is expected to be higher in summer than other seasons; Maria et al. (2006) indicated the lowest prevalence of PSE in winter whilst Van de Perre et al. (2010) reported higher prevalence of PSE in summer than in spring or autumn. Guise and Penny (1989) and Lambooij and Engel (1991) reported that when pigs kept in environments with low temperatures, pigs group together to reduce heat loss. However, huddling behaviour reduces the space allowance leading pigs to fight or climb over the backs of other pen-mates to seek a place to rest, hence the higher incidence of pork with lower pHu in winter.

Season affected the WBSF values, with lowest WBSF values recorded in autumn (18.5) and highest WBSF values were reported in spring (27.6) season. Our findings suggest that WBSF values might be a consequence of the low pHu registered in autumn. Muchenje et al. (2008) reported no significant relationship between a meat tenderness and pH, although Byrne et al. (2000), Strydom et al. (2000) and Vestergaard et al. (2000) showed that meat tenderness is related to ultimate pH (pHu) value and meat colour. Warner–Bratzler shear force is accepted as a good predictor of tenderness observed sensorial and could be used as a criterion to determine meat acceptability (Sanudo et al., 2003). Meat tenderness and texture are important factors for
consumers since they determine the commercial value of the meat and the way it will be cooked (Lepetit & Culioli, 1994).

Season of slaughter had a significant influence on the major components of cooking loss, with highest TL values reported in autumn (13.7) and lowest in winter (6.1). Small differences were also observed on EL values with seasons. The differences in cooking and thawing losses in the current study and those reported by other authors may be attributed to several factors such as differences in ageing, cooking method applied, cooking temperatures, duration of cooking temperatures, pH and Marbling (Jama et al., 2008; Yu et al., 2005).

Age had a significant influence on pHu, with highest (P<0.05) pHu values from 7 and 10 month-old pigs than 6 and 8 month-old pigs, but 9 month-old pigs having the lowest pHu values. These results can be attributed to the fact that an animal’s behaviour differs with an animal’s age and the stage of growth (Terlouw et al., 2009). The lower pHu values measured in younger pigs (6 and 8 months) and older pigs (9 months) might reflect higher glycogen usage during the pre-slaughtering phases. Meat from 9 months old pigs showed high a* values compared to all age categories (6, 7, 8 and 10 months) having light meat than 9 months. These results are most likely to be due to the different state and concentrations of myoglobin of different ages.

Age at slaughter significantly affected the WBSF values, with low WBSF values reported in 6 month-old pigs than the older pigs suggested that WBSF values increases with an age of an animal. Sources of tenderness variation in beef for instance may be attributed to animal’s age, sex, liveweight; breed and ante-mortem stress (Muchenje et al., 2009). Meat tenderness is a
function of the collagen content, heat stability and the myofibrillar structure of muscle (Muir et al., 2000), and these appear to be affected mainly by the rate of growth of the animal rather than the breed per se (Muchenje et al., 2009). In the current study, total CL and EL increased with age suggesting increased denaturation of protein with age, or increased cross-linking of collagen with age, resulting in decreased water-holding capacity with increased moisture loss upon heating or cooking (Schonfeldt & Strydom, 2011). Therefore, the ability of the muscle to retain water decreases with increased age leading in higher cooking losses in cuts from older animals, with an associated drier end-product, without the rapid release of meat fluid during the first few chews as found in meat from young animals (Schonfeldt & Strydom, 2011).

3.5. Conclusion

It can be concluded that pig breeds vary in pHu and considerations should be made on different seasons of slaughter when assessing pork quality. Precautions should also be made on age categories on an animal, the younger the animal, the less force is needed to shear it, low CL and EL and therefore good quality meat. Meat quality can also be affected by pre-slaughter conditions; therefore, further investigation needs to be done on the effects of transportation time, distance, stocking density, temperature and lairage time on technological quality attributes of pork from small holder abattoirs.
3.6. References


Chapter 4: Effects of transportation time, distance, stocking density, temperature and lairage time on technological properties of pork

By

Christian Sabelo Gajana

Abstract

The current study determined the effects of transportation time, distance, stocking density, temperature and lairage time on technological quality attributes of pork. A total of 158 pork samples were evaluated for physico-chemical meat attributes. Principal component (PC) analysis was performed in order to examine the technological quality attributes of pork (n=9) traits. Only a positive (P < 0.05) relationship between distance and transportation time was observed on TL% of pork whilst no significant relationship was reported between all the other pre-slaughter variables and technological quality attributes of pork. Highest risks of PSE occurrences were observed with more space allowance of 0.4 m$^2$ per 100 kg during transportation. Reduced risks of PSE occurrences were observed with space allowance of 0.35 m$^2$ per 100 kg. The pHu values were positively correlated to WBSF values (P < 0.001). The L* value were positively correlated to b* (P < 0.001), and negatively correlated to a* values while CL and EL were positively correlated to L*. In the current study, transportation time, distance, stocking density, temperature and lairage time did not show significant relationship with technological quality attributes measured in this study; except for transportation time and distance travelled which had a positive relationship with TL%. The risks of PSE occurrences are dependent on stocking density and transportation time.

**Key words:** Principal component analysis, PSE, DFD, pHu and WBSF values, correlations
4.1. Introduction

Appropriate pre-slaughter handling of pigs is very important, not only from a welfare point of view, but also from a pork quality point of view. The way animals respond to pre-slaughter stress depends on breed, age and the season of slaughter (Chapter 3). Pre-slaughter handling includes crowding, loading and unloading, adverse weather conditions, feed and water deprivation, lairage, length of travel, mixing animals from different groups, restraint, and fatigue are the causatives of stress (Ritter et al., 2007; Dalla Costa et al., 2007; Adenkola et al., 2008). Indicators of pre-slaughter stress are commonly evaluated in terms of behaviour, biochemical function, endocrine and pathological variables (Ferlazzo, 2003). When pigs are stressed, their glycogen content is reduced thus, leads to lower lactic acid production and therefore results in meat with higher ultimate pH (pH\textsubscript{u}) (Ndou et al., 2011; Muchenje et al., 2009). Muscles with higher ultimate pH are not ideal to be converted to meat due to acidity that leads to dark colour in final meat product (Purchas et al., 2002). An ideal ultimate pH for meat ranges from 5.5-5.8 (Ninna Costa et al., 1999). This pH produces the neutral and desirable properties for table cuts (Simmons et al., 2000). However, variation in ultimate pH influences the meat quality characteristics such as colour, shelf-life, water holding capacity and technological yields (Gispert et al., 2000).

Meat colour is the most important factor affecting consumer acceptance, purchasing decisions and satisfaction of meat products (Juncher et al., 2001; Muchenje et al., 2008). Colour measurements are done using the Commission International De l’ Eclairage (CIE) colour system (Commission International De l’ Eclairage, 1976). The three fundamental colour coordinates are L*, a* and b*. The L* measure the lightness and is a measure of the light reflected (100 =
white; 0 = black); a* measures positive red, negative green and b* measures positive yellow, negative blue (Commission International De l’ Eclairage, 1976). Carcasses with L* value 49-60 were classified as normal pork quality, L* values from 42-48 were classified as DFD pork and carcasses with L* values 60-66 were classified as pale soft exudative (PSE) pork (Warriss & Brown, 1993, 1995). However, when the muscle glycogen has been used up rapidly during the handling, transport and pre-slaughter period, after slaughter there is little lactic acid production which results in DFD meat, and this condition is measured by L* coordinates (Commission International De l’ Eclairage, 1976).

Pigs managed according to a chain assurance quality protocol to avoid established risk factors during transport and lairage by the control of parameters such as the driver’s experience, transport time, stocking density on truck, offloading time, group size in lairage, stocking density and lairage time, showed better potential for improved meat quality through the slaughterhouse procedures (Lammens et al., 2007). The meat quality response to pig handling in the 24 hours before slaughter is very important in determining the yield of the carcass and the technological quality of meat for the processing industry (Alvarez et al., 2009). There is no doubt that poor environmental conditions during pre-slaughter handling, while the animals are still alive, can irreversibly affect the quality of the meat. Furthermore, quality can be improved with the knowledge of these processes and guaranteed only through adequate control of different stages before slaughter (Alvarez et al., 2009).

There are no common recommendations in the literature for ideal pre-slaughter handling procedures for achieving the highest quality and yield of pork meat from small holder abattoirs.
Most studies on improving meat eating quality have been conducted in high input large-scale production systems. However, the different pre-slaughter handling procedures of improving meat eating quality and consumer health also need to be evaluated in low input production systems. Hence, the objective of this study was to determine the effects of pre-slaughter handling on pork quality from smallholder abattoir by measuring the ultimate pH and meat colour from pigs delivered for the slaughter at a smallholder abattoir.
4.2. Materials and methods

4.2.1. Description of study Site

The study site is the same as explained in the previous section 3.2.1 of Chapter 3

4.2.2. Data collection procedures

A variety of pigs was monitored through deliveries at the slaughterhouse. The slaughterhouse was visited on two consecutive days twice a month: on the first day, handling of pigs prior to slaughter (i.e., transportation time, distance from farm to abattoir, stocking density, lairage duration and day temperature) was recorded. On the second day meat pHu and colour was measured at 24 h post-mortem.

4.2.3. Determination of transportation time and distance from farm to abattoir

The drivers were interviewed through the aid of structured questionnaires in order to have an idea of the driving experience and start of the transport. Transport time and unloading time was obtained by calculating the time between the beginning of the journey and arrival at the abattoir. Lairage duration was determined as the time between the time of arrival at the abattoir and the beginning of the slaughter process. Information about stocking density, the number of pigs per compartment, the number of dead pigs on arrival, the number of emergency slaughtering, and the size (length, width, height) of a lorry compartment, the type of springs, mechanical ventilation and bedding material were recorded.

4.2.4. Carcass pH, temperature and colour determination

Determination of pHu, colour (L*, a* and b*), cooking and thawing loss percentage and WBSF are the same as detailed in section 3.2.2 of Chapter 3.
4.2.5. Statistical analysis

The effects of distance, stocking density, temperature and lairage time; on colour and pH was analyzed using the regression analysis with distance (\(\chi_1\)), stocking density (\(\chi_2\)), temperature (\(\chi_3\)) and lairage time (\(\chi_4\)) as the independent variables whilst L*,a*,b* and pHu where the dependent variables. The strength of relationships between technological quality attributes were determined using Pearson’s correlation coefficient (SAS, 2003). Principal Component Analysis (PCA) was used to interpret the relationship between technological quality attribute of pork (SAS, 2003).
4.3. Results

4.3.1: Effect of varying distance, transportation time, temperature, lairage time and stocking density on technological quality attributes of pork

Linear regression analysis for the effect of distance, temperature, lairage and stocking density on technological quality attributes of pork are presented in Table 4.1. Distance and transportation time had negative effects on TL%. In this study, no significant relationship was reported between all the pre-slaughter variables (transportation time, distance, stocking density, temperature and lairage time) and technological quality attributes (pHu, L*, a*, b*, WBSF, TL, CL and EL) of pork.
Table 4.1: Effect of varying, transportation times, lairage time, stocking density, temperature and distance on technological quality attributes of pork

<table>
<thead>
<tr>
<th>Variables</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>pHu</td>
<td>$Y = 5.91(0.0001) - 0.05(0.24)X_1 - 0.10(0.24)X_2 - 0.06(0.09)X_3 - 0.01(0.05)X_4 + 0.01(0.80)X_5$</td>
</tr>
<tr>
<td>L*</td>
<td>$Y = 72.6(0.001) + 0.23(0.75)X_1 - 0.96(0.50)X_2 + 0.28(0.63)X_3 + 0.05(0.46)X_4 - 0.45(0.13)X_5$</td>
</tr>
<tr>
<td>a*</td>
<td>$Y = 8.74(0.22) + 0.03(0.93)X_1 + 0.03(0.97)X_2 + 0.18(0.45)X_3 - 0.02(0.60)X_4 - 0.01(0.95)X_5$</td>
</tr>
<tr>
<td>b*</td>
<td>$Y = 18.58(0.02) + 0.13(0.69)X_1 + 0.20(0.76)X_2 - 0.31(0.23)X_3 + 0.01(0.80)X_4 - 0.15(0.27)X_5$</td>
</tr>
<tr>
<td>WBSF</td>
<td>$Y = -13.3(0.62) - 0.26(0.83)X_1 + 0.19(0.93)X_2 + 0.21(0.81)X_3 - 0.13(0.28)X_4 + 0.79(0.10)X_5$</td>
</tr>
<tr>
<td>TL</td>
<td>$Y = -48.9(0.030) + 3.2(0.001)X_1^{**} + 1.07(0.55)X_2 - 0.45(0.54)X_3 + 0.16(0.10)X_4 + 0.83(0.03)X_5^{*}$</td>
</tr>
<tr>
<td>CL</td>
<td>$Y = -1.01(0.98) + 1.62(0.41)X_1 + 2.13(0.56)X_2 - 0.47(0.75)X_3 - 0.24(0.21)X_4 + 0.59(0.45)X_5$</td>
</tr>
<tr>
<td>EL</td>
<td>$Y = -27.8(0.52) + 2.98(0.12)X_1 + 3.92(0.27)X_2 - 0.72(0.62)X_3 - 0.18(0.34)X_4 + 1.08(0.16)X_5$</td>
</tr>
</tbody>
</table>

*Significant (P<0.05), ** significant (P<0.001)

Y: pH, L*, a*, b*, WBSF, TL, CL, EL

$X_1 = $ transportation time; $X_2 = $ lairage time; $X_3 = $ stocking density; $X_4 = $ temperature; $X_5 = $ distance
4.3.2: Effect of transportation time and stocking density on risks of PSE occurrences in pork meat.

The Risk of PSE pork meat according to transportation time and stocking density during transportation (0.25–0.4 m\(^2\)/100 kg pig) are presented in Figure 4.1. There were differences in risks of PSE occurrences with transportation time and stocking density. Highest risks of PSE occurrences were observed when space allowance during transportation was increased by 0.4 m\(^2\) per 100 kg. The lowest risks of PSE occurrences were observed when moderate space allowance of 0.35 m\(^2\) during transportation was given.
Figure 4.1: Risk of PSE pork meat according to transportation time and stocking density during transportation (0.25–0.4 m²/100 kg pig).
4.3.3: Pearson’s correlation coefficients between technological qualities attributes of pork

Correlations between the individual technological qualities attributes variables, which were low to moderate and a lot of correlations were not significant (P > 0.05) are presented in Table 4.4. Ultimate pH was positively correlated to WBSF (r = 0.29) but negatively correlated to TL (r = -0.20). The L* values were negatively correlated to a* (r = -0.33), positively correlated to b*, CL (r = 0.21), EL (r = 0.19). The redness (a*) values were positively correlated to b* (r = 0.35) but negatively correlated to EL (r = -0.17). The b* values were positively correlated to CL (r = 0.19) and EL (r = 0.16). The WBSF values were positively correlated to CL (r = 0.18) and EL (r = 0.19). The TL were also positively correlated to EL (r = 0.30). The CL were positively correlated to EL (r = 0.89).
Table 4.2: Pearson’s correlation coefficients between technological quality attributes of pork

<table>
<thead>
<tr>
<th></th>
<th>T24</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>WBSF</th>
<th>TL</th>
<th>CL</th>
<th>EL</th>
</tr>
</thead>
<tbody>
<tr>
<td>pHu</td>
<td>0.04</td>
<td>-0.10</td>
<td>-0.08</td>
<td>-0.12</td>
<td>0.29***</td>
<td>-0.20*</td>
<td>-0.01</td>
<td>-0.03</td>
</tr>
<tr>
<td>T24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L*</td>
<td></td>
<td>-0.07</td>
<td>0.02</td>
<td>-0.06</td>
<td>0.03</td>
<td>0.02</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>a*</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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<td>b*</td>
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<tr>
<td>WBSF</td>
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<td></td>
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<tr>
<td>TL</td>
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<td>CL</td>
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<tr>
<td>EL</td>
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</tr>
</tbody>
</table>

Significantly correlated at *P < 0.05, **P < 0.01, ***P < 0.001
4.3.4: Principal component analysis for the technological quality attributes of pork

The results of the PC analysis are presented in Table 4.5 and in Figure 4.1 for technological quality attributes. The first four PCs explain about 95% of the total variation for technological quality attributes measurements (47%, 31%, 9% and 8%, respectively). In other words, 95% of the total variance for technological quality attributes, in the 9 considered variables can be condensed into four new variables (PCs). The radar plot (Figure 4.3) shows that for the first component (46.88% explained variation) the most important variables were: cooking loss and evaporation loss. The second component (30.91% explained variation) was defined by two variables (Lightness L*, redness a*). For the third component (9.29% explained variation) the most important variable was yellowness b*.
Table 4.3: Results from the principal component analysis for the principal components of pork technological quality attribute measurements.

<table>
<thead>
<tr>
<th>Component</th>
<th>Eigenvalue</th>
<th>Portion of variance (%)</th>
<th>Cumulative variance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>232.32</td>
<td>46.88</td>
<td>46.88</td>
</tr>
<tr>
<td>2</td>
<td>153.20</td>
<td>30.91</td>
<td>77.78</td>
</tr>
<tr>
<td>3</td>
<td>46.03</td>
<td>9.29</td>
<td>87.07</td>
</tr>
<tr>
<td>4</td>
<td>40.06</td>
<td>8.08</td>
<td>95.15</td>
</tr>
<tr>
<td>5</td>
<td>18.09</td>
<td>3.65</td>
<td>98.80</td>
</tr>
<tr>
<td>6</td>
<td>4.52</td>
<td>0.91</td>
<td>99.72</td>
</tr>
<tr>
<td>7</td>
<td>1.06</td>
<td>0.21</td>
<td>99.93</td>
</tr>
<tr>
<td>8</td>
<td>0.28</td>
<td>0.06</td>
<td>99.99</td>
</tr>
<tr>
<td>9</td>
<td>0.06</td>
<td>0.01</td>
<td>100</td>
</tr>
</tbody>
</table>
Figure 4.2: Scree Plot of Eigenvalues for the technological quality attributes of pork measurements
Figure 4.3: Radar diagram for technological quality attributes of pork.
4.4. Discussion

In this study, no significant relationship was reported between all the pre-slaughter variables and technological quality attributes of pork (Table 4.1). Only distance and transportation time had a positive relationship with TL% of pork. Lack of relationship between pre-slaughter variables and technological quality attributes of pork may be attributed to the lack of variation in distance travelled from farm to abattoir; all the pigs brought for slaughter came from one farm (56 km away from the abattoir) and were almost of the same breed, same production system, same truck and driver. Under the controlled commercial conditions of a study by Maria et al., 2003 (same type of animal, same age, same production system and same vehicle and driver), transport time of up to 6 h did not significantly affect the instrumental quality of meat.

In the present study, pHu was positively correlated to WBSF values (P < 0.001). This may be attributed to the pre-slaughter glycogen depletion which may result in meat with a higher ultimate pH (pHu) (Kannan, Chawan, Kouakou, & Gelaye, 2002) and dark colour (Purchas, Yan, & Hartly, 1999) and therefore tough meat that will require more force to shear it. Meat tenderness is related to ultimate pH (pHu) value and meat colour (Byrne et al., 2000; Strydom et al., 2000; Vestergaard et al., 2000), although there are some cases where such relationships may not be significant (Muchenje et al., 2008). An increase in pHu does not necessarily result in tougher meat as other parameters with regard to meat tenderness may be involved (Muchenje et al., 2008). Tenderness varies, mainly due to changes to the myofibrillar protein structure of muscle in the period between animal slaughter and meat consumption (Muir et al., 2000; Muchenje et al., 2009).
The lightness of the meat colour (L*) was positively correlated with b* (P < 0.001), and negatively correlated with a*. The CL and EL values were positively correlated with L*. McCann et al. (2008) reported positive correlations between a*, b* and chroma (P < 0.001), L* was negatively correlated to pHu (P < 0.05) as were b* and chroma. Strong correlations were observed between a* and values for b*, chroma and hue. In the current study, a* values were positively correlated to b* (P < 0.001) but negatively correlated with EL (P < 0.01). There were positive correlation between CL and EL. Both CL and EL were positively correlated between WBSF values.

The results of the present study indicate that increase in transport time increase the incidence of PSE meat. However, in the present study, the average time for transportation was only 1.75 h, an interval that could be too short to develop DFD pork (Guardia et al., 2005). This agrees with Warriss, Brown, Bevis and Kestin (1990), who concluded that a period of transportation from 1 to 4 h was too short to affect the incidence of DFD pork. When an animal is subjected to acute stress, a quick glycolysis takes place, and therefore, the meat pH gets acidified more rapidly than normal, increasing the PSE meat likelihood. Perez et al. (2002) concluded that pigs subjected to short transport (15 min) showed a more intense stress response and poorer meat quality than pigs subjected to moderately long transportation (3 h), when they are immediately slaughtered on arrival at the slaughterhouse. Transport for 3 h may have allowed the animals to adapt to the transport conditions and then could act as a resting period like a lairage time. On the other hand, Guardia et al. (2004) indicated that, for transits longer than 3 h, the risk of PSE increases with stocking density during transport, while the opposite occurs for shorter transits.
The effect of transportation time on the risk of PSE condition depends on stocking density (Guardia et al., 2004; Mota-Rojas et al., 2006). For a high stocking density (0.25 m²/100 kg pig), there is less effect of transportation time and little change in risk of PSE condition between transits of 1–7 h. At low stocking density (0.5 m²/100 kg pig), up to a 6% difference in PSE meats was observed between 1 and 7 h transport time. The maximum PSE risk was observed at 1 h of transport (~8%), and the minimum at 7 h (~1%; Guardia et al., 2005). However, in the current study, PSE risk depended on stocking density.

The results obtained show the potential negative effect that excessive space allowance (0.4 m² per 100 kg pig) may have on the occurrence of PSE meat. When space availability was increased from 0.2 to 0.35 m² per 100 kg, pigs represented low risks of production of PSE meat but when space availability was increased to above 0.35 m² per 100 kg, pigs represented very high risks of production of PSE meat. Guardia et al. (2005) indicated that for journeys shorter than 3 h, increases in the availability of space during transportation raise the risk of both DFD and PSE pork. Alvarez et al. (2009) also showed that PSE risk increases with the stocking density in the first 4 h of transportation while this behavior changes up to 4 h, observing a decrease in the PSE risk as stocking density increase. All pigs must at least be able to lie down and stand up in their natural position during transportation. In order to comply with these minimum requirements, the loading density for pigs of around 100 kg should not exceed 235 kg per m² or 0.425 m² per 100 kg pig (Guardia et al., 2005).

The first four PCs explain about 95% of the total variation for technological quality attributes measurements (47%, 31%, 9% and 8%, respectively). In other words, 95% of the total variance
for technological quality attributes, in the nine considered variables can be condensed into four new variables (PCs). The results achieved with the PC analysis applied to analyse the technological quality attributes variables of pigs are similar with the results reported by other analogous studies with other species. In rabbits, Hernández et al. (2000) analysed meat quality using 23 variables, including pH, meat colour, water holding capacity, cooking loss, fatty acid composition and sensory parameters. They found that the first four PCs for meat quality explained 62% of the total variation.

Destefanis et al. (2000) with meat quality measurements (pH, chemical analysis, colour, hydroxyproline content, lightness, hue, drip losses, cooking losses, shear force and sensory variables) in beef showed that 62.5% of the total variation is explained by the first three components. In lambs, Cañéque et al. (2004) analysed carcass quality and meat quality measurements as separate sets of variables. Their results showed that the first four components explained 72% of total variation for carcass quality measurements and 50% for the meat quality measurements. In goats, Santos et al. (2008) analysed carcass quality and meat quality measurements as separate aspects sets of variables. They showed that the first four components explained about 80% of the total variation for carcass quality measurements (35%, 21%, 16% and 9%, respectively) and 68% for the meat quality traits (31%, 17%, 11% and 9%, respectively).

4.5. Conclusion

Transportation time, distance, stocking density, temperature and lairage time did not show a significant relationship with technological quality attributes measured in this study; except for
transportation time and distance travelled which had a positive relationship with TL%. Many of the correlations were between low to moderate; very few correlations were high, therefore the relationships were not particularly that strong. The risk of PSE increased with more space availability more than 0.4 m² per 100 kg pig. Our results showed that stocking density of 0.35 m² per100 kg pig during transport would reduce the risk of PSE pork.
4.6. References


Chapter 5: General discussion, conclusions and recommendations

5.1. General discussion

The objective of the current study was to determine the effect of pre-slaughter handling on technological quality attributes of pork and how it affects the quality of pork from a smallholder abattoir. The effects of breed, age and season of slaughter on technological quality attributes of pork were determined in Chapter 3. In Chapter 4, the effects of transportation time, distance, stocking density, temperature and lairage time on technological properties of pork were determined.

In chapter 3, Differences in pHu between large white and landrace breeds suggests that genetic factors are important to be considered when improving the quality of pork. Season had a significant influence on pHu, with low pHu reported in autumn (37%) season than other seasons. The effect of season was also observed on WBSF values. The lowest WBSF values were recorded in autumn (18.5) and highest WBSF values were reported in spring (27.6) season. The variation in WBSF values indicates that WBSF values might be a consequence of the low pHu registered in autumn. Age at slaughter significantly affected the pHu and WBSF values, suggested that pHu and WBSF values increase with the age of an animal. Sources of tenderness variation in beef for instance may be attributed to the animal’s age, sex, liveweight; breed and ante-mortem stress (Muchenje et al., 2009).

The high incidence of pork with low pHu registered in this study indicates that environmental factors should be taken into account whenever the effects of seasonal conditions on pork quality are evaluated (Dalla Costa et al., 2007). According to Maria et al. (2006) transport time may
affect several measures of meat quality but this effect depends on the time of year the rabbits were transported. The effect was higher in summer than in winter, therefore the time of year might be a medium stressor that acts independently of transport time.

Since all the pigs brought for slaughter came from one farm (56 km away from the abattoir) and were almost of the same breed, same production system, same truck and driver (Chapter 4); no significant relationship was reported between all the pre-slaughter variables and technological quality attributes of pork. Only distance and transportation time had a positive relationship with TL% of pork. Some correlations between the individual technological qualities attributes variables were reported in the current study. However, many of the correlations were low to moderate with few high correlations suggesting that the relations between the measured variables were not particularly that strong. The results obtained in this study show the potential negative effects that excessive space allowance above 0.4 m$^2$ per 100 kg may have on the occurrence of PSE meat. The stocking density of 0.35 m$^2$ per 100 kg pig was shown to be ideal in reducing the risks of PSE occurrences. The first four PCs explain about 95% of the total variation for technological quality attributes measurements (47%, 31%, 9% and 8%, respectively). In other words, 95% of the total variance for technological quality attributes, in the 9 considered variables can be condensed into four new variables (PCs). The results achieved with the PC analysis applied to analyse the technological quality attributes variables of pigs are similar with the results reported by other analogous studies with other species (i.e. rabbits, Hernández et al., 2000; lambs, Cañeque et al., 2004; goats, Santos et al., 2008).
5.2. Conclusions

It was concluded that pig breeds vary in pHu and considerations should be made on different seasons of slaughter when assessing pork quality. Precautions should also be made on age categories of the animal when improving the quality of pork. Transportation time, distance, stocking density, temperature and lairage time did not show a significant relationship with technological quality attributes measured; except for transportation time and distance travelled which had a positive relationship with TL%. The risk of PSE increased with more space availability more than 0.4 m² per 100 kg pig, but a stocking density of 0.35 m² per 100 kg was an ideal reducing the risk of PSE pork.

5.3. Recommendations

Pre-slaughter handlings play an important role in pork production. Therefore, these are some areas that require further research on how they affect the quality of pork from small abattoirs:

- Farmers perceptions of pork quality and how pork quality is affected by animal welfare practices
- The effects of the marketing channel on bruises
- Effects of varying distance, temperature, lairage and stocking density on technological quality attributes need further investigation. For the current study, there was a lack of variation in distance travelled from farm to abattoir since all the pigs brought for slaughter came from one farm (56 km away from the abattoir). However, variations in distance from farm to abattoir, production systems, speed of the truck and type of road might produce some interesting results.
- The effects of pre-slaughter conditions on blood constituents and their relationship with technological attributes of pork needs to be further explored as well
5.4. References


Appendix 1: Pig transportation sheet

Pig transportation record sheet

<table>
<thead>
<tr>
<th>Transportation details</th>
<th>date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivery date (2010)</td>
<td></td>
</tr>
<tr>
<td>Loading /departure time</td>
<td></td>
</tr>
<tr>
<td>Time of arrival</td>
<td></td>
</tr>
<tr>
<td>Time of slaughter</td>
<td></td>
</tr>
<tr>
<td>Vehicle dimensions (L×W)</td>
<td></td>
</tr>
<tr>
<td>No. of pigs in vehicle</td>
<td></td>
</tr>
<tr>
<td>Day temperature</td>
<td></td>
</tr>
<tr>
<td>Farm to abattoir (km)</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 2: Carcass and meat quality measurements record sheet

<table>
<thead>
<tr>
<th>Carcass no.</th>
<th>Breed</th>
<th>Age</th>
<th>Sex</th>
<th>Class</th>
<th>Weight</th>
<th>pH$_{24}$</th>
<th>pH</th>
<th>T°c</th>
<th>Colour at pH 24 (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>pH</td>
<td></td>
<td></td>
<td>L*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>