

## Book Chapter

# Changes in the Physico-Chemical Quality of Red Meat During the Distribution of Carcasses from the Abattoir to the Retailers

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## Abstract

The objective of this study was to investigate the effect of the distribution chain, distance between the abattoir and meat retailer, storage duration of meat at the meat retailer and meat retailer class on the physico-chemical quality of red meat. Beef (n = 150), pork (n = 150) and mutton (n = 150) samples were collected during the loading process of carcasses into refrigerated trucks, at the offloading point and during marketing

to measure the effect of the distance between the abattoir and meat retailer, storage duration of meat at the meat retailer and meat retailer class (butcher, middle and high class) on the meat quality attributes. Meat quality attributes measured were; lightness ( $L^*$ ), redness ( $a^*$ ), yellowness ( $b^*$ ),  $pH_u$ , cooking loss (CL%), Warner–Bratzler shear force (WBSF) and meat temperature (TM). The distribution stage had an effect ( $p < 0.05$ ) on some of the meat quality attributes, specifically the  $a^*$  values for all meat types during loading ( $18.5 \pm 0.93$ ), off-loading ( $15.8 \pm 0.93$ ) and display ( $20.2 \pm 0.94$ ) points. Abattoir to meat retailer distance had a significant effect on  $L^*$ ,  $a^*$ , hue angle and chroma values ( $p < 0.05$ ). Storage duration at the retailer point significantly affected  $L^*$  and  $a^*$  values of meat ( $p < 0.05$ ). Meat retailer class affected WBSF and meat yellowness ( $p < 0.05$ ). In conclusion, the distribution chain, distance between the abattoir and meat retailer, storage duration of meat at the meat retailer and meat retailer class all affect the physico-chemical quality of red meat.

## Keywords

Abattoir-to-Meat Retailer Distance; Distribution Chain Stage; Lightness; Meat Quality; Meat Storage Duration; Redness; Yellowness

## Introduction

Product quality has been recognized as one of the most essential food product characteristics to consider throughout the supply chain [1]. Maintaining high quality food is important for the supply chain performance [2]. Controlling food product quality throughout the food supply chain has been identified as one of the main challenges in the food industry [3]. Quality assurance is likely to dominate the process of production and distribution in food chains in the future [4]. However, regardless of this, quality standards should always be met when the product is sold to the consumer. Therefore, continuous efforts to improve the quality of meat that is delivered to consumers are encouraged. The main aim of the supply chain and distribution channel is to try and maintain meat product quality. Maintaining high yellowness

( $b^*$ ), redness ( $a^*$ ), lightness ( $L^*$ ) and ultimate pH levels along the distribution chain stage can improve meat consumers' acceptance [5]. Should quality be affected, consumers can strongly reject the meat, hence high chances of developing a negative attitude towards the product may occur.

It is speculated that the distribution chain stage may have a profound influence on essential meat quality attributes such as juiciness, tenderness, firmness and appearance. Meat handlers have reported perceiving that the distribution chain stage may affect the quality of meat that is supplied to the consumers [6]. Therefore, it is important to determine the physico-chemical quality changes of meat when it is distributed from the abattoirs to the retailer to discover if the meat handler's perception matches with results of the instrumental measurements. Meat is composed of physical and chemical components [7]. Physico-chemical characteristics are some of the determinants of meat quality and its acceptability by consumers [7]. Meat chemical attributes include the pH and physical attributes include tenderness, colour, cooking loss, flavour and juiciness. However, it is important to note that the major parameters considered in the assessment of meat quality are appearance, juiciness, tenderness and flavour [8]. The demand or market price of meat depends on immediate visual meat quality and subsequent on-plate-on-palate feeling [9]. Colour is the first meat quality attribute in meat acceptance by consumers [10]. Meat is expected to have a desirable colour that is uniform throughout the entire cut. Contrastingly, meat pH, overall flavour, tenderness, cooking loss and juiciness of the meat tend to change during display. Meat colour changes from red to brown during retail display due to metmyoglobin formation and other individual factors; and their interactions prior to purchase [11].

Previous studies mainly focus on the effect of animal diets on meat quality [7]. More studies should focus on the effect of the post-slaughter process on meat quality as it also affects meat quality [12]. After inspection, carcasses are transported from the abattoir to the supermarkets or meat retailers for consumers to purchase. There is insufficient research conducted which follow the supply chain, specifically the distribution chain stage to

ensure that the meat quality remains the same. This is due to the effect of meat product transportation to retail outlets and their storage on meat quality being less investigated [13].

The travelling distance during animal transportation from the farm to the abattoir before slaughter affects meat quality [14]. Storage temperature may differ from that of the abattoir in the meat transport and at the meat retailer and temperature change affects microbial development which affects meat quality [15]. However, there is no information available on the effect of meat transportation distance after slaughter on meat quality. Therefore, it is important to determine factors affecting meat quality during the distribution chain stage, from the abattoir to retail stores as temperature may differ during meat transportation from the abattoir to the meat retailers. Meat storage conditions and duration at meat retailers can affect meat quality characteristics and need investigation.

A past study [16] demonstrated that consumers found that meat quality differed according to the meat outlet class. It should be borne in mind that, retailers which sell meat directly to consumers fall into different categories. Meat retail outlets are classified as high class (retail shops with a reputation/guaranteed to sell high quality products), middle class (retail shops sell meat cuts at an affordable price usually to consumers of the middle class) or low class (retail shops that sell meat cuts at a cheap/inexpensive price usually to consumers who cannot afford to buy expensive products and deliver poor quality products) [17]. High class meat outlets sell quality meat cuts from highly reputable farms or abattoirs, middle class meat outlets sell meat with moderate quality and regard for meat sources and the low class meat outlets lack regard for quality meat cuts [17]. Most of the time these different retailers are supplied by the same suppliers and differences in meat quality due to handling may appear. Therefore, it is important to understand factors which causes the change in meat quality once the meat reaches the meat retailers. The difference in storage, temperatures, packaging type, storage duration of meat and other factors per meat retailer may influence meat quality. It is important to also note that there is scanty information on the post-slaughter handling of carcasses

by different classes of retailers in both rural and urban set-ups. Hence, the objective of this study was to investigate the effect of the distribution chain stage, distance between the abattoir and meat retailer, storage duration of meat at the meat retailer and meat retailer class on physico-chemical quality of red meat.

## **Materials and Methods**

### **Study Site**

The study was conducted at a selected high throughput abattoir in East London, Eastern Cape Province, South Africa (32.97° S 27.87° E and 542 m altitude). The abattoir is located 120 km south east of the University of Fort Hare, Alice campus, and is governed by the Meat Safety Act of 2000 and SAMIC [18]. This abattoir slaughters up to 1000 livestock units per day and delivers loads of carcasses to the retail shops per day. The carcasses were cooled for 48 h before transportation to outlets. Ethical clearance was approved by the Research Ethics Committee of the University of Fort Hare, South Africa (UFH/UREC, MUC0101SRAN01).

### **Experimental Design**

Regardless of the farm origin and breed of the carcass, a total of four hundred and fifty samples were collected from mutton (n = 150), beef (n = 150) and pork (n = 150) carcasses during the loading stage at the abattoir, at the offloading point and during marketing at the meat retailers. Therefore, a make-up of fifty samples (n = 50) were collected in each of the three different stages. Randomly, the chump, leg, loin chop, rib, shoulder or brisket portions of each whole carcass per meat type were sampled and pooled as a representative of each carcass. The same meat cut was sampled per distribution stage and stored at 5 °C in a cooler box containing ice packs pending further analysis. Fifty carcasses for each species were randomly selected at the abattoir before loading the refrigerated trucks for delivery to the retail shops where different portions of meat samples were collected.

## Measurement of the Red Meat Quality per Distribution Chain Stage

Ultimate pH ( $pH_u$ ) and colour coordinates (lightness,  $L^*$ ; redness,  $a^*$  and yellowness,  $b^*$ ), hue angle, chroma, CL% and meat temperature ( $T_m$ ) were measured from meat samples collected from the same carcass (beef, pork and mutton) during loading into meat trucks for transport to meat outlets, off-loading of meat from the meat truck at the meat outlets and display of meat at meat outlets. Meat sampling at loading, meat sample, pooled samples from the chump, leg, loin chop, rib, shoulder or brisket portions, per meat type, were sampled as they were loaded into the meat truck. At loading, all carcasses were loaded by hanging in the same refrigerated truck (5 °C) and offloaded at the storage facilities in each retail shop which differed per size. At the off-loading point, before the carcasses were packed at the storage room, meat samples were collected from the same carcasses and meat parts: chump, leg, loin chop, rib, shoulder or brisket portion. Bar codes were used to trace carcasses for identification purposes.

After off-loading, meat outlets displayed the same meat that had been sampled during loading and off-loading for consumers to purchase. Therefore, meat outlets (butcher, middle and top class) were approached to purchase meat samples of the carcasses displayed at the meat outlets that had been previously sampled during loading and off-loading to measure  $pH_u$ , colour coordinates (lightness,  $L^*$ ; redness,  $a^*$  and yellowness,  $b^*$ ), hue angle, chroma, CL% and meat temperature ( $T_m$ ) during display at the meat outlets. The storage temperature at which the meat was kept under by the meat retailers, as well as the storage duration (number of days it takes for the meat to be displayed in shelves after reaching retailers as well as storage days after slaughter at the abattoir) were recorded.

At the display point or when the meat was displayed in shelves for the consumers to purchase, other meat samples from the same carcasses were purchased where ultimate pH ( $pH_u$ ), colour coordinates, CL% and tenderness were measured. All the samples were delivered to the Meat Science Laboratory in a

cooler box containing ice at  $\leq 4$  °C where they were kept in a fridge pending cooking loss and tenderness evaluations.

### **Measurement of the Effect of Distance between the Abattoir and Meat Outlet on Meat Quality**

The distance (km) from the abattoir to the meat outlet was recorded to determine the effect of the distance from the abattoir to meat on pHu, colour coordinates (lightness,  $L^*$ ; redness,  $a^*$  and yellowness,  $b^*$ ), hue angle, chroma, CL% and meat temperature ( $T_m$ ). Meat samples were pooled across red meat sources and portions and analysed for pHu, colour coordinates (lightness,  $L^*$ ; redness,  $a^*$  and yellowness,  $b^*$ ), hue angle, chroma and meat temperature ( $T_m$ ).

### **Measurement of the Storage Days on the Meat Quality**

To measure the effect of meat storage duration on meat quality variables, the days that the meat was stored at the abattoir after slaughter and at the meat outlet before it was displayed for purchase by consumers were recorded. Meat samples were taken to measure their pHu, colour coordinates (lightness,  $L^*$ ; redness,  $a^*$  and yellowness,  $b^*$ ), hue angle, chroma, pHu, CL% and meat temperature ( $T_m$ ).

### **Measurement of the Meat Quality across Types of Meat Outlets**

To measure the meat quality across types of meat outlets, butcher, middle and top class, the red meat sources (beef, mutton and pork) were sampled and pooled from the chump, leg, loin chop, rib, shoulder or brisket portion per red meat source. Meat samples were pooled across red meat sources and portions and analysed for pHu, colour coordinates (lightness,  $L^*$ ; redness,  $a^*$  and yellowness,  $b^*$ ), hue angle, chroma and meat temperature ( $T_m$ ).



## Meat Quality Measurements and Calculations

### Determination of Meat Ultimate pH, Temperature and Colour

A portable fibre-optic pH and meat temperature (T<sub>m</sub>) meter probe with a sharp metal sheath to prevent damage from raw meat (CRISON pH 25 Instruments S.A., Alella, Spain) was used to measure the ultimate pH and temperature of the meat samples from beef, pork and mutton carcasses at each stage. The pH meter was calibrated before taking measurements using pH 4, pH 7 and pH 9 standard solutions (CRISON Instruments, SA, Alella, Spain). Both pH<sub>u</sub> and T<sub>m</sub> were recorded accordingly.

Colour measurements taken from different cuts of mutton, beef and pork samples: chump, leg chop, loin chop, rib chop, shoulder chop and brisket chop, were pooled per meat type during the test for the effect of the distribution chain stage on meat quality. However, colour measurements conducted on pooled samples across meat types were used for the test of the effect of the storage duration and retailer class on meat quality. The lightness ( $L^*$ ), redness ( $a^*$ ) and yellowness ( $b^*$ ) values [19] were determined using a Minolta colour-guide 45/0 BYK-Gardener GmbH machine, with a 20 mm diameter measurement area and illuminant D65-day light, with 10° observation angle. The machine was calibrated in each stage before taking measurements using the green, black and white colour standard samples provided for this purpose. Three readings were taken from each meat sample by rotating the instrument 90° between each measurement, in order to obtain a representative average value of the colour. The colour values were recorded and compared with pH<sub>u</sub> of the same meat samples. The chroma and hue angle (HA) were calculated using the following formulae [20], which are related to the colour intensity of the meat, and calculated according to the formula:  $C^* = (a^{*2} + b^{*2})^{0.5}$  [18]; and hue angle (HA), in degrees, was calculated according to the formula:  $HA = [\tan^{-1}(\frac{b^*}{a^*})]$  [20].

## Determination of Warner–Bratzler Shear Force and Cooking Loss of the Meat Sample

The meat samples for the analysis of cooking loss and Warner–Bratzler shear force (WBSF) values were taken out of the fridge a day before and left to thaw at room temperature (25 °C) [21]. Immediately after thawing, the samples were weighed, labelled and placed in plastic bags and cooked in a water bath at 85 °C for 45 min [22]. The internal temperature was determined via a hand-held thermometer. Thereafter, the samples were allowed to cool at room temperature for 30 min and then weighed again to determine cooking loss. The values for cooking loss (CL%) were calculated using the following formula:

$$\text{Cooking loss (CL)\%} = \frac{\text{Weight before cooking} - \text{weight after cooking}}{\text{Weight before cooking}} \times 100$$

For determination of Warner–Bratzler shear force (WBSF), three subsamples measuring 10 mm in diameter were cored parallel to the grain of the cooked meat from each cut/portion. The samples were sheared perpendicular to the fibre direction using a Warner–Bratzler shear force (WBSF) device mounted on an Instron (Model 3344) Universal testing apparatus (cross head speed at 400 mm/min, one shear in the centre of each core). The mean maximum load (N) was recorded for the batch.

## Statistical Analyses

The statistical analysis of physico-chemical meat quality parameters (pH,  $L^*$ ,  $a^*$ ,  $b^*$ , CL% and WBSF values) were performed using a general linear model procedure in SAS (Analysis Systems, 2011). A factorial experiment with three factors (distribution chain stage grouped by meat type, effect of storage duration at the abattoir after slaughter and at the retailer storage rooms; and effect of distance) was laid out in a randomised complete block design and analysis of variance was calculated using the following model:

$$Y_{ijkl} = \mu + A_i + B_j + C_k + D_l + \varepsilon_{ijkl}$$

where  $Y_{ijk}$  = response variable,  $\mu$  = overall mean common to all observations,  $A_i$  = effect of the distribution chain stage grouped

by meat type,  $B_j$  = effect of the distance between abattoir and meat outlet,  $C_k$  = effect of the storage duration by meat outlets,  $D_l$  = effect of meat outlet class and  $E_{ijk}$  = random error.

## Results and Discussion

### Effect of the Distribution Chain Stage on the Physico-Chemical Properties of Beef, Pork and Mutton

The results of physico-chemical properties of beef, pork and mutton as affected by the distribution chain stage are presented as mean  $\pm$  SE in Table 1. There was a significant difference ( $p < 0.05$ ) in  $L^*$ ,  $a^*$  and  $b^*$  values for beef, pork and mutton.  $L^*$  values for mutton and pork did not differ that much at the offloading stage but significant differences in the  $L^*$  values for beef across different stages were observed. Lightness ( $L^*$ ) values at the loading point for beef were  $34.5 \pm 2.20$ . At the offloading point, a significant decrease was observed ( $L^* = 29.9 \pm 1.01$ ). Differences in  $L^*$  values for beef could be ascribed to beef carcasses being fragmented into quarters at the abattoir before transportation for spatial purposes in the delivery vehicles. Meat colour change can be caused by either oxygenation or oxidation of the pigment myoglobin [23]. Changes in colour on the surface of the carcasses were expected to occur due to the muscles of the beef carcasses being exposed to air in the present study.

It should be noted that after slicing or cutting the carcass, the surface typically changes in colour from purple to red due to oxygenation, or blooming. While during oxidation, the myoglobin turns from purple (deoxygenated) to brown (metmyoglobin) [24]. Oxidation initiates at the junction of the oxygenated and deoxygenated layers where the oxygen partial pressure is low [25]. This junction moves progressively towards the meat surface and in the process the surface colour changes from red to brown. Management of meat colour stability can be achieved by manipulating a range of non-genetic factors such as vitamin E concentration [26] and chill rate [27]. However, it should be noted that although there were some differences in  $L^*$  values for beef along the different stages, the  $L^*$  values still fell within the stipulated range. Therefore, the  $L^*$  values indicated freshness in meat at all distribution chain stages.

**Table 1:** Mean values ( $\pm$ SE) for colour ( $L^*$ ,  $a^*$  and  $b^*$ ), pH, hue angle, chroma, tenderness and cooking loss % of red meat as affected by meat type.

Stage	Meat Type	$L^*$	$a^*$	$b^*$	Hue Angle	Chroma	pH <sub>u</sub>	CL%	Tm
Loading	Beef	34.5 <sup>b</sup> $\pm$ 2.20	18.5 <sup>c</sup> $\pm$ 0.93	9.6 <sup>b</sup> $\pm$ 0.90	5.5 <sup>b</sup> $\pm$ 0.63	18.5 <sup>b</sup> $\pm$ 1.00	6.4 <sup>c</sup> $\pm$ 0.12	22.0 <sup>a</sup> $\pm$ 1.76	23.4 <sup>b</sup> $\pm$ 2.16
	Pork	51.6 <sup>c</sup> $\pm$ 2.01	10.6 <sup>a</sup> $\pm$ 0.94	11.6 <sup>c</sup> $\pm$ 0.91	5.1 <sup>a</sup> $\pm$ 0.60	20.6 <sup>c</sup> $\pm$ 0.99	6.1 <sup>a</sup> $\pm$ 0.12	21.8 <sup>a</sup> $\pm$ 1.75	24.4 <sup>b</sup> $\pm$ 2.15
	Mutton	32.5 <sup>a</sup> $\pm$ 2.10	15.6 <sup>b</sup> $\pm$ 0.92	7.9 <sup>a</sup> $\pm$ 0.87	8.1 <sup>b</sup> $\pm$ 0.61	13.8 <sup>a</sup> $\pm$ 1.12	6.3 <sup>b</sup> $\pm$ 0.12	20.9 <sup>a</sup> $\pm$ 1.69	15.8 <sup>a</sup> $\pm$ 2.13
Off-loading	Beef	29.9 <sup>a</sup> $\pm$ 1.01	15.8 <sup>c</sup> $\pm$ 0.93	9.7 <sup>b</sup> $\pm$ 0.90	5.9 <sup>b</sup> $\pm$ 0.63	18.5 <sup>b</sup> $\pm$ 1.00	6.3 <sup>c</sup> $\pm$ 0.12	21.1 <sup>a</sup> $\pm$ 1.76	23.5 <sup>b</sup> $\pm$ 2.15
	Pork	50.3 <sup>c</sup> $\pm$ 1.01	8.6 <sup>a</sup> $\pm$ 0.92	10.6 <sup>c</sup> $\pm$ 0.91	5.5 <sup>a</sup> $\pm$ 0.60	21.7 <sup>c</sup> $\pm$ 0.99	6.1 <sup>a</sup> $\pm$ 0.12	22.8 <sup>a</sup> $\pm$ 1.75	23.4 <sup>b</sup> $\pm$ 2.15
	Mutton	31.7 <sup>b</sup> $\pm$ 1.30	11.2 <sup>b</sup> $\pm$ 0.94	7.7 <sup>a</sup> $\pm$ 0.87	8.8 <sup>b</sup> $\pm$ 0.61	14.7 <sup>a</sup> $\pm$ 1.12	6.1 <sup>b</sup> $\pm$ 0.12	22.9 <sup>a</sup> $\pm$ 1.69	14.6 <sup>a</sup> $\pm$ 2.14
Display	Beef	31.2 <sup>a</sup> $\pm$ 1.01	20.2 <sup>c</sup> $\pm$ 0.94	8.9 <sup>b</sup> $\pm$ 0.90	6.3 <sup>b</sup> $\pm$ 0.63	17.8 <sup>b</sup> $\pm$ 1.00	6.4 <sup>c</sup> $\pm$ 0.12	23.4 <sup>a</sup> $\pm$ 1.76	23.5 <sup>b</sup> $\pm$ 2.15
	Pork	49.7 <sup>c</sup> $\pm$ 2.02	11.5 <sup>a</sup> $\pm$ 0.93	10.0 <sup>c</sup> $\pm$ 0.91	6.2 <sup>a</sup> $\pm$ 0.60	22.6 <sup>c</sup> $\pm$ 0.99	6.2 <sup>a</sup> $\pm$ 0.12	23.9 <sup>a</sup> $\pm$ 1.69	22.9 <sup>b</sup> $\pm$ 2.15
	Mutton	33.6 <sup>b</sup> $\pm$ 2.10	17.1 <sup>b</sup> $\pm$ 0.92	8.7 <sup>a</sup> $\pm$ 0.87	8.4 <sup>b</sup> $\pm$ 0.61	15.8 <sup>a</sup> $\pm$ 1.12	6.4 <sup>b</sup> $\pm$ 0.12	21.6 <sup>a</sup> $\pm$ 1.69	15.4 <sup>a</sup> $\pm$ 2.14

<sup>abc</sup> Means in the same column without the same superscripts are significantly different ( $p < 0.05$ ); SE = standard error;  $L^*$  = lightness;  $a^*$  = redness;  $b^*$  = yellowness; CL% = cooking loss, TM = meat temperature.

Differences in pork and mutton carcasses did not occur because during delivery, the carcasses were delivered as a whole, therefore there was no penetration of oxygen straight into the muscle. Differences in the redness ( $a^*$ ) values across different species were observed. Beef was observed with higher  $a^*$  values ( $18.5 \pm 0.93$ ) compared to pork ( $10.6 \pm 0.94$ ) and mutton ( $15.6 \pm 0.92$ ). Differences in the colour of meat from different species were expected. However, differences in redness values across different species decreased and later on increased with stage. At the off-loading point, slight decreases in  $a^*$  values were observed in all the species. Pork was observed with ( $8.6 \pm 0.92$ ), beef ( $15.8 \pm 0.93$ ) and mutton ( $11.2 \pm 0.94$ ), thereafter a significant increase at the display point or during marketing occurred. These differences could be associated to the fact that the muscles that were collected and measured at the offloading point were taken from the surface of the carcasses, hence colour changes in the surface might have occurred due to exposure to oxygen.

The significant increase in the redness values at the display point can be due to the fact that the muscle purchased during marketing is trimmed from the inner parts of the carcass where the penetration of oxygen does not occur. Hence different muscles tend to differ in colour. Significant differences for  $b^*$ , hue angle, chroma and meat temperature were observed across different species or meat types, but no differences occurred across the distribution stages. There were no significant differences in the cooking loss values of different meat types although differences were observed across different stages. Meat tenderness is a function of collagen content, heat stability and myofibrillar structure of muscle, though animal growth rate rather per animal than breed mainly affect these meat variables. In a previous study, WBSFs (Warner–Bratzler shear force values) were lower during the loading stage compared to the offloading and display points in all meat types [28]. The observed yellowness values in the current study were within the stipulated range (6.1–11.3) and this agrees with other findings [7,29].

## Effect of Distance on the Physico-Chemical Attributes of Red Meat

Differences in the quality attributes of meat as affected by distance were observed and are depicted in Table 2. This distance (km) was recorded when refrigerated trucks that were carrying the carcasses were followed to the shops for delivery and time taken for the refrigerated truck containing meat to reach meat outlets was not regarded. The distance at the abattoir after loading the carcasses was zero. Distance had a significant effect on  $L^*$ ,  $a^*$ , hue angle and chroma values. The  $L^*$  values which were recorded for the carcasses at the abattoir did not change after reaching the supply points at 15, 20 and 25 km. However, a significant difference of  $L^*$  values for carcasses that were transported for 60 km was observed. This could imply that, the longer the distance that is covered when transporting the carcasses, the greater are the chances of the meat quality traits being affected since there are usually a lot of offloading points found along the way to other retailers, whereby doors could be open for longer periods with air flowing inside the refrigerated trucks.

A previous study [30] highlighted that issues of first priority when considering cold store requirements during transportation include the initial temperature of the incoming meat, size of the cabinets, targeted temperature of storage, temperatures of the surroundings, mechanical characteristics (location of refrigeration machinery, compressors, ventilation and insulation) and energy/cost matters. However,  $b^*$ ,  $pH_u$ , cooking loss and meat temperature were not affected by distance. The results of temperature and distance were not expected as change in temperature inside the refrigerated trucks during the offloading points were observed. However, this proves that the storage temperatures used in the vehicles transporting the carcasses are important for maintaining the quality of the meat.

**Table 2:** Mean values ( $\pm$ SE) for colour ( $L^*$ ,  $a^*$  and  $b^*$ ), pH, hue angle, chroma, tenderness and cooking loss % of red meat (pooled samples from beef, mutton and pork) as affected by distance covered from the abattoir to the supply points.

Parameter	Distance (km)				
	0	15	20	25	60
Lightness ( $L^*$ )	28.7 <sup>a</sup> $\pm$ 1.98	20.8 <sup>a</sup> $\pm$ 7.45	30.3 <sup>a</sup> $\pm$ 1.61	32.7 <sup>a</sup> $\pm$ 1.52	34.8 <sup>b</sup> $\pm$ 1.68
Redness ( $a^*$ )	11.4 <sup>a</sup> $\pm$ 0.86	11.4 <sup>a</sup> $\pm$ 3.32	15.4 <sup>b</sup> $\pm$ 0.70	15.4 <sup>b</sup> $\pm$ 0.66	16.7 <sup>c</sup> $\pm$ 0.73
Yellowness ( $b^*$ )	9.5 <sup>a</sup> $\pm$ 0.84	10.3 <sup>a</sup> $\pm$ 3.13	9.8 <sup>a</sup> $\pm$ 0.67	10.6 <sup>a</sup> $\pm$ 0.65	9.9 <sup>a</sup> $\pm$ 0.70
Hue Angle	8.1 <sup>c</sup> $\pm$ 0.58	7.2 <sup>c</sup> $\pm$ 2.22	6.04 <sup>b</sup> $\pm$ 0.46	6.16 <sup>b</sup> $\pm$ 0.44	5.4 <sup>a</sup> $\pm$ 0.48
Chroma	15.0 <sup>a</sup> $\pm$ 1.04	18.7 <sup>b</sup> $\pm$ 0.79	18.4 <sup>b</sup> $\pm$ 0.84	18.7 <sup>b</sup> $\pm$ 0.79	19.5 <sup>b</sup> $\pm$ 0.87
pH <sub>u</sub>	6.1 <sup>a</sup> $\pm$ 0.15	6.3 <sup>a</sup> $\pm$ 0.12	6.3 <sup>a</sup> $\pm$ 0.12	6.3 <sup>a</sup> $\pm$ 0.12	6.4 <sup>a</sup> $\pm$ 0.12
CL%	23.0 <sup>a</sup> $\pm$ 1.61	23.2 <sup>a</sup> $\pm$ 1.34	24.5 <sup>a</sup> $\pm$ 1.31	24.5 <sup>a</sup> $\pm$ 1.23	25.6 <sup>a</sup> $\pm$ 1.36
WBSF	18.3 <sup>a</sup> $\pm$ 3.72	20.4 <sup>a</sup> $\pm$ 1.34	19.6 <sup>a</sup> $\pm$ 1.76	21.3 <sup>a</sup> $\pm$ 1.34	22.6 <sup>a</sup> $\pm$ 1.32
Tm	20.7 <sup>a</sup> $\pm$ 1.98	20.6 <sup>a</sup> $\pm$ 7.61	23.1 <sup>a</sup> $\pm$ 1.60	22.1 <sup>a</sup> $\pm$ 1.52	24.2 <sup>a</sup> $\pm$ 1.67

<sup>abc</sup> Means in the same row without the same superscripts are significantly different ( $p < 0.05$ ), SE = standard error; WBSF = Warner–Bratzler shear force; CL% = cooking loss.

## Effect of Storage Duration

Table 3 shows the results on effect of storage duration (in days) at the abattoir after slaughter and at retail shops on some of the important meat quality attributes in red meat (pooled beef, mutton and pork samples). This storage duration represents the number of days at storage in the abattoir after slaughter and at the shops after delivery before display. The meat handlers at the abattoir during the data collection revealed that carcasses can be kept for more than two weeks in their chiller rooms after slaughter before transportation to the retail shops. However, at the retail shops, the meat is not sold immediately after reaching their shops. It can still be stored for a number of days before cutting for marketing purposes or for consumer purchasing [31]. Storage duration had a significant effect ( $p < 0.05$ ) on meat temperature, lightness ( $L^*$ ) and redness ( $a^*$ ) values. However,  $b^*$ , hue angle, ultimate pH and cooking loss were not affected by the storage duration. Increasing meat storage duration enhances meat quality by increasing intramuscular fat, cooking loss, water holding capacity and myofibrillar fragmentation index [32].



**Table 3:** Mean values ( $\pm$ SE) for colour ( $L^*$ ,  $a^*$  and  $b^*$ ), pH, hue angle, chroma, tenderness and cooking loss % of red meat (pooled samples from beef, mutton and pork) as affected by storage duration at meat retailers.

Parameter	Storage Duration (Days)									
	0	1	2	3	4	5	6	7	8	9
Lightness ( $L^*$ )	31.0 <sup>b</sup> $\pm$ 2.45	25.1 <sup>a</sup> $\pm$ 0.01	27.9 <sup>a</sup> $\pm$ 2.25	31.5 <sup>b</sup> $\pm$ 2.06	22.7 <sup>a</sup> $\pm$ 4.67	31.3 <sup>a</sup> $\pm$ 2.21	29.7 <sup>b</sup> $\pm$ 3.39	23.8 <sup>a</sup> $\pm$ 7.64	26.3 <sup>a</sup> $\pm$ 3.91	32.7 <sup>b</sup> $\pm$ 2.58
Redness ( $a^*$ )	15.7 <sup>a</sup> $\pm$ 1.07	14.5 <sup>a</sup> $\pm$ 0.87	14.6 <sup>a</sup> $\pm$ 0.97	14.5 <sup>a</sup> $\pm$ 0.89	13.2 <sup>a</sup> $\pm$ 2.03	14.4 <sup>a</sup> $\pm$ 0.96	14.5 <sup>a</sup> $\pm$ 1.47	10.7 <sup>a</sup> $\pm$ 3.32	18.0 <sup>b</sup> $\pm$ 1.70	16.9 <sup>b</sup> $\pm$ 1.12
Yellowness ( $b^*$ )	10.3 <sup>a</sup> $\pm$ 1.03	9.9 <sup>a</sup> $\pm$ 0.84	10.1 $\pm$ 0.94	9.7 <sup>a</sup> $\pm$ 0.87	7.4 <sup>a</sup> $\pm$ 1.96	10.4 <sup>a</sup> $\pm$ 0.93	9.3 <sup>a</sup> $\pm$ 1.43	6.3 <sup>a</sup> $\pm$ 3.21	11.9 <sup>b</sup> $\pm$ 1.64	11.7 <sup>b</sup> $\pm$ 1.08
Hue Angle	5.5 <sup>a</sup> $\pm$ 0.71	6.3 <sup>b</sup> $\pm$ 0.58	6.1 <sup>b</sup> $\pm$ 0.65	5.9 <sup>a</sup> $\pm$ 0.60	5.8 <sup>a</sup> $\pm$ 1.36	6.5 <sup>b</sup> $\pm$ 0.64	5.8 <sup>a</sup> $\pm$ 0.98	9.8 <sup>c</sup> $\pm$ 2.22	5.3 <sup>a</sup> $\pm$ 1.14	9.8 <sup>c</sup> $\pm$ 1.14
Chroma	18.8 <sup>a</sup> $\pm$ 1.18	17.7 <sup>a</sup> $\pm$ 1.05	17.9 <sup>a</sup> $\pm$ 1.17	17.4 <sup>a</sup> $\pm$ 1.07	15.0 <sup>a</sup> $\pm$ 2.44	18.0 <sup>a</sup> $\pm$ 1.15	17.5 <sup>a</sup> $\pm$ 1.07	11.9 <sup>a</sup> $\pm$ 3.99	21.9 <sup>b</sup> $\pm$ 2.05	20.5 <sup>a</sup> $\pm$ 1.34
pH <sub>u</sub>	6.1 <sup>a</sup> $\pm$ 0.19	6.2 <sup>a</sup> $\pm$ 0.12	6.0 <sup>a</sup> $\pm$ 0.17	6.2 <sup>a</sup> $\pm$ 0.15	6.3 <sup>a</sup> $\pm$ 0.65	6.1 <sup>a</sup> $\pm$ 0.17	6.3 <sup>a</sup> $\pm$ 0.26	6.3 <sup>a</sup> $\pm$ 0.58	6.4 <sup>a</sup> $\pm$ 0.29	6.6 <sup>a</sup> $\pm$ 0.19
CL%	22.9 <sup>a</sup> $\pm$ 1.98	22.3 <sup>a</sup> $\pm$ 1.64	22.8 <sup>a</sup> $\pm$ 1.98	23.3 <sup>a</sup> $\pm$ 1.67	18.3 <sup>a</sup> $\pm$ 3.79	22.7 <sup>a</sup> $\pm$ 1.79	21.6 <sup>a</sup> $\pm$ 2.75	19.8 <sup>a</sup> $\pm$ 6.20	20.1 <sup>a</sup> $\pm$ 3.17	22.0 <sup>a</sup> $\pm$ 2.09
Tm	24.7 <sup>a</sup> $\pm$ 2.44	21.6 <sup>a</sup> $\pm$ 2.01	22.5 <sup>a</sup> $\pm$ 2.24	20.8 <sup>a</sup> $\pm$ 2.05	20.3 <sup>a</sup> $\pm$ 4.66	22.3 <sup>a</sup> $\pm$ 2.19	17.7 <sup>a</sup> $\pm$ 3.38	18.1 <sup>a</sup> $\pm$ 7.61	23.9 <sup>a</sup> $\pm$ 3.89	20.3 <sup>a</sup> $\pm$ 2.57

<sup>abc</sup> Means in the same row without the same superscripts are significantly different ( $p < 0.05$ ); SE = standard error; Tm = meat temperature; CL% = cooking loss.

## Effect of Meat Retailer Class on Physico-Chemical Attributes of Red Meat

Meat outlets are categorized as either a butcher (low class), middle class or top class. The low-class meat outlet tends to have meat of low quality due to substandard meat safety standards compared to the top-class meat outlets. While the middle-class meat outlets have intermediate meat quality. Results of the retailer class effects on physico-chemical attributes of red meat are presented in Table 4. There were significant retailer effects ( $p < 0.05$ ) on the  $L^*$  value and WBSF of the pooled red meat samples (chump, leg, loin chop, rib, shoulder, or brisket portion). However,  $b^*$ ,  $a^*$ , hue angle, chroma and meat temperature were not affected by the retailer class. The pH<sub>u</sub> range was similar regardless of retailer class. The pH<sub>u</sub> range in the current study was between 6.2 and 6.3. A previous study [6] found that meat pH above 6.0 is undesirable as it leads to dark firm dry meat. Higher meat pH (>5.8) leads to undesirable meat colour which is unattractive to consumers [33]. pH<sub>u</sub> greater than 6.0 is usually regarded as a critical value and is associated with DFD condition in both pork and beef [34]. Therefore, the observed pH<sub>u</sub> in the current study could be considered to be on the higher range.

**Table 4:** Mean values ( $\pm$ SE) for colour ( $L^*$ ,  $a^*$  and  $b^*$ ), pH, hue angle, chroma, tenderness and cooking loss % of red meat (pooled samples from beef, mutton and pork) as affected by shop type.

	Butcher	Middle	Top
Lightness ( $L^*$ )	28.1 <sup>ab</sup> $\pm$ 2.14	29.3 <sup>b</sup> $\pm$ 2.14	27.2 <sup>a</sup> $\pm$ 2.14
Redness ( $a^*$ )	14.9 $\pm$ 0.93	14.5 $\pm$ 0.93	14.5 $\pm$ 0.93
Yellowness ( $b^*$ )	10.1 $\pm$ 0.89	9.6 $\pm$ 0.91	9.4 $\pm$ 0.90
Hue Angle	6.2 $\pm$ 0.62	6.3 $\pm$ 0.60	6.2 $\pm$ 0.62
Chroma	18.0 $\pm$ 1.12	17.6 $\pm$ 0.99	17.4 $\pm$ 1.00
pH <sub>u</sub>	6.3 $\pm$ 0.16	6.2 $\pm$ 0.12	6.3 $\pm$ 0.17
WBSF (N)	21.4 <sup>ab</sup> $\pm$ 1.74	20.7 <sup>a</sup> $\pm$ 1.75	22.6 <sup>b</sup> $\pm$ 0.93
Meat Temperature ( $^{\circ}$ C)	20.6 $\pm$ 2.13	21.1 $\pm$ 2.15	21.9 $\pm$ 2.14

<sup>ab</sup> Means in the same row without the same superscripts are significantly different ( $p < 0.05$ ). SE = standard error; WBSF = Warner–Bratzler shear force; N = Newtons;  $^{\circ}$ C = degrees Celsius; Top class = high priced retailers; Middle class = moderately priced.

Nevertheless, an ultimate meat pH range of 6.4 has been reported in previous studies [17,35]. Storage conditions may induce high meat pH<sub>u</sub>, for instance, meat storage temperature of 0 °C caused high meat pH [36]. Therefore, high meat pH<sub>u</sub> at point of purchase may not necessarily suggest that the meat is undesirable, but might mean the lack of desirable colour found in meat immediately after slaughter. This proves that the ultimate pH at the point of purchase for meat is greater than 6.0. Although there was a significant difference in the  $L^*$  values for the different retailer classes, but the lightness values did not differ that much. According to the results of the meat quality attributes, there is no difference in the quality of meat purchased from a butcher, top class and middle-class retail shops. Contrastingly, previous results showed that the place of purchase ranks as one of the most useful factors in assessing meat quality in the shop [37], implying that the meat quality differs per meat retail shop class.

## Conclusions

The results of this study demonstrated that meat distribution chain stages (loading, off-loading and display) change the meat quality of beef, mutton and pork. Moreover, the results showed that the distance travelled from the abattoir to the meat outlets increased lightness ( $L^*$ ), redness ( $a^*$ ) and chroma but decreased hue angle of meat and did not affect yellowness ( $b^*$ ), pH<sub>u</sub>, CL%, WBSF and TM of meat. The results also indicated that storage duration of meat at the abattoir only changed chroma, hue angle, yellowness ( $b^*$ ), lightness ( $L^*$ ) and redness ( $a^*$ ) of meat. In addition, the results illustrated that meat retailer type (butcher, middle or top class) only changed the lightness ( $L^*$ ), WBSF and meat temperature. More similar studies are recommended to improve the findings of the current study.

## Contribution of the Manuscript to the Journal

The present study evaluates the effect of abattoir-to-meat retailer distance, storage duration at the meat retailer and meat retailer class on the physicochemical properties of red meat. This study provides information that has health implications as it can help

prevent the outbreaks of foodborne diseases that may negatively affect meat consumer health if abattoir-to-meat retailer distance, storage duration at the meat retailer and meat retailer class effects on meat quality are not factored by meat producers. In addition, it outlines the role of the food distribution chain in serving to protect and ensure product safety delivery at all points. The meat industry would use evidence-based information to prevent the negative effects of abattoir-to-meat retailer distance, storage duration at the meat retailer and meat retailer class on meat quality to maintain the high quality of their meat products to reduce meat spoilage that can deter meat sales if the above-mentioned factors are not considered. In conclusion, this study's findings would help sustain the high quality of meat products and subsequently the profitability of the meat industry. In this manner, this serves sustainable development which focuses on equal economic growth that generates wealth for all without harming the environment and the consumers at large. Moreover, the information contained in the manuscript adds value for future generations by sustaining the needs and demands of the present without compromising the health of the future generation.

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