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Peer reviewed version

Link to published version (if available):
10.1016/j.meatsci.2016.12.014

Link to publication record on the Bristol Research Portal
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Assessment of the meat quality of lamb *M. longissimus thoracis et luborum* and *M. triceps brachii* following three different Halal slaughter procedures.

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Abstract

A total fifteen male and fifteen female spring lambs were allocated to three groups: traditional Halal slaughter without stunning (TNS), slaughter following electric head-only stunning (EHOS) or post-cut electric head-only stun (PCEHOS) and their meat quality was determined. Instrumental and sensory analyses were carried out on two muscles; *Longissimus thoracis et lumborum* (LTL) and *Triceps brachii* (TB). Additionally, the effects of sex and muscle type were also assessed. No differences were found among slaughter methods for pH, drip loss and shear force. TB had a higher pHu and was more tender than LTL. Muscles from EHOS and PCEHOS lambs discoloured more quickly than TNS muscles. There were no differences in the measured sensory attributes, with the exception of EHOS meat being tougher than PCEHOS and NS meat. This study showed that the three slaughter methods had no substantial effect on lamb meat quality hence, EHOS and PCEHOS which are more welfare friendly should be adopted for routine slaughter of lambs.

1. Introduction

In the past decade, there has been a worldwide decline in the per capita consumption of lamb. Abdullahi, Zainal, and Mahfoor (2007) believe that the reduced consumption is related to the high price of lamb relative to other red meats. The price factor, however, exerts only a minor influence relative to other more important factors like meat quality, product image, food safety, and human health implications of eating meat as well as changes in consumer preference (Bernabéu and Tendero, 2005). In addition, the welfare of meat animals has also become increasingly important to consumers (Blokhuis, Jones, Geers, Miele, & Veissier, 2003). Factors prior to and during slaughter are becoming important considerations due to their influence on the image as well as the quality of the final product (Sañudo, Sanchez, and Alfonso, 1998; Velarde, Gispert, Diestre, & Manteca, 2003).

Legislation in most European countries requires that animals are stunned before slaughter to ensure an immediate loss of consciousness (EU Council Directive 93/119, 1993). Exemptions are however usually made for animals slaughtered by religious groups including Muslims and Jews (Velarde et al., 2014). In countries where religious slaughter is permitted by law, the slaughter of meat animals is either carried out by the Jewish (Shechita) or the Muslim (Halal) method. The Halal meat markets are undergoing a period of unprecedented growth in most European countries, with countries like the UK and France experiencing a yearly growth for well over a decade (Lever & Miele, 2012). Halal lamb accounts for about 20% of the total lamb consumption in the UK and is, therefore, a very important contributor to the British economy (EBLEX, 2010). There has however, always been a debate about the ethics of traditional Halal slaughter (TNS) due to the absence of pre-slaughter stunning.

Pre-slaughter stunning is important for enhancing both the welfare of the animal and the quality of the final product (Önenç & Kaya, 2004; Velarde & Dalmau, 2012; Mustafa M.

Farouk, 2013). Halal slaughter requires that the animal must be alive at the point of slaughter and the slaughter procedure should promote maximum blood drainage, thus ensuring that Muslims do not consume blood in agreement with the Quranic injunction prohibiting blood consumption (Masri, 1989; 2007).Therefore, stunning methods employed must conform to these requirements. Consequently, most studies on religious slaughter have focused on the amount and rate of blood loss and residual blood in meat (Anil et al., 2004; Anil et al., 2006; Khalid, Knowles, & Wotton, 2015).

Electric head-only stunning (EHOS), when done properly, does not kill the animal pre-slaughter nor affect blood flow during exsanguinations thus making it an acceptable stunning method in most commercial Halal slaughter plants (Khalid et al., 2015). However, there are still many Muslims who oppose its use (Farouk, 2013). A potential Halal slaughter method is Post-Cut Electric Head-Only Stunning (PCEHOS) (Farouk, 2013; Salamano et al., 2013). The PCEHOS method, without doubt, ensures that the animal is alive at the point of bleed, it is performed within 5 s post neck-cut, thus minimising any potential welfare concerns and it does not affect blood flow during exsanguination, thus satisfying the Halal slaughter requirements (Gregory, 2005; Velarde et al., 2010; Khalid et al., 2015).

Meat quality also needs to be taken into consideration when the effectiveness of the stunning system is being evaluated (Velarde et al., 2003). Previous studies have shown that pre-slaughter stunning could influence the efficiency of exsanguination, muscular activity, as well as cause downgrading conditions including pelt burn, blood splash and blood speckling (see review by Farouk et al., 2014). However, few studies have looked at the effects of religious slaughter on meat quality (Anil et al., 2004; Önenç & Kaya, 2004; Anil et al., 2006) and none has assessed meat quality parameters such as water holding capacity (WHC), or palatability traits like tenderness, juiciness and flavour as affected by the PCEHOS in lambs.

Studies are needed to provide information on the effects, if any, of the different Halal slaughter methods on lamb meat quality parameters. The aim of this study was therefore to assess the meat quality of lamb *M. longissimus thoracis et luborum* and *M. triceps brachii* as affected by three different Halal slaughter methods: the traditional Halal slaughter without stunning (TNS), slaughter following electric head-only stunning and (EHOS) and post-cut electric head-only stunning (PCEHOS).

2. Materials and methods

This research compared legally permitted methods of slaughter in the UK and was approved by the University of Bristol, UK ethics committee (<mark>UIN number is UB/12/022</mark>). It was conducted in the UK in compliance with all requirements for such experiments. In total, 30 lambs were used for the study.

2.1. *Animals*

The 30 lambs, 15 males and 15 females with respective mean live-weights at slaughter of 38.2 kg ± 1.32 and 37.8 kg ± 1.07, were obtained from a local farm. They arrived at the lairage 18 h prior to slaughter and were put into designated pens, rested and allowed free access to feed and water.

2.1.1. *Stunning and Slaughter*

All stunning and slaughter were carried at Euro Quality Lambs Ltd, Craven Arms, UK. The usual slaughter method for the slaughter plant used is the EHOS. For the purposes of this study, PCEHOS and TNS were also tested. The 30 lambs were uniformly distributed, with respect to carcass weight and grades, into the three treatment groups.

The stunning and slaughter methods have been described in detail by (Khalid et al., 2015). Briefly, during slaughter, each animal was removed from the pen and taken to the slaughter

area where it was assigned to a treatment group (n= 5 males and 5 females per group). All lambs were restrained using a v-shaped rubber belt restrainer (Approved Design Ltd, Walsall, UK,) in which they were either stunned or slaughtered depending on the treatment. The heads of the lambs were wetted before stunning them. Lambs subjected to EHOS were stunned in the restrainer, ejected onto a platform and slaughtered (bled) in a horizontal position whilst those subjected to TNS and PCEHOS were slaughtered and bled in the restrainer. The neck cut was made within 5 seconds before or after stunning for the PCEHOS and EHOS treatments respectively severing all the vessels in the animal's neck with one cut. All lambs were bled for 20 seconds before being hoisted onto the processing line. The stun parameters for EHOS and PCEHOS were a constant current of 1.0A, a frequency of 400Hz and stun duration of 3 seconds. These parameters are based on the requirements of (EC Regulation, 2009) and the recommended parameters specified by the International Halal Integrity Alliance (IHIA, 2010) of 0.6 A for lambs for 1-3 seconds (frequency was not specified). After evisceration and dressing, all carcasses were chilled under commercial conditions for 24 h. The conformation score (an extent of the scale from S = exceptional to P = poor conformation) and fatness score (the scale from 1 = very low to 5 = very high fatness) were assessed according to the EUROP classification system (Commission Regulation EEC 461/93). For the purpose of statistical analysis, the scale of the conformation score was quantified from the grade E = 5 to the grade P = 1.

The *M. longissimus thoracis et lumborum* (LTL) and *Triceps brachii* (TB) from each side of the carcass were removed, vacuum packed and transported under chill conditions to the University of Bristol for meat quality assessment.

2.2. *Instrumental Measurements*

2.2.1. *pH*

At 48 h post-mortem, the muscles were trimmed of external fat, epimysial connective tissue and accessory muscles. The ultimate pH (pHu) of both muscles was measured using a pH glass electrode (Testo Instruments, Alton, UK).

2.2.2. *Drip loss*

Two 20 mm wide steaks were cut from the LTL from each replicate, weighed and hung up by a thread with the longest dimension being vertical. The meat samples were then put in a net bag with both sides cut open and then finally placed in a plastic bag while ensuring that the mesh did not touch the plastic bag. The plastic bag was then sealed and suspended in a cold room at 2°C for 48 h. After 48 h, the chops were reweighed and the difference in weight recorded as the drip loss.

2.2.3. *Colour*

Two 20 mm wide steaks were cut from the LTL and TB from each replicate were cut and modified atmosphere packed (MAP) (80% oxygen, 20% CO_2) and displayed under simulated retail display conditions (700 lux, 16h light 8 h dark at 3°C). Colour was measured daily on each sample from 24 h post packing at three separate positions using a Minolta Chromameter (model CR-300, Minolta Camera Company, Milton Keynes, UK) to determine to determine lightness (L*), redness (a*) yellowness (b*) and Chroma (C*) until the samples discoloured. Chroma (C*) was calculated as: $\sqrt{(a^{*2} + b^{*2})}$.

2.2.4. *Shear force*

The remaining LTL from one side of the carcass and the whole of the LTL from the other side of the carcass together with the remaining TB muscles were weighed and vacuum packed individually, aged at 2°C for seven days and subsequently frozen. For instrumental textural analysis, muscles were thawed overnight in a chiller at 4°C and then cooked in their

vacuum bags in a water bath at 80°C until the temperature at the geometric centre of the meat reached 78°C (approximately 20 min). The samples were then placed in iced water and allowed to cool overnight in a 2°C chiller. The samples were dried with paper and weighed. Ten blocks from each sample measuring 10 mm^2 in cross section and 20 to 30mm in length parallel to the muscle fibre direction were then cut from each sample. The blocks were sheared across the fibre direction using Volodkevitch jaws on a TA XT2 plus Texture Analyser (Stable Micro Systems Ltd., Godalming, Surrey, UK). The maximum peak force at shear for 7-10 blocks was averaged for each sample was recorded.

2.3. *Sensory analysis*

Only the LTL muscles were used in the sensory test. The whole LTL samples were thawed overnight in a domestic refrigerator at 4°C and then ten 20m thick steaks were cut from each and grilled under a grill, turning them every 2 minutes until they reached a centre temperature of 72°C as measured by a thermocouple probe. These chops were then trimmed of exterior fat, cut into cubes, wrapped in pre-coded foil and kept warm prior to serving for taste panel evaluation. The samples were assessed under controlled conditions in purpose-built panel room with separate booths. The booths were illuminated by red light so that the taste panellists were unaware of colour variations if any. The panellists were made up of 10 females, aged 35–55, selected in accordance with the British Standard for selection, training and monitoring of assessors (BSI, 1993) and had received further training in the sensory assessment of meat broadly in line with the methods of Cross, Moen, and Stanfield (1978). They assessed the samples on eight point category scales for texture (1 = extremely tough to 8 = extremely tender), juiciness (1 = extremely dry to 8 = extremely juicy), lamb odour/flavour/abnormal flavour intensity (1 = extremely weak to 8 = extremely strong) and the hedonic flavour/overall liking (1 = dislike extremely to 8 = like extremely) as used by

Nute et al. (2007). Each panellist tested 30 samples. However, to prevent sensory fatigue, the sensory test was done in five sessions and six samples were tested per session. The assessors were instructed to rinse their mouth out with water and to use palate cleaners, bread when necessary. The assessors used direct entry into a computerised sensory assessment programme (Fizz, Version 2.10c, Biosystems, Couternon, France) to record their results.

2.4. *Statistical Analysis*

Instrumental measurements data and the initial colour measurements were analysed using the generalised linear model procedure (Proc GLM) in SAS (2013) with the fixed effects of sex, slaughter method and muscle type as well as their interactions, and individual lamb nested in the sex*slaughter method interaction as a random effect. Differences were identified using the least significant difference mean comparison test when the F-value for the slaughter method was significant ($P < 0.05$).

A repeated measure analysis was performed on the colour measurements using Proc MIXED in SAS (2013) with fixed effects of sex, slaughter method and muscle type and their interactions, individual lamb nested in the sex*slaughter method interaction as a random effect and the day of measurement as the repeated factor. Differences were identified using the least significant difference mean comparison test when the F-value for the feeding effect was significant ($P < 0.05$). In all analyses, non-significant interactions ($P > 0.05$) were excluded from the model.

Results of the sensory evaluation were analysed using MINITAB version 13.0 (MINITAB, PA, USA) and a general linear model (GLM) of analysis of variance (ANOVA).

3. Results

There were no interactions (P > 0.05) among slaughter method, sex and muscle type on any of the measured quality traits; which the exception of colour. Therefore, the results presented are focused on the main treatment effects.

The classification of all 30 lambs used for the study is shown in Table 1. The male lambs were fatter (P < 0.05) than their female counterparts; there were, however, no differences (P > 0.05) in their conformation. There were no differences (P > 0.05) in the conformation and fatness of lambs under the three stunning treatments.

There was no effect of stunning treatments or sex on ultimate pH, instrumental texture or drip loss (Table 2). There were however, significant differences (P < 0.001) in the pHu and texture of the two muscle types. The TB had a higher pHu and was more tender than the LTL.

Colour was not measured until 24 h after packing as it takes several hours for the full bloom to occur. There were no interactions (P > 0.05) between the stunning treatment and sex of lambs on the measured colour coordinates after 24 h of blooming (Table 3). The a*, b* and C* coordinates were not affected by stunning treatment during this period. Significant differences (P < 0.05) were however observed in the L* coordinate among stunning treatments. Meat from PCEHOS lambs was lighter (P < 0.05) than EHOS and TNS lambs. For a*, b* and C* coordinates, meat from male lambs had higher (P < 0.01) values than the meat from female lambs after 24 h of blooming. The LTL muscles had higher (P < 0.01) a*, b* and C* values than TB muscles while the reverse was true for L*.

There were no effects of stunning on either muscle for any of the colour coordinates measured over the study period with the exception of the C* coordinate (Table 4). The sex of lambs has an effect (P < 0.05) on the a* and C* coordinates in both muscle types, and on the b* (P < 001) coordinate in the TB muscle. All colour coordinates in both muscles declined

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over the 8-day period of simulated display (Table 4). By day 5, all the TB steaks had completely discoloured and hence colour measurements were discontinued after day 6.

Significant (P < 0.05) stunning and day or sex and day interaction for muscle types are illustrated in Figures 1 and 2.The rate of change of Chroma (C*) with days displayed as affected by either stunning treatment or sex of lambs are shown in Figure 1 for LTL muscle and Figure. 2 for TB muscle. There was no difference (P > 0.05) in C* value for LTL among stunning treatment until day 4 of measurement when meat from EHOS and PCEHOS lambs began to have a lower (P < 0.05) C* value (Fig. 1). The differences between stunning treatments were more pronounced (P < 0.01) from Day 5 of measurement until Day 8 when all the LTL samples have discoloured. When the lamb steaks were measured each day, it was clear that a Chroma value of about 17 was when the meat began to look brown to the observer. Taking this as a cut-off point for colour shelf-life, it can be seen that the TNS LTL steaks had two days longer colour shelf-life than the EHOS or PCEHOS LTL steaks. There was no interaction (P > 0.05) between sex and day of measurement on the rate of change of chroma for LTL muscles.

There was no interaction (P > 0.05) between stunning treatment and day of measurement on the rate of change of chroma for TB muscles.Taking the same chroma cut-off point for the TB meat, steaks from the female lambs discoloured by day 3 and thus steaks from male lambs had two-day more colour shelf-life (P < 0.001) than meat from male lambs (Fig. 2).

The effects of sex and stunning treatment on sensory characteristics of lamb meat are presented in Table 5. The LTL steaks from EHOS lambs were significantly tougher (P < 0.001) than steaks from the TNS and PCEHOS treated lambs. However, no significant differences (P < 0.05) were found for juiciness, lamb flavour intensity, abnormal flavour or flavour liking. Similarly, there were no effects (P < 0.05) of sex on meat tenderness,

juiciness, lamb flavour intensity, and abnormal flavour, with the exception of meat from female lambs having a better ($P < 0.05$) overall hedonic flavour liking than that of the males.

4. Discussion

The slaughter of animals results in involuntary convulsive movements (Blackmore & Newhook, 1982) which can alter the ultimate pH of meat (Petersen & Blackmore, 1982). In this present study, however, even at 48 h post-mortem, the stunning treatments did not affect pHu. This agrees with the report of Petersen and Blackmore (1982) who found no apparent effect of the stunning method on pH of lambs at 15 h post-mortem. Paulick, Stolle, and von Mickwitz (1989) also found no significant differences in the pH of lambs slaughtered with or without previous stunning at 48 h post-mortem although they observed a sharp drop in the pH of the electrically stunned lambs. In this study, however, it was not possible to compare the rate of pH decline of all three methods at the same time hence the initial pH, as well as the rate of pH, were not measured.

The higher ultimate pH observed in the triceps muscles corroborate earlier observations. Shoulder muscles generally have higher ultimate pH values than the LTL and they are also more affected by stress situations (Bray, Graafhuis, & Chrystall, 1989). Wiklund, Andersson, Malmfors, Lundström, and Danell (1995) reported that this high ultimate pH is not only affected by physical activity but also the fibre type distribution within the muscle. Wiklund et al. (1995), working with reindeer, similarly recorded higher ultimate pH values in TB muscles than in LTL and *M. biceps femoris*.

The values recorded for drip loss were much higher than those reported by Doherty, Sheridan, Allen, McDowell, and Blair (1996) (0.24% to 0.46%) after 7 and 28 days of storage in different packaging systems. However, Ingólfsson and Dransfield (1991) suggested that drip loss of up to 2.7% is acceptable. The differences in the value of Doherty et al. (1996)

could be attributed to the method used in determining drip loss as they measured the amount of drip obtained in the modified atmosphere packs from each lamb after storage. The various stunning treatments had no influence on the amount of exudate from LTL in the current study. Vergara, Linares, Berruga, and Gallego (2005) reported a higher drip loss value in non-stunned lambs compared to their compared to their stunned compared. Differences in drip loss between stunned and non-stunned animals have been associated with a delayed drop in pH in muscles after death as well as differences in pHu (Støier, Aaslyng, Olsen, & Henckel, 2001; Maltin, Balcerzak, Tilley, & Delday, 2003; Vergara et al., 2005). In the present study, however, the stunning treatments did not affect ultimate pH and as a result, drip loss was also not affected.

The difference in chroma (C*) values for the muscles of the two electrically stunned groups after 24 h of blooming can be attributed to the time post-mortem each stunning was carried out. The passage of electricity through muscles in the form of electrical stimulation predisposes them to earlier discoloration (Ledward, 1985; van Laack & Smulders, 1990; Wiklund, Stevenson-Barry, Duncan, & Littlejohn, 2001), thus making non-stimulated muscles more colour stable. In the present study, the effect of electrical stunning could be likened to that of electrical stimulation as both involve the use of electrical current. This could possibly explain why the LTL muscles from the two electrically stunned procedures discoloured more quickly (low C* values on day five) than the non-stunned ones. The pale appearance (higher L*) seen in the PCEHOS muscle after 24 h of blooming could be attributed to the effect of the electrical stunning. In this regard, muscles from EHOS animals were also expected to have a pale appearance but this was however not the case. Stunning after bleeding is more likely to produce an electrical stimulation effect than stunning before bleeding. Electrically stimulation accelerated the rate of pH decline in lamb muscles (Polidori, Lee, Kauffman, & Marsh, 1999). Therefore, it is possible that the PCEHOS

muscles were lighter because their rate of pH decline was faster whilst the muscle was hot thus producing a small PSE-like condition.

The LTL was more colour stable than TB in the present study. This agrees with the results of Ledward (1971,1985) and Renerre (1984) who found LTL muscle more colour stable than most of the major muscles in beef. Ledward (1985) attributed the stability of LTL to its inherent nature and its position deep in the shoulder region of the carcass which aids rapid cooling. When muscles are positioned deep in carcasses, their rate of cooling is affected, while the combination of low pH (below 6) and high temperature gives them an initial pale colour and they become susceptible to metmyoglobin formation (Ledward, 1985). Although the pHu of the triceps was higher than the LTL, the values recorded were much lower than pH 6 thus the explanation of Ledward (1985) might be applied in this instance. The faster discolouration of the TB muscle than the LTL explains why the colour measurement was discontinued after day six. Meat from lambs generally has a higher post-mortem oxygen consumption rate than beef (Echevarne, Renerre, & Labas, 1990) and thus they discolour more rapidly during storage. In the present study, it was observed that the type of muscle also played a major role in the rate of discoloration of lamb meat.

The LTL muscle was redder (higher a*) than the TB after 24 hours of blooming. Similarly, muscles from the male lambs had higher a* than those from the female lambs. The redness of meat colour is produced by oxygenation of deoxymyoglobin to oxymyoglobin, due to exposure to oxygen (Young, Priolo, Simmons, & West, 1999). A thick oxymyoglobin layer masks the development of an underlying metmyoglobin layer at high oxygen partial pressures which in turn extends displays (Hood, 1984; Singh, Wani, Saengerlaub, & Langowski, 2011). It may be possible that muscles from the male lambs as well as the LTL had a thicker layer of oxymyoglobin than the muscle from female lambs or the TB muscle, this may have extended

their colour shelf life. The type of slaughter method the lambs were subjected to had no effect on a* and b* values. These results agree with the findings of Vergara and Gallego (2000) and Vergara et al. (2005) who also found no significant difference in a* and b* values between over wrapped meat from electrically stunned lambs and that from non-stunned lambs when meat colour was measured at 24 h post-mortem.

Shear force was not affected by any of the slaughter methods in the current study. Bond, Can, and Warner (2004) reported that stress before slaughter has no significant effect on shear force values although shear force values tend to decrease with ageing. Similarly, Vergara et al. (2005) found no significant difference between the shear force of electrically stunned and non-stunned lambs after being aged for 7 days. Similar results have been reported previously (Vergara & Gallego, 2000; Linares, Bórnez, & Vergara, 2007, 2008). Shear force values of lambs below 4 kg (39.23 N) is classified as tender (Perry, Thompson, Hwang, Butchers, & Egan, 2001; Geesink, Sujang, & Koohmaraie, 2011). In this regard, both LTL and TB muscles from the lambs used in this study can also be generally classified as being tender as all values were well below 39.23 N. The low shear force values obtained by both muscles could principally be due to the effect of ageing and the young age of the lambs. The lack of difference in shear force values between the sexes could be due resulted from increased fatness in the male lambs thus making their meat appear as tender as that of the female lambs. Nevertheless, these were spring lambs and the difference between male and females is usually more apparent much later in the season. These results are interesting and are contrary to what is generally known where females start to mature earlier and lay down fat before males; so are fatter. This may, therefore, warrant further investigation.

pHu and temperature have a great influence on the final tenderness of meat (Yu & Lee, 1986; R. L. van Laack, Stevens, & Stalder, 2001). It seems therefore that the difference in

tenderness between the two muscles was due to the final pH reached in each muscle and the position of the muscle in the carcass. The pHu of the two muscles were within the normal range of 5.4 to 5.7 (Maltin et al., 2003). Therefore, differences in the mean shear force for the two muscles could be attributed to their position in the carcass which in turn affects their chilling rate (R. L. J. M. van Laack & Smulders, 1990). The triceps, being deep-seated in the carcass, will presumably take a much longer time to cool and, therefore, prolonging the activities of proteolytic enzymes while the carcass is still warm, thereby aiding in the process of tenderisation. Nevertheless, differences in tenderness could also be due to the difference in fibre type (Maltin et al., 2003).

There was a contradiction between the scores from the sensory evaluation and the values of the shear force. Although there were no differences in mechanical shear force due to slaughter method, the scores from the sensory analysis showed that EHOS meat was slightly tougher than either of the other two treatments. Although this inconsistency was unexpected, the difference in results may be due to the different cooking methods used and the centre temperature reached. Panellists may also be experiencing different attributes, as they will possibly be influenced more by fat and juiciness than an instrumental method. However, a similar result was obtained for both shear force and texture in relation to the sex of the lambs. This agrees with the findings of Dransfield, Nute, Hogg, and Walters (1990) who also saw no difference in tenderness of male and female lambs.

Fat is strongly implicated in lamb meat flavour and increased fattiness alone can have a greater effect on the flavour of lamb meat (Young & Braggins, 1994). Consequently, the increased level of fatness in the male lambs could have played an important role in the scoring of their flavour liking attribute. Lamb meat, in general, produces an objectionable species- specific flavour disliked by many consumers, it is therefore not surprising that the

slightly fatter male lambs had a lower score for flavour indicating that the female lambs had a better flavour than the males, although this was the result of a small panel of people who do not represent the whole population.

5. Conclusion

In conclusion, electrical stunning of lambs caused faster discolouration of meat than the non-stunning method. Sex of lambs and muscle type were more important in determining meat colour than the slaughter methods. The traditional Halal non-stun slaughter prolonged meat colour shelf life but it did not affect the other meat quality attributes Overall, there were no substantial differences in meat quality as affected by the various slaughter methods. Hence, as a balance between animal welfare and meat quality, it is recommended that electrical head-only stun should or the post-cut electric head-only stun be adopted for routine slaughter of lambs. Further experiments should be carried out on post-cut electric head-only stun principally on the rate of pH decline to fully understand its effects on lamb meat quality.

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Tables and figures

Table 1

Comparison of fatness and conformation of lambs used in the present study

Parameter	Stunning method				Sex			Level of significance	
	EHOS	TNS	PCEHOS	SE	Female	Male	SE	Stun	Sex
n	10	10	10		15	15			
Conformation	2.90	3.10	2.80	0.21	2.87	3.00	0.26	ns	ns
Fatness	3.05	3.15	3.15	0.07	3.03	3.20	0.06	ns	*

SE = standard error; ns = not significant;
Significance at * P < 0.05
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Table 2

The Effects of sex, stunning treatment and muscle type on pHu, texture and drip loss

Parameter	Stunning method				Sex			Muscle			Level of significance		
	EHOS	TNS	PCEHOS	SE	Female	Male	SE	LTL	TB	SE	Stun	Sex	Muscle
n	10	10	10		15	15		30	30				
pHu	5.48	5.53	5.51	0.01	5.51	5.49	0.01	5.44	5.57	0.01	ns	ns	***
Shear force (N)	20.59	24.32	21.67	1.96	22.65	21.67	1.57	26.97	17.36	1.57	ns	ns	***
Drip loss (%)[1]	1.07	1.33	1.23	0.10	1.21	1.22	0.09	–	–	–	ns	ns	–

[1]Drip loss was measured on LTL muscle only
EHOS = electric head only stunning; PCEHOS = post-cut electric head-only stun; TNS = traditional non stun; LTL = *M. longissimus thoracis et luborum*; TB =*M. triceps brachii*; SE = standard error; ns = not significant.
Significance at *** P < 0.001

Table 3

The effects of stunning, sex, and muscle type on colour coordinates (L*, a*, b*and C*) after 24 h of blooming

	Stunning method				Sex			Muscle			Level of significance			
Colour coordinate	EHOS	TNS	PCEHOS	SE	Female	Male	SE	LTL	TB	SE	Stun	Sex	Muscle	Stun×Sex
n	10	10	10		15	15		30	30					
L*	41.66[a]	42.28[a]	43.50[b]	0.38	42.49	42.52	0.31	42.08	42.93	0.19	**	ns	***	ns
a*	17.84	17.99	17.32	0.21	17.26	18.17	0.17	18.10	17.34	0.09	ns	***	***	ns
b*	9.59	9.52	9.41	0.13	9.25	9.76	0.11	9.65	9.36	0.07	ns	**	**	ns
C*[1]	20.11	20.31	19.97	0.24	19.71	20.55	0.21	20.55	19.72	0.10	ns	**	***	ns

[1]Chroma (C*) was calculated as: $\sqrt{(a^{*2} + b^{*2})}$

EHOS = electric head-only stun; PCEHOS = post-cut electric head-only stun; TNS = traditional non stun; LTL = *M. longissimus thoracis et luborum*; TB =*M. triceps brachii*; S×M = sex and muscle interaction; St×M = stun and muscle interaction; ns = not significant; SE = standard error; ns = not significant.

[a,b]Means within a row with different superscripts for stunning method differ significantly (P < 0.05).

Significance at *P < 0.05, ** P < 0.01*** P < 0.001.

Table 4

The effects of stunning, sex, and muscle type on colour coordinates (L*, a*, b*and C*) over the study period

Colour coordinate	Stunning method				Sex			Level of significance		
	EHOS	TNS	PCEHOS	SE	Female	Male	SE	Stun	Sex	Day
n	10	10	10		15	15				
M. longissimus thoracis et luborum										
L*	40.45	41.78	42.38	0.57	41.32	41.75	0.46	ns	ns	***
a*	15.66	16.06	15.39	0.23	15.35	16.07	0.19	ns	*	***
b*	9.03	9.41	9.28	0.16	9.10	9.38	0.13	ns	ns	***
C*[1]	18.09	18.73	17.90	0.21	17.89	18.59	0.17	*	**	**
M. triceps brachii										
L*	42.88	42.78	43.35	0.37	43.22	42.79	0.30	ns	ns	***
a*	15.14	15.39	14.84	0.20	14.58	15.66	0.16	ns	***	***
b*	9.12	8.98	8.82	0.12	8.76	9.18	0.10	ns	**	***
C*[1]	17.68[ab]	17.90[b]	17.21[a]	0.17	17.07	18.12	0.14	*	***	***

[1]Chroma (C*) was calculated as: $\sqrt{(a^{*2} + b^{*2})}$

EHOS = electric head-only stun; PCEHOS = post-cut electric head-only stun; TNS = traditional non stun; ns = not significant; SE = standard error; ns = not significant.

[a,b]Means within a row with different superscripts for stunning method differ (P < 0.05).

Significance at *P < 0.05, ** P < 0.01*** P < 0.001.

Table 5

The Effect of stunning method and sex on sensory attributes of lamb loin steaks

Sensory attribute	Stunning method				Sex			level of significance	
	EHOS	TNS	PCEHOS	SE	Female	Male	SE	Stun	Sex
n	10	10	10		15	15			
Tenderness	4.44[a]	5.34[b]	5.40[b]	0.13	5.12	5.00	0.11	***	ns
Juiciness	5.36	5.59	5.50	0.08	5.46	5.51	0.07	ns	ns
Lamb flavour intensity	4.97	5.02	4.95	0.08	4.92	5.05	0.07	ns	ns
Abnormal flavour	2.46	2.33	2.49	0.09	2.39	2.46	0.08	ns	ns
Flavour liking	5.41	5.68	5.54	0.11	5.68	5.41	0.09	ns	*

EHOS = electric head only stunning; PCEHOS = post-cut electric head-only stun, TNS = traditional non stun;

SE = standard error; ns = not significant.

[a,b] Means in a row with different superscripts for stunning method differ significantly $P < 0.05$
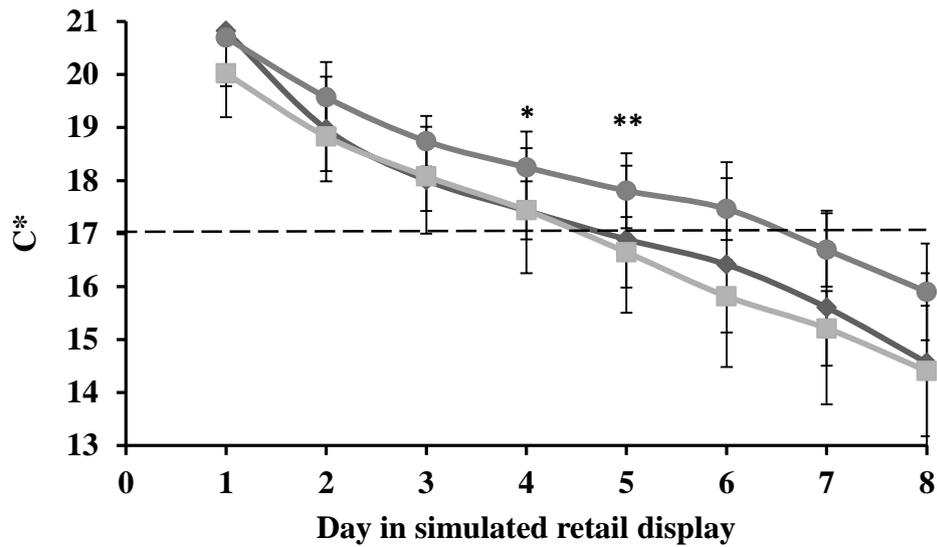
Significance at $*P < 0.05$, $*** P < 0.001$.

Fig. 1. Rate of change in colour C* (chroma value), in simulated retail display, of modified atmosphere packed *Longissimus thoracis et luborum*from three different stunning methods (EHOS: electric head-only stun (♦); PCEHOS: post-cut electric head-only stun (■); TNS: traditional non stun (●)).Significance at * P < 0.05 and ** P < 0.01 for day 4 and days 5 to 8 respectively.

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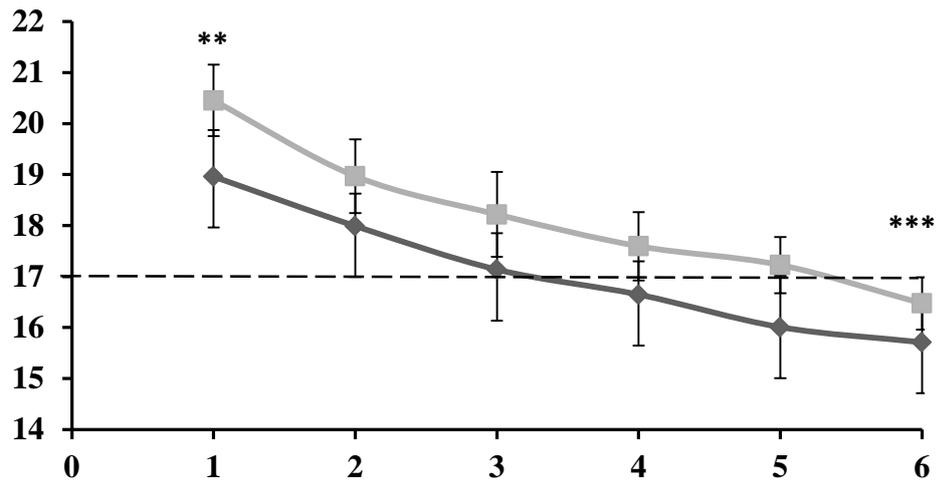
Fig. 2. Comparison of the rate of change in C* (chroma value) in simulated retail display of modified atmosphere packed *M. triceps brachii* from carcasses of male (■) and female (◆) lambs. Significance at ** $P < 0.01$ and *** $P < 0.001$ for day 1 to 5 and day 8 respectively.