Comparison of carcass and meat quality in goats subjected to preslaughter head-only electrical stunning or slaughtered without stunning

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\textbf{ABSTRACT}

The effects of slaughter without stunning in comparison with head-only electrical stunning (HOES) on carcass hemorrhages and meat quality in goats were evaluated. Sixteen Boer crossbred bucks were subjected to either non-stun (NS) or HOES (1 A, for 3 s at 50 Hz). Meat quality traits such as pH, water holding capacity (WHC), color, tenderness, myofibril fragmentation index (MFI) and sarcomere length were assessed on semitendinosus (ST) muscle, while the incidences of hemorrhage were morphologically examined on shoulders and legs of each carcass. The results indicate no differences (\(p > 0.05\)) in meat quality traits between NS and HOES goats. However, carcases obtained from the head-only electrically stunned goats had higher (\(< 0.05\)) incidence of hemorrhages than those slaughtered without stunning. HOES prior slaughter increased carcass hemorrhages without adversely affecting meat quality traits in goats.

\textbf{1. Introduction}

The last step of the meat production chain (slaughter) is a very delicate operation and has received much debate as regards to its humaneness (Sabow, Sazili, Zulkiifli, Goh, Ab Kadir, Adeyemi et al., 2013; Salwani et al., 2015). Slaughter procedures are generally regulated by legislation and codes of practice that are species specific. However, the suitability of commonly used methods does not only depend on species but also the availability of facilities, consumer demands and/or perceptions and economic considerations (Anil, 2012).

The major types of slaughter methods are conventional and religious methods (Nakynsige, Fatimah et al., 2014). Religious slaughter is devoid of stunning and it entails killing an animal with a sharp knife by neck incision, severing the carotid arteries, jugular veins, trachea and esophagus thereby enabling a fast and complete bleeding (Farouk, 2013; Sabow et al., 2016). In contrast, conventional slaughter involves stunning of animal prior to exsanguination (Farouk et al., 2014; Salwani et al., 2015). According to the EU Council Directive (EU, 1993) and Council Regulation ((EC) No 1099/2009) (European Community [EC], 2009), animals must be stunned at the point of slaughter to render them unconscious and insensible to distress and pain from the act of slaughter. Among the various stunning techniques adopted by the meat industry, the electrical stunning system is the most widely used in sheep and goats (Robins, Pleiter, Latter, & Phillips, 2014; Zivotofsky & Strous, 2012). Electrical stunning is accomplished by passage of a sufficient amount of current through the central nervous system (McNeal, Fletcher, & Buhr, 2003). It works by producing brain dysfunction and unconsciousness either temporarily in which case the animal dies as a result of...
bleed out (exsanguination); head-only electrical stunning (HOES) or with subsequent killing by cardiac arrest; heat-to-body electrical stunning (Farouk, 2013; Nakyinsige et al., 2013; Sabow et al., 2016). The HOES method has been accepted by some Muslim representatives and communities (Farouk et al., 2014). The basis for this is that HOES is not known to result in the death of animals (Salamano et al., 2013). However, it has been shown to have adverse effects on carcass and meat quality, which is the main problem in the meat industry. Visual carcass defects such as hemorrhages (blood splash and blood spots) are among the drawbacks on carcass characteristics which affect consumer acceptance of the meat. Meanwhile, hemorrhages are not usually encountered in slaughter without any form of stunning (i.e. traditional halal slaughter).

Stunning and slaughter procedures need to maintain product quality as well as protect animal welfare. Although there have been some researches in this area, most information originates from work in sheep and cattle (Anil, 2012). There is dearth of information regarding the effects of slaughter methods on carcass characteristics and meat quality in goats. Thus, this study was conducted to determine the effect of slaughtering method (HOES or traditional halal slaughtering (no stunning)) on carcass and meat quality characteristics in crossbred Boer bucks.

2. Material and methods

2.1. Animal welfare

The experimental protocol was approved by the Institutional Animal Care and Use Committee (IACUC) of the Universiti Putra Malaysia (Approval No. R052/2015).

2.2. Animals, stunning and slaughter procedure

Sixteen crossbred Boer bucks between the ages of 8–10 months with an average body weight of 28.85 ± 1.35 kg, reared and managed under similar condition were purchased from a commercial goat farm. The goats were divided into two groups of 8 animals each and randomly assigned to either traditional halal slaughter without stunning (NS) or preslaughter HOES. The first group of animals were slaughtered without stunning following the halal slaughtering procedure as outlined in the MS1500: 2009 (Department of Standards Malaysia, 2009). In the second group, animals were stunned electrically using the head-only technique at a constant of 1 A, 50 Hz for 3 s, the head electrodes are placed between the eyes and the ears on both sides. The procedure was carried out using electrical stunning transformer type CS-1 system (Karl Schermer, Ettlingen, Germany) connected to double-electrode scissor-type dry stunning tongs (Z3, Karl Schermer, Ettlingen, Germany). Immediately after stunning, the goats were bled to drain excess blood from the carcass. The average stun-to-stick interval was 8.61 ± 0.11 s.

2.3. Carcass evaluation

Carcass evaluation was carried out using the method of Velarde, Gisbert, Diestre, and Manteca (2003). Hemorrhages in the leg and shoulder of each carcass were scored according to their incidences and sizes. The incidence and severity of speckles on the carcass was estimated visually, using the 5-point grading scale (0 score, no speckle, to a 5 score which indicates large fiery red areas) developed by the Meat Industry Research Institute of New Zealand (Kirton, Frazerhurst, Bishop, & Winn, 1981).

2.4. Sample handling and storage

After evisceration, the right semitendinosus (ST) muscle were separated into three parts. The first portion (about 20 g) was properly labeled, vacuum packaged and stored in a 4°C chiller for drip loss determination. The second portion was snap frozen in liquid nitrogen (Malaysian Oxygen Bhd., Malaysia) and stored at −80°C until subsequent determination of muscle pH at 0 day, while the third portion remain on the carcasses hung in the 4°C chiller and subsequent sampling was carried out at specific periods (24 h and 7 days).

2.5. Determination of meat quality traits

Both the pre- and post-rigor pH of the muscle was measured using a portable pH meter (Mettler Toledo, AG 8603, Switzerland) following the method described by Nakyinsige, Sazili et al. (2014).

Color was determined in triplicate using Color Flex spectrophotometer (Hunter Lab Reston, VA, USA). L* (Lightness), a* (redness) and b* (yellowness) were measured using D65 illumination and 10° standard observer, tristimulus values (X, Y, Z) and reflectance at a specific wavelength (400–700 nm) (Sabow, Sazili, Zulkifli, Goh, Ab Kadir, & Adeyemi, 2015). The ST muscle sample of approximately 12 mm of thickness (AMSA, 2012) were bloomed at 25°C for 30 min and placed with the bloomed surface facing base of the color flex cup.

Drip loss and cooking loss were determined by the methods described by Adeyemi, Sabow, Abubakar, Samsudin, and Sazili (2016). The samples were cooked in a preheated water bath set at 80°C. The cooking was stopped once the internal temperature of the samples has reached 80°C as monitored using a stabling temperature probe (HI 145–00 thermometer, HANNA® instruments, Woonsocket, RI, USA).

The meat samples used for the determination of cooking loss were collected and used to determine tenderness using the Volodkovitch bite jaw attached to a TAHD plus® texture analyzer (Stable Micro System, Surrey, UK). Sample preparation was conducted using the procedure previously described by Szil et al. (2005). Triplicate blocks of 1 cm (height) × 1 cm (width) × 2 cm (length) were cut from each sample and the average shear force of the blocks was used for the analysis. The myofibril fragmentation index (MFI) was determined in line with the method of Hopkins, Littlefield, and Thompson (2000) and Nakyinsige, Sazili et al. (2014). Sarcomere length was measured according to the methods described by Kandepan, Anjaneyulu, Kondaiah, Mendiratta, and Lakshmanan (2009). The length of sarcomere was examined with an image analyzer microscope (Olympus, BX. 51. TF, Tokyo, Japan) as described by Sabow, Sazili, Aghwan, et al. (2015). Ten myofibrils (each myofibril contains at least 10 sarcomeres) were selected to calculate the average length of the sarcomere.
2.6. Data analysis

The data were checked for normality using the PROC UNIVARIATE procedure of Statistical Analysis System (SAS, 2007) and were found to be normally distributed. The experiment followed a completely randomized design. Data analysis for meat quality traits was performed using the MIXED procedure of SAS version 9.2 software (SAS, 2007) in which dietary treatments, postmortem storage days and interaction between dietary treatments and postmortem storage were fitted as fixed effects in a repeated measure analysis. Duncan multiple range test was used to test the significance of variance between the means of the parameters at significant level of $p < 0.05$. Carcass evaluation (speckles) was analyzed using $T$-test.

3. Results and discussion

3.1. Carcass characteristics

Hemorrhages are considered major quality defects, and can cause undesirable discoloration and reduce the shelf life of meat (Alvarado, Richards, O’Keefe, & Wang, 2007). In this study, carcasses from the HOES group had higher scores for speckles ($p < 0.05$) than those from NS (Table 1). This could be attributed to the higher intensity in muscle contraction and a rise in blood pressure with rupture of blood vessels. Similarly, Gregory (1998) attributed the higher incidence of hemorrhages in the carcasses from the electrically stunned group to higher muscle contractile forces. This finding is consistent with the that of Gregory (2007) who observed that HOES induces an increase in blood pressure, which when accompanied by strong skeletal muscle activity during the tonic and clonic phases, can lead to hemorrhages in the carcass.

Some hemorrhages are associated with hyper contracted and disrupted muscle fibers, which indicate that they are caused by severe muscular strain. In general, hemorrhages are found near venules or veins where rupture has occurred, which indicates that venous blood pressure increase can cause rupture of venules and small vein (Kranen, Lambooij, Veerkamp, Van Kuppevelt, & Veerkamp, 2000). During electrical stunning, blood pressure changes, and muscle spasms

![Table 1](image-url)

| Parameter               | Aging (day) | Treatment | p-value | SEM | Treatment | p-value | Treatment × aging |
|-------------------------|-------------|-----------|---------|-----|-----------|---------|------------------|
| pH                      | 0           | NS        | 6.587   | 0.146 | 6.540     | 0.146   | 0.001            |
|                         | 1           | HOES      | 6.228   | 0.043 | 6.133     | 0.043   | 0.001            |
| Lightness (L* )         | 1           | NS        | 32.521  | 0.081 | 31.534    | 0.081   | 0.001            |
|                         | 7           | HOES      | 35.122  | 0.081 | 35.118    | 0.081   | 0.001            |
| Redness (a*)            | 1           | NS        | 13.653  | 0.001 | 12.889    | 0.001   | 0.001            |
|                         | 7           | HOES      | 11.628  | 0.001 | 11.487    | 0.001   | 0.001            |
| Yellowness (b*)         | 1           | NS        | 10.405  | 0.001 | 10.725    | 0.001   | 0.001            |
|                         | 7           | HOES      | 14.877  | 0.001 | 14.286    | 0.001   | 0.001            |
| Drip loss (%)           | 1           | NS        | 0.943   | 0.001 | 1.106     | 0.001   | 0.001            |
|                         | 7           | HOES      | 3.121   | 0.001 | 3.269     | 0.001   | 0.001            |
| Cooking loss (%)        | 1           | NS        | 39.894  | 0.001 | 40.497    | 0.001   | 0.001            |
|                         | 7           | HOES      | 33.855  | 0.001 | 29.116    | 0.001   | 0.001            |
| Shear force (kg)        | 1           | NS        | 1.194   | 0.001 | 1.149     | 0.001   | 0.001            |
|                         | 7           | HOES      | 0.943   | 0.001 | 1.106     | 0.001   | 0.001            |
| MFI                     | 1           | NS        | 68.839  | 0.001 | 69.457    | 0.001   | 0.001            |
|                         | 7           | HOES      | 87.534  | 0.001 | 94.809    | 0.001   | 0.001            |
| Sarcomere length (µm)   | 1           | NS        | 1.548   | 0.001 | 1.631     | 0.001   | 0.001            |
|                         | 7           | HOES      | 1.733   | 0.001 | 1.815     | 0.001   | 0.001            |
| Speckles (scores*)      | Leg         | NS        | 0.541^a| 0.001 | 2.890^a   | 0.001   | –                |
|                         | Shoulder    | HOES      | 0.230^a| 0.001 | 2.500^a   | 0.001   | –                |

NS: Non-stunning; HOES : Head-only electrical stunning.

*a,b* Means with different letters are significantly different at $p < 0.05$.

MFI: Myofibrillar fragmentation index.

SEM: Standard error of mean.

*M* score indicates the absence of splash, 1 and 2 scores indicate the incidence of one or very few mainly small hemorrhages, and 3 and 4 scores show a very badly splashed carcass and score 5 indicates large fiery red areas from which many pinprick-like areas merge (Kirton et al., 1981).

NS: Sin aturdimiento; HOES: Aturdimiento eléctrico limitado a la cabeza.

*a,b* Los promedios con diferentes letras son significativamente diferentes a $p < 0.05$.

MFI: Índice de fragmentación miofibrilar.

SEM: Error estándar del promedio.

*0 score indicates the absence of splapticuras, los resultados 1 y 2 indican la incidencia de una o unas pocas hemorragias mayoritariamente pequeñas, los resultados 3 y 4 muestran un cuerpo muy salpicado y el resultado 5 indica grandes áreas con un rojo ardiente en las cuales emergen muchas áreas con apariencia de pinchazo (Kirton et al., 1981).*
and/or convulsions can cause ruptures and hemorrhages in vessel. In a recent review, Farouk et al. (2014) summarized the outcomes of a number of studies and outlined that the influence of stunning techniques on the severity of blood splash is in the sequence: no stun < percussion < captive bolt < head-to-back electrical stun < head-only electrical stun which is in tandem with the current findings.

3.2. Meat quality traits

3.2.1. pH values

The results of muscle pH obtained from goats subjected to slaughter without stunning (NS) and HOES are presented in Table 1. The pre-rigor pH values for both slaughtering methods were not significantly different. Similarly, Vergara, Linares, Berruga, and Gallego (2005) found no significant differences in pHr (immediately after dressing) between non-stunned and electrically stunned lambs. After rigor, the values of muscle pH did not differ between NS and HOES groups. This finding is in tandem with those of Velarde et al. (2003) and Vergara and Gallego (2000) who reported similar ultimate pH in non-stunned and electrically stunned lambs. Regardless of the treatment, the pH values reduced significantly with ageing period. This observation could be due to the conversion of glycogen to lactic acid through anaerobic glycolysis (Adeyemi & Sazili, 2014). Similar observation was observed during chill storage of semimembranosus muscle in goats (Adeyemi Sabow, Shittu, Karim, Karsani, & Sazili, 2015).

3.2.2. Color values (L*, a* and b*)

The first assessment made by consumers of red meat for quality is based on its color (Adeyemi, Sabow, Abubakar, Samsudin, & Sazili, 2016). As shown in Table 1, color coordinates (L*, a* and b*) were not affected by slaughter methods on days 1 and 7 postmortem. The present findings are in agreement with those of Velarde, Gisbert, Dietre and Manteca and Vergara and Gallego (2000) in lambs and Onenc and Kaya (2004) in cattle with no significant differences in L*, a* and b* values between non-stunned and electrically stunned animals. Regardless of slaughter method, ageing time had no effect on the redness of ST muscle in goats. This observation contradicts the findings of Adeyemi, Sabow, et al. (2016) who observed a reduction in the redness of caprine longissimus muscle aged for 7 days. Postmortem ageing had no effect on the yellowness of ST muscle in goats. Similarly, postmortem ageing did not affect the yellowness of longissimus muscle in goats (Adeyemi, Sabow, et al., 2016).

Regardless of slaughter method, there was a significant increase in lightness over storage. The improvement in lightness value during postmortem storage is in tandem with the findings of Hou et al. (2014) and Zakrys, Hogan, O’Sullivan, Allen, and Kerry (2008). In contrast, postmortem ageing had no effect on the lightness of longissimus muscle (Adeyemi, Sabow, et al., 2016) and semimembranosus muscle in goats (Adeyemi, Sabow, Shittu, Karim, & Sazili, 2015).

3.2.3. Water holding capacity

Water holding capacity (WHC) is defined as the ability of meat to reserve an essential quantity of both inherent and added water which are quality attributes for the meat industry and the consumers (Adeyemi Sabow, Shittu, Karim, Karsani, & Sazili, 2015; Modzelewksa-Kapitula, Kwiatkowska, Jankowska, & Dąbrowska, 2015). The results of drip loss and cooking loss of chevon obtained from goats subjected to different slaughtering method are shown in Table 1. Slaughter method had no effect (p > 0.05) on drip loss and cooking loss at 1 and 7 days of postmortem period. The resemblance in WHC during the first 7 days of postmortem could perhaps be due to the similarity in ultimate pH of the ST muscle of the NS and HOES goats. Nakyinsige, Szalli et al. (2014) reported that WHC is affected by muscle pH decline during postmortem. The present findings are in agreement with that of Onenc and Kaya (2004) who found no significant difference in WHC of beef cattle slaughtered without stunning or subjected to preslaughter electrical stunning prior to slaughter. During postmortem, the level of drip loss significantly increased while cooking loss decreased. Earlier studies (Bertram et al., 2007; Traore et al., 2012) have reported that the ability of protein in fresh meat to maintain its water is reduced during chilled storage. Lonergan, Huff-Lonergan, Rowe, Kuhlers, and Jungst (2001) demonstrated that the oxidative process, taking place in protein fractions, may affect the ability to bind its water and this could result in a poor water holding capacity. Similarly, an increase in drip loss was observed during postmortem ageing of gluteus medius muscle in goats (Adeyemi, Shittu, Sabow, Ebrahim, & Sazili, 2016).

3.2.4. Shear force values

Shear force is inversely related to tenderness and it is considered one of the most important factors affecting consumer acceptability of meat (Ferguson & Warner, 2008). Shear force values are shown in Table 1. The average shear force values of goat meat obtained from non-stunned and HOES techniques did not differ (p > 0.05). Similarly Linares, Bórnez, and Vergara (2007) and Büyükkünal and Nazlı (2007) reported no significant difference between electrically stunned and non-stunned lambs in terms of shear force values. Shear force values for both treatments reduced with ageing time. The improvement of tenderness in meat could be due to rigor resolution caused by the actions of the enzymes through the breakdown of collagen binding muscle fibers together under postmortem conditions (Adeyemi & Sazili, 2014; Li et al., 2012; Sazili et al., 2013).

3.2.5. MFI and sarcomere length

Myofibrillar fragmentation index (MFI) is a reliable indicator of proteolysis and offers a measure of the tenderization process. It measures the extent of ageing through changes in the fragility of the myofilaments which proceeds through the weakening of the Z-line proteins (Li et al., 2012). Table 1 shows the result for MFI. Slaughter method had no effect (p > 0.05) on MFI values on 1 and 7 days postmortem. This explains the similarity between meat from NS and HOES animals in terms of shear force values. Hou et al. (2014) and Marino et al. (2013) found a strong relationship between MFI and shear force. In line with the present findings, Sabow, Sazili, Aghwan, et al. (2015) reported that MFI values were not affected in goats subjected to different methods of slaughter. Irrespective of slaughter method, the MFI was significantly higher on day 7 compared with day 1 postmortem. The increment in MFI could be due to the degradation of the muscle myofibrillar proteins during postmortem storage. This result is
consistent with those of Hou et al. (2014), Sabow, Szazli, Aghwan, et al. (2015), Nakynisige, Szazli et al. (2014) and Hopkins, Martin, and Gilmour (2004), who showed an increased myofibrillar protein fragmentation as a consequence of proteolysis during postmortem ageing of meat.

The extent of muscle contraction was measured as the sarcomere length. The changes in sarcomere length in goat muscles obtained from different methods of slaughtering were not different (p > 0.05) (Table 1). This suggests that both methods of slaughter reduced overlapping of actin and myosin at the same rate. These results are similar to those of Sabow, Szazli, Zulkifli, Goh, Ab Kadir, and Adeyemi (2015) who demonstrated that slaughtering goats without rendering them unconscious did not influence the sarcomere length values. The length of sarcomere increased with increase in postmortem storage regardless of the treatment group. This could be due to the reduction in the overlapping of myofibrillar proteins (actin and myosin) during ageing. The present finding is in line with that of Pen, Kim, Luc, and Young (2012) who observed that the increase in sarcomere length is associated with increase in postmortem ageing.

4. Conclusion

The current study demonstrated that the physicochemical parameters of meat obtained from goats subjected to slaughter without stunning are comparable with those obtained from head-only electrical stun. However, carcasses from head-only electrically stunned goats had higher incidence of hemorrhages compared with those from the slaughter without stunning. There are significant changes in some quality attributes of goat meat during refrigerated storage. Since the current stunning method has disadvantages relating to carcass quality, there is a need for research to develop alternative reversible electrical stunning method, which would fulfill the welfare of animals and improve carcass and meat quality requirements.

Acknowledgments

The research was funded by the Ministry of Higher Education, Malaysia through the Universiti Putra Malaysia Grant Scheme (Project No. GP-IBT/2013/9409300).

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Ministry of Higher Education, Malaysia: Grant Number [GP-IBT/2013/9409300].

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