Influence of slaughter methods that are indigenous to Nguni people on meat physico-chemical characteristics of goat meat

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Abstract

Background: Resource-limited households in smallholder farming systems slaughter goats use indigenous methods for performing traditional ceremonies and meat consumption. Although extensive research has been done to determine the effect of slaughter methods on meat physico-chemical characteristics, there is paucity of information on methods which are indigenous to Nguni people. Therefore, the objective of the study was to determine meat quality of Nguni goats slaughtered using indigenous slaughter methods.

Methods: Thirty 15-18-month old wethers were randomly assigned to three slaughter methods; transverse neck incision (TNI), suprasternal notch piercing (SNP) and undershoulder blade chest floor point of elbow piercing (CFP) to the direction of the heart. Postmortem, the m. longissimus thoracis et lumborum (LTL) was sampled for meat quality measurements.

Results: Wethers slaughtered using the SNP method had greater ultimate pH values when compared with TNI and CFP slaughter methods. Wethers slaughtered using SNP method had greater rate of pH decline when compared with TNI and CFP slaughter methods. Whethers slaughtered using the SNP method had lower meat redness (a*), yellowness (b*), and chroma (C*) values when compared with TNI and CFP slaughter methods. Slaughter method had no effect (P ≥ 0.05) on drip loss, water holding capacity, cooking loss and shear force.

Conclusions: Overall, Nguni wethers slaughtered using the TNI and CFP methods produced chevon with fresh meat appearance.

Keywords: chroma, suprasternal notch piercing, transverse neck incision, redness, ultimate pH, yellowness.
1. Introduction

In developing countries (e.g. Africa and the Middle East) where more than 90 % of the world’s goat population is found [1], goats are ranked as the second most important and abundant livestock species following cattle. Such importance is due to their ability to graze and browse poor quality forage, survive drought and saline conditions [2]. Furthermore, goats have high prolificacy making them a short term investment [3]. Goats are owned and kept by farmers for meat (chevon), milk, manure, skins and hides [4]. Although goats are kept for socio-economic purposes, the primary reason for keeping them is to use them for religious and cultural purposes [5].

In 2018, the world’s total goat population was estimated at 1 billion with 40 % of these goats found in Africa [1]. Southern Africa’s total goat population contributes approximately 2 %, where 50 % these goats are found in South Africa [6]. In South Africa, where the total goat population is equally distributed between smallholder and commercial farming systems, more than 95 % of goats are sold informally in private markets for slaughter during cultural beliefs [7]. When performing cultural practices, goats are slaughtered informally using indigenous slaughter methods [8; 9]. Indigenous slaughter methods include the transverse neck incision (TNI), under shoulder blade chest floor point of elbow piercing (CFP) and suprasternal notch piercing (SNP) to the direction of the heart using a short spear [8]. Goats slaughtered using indigenous slaughter methods (TNI, CFP and SNP) had different bleeding time and efficiency, blood volume in the thoracic cavity, time to loss of sensitivity and cardiac arrest and comparable behavioral responses and dressing percentages and similar behavioural responses [10]. These slaughter methods are used when when performing traditional ceremonies [4] such as connecting the living and the dead, cleansing the deceased, and
celebration of marriages and births. Although these indigenous slaughter methods are permitted under the provision of the South African Meat Safety Act 40 of 2000 [9], animal welfare advocates consider these methods as inhumane as no stunning is involved. Animal rights activists trivialise the religious and cultural functions of these slaughter techniques. Immediately after slaughter and dressing, in most cases, the carcasses are stored under room temperature conditions for 24 hours where they are hanged using hocks for them to cool slowly, dry and allow maximum blood loss. This is important because consuming meat with blood is prohibited as ancestors spirits do not accept meat with blood [11]. Offals are cleaned and consumed on the day of slaughter as they are highly perishable.

Cultural beliefs invoked when celebrating circumcision, marriages and births, venerating ancestors, avenging evil spirits, and performing a ritual during funerals are integral to most African cultures [11; 12]. Meat consumed after performing traditional ceremonies leads to increased protein intake resulting in a decrease of protein-energy malnutrition and dietary deficiency [13]. Although several studies has been done to assess the effect of slaughter methods on chevon quality [14; 15; 16], however, the effect of effect of TNI, SNP and CFP methods on chevon quality is poorly understood. Therefore, understanding the effect of TNI, SNP and CFP methods on chevon quality is crucial for communities to improve food security within local cultural practices.

The effects of indigenous slaughter methods on chevon quality has, however, not been investigated since resource-limited households interpret carcass characteristics as physical-chemical. Understanding the effect of slaughter methods on meat physico-chemical characteristics could assist farmers to select a slaughter method that promote their culture and enhance modern consumer acceptability without compromising animal welfare and meat
quality. The objective of the current study was, therefore, to assess the effect of TNI, SNP and CFP methods on meat physico-chemical characteristics from Nguni goats. It was hypothesized that meat quality from Nguni goats slaughtered using indigenous slaughter methods are comparable to that of goats slaughtered using conventional methods.

2. Material and methods

2.1. Goats and experimental design

Thirty clinically healthy Nguni wethers (about 15-18 months old based on dentition) with body weight averaging 16.8 ± 1.84 kg where bought from the local rural farmers of Nongoma (27°53′S 31°38′E) were they were managed on communal rangelands dominated by Vachellia karroo browse species. Goats were kept in the the same kraal and randomly assigned to each slaughter treatment. Classification of goats as Nguni breed was based on their multiple coat colour patterns, small and compact frame size [17]. Goats were slaughtered randomly after 24 hours of fasting where clean water was provided ad libitum. Slaughtering of goats was completed within a day where the process began at 05h00 in morning and ended at 09h00.

2.2. Treatments

Thirty wethers were randomly assigned to three slaughter treatments (n=10/treatment) and subjected to; transverse neck incision (TNI), under shoulder blade chest floor point of elbow piercing (CFP; Figure 2B) and suprasternal notch piercing with a short spear (SNP; Figure 2C). Briefly, goats were slaughtered without stunning using either a sharp knife or a short spear specifically designed for slaughtering of goats. Transverse neck incision slaughter technique involved the use of a sharp knife for cutting the skin, muscles (brachiocephalic, sternocephalic, sternohyoid, and sternothyroid), trachea, oesophagus, carotid arteries, jugular
veins and the major, superficial and deep nerves of the cervical region [18]. Cuts were defined as a change in the direction of movement of the knife (e.g. the forward movement of the knife would count as one cut, while the corresponding reverse movement would be recorded as a second cut).

Suprasternal notch piercing (SNP) targeting the heart was performed by two experienced slaughtermen using short spears. During slaughter, each goat was allowed to stand upright using rear/hind legs. One slaughter man held the left front leg and the head (using horns) while the second slaughter man held the right front leg and the spear which was used for piercing the goat in the suprasternal notch in the direction of the heart. Goats were allowed to bleed into a 5 litre (L) water bucket.

Under shoulder blade chest floor point of elbow (CFP), piercing involved the use of a short spear and five slaughtermen. These slaughtermen held each goat in dorsal recumbent position by holding all legs sideways. The fifth slaughter man was responsible for piercing each goat on the heart girth position, next to the chest floor and point elbow to the direction of the heart. Goats were also allowed to bleed into a 5 litre (L) water bucket.

2.3. Meat sampling and storage

Following exsanguination, carcasses were dressed as described by [10]. Forty-five minutes after slaughter, *M. longissimus thoracis* (LTL) muscles were removed from the left and right sides of each carcass for meat quality analyses. The LTL muscles were then vacuum-packed and stored in polystyrene cooler boxes and transported to the animal science laboratory at University of KwaZulu Natal, Pietermaritzburg, South Africa for meat quality analyses. The slaughter point and animal science laboratory are 380 km apart. Eleven hours later on arrival
at the lab, meat samples were unpacked from the cooler box and stored at room temperature 
(23 °C) until 24 hours after slaughter.

2.4. Measurements

2.4.1. Meat pH
Post-mortem pH were measured 45 minutes after slaughter and thereafter for a period of 24 
hours (11, 13, 15, 17, and 24). Post mortem rate of decline of pH in meat were measured 
using a portable pH meter probe (CRISON pH25, CRISON instrument SA, Spain).

2.4.2. Meat colour
Meat colour was measured 24 hours after slaughter using a colour meter (HunterLab, 
ColorFlex EZ Spectrophotometer). The parameters used to evaluate meat colour followed 
colour CIE (1976) coordinates which measured: lightness ($L^*$), redness ($a^*$) and yellowness 
($b^*$) from three locations on the cut surface of individual meat samples. Three replicate 
measurements were done. Areas of connective tissue and intramuscular fat per sample were 
avoided. Colour saturation was calculated as the square root of the sum of $a^{*2}$ and $b^{*2}$.

2.4.3. Drip loss and water holding capacity
Drip loss was determined by the standard bag method [19]. Drip loss was measured as the 
weight loss during the suspension of a standardized muscle sample (40–50 g and 
approximately 30 × 60 × 25 mm) in an airtight transparent plastic bag over 48 h at 4°C. Drip 
loss was expressed as a percentage of the weight loss in 48 hours over the initial weight 
sample.
Water holding capacity (WHC) was determined by compressing approximately 3 – 4 gram of meat with 30 kg of weight for 5 minutes using a texture analyser (Stable Micro System, Model TA.XT 2i/25, UK). The water content of meat was determined by multiplying the initial weight of meat with 0.7. Water loss was determined by subtracting final weight from the initial weight. Water holding capacity was therefore calculated by subtracting water loss from water content, dividing by water content and multiplying by 100.

2.4.4. Cooking loss and shear force

Fresh LT L meat samples were cut and weighed (initial weight) to form individual standardized slices of approximately 50 mm thick. Prepared meat samples were then placed in a RATIONAL Granite-enamelled container 20 mm deep. A RATIONAL SCC 61E self-cooking centre (Landsberg, Munich, Germany) was used to roast *M. longissimus thoracic* (LT L). Briefly, the hot plate was preheated for 5 min to 205 °C. Immediately after preheating, RATIONAL Granite-enamelled container 20 mm deep was placed onto a RATIONAL Grid, stainless steel 1/1GN were meat was roasted for 4 min. After completing the cooking process, meat samples were cooled at room temperature and weighed. Therefore, the cooking loss was calculated as the percentage difference in weight before and after cooking.

Following cooking, sub-samples of specified core diameter parallel to the grain of the meat was used. Samples were sheared perpendicular to the fibre direction using a texture analyser model TA.XTplus, texture analyser (Stable Micro System, Model TA.XT 2i/25, UK) as outlined by [20]. The mean maximum load recorded for the three cores were represented as the average of peak force in Newton’s (N) for each sample.

2.5. Statistical analyses
All data were analysed using [21]. A general linear model (GLM) procedure with repeated measures analysis was used to test the effect of indigenous slaughter method on the rate of pH decline of meat in hours.

The model used was the following:

\[ Y_{ij} = \mu + S_i + T_j + (S \times T)_{ij} + b_lW_k + \varepsilon_{ijk} \]

Where:

\( Y_{ijk} \) = Response variables (pH, \( a^* \), \( b^* \), \( L^* \), water holding capacity, shear force, and cooking loss);

\( \mu \) = population mean common to all observation;

\( S_i \) = effect of indigenous slaughter methods;

\( (S \times T)_{ij} \) = the interaction between slaughter method and time (hours);

\( b_lW_k \) = co-variant (initial temperature or pH); and

\( \varepsilon_{i} \) = residual error.

A general linear model was used to test the effect of the slaughter method on meat physico-characteristics of Nguni goats. Comparisons of least-square means were done using the PDIFF option of [21]. The significance threshold was set at \( P \leq 0.05 \).

PROC REG was also used to determine relationships between slaughter methods and meat pH over time. The slope of each curve was tested if it was significantly different from each other using the TEST statement of regression procedure for each slaughter method.

3. Results
Slaughter method had no effect (P ≥ 0.05) on initial meat pH (Table 1) and pH changes (Figure 1), however its interaction with time was significant (P ≤ 0.05). Initial meat pH was highest for TNI followed by SNP and CFP slaughter methods. Ultimate meat pH was highest for SNP followed by TNI and CFP methods. Ultimate meat pH was greater (P ≤ 0.05) for the SNP slaughter method when compared with TNI and CFP slaughter methods (Table 1). Rate of pH decline in meat was highest for SNP followed by TNI and CFP slaughter methods. Rate of pH decline in meat was higher (P ≤ 0.05) for SNP when compared with TNI and CFP slaughter methods (Table 2).

Slaughter method had an effect (P ≤ 0.05) on meat redness and yellowness (Table 1). Meat redness was highest for TNI followed by CFP and SNP slaughter methods. Redness (a*) values of meat from goats slaughtered using SNP method were lower (P ≤ 0.05) compared values of meat from goats slaughtered using TNI and CFP methods (Table 1). Meat yellowness (b*) values of goats slaughtered using SNP method were lower (P ≤ 0.05) compared values of meat from goats slaughtered using TNI and CFP methods (Table 1). Slaughter method had no effect (P ≤ 0.05) on the lightness (L*) and hue (H*) coordinates of meat (Table 1). Slaughter method had an effect (P ≤ 0.05) on chroma coordinates. Chroma coordinates were highest for TNI followed by CFP and SNP slaughter methods. Chroma coordinates for meat from goats slaughtered using SNP was lower (P ≤ 0.05) than those of meat from TNI and CFP slaughter methods (Table 1). Slaughter method had no effect (P > 0.05) on drip loss, WHC, cooking loss and shear force.

4. Discussion

The high ultimate pH value reported for SNP slaughter treatment could be explained by prolonged stress before and during slaughter, which may have lead to reduction in glycogen
levels, and therefore low post-mortem lactic acid production [22; 23; 15]. The high pH observed in meat from animals slaughtered using the SNP method suggest these animals were more stressed than those slaughtered using other methods. The the causes of stress are, however, not immediately clear. The prolonged stress could be related to the nature, frequency, strength, severity, intensity, and/or duration of stressor(s) before and during slaughter. Such stressors include animal handling before and during slaughter and pain experienced by the animal during sticking and exsanguination. These factors were not measured in the current study and merit investigation.

The lower meat redness (a*) observed for whethers slaughtered using the SNP slaughter method may be related to the high pH observed for this slaughter method. The pH effect on a* has been associated with oxygen consumption [24; 25]. High pH often results in low protein denaturation, which creates a more closed tissue structure. The closed structure of meat reduce the diffusion of oxygen into the meat from the surface and any oxygen that do not reach the interior is then utilised by high cytochrome activity encouraged by high pH [26]. As a result less oxygenated myoglobin is formed, and consequently meat looks less red.

The observation that the SNP method had lower meat yellowness (b*) values than other methods could also be explained by the effect of high muscle pH on oxygenation of the myoglobin [27; 28; 29]. The lower chroma (C*, color intensity) values observed for the SNP slaughter method compared to other methods also corresponds high pH values, which negatively correlates with low oxymyoglobin content in the meat [30]. It is well known that a decrease in oxymyoglobin content in meat is accompanied by lower values of a*, b* and C* [31; 32].
The finding that slaughter method had no effect on drip loss, WHC, cooking loss and shear force agree with earlier reports [33; 34; 16]. Overall, the high pHu (6.4-6.8), WHC, and low drip loss, a*, b*, and chroma values reported across slaughter methods are a characteristic of dark firm and dry (DFD) meat [26]. This implies that all the goats across treatments had prolonged stress before and/or during slaughter and that could be related to the high temperamental behaviour of the Nguni goat breed among other stress factors [35]. Further studies to determine the pre-, peri- and post-mortem glycogen reserves, lactic acid concentration in muscles and stress hormones in Nguni goats could be important in explaining the effect of their temperamental behaviour on meat quality. Causes of pre- and peri-mortem stress which could be important in minimising in DFD meat from Nguni goats also merit investigation.

5. Conclusions

Nguni goats slaughter using SNP slaughter method had higher pHu which resulted in lower meat redness, yellowness and chroma values. It was concluded that Nguni goats slaughtered using TNI and CFP methods produce chevon with better meat colour than those slaughtered using the SNP method. The high meat pHu, WHC, and low drip loss and colour (a*, b*, and chroma) are indicative of DFD meat. Further studies to determine causes of DFD meat in Nguni goats slaughtered using indigenous methods could be important.

List of abbreviations

TNI - transverse neck incision
SNP - suprasternal notch piercing
CFP - under shoulder blade chest floor point of elbow piercing
LTL - m. longissimus thoracis et lumborum
Declarations

Ethics approval

Ethical clearance for this study was granted by the Animal Ethics Committee of the University of KwaZulu-Natal (AREC/001/018D).

Consent for publication

Not applicable.

Availability of data and material

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests
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Authors contributions

ZMM designed, collected and analysed data and wrote the manuscript. MC supervised the study and the writing of the manuscript. CM read and approved the final version of the manuscript.

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References

1. FAOSAT. Food and Agriculture Organizations of the United Nations. http://www.fao.org/faostat/en/#data/QA. 2020. Access 18 May 2020.

2. Mdletshe ZM, Chimonyo M, Marufu MC, Nsahlai IV. Effects of saline water consumptions on physiological responses in Nguni goats. Small Rumin Res. 2017;153:209-211.

3. Lebbie SHB. Goats under household conditions. Small Rumin Res. 2004;51:131–136.

4. Rumosa Gwaze F, Chimonyo M, Dzama K. Communal goat production in Southern Africa: a review. Trop Anim Health Prod. 2009;41(7):1157-1168.

5. Mdletshe, Z.M., Ndlela, S.Z., Nsahlai, I.V., & Chimonyo, M. Farmer perceptions on factors influencing water scarcity for goats in resource-limited communal farming environments. Trop Anim Health Prod. 2018;50(7):1617–623.
6. Mohlatlole RP, Dzomba EF, Muchadeyi FC. Addressing production challenges in goat production systems of South Africa: The genomics approach. Small Rumin Res. 2015;131:43-49.

7. National Agriculture Marketing Council. Report on the investigation into the potential for the south african goat industry. 2005. https://www.nda.agric.za/docs/AAPS/NAMC1.pdf. Accessed 19 May 2020.

8. Msimang, CT. Kusadliwa ngoludala. (2nd ed). Pietermaritzburg, South Africa: Shuter & Shooter (Pty) Ltd; 2007.

9. Qekwana DN, Oguttu JW. Assessment of Food Safety Risks Associated with preslaughter activities during the traditional slaughter of goats in Gauteng, South Africa. J Food Prot. 2014;77(6):1031-1037.

10. Mdletshe ZM, Marufu MC, Chimonyo M. Effect of Indigenous Slaughter Methods on the Behavioural Response, Bleeding Efficiency and Cardiac Arrest of Nguni Goats. Animals. 2020;10(247). https://doi.org/10.3390/ani10020247.

11. Ntuli MS. Ucwaningo olunzulu ngesiko lokubuyisa ithongo. MA Thesis. University of Zululand, Empangeni; 2004.

12. Qekwana DN, McCrindle CME, Oguttu JW, Grace D. Assessment of the occupational health and food safety risks associated with the traditional slaughter and consumption of goats in Gauteng, South Africa. Int J Environ Res Public Health. 2017;14:420-429.

13. Scho¨nfeldt HC, Hall NG. Dietary protein and malnutrition in Africa. Br J Nutr. 2012;108:69-76.

14. Velarde A, Gispert M, Diestre A, Manteca X. Effect of electrical stunning on meat and carcass quality in lambs. Meat Sci. 2003;63:35–38.
15. Sabow AB, Sazili AQ, Zulkifil I, Goh YM, AB Kadir MZA, Adeyemi KD. Physico-chemical characteristics of Longissimus lumborum muscle in goats subjected to halal slaughter and anesthesia (halothane) pre-slaughter. Anim Sci J. 2015;86:981-991.

16. Sabow AB, Adeyemi KD, Idrus Z, MengGY, Kadir MZAA, Kaka U, Aghwan ZA, Abubakar AA, Sazili AQ. Carcase characteristics and meat quality assessments in goats subjected to slaughter without stunning and slaughter following different methods of electrical stunning. Ital J Anim Sci. 2017;16 (3):416-430.

17. Snyman MA. South African goat breeds : Indigenous veld goat. Info-pack ref. 2014/004. Grootfontein Agricultural Development Institute; 2014.

18. Kiran M, Naveena BM, Smrutirekha M, Baswa Reddy P, Rituparna B, Praveen Kumar Y, Venkatesh Ch, Rapole S. Traditional halal slaughter without stunning versus slaughter with electrical stunning of sheep (Ovis aries). Meat Sci. 2019;148:127–136.

19. Christensen LB. Drip loss sampling in porcine m. longissimus dorsi. Meat Sci. 2003;63(4):469-477.

20. Honikel KO. Reference Methods for the Assessment of Physical Characteristics of Meat. Meat Sci. 1998;49(4):447-57.

21. SAS. USA: Statistical Analysis System Institute Inc. Users guide, version 9.4. Carry, NC, USA; 2010.

22. Kim YHB, Warner RD, Rosenvold K. Influence of high pre-rigor temperature and fast pH fall on muscle proteins and meat quality: a review. Anim Prod Sci. 2014;54:375-395.

23. Simela L, Webb EC, Frylinck L. Effect of sex, age, and pre-slaughter conditioning on pH, temperature, tenderness and colour of indigenous South African goats. S Afr J Anim Sci. 2004;34:208-211.
24. McKeith RO, King DA, Grayson AL, Shackelford SD, Gehring KB, Savell JW, Wheeler TL. Mitochondrial abundance and efficiency contribute to lean color of dark cutting beef. Meat Sci. 2016;116:165–173.

25. Zhang Y, Hopkins DL, Zhao X, van de Ven R, Mao Y, Zhu L, Luo X. Characterisation of pH decline and meat color development of beef carcasses during the early postmortem period in a Chinese beef cattle abattoir. J Integr Agric. 2018;17:1691–1695.

26. Warriss PD. Meat science: An introductory text (2nd ed.). CABI, UK; 2010.

27. Lindahl G, Lundström K, Tornberg E. Contribution of pigment content, myoglobin forms and internal reflectance to the colour of pork loin and ham from pure breed pigs. Meat Sci. 2001;59:141–151.

28. Karamucki T, Jakubowska M, Rybarczyk A, Gardzielewska J. The influence of myoglobin on the colour of minced pork loin. Meat Sci. 2013;94:234–238.

29. Herna´ndez B, Sa´enz C, Alberdi C, Din˜ eiro JM. CIELAB color coordinates versus relative proportions of myoglobin redox forms in the description of fresh meat appearance. Int J Food Sci Technol. 2016;53:4159–4167.

30. Abril M, Campo MM, Önenç A, Sańudo C, Alberti P, Negueruela AI. Beef colour evolution as a function of ultimate pH. Meat Sci. 2001;58:69-78.

31. Gašperlin L, Žlender B, Abram V. Colour of norma land high pH beef heated to different temperatures as related to oxygenation. Meat Sci. 2000;54:391–398.

32. Lindahl G, Karlsson AH, Lundström K, Andersen HJ. Significance of storage time on degree of blooming and colour stability of pork loin from different crossbreeds. Meat Sci. 2006;72:603–612.

33. Vergara H, Linares MB, Berruga MI, Gallego L. Meat quality in suckling lambs: effect of pre-slaughter handling. Meat Sci. 2005;69:473–478.
34. Agbeniga B, Webb EC, O’Neil HA. Influence of Kosher (Shechita) and conventional slaughter techniques on shear force, drip and cooking loss of beef. S Afr J Anim Sci. 2013;43:98-102.

35. Ndou SP, Muchenje V, Chimonyo M. Behavioural responses of four goat genotypes to successive handling at the farm. Afr J Biotechnol. 2010;9(47):8118–8124.
Figure 2: Visual pictures of a spear (A), chest-floor point-of-elbow (B), and suprasternal notch piercing (C).

Adapted from [10].

Figure 1: The relationship between meat pH and time for TNI, SNP and CFP slaughter methods.
Table 1: Effects of TNI, SNP and CFP slaughter methods on colour parameters ($a^*$, $b^*$, $L^*$, $h$ and $C$), drip loss, cooking loss, shear force and water holding capacity of goat meat

| Variable                          | Slaughter method | Significance |
|-----------------------------------|------------------|--------------|
|                                   | TNI              | SNP          | CFP          |
| **pH**$_{45\text{ min}}$         | 7.8 ± 0.102      | 7.7 ± 0.102  | 7.6 ± 0.102  | NS           |
| **pH**$_{24\text{ h}}$           | 6.42 ± 0.13$^a$  | 6.82±0.13$^b$| 6.40 ± 0.13$^a$| *            |
| **Drip loss (%)**                 | 3.0 ± 0.75       | 1.75 ± 0.87  | 1.88 ± 0.75  | NS           |
| **Water holding capacity (%)**    | 74.18 ± 1.28     | 75.64 ± 2.21 | 72.88 ± 1.57 | NS           |
| **Colour parameters**             |                  |              |              |
| $a^*$                             | 16.4 ± 0.56$^a$  | 14.7 ± 0.56$^b$| 16.3 ± 0.56$^a$| *            |
| $b^*$                             | 13.5 ± 0.61$^a$  | 11.5 ± 0.61$^b$| 13.2 ± 0.61$^a$| *            |
| $L^*$                             | 29.5 ± 1.02      | 28.3 ± 1.02  | 30.6 ± 1.02  | NS           |
| $H^*$                             | 0.69 ± 0.01      | 0.66 ± 0.01  | 0.68 ± 0.01  | NS           |
| $C^*$                             | 21.24 ± 0.78$^a$ | 18.68 ± 0.78$^b$| 21.02 ± 0.78$^a$| *            |
| **Cooking loss (%)**              | 22.73 ± 2.3      | 21.6 ± 3.0   | 19.4 ± 2.6   | NS           |
| **Shear force (N)**               | 9.52 ± 0.72      | 10.73 ± 0.83 | 10.55 ± 0.72 | NS           |

$a$, $b$, $c$ Means in the same row with different superscripts are significantly different at $P \leq 0.05$; *$p \leq 0.05$; **$p \leq 0.01$; NS-$p > 0.05$. NS: not significant; $L^*$: lightness; $a^*$: redness; $b^*$: yellowness.
Table 2: The relationship between meat pH and temperature for TNI, SNP and CFP slaughter methods

| Independent variable | Parameter estimates (time) |
|----------------------|---------------------------|
|                      | Intercept  | $P$ intercept | Slope  | $P$ slope | RMSE |
| pH                   |             |               |        |           |      |
| TNI                  | 6.31 ± 0.65 | ≤0.0001       | 0.02 ± 0.03$^a$ | 0.591    | 0.54 |
| SNP                  | 6.7 ± 0.13  | ≤0.0001       | 0.04 ± 0.03$^b$ | 0.033    | 0.44 |
|                      |             |               |        |           |      |
| CFP                  | 9.44 ± 1.39 | ≤0.0001       | -0.20 ± 0.10$^a$ | 0.055    | 0.49 |

$^a$, $^b$, $^c$Means in the same column with different superscripts are significantly different at $p \leq 0.05$; *$p \leq 0.05$; **$p \leq 0.01$; NS-$p > 0.05$. 