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ARTICLE

Evaluation of Meat Color and Physiochemical Characteristics in Forequarter Muscles of Holstein Steers

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Abstract

The beef forequarter muscle comprises approximately 52% of carcass weight. The objective of this study was to evaluate the physiochemical characteristics and meat color from forequarter muscle of Holstein steers. Fifteen forequarter muscles were trimmed of external connective tissue and fat. An experimental group of eight Holstein steers was assessed using meat color, water-holding capacity, drip loss, and Warner–Bratzler shear force value at the same quality grade. The M. *omotransversarius* (0.45 kg) had the highest (p<0.05) lightness (L*) value, whereas the M. *teres major* (0.4 kg) and M. *triceps brachii (caput laterale)* (0.52 kg) had the lowest (p<0.05) values. The M. *semispanitus capitus* (1.48 kg), which is a neck muscle, had the highest values for both redness (a*) and yellowness (b*), whereas the lowest (p<0.05) values were for the M. *teres major*. The M. *omotransversarius*, M. *latissimus dorsi* (1.68 kg), and M. *rhomboideus* (1.2 kg) were ranked high (p<0.05) in water-holding capacity. The drip loss value was the highest for the M. *longissimus dorsi thoracis* (p<0.05; 1.86 kg), while the M. *infraspinatus* (2.28 kg), M. *supraspinatus* (1.38 kg), M. *brachiocephalicus* (1.01 kg), and M. *pectoralis superficialis* (1.18 kg) had the lowest (p<0.05). The Warner–Bratzler shear force value indicated that the M. *pectoralis profundus* (3.39 kg), M. *omotransversarius*, and M. *brachiocephalicus* were the toughest (p<0.05), whereas the M. *subscapularis* (0.86 kg), M. *longissimus dorsi thoracis*, M. *teres major*, and M. *infraspinatus* were the most tender cuts (p<0.05). Here, muscle type explained most of the variability in the forequarter physiochemical characteristics. Thus, our findings suggest that these muscle profile data will allow for more informed decisions when selecting individual muscles to produce value-added products from Holstein steers.

Keywords: color, drip loss, forequarter muscle, shear force, water-holding capacity

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Introduction

The total carcass weight of the beef muscle of steers comprises approximately 52% forequarter (e.g., primal chuck and rib and the rough brisket, plate, and shank) and 48% hindquarter muscle. The difference in market value between the fore- and hindquarters is defined by consumer demand and differs depending on eating quality and physiochemical characteristics. The beef forequarter (e.g., neck and brisket muscle) market has been depressed due to variations in forequarter yield and the palatability characteristics of the muscle types (Johnson *et al.,* 1988). Removing external fat and epimysium (i.e., external connective tissue) from muscle significantly increases the ability to identify and separate the muscles into types of meat products for export and higher prices. Several reports on the composition and properties of cow muscle have been published. The value of the forequarter is low, despite its composing 50% of total carcass weight. Muscle physiochemical characteristics and color are important traits for increasing market value (Seong *et al.,* 2014; Xu *et al.,* 2012).

Holstein cows are commonly known as milk producers, but male Holsteins are sold as a domestic beef source in Korea, although they are of inferior quality (Han and Lee, 2010; Kim *et al.,* 1993). However, Holstein steers have a higher quality grade than do native beef cattle due to higher marbling scores (McKenna *et al.,* 2002). Holsteins differ in accumulated fat depots compared with traditional beef bred cattle, such as Angus. Holstein carcasses also have less muscle, a smaller ribeye area, and different muscle shapes. Holstein had higher intramuscular fat content than that of Angus from 12 to 24 mon of age. The size of marbling flecks were increased in Angus compared with Holstein intramuscular muscle tissue (Albre-

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cht *et al*., 2006). Increased consumer's demands for a healthful and tasty product have created more interest in Holstein steers because they produce a high quality product with less external fat than traditional beef breed steers (Siemens, 2012).

The forequarter muscles have various chemical characteristics, including pH, color, and carcass weight of the muscle or muscle groups (Jeremiah *et al.,* 2003c; Walsh *et al.,* 2010). Color is an important property for consumers deciding on fresh meat purchases. Therefore, these differences in meat color based on muscle types in Holstein steers are of interest. Discolored meat is related to the conversion of oxymyoglobin to metmyoglobin (Ledward, 1984). The traits were observed in chuck and round muscle (Von Seggern *et al*., 2005). However, the change of traits was difficult to explain. The variations of chemical and cook properties were observed in Mexcian beef forequarter muscle (Chávez *et al*., 2012).

Shear force-related tenderness is an organoleptic test used by consumers to judge meat quality. Meat tenderness is influenced by muscle characteristics at slaughter (Maltin *et al.,* 2003) and by post-mortem changes (Park *et al.,* 2015). Water-holding capacity (WHC) is an important property of fresh meat, and meat yield and quality are affected by WHC. WHC is measured by drip loss, but other methods can be used (Honikel, 1998; Honikel and Hamm, 1994). Proteins influence WHC and drip loss during meat processing. Drip loss is characterized as fluid loss from fresh or uncooked meat. The beef industry is economically important worldwide. Therefore, a reduction in meat yield due to drip loss could have serious consequences. Beef quality, including meat color, drip loss, and WHC is the primary determinant of consumer acceptance during purchase. The forequarter muscles most commonly marketed are the neck, chuck, and brisket.

The meat composition and physical properties of muscles have been characterized for higher eating quality in the last years. However, the majority of muscle studies are located in the hindquarter, although forequarter muscle is composed of 52% of the whole carcass weight. Thus, the objective of this study is to assess physiochemical characteristics and meat color on different muscle regions in forequarter muscle of Holstein steers.

Material and Methods

Animals and sample preparation

We assumed that Holstein steers have a wide range of marbling scores (MS) between 5 and 8. In this study, we used eight Holstein steers (carcass weight, 302.5±7.3 kg; from 18 to 20 mon of age) slaughtered at the Meat Laboratory and conducted in accordance with the Animal Experimental Guidelines provided by National Institute of Animal Science Institutional Animal Use and Care Committee (NIASIAUCC), Republic of Korea. Roughage was offered *ad libitum* and the animals had free access with freshwater during the entire period. The animals had been fed a supplement containing 15-20% digestible crude protein and 70-80% total digestible nutrients to promote development of the rumen and increase growth. Fifteen individual beef muscles [(i.e., *Muscle brachiocephalicus*, *infraspinatus*, *latissimus dorsi*, *longissimus dorsi thoracis*, *omotransversarius*, *pectoralis profundus*, *pectoralis superficialis*, *rhomboideus*, *semispanitus capitus*, *serratus ventralis*, *subscapularis*, *supraspinatus*, *teres major*, *triceps brachii* (*caput laterale*), *and triceps brachii* (*caput longum*))] were seamed out from the forequarters of carcasses 24 h post-mortem. The samples were trimmed using the Pret decoupe (PAD) style to remove all subcutaneous and intramuscular fat and epimysial connective tissue. All samples were collected from the forequarter on one side. Individual weights of all carcass components were taken (Table 1). The heavy internal connective tissue sheath was removed from the forequarter muscles. All muscles were vacuum packed and stored at 2-4°C for 14 d post-mortem. The muscles were re-formed using the Activa ^{TM}TG-RM cold-setting transglutaminase preparation system (Ajinomoto, Ltd., Japan) to create uniform steaks, as follows: Activa^{TM}, at a level of 1% of meat weight, was whisked with water at 4% of meat weight until homogenous, and the suspension was mixed by hand with meat chunks, ensuring that each piece was fully coated. The meat pieces were placed in layers in a polythene-lined rectangular-shaped mould (1.5-2.0-kg meat/mould), vacuum packed, and held at 2°C overnight to allow completion of the protein cross-linking bonding reaction. The formed meat was removed from the moulds and liners and cut into 2.54-cm-wide steaks. The steaks were vacuum-packed and frozen at 20°C, except those used for the drip loss test.

Color evaluation

Surface color parameters including the lightness (L*), redness (a*), and yellowness (b*) of the meat samples were evaluated using a Minolta Color Reader (CR-400; Minolta, Japan). The CR-400 meter has an ø8 mm aperture size and illuminant D65 using Pulsed xenon lamp. The colorimeter was standardized (L*=86.3, a*=0.3165, b*=0.3142) with a calibration plate before measurements.

Sub-samples were overwrapped with polyvinyl chloride (PVC) film during storage. Color was measured on the cut surface of the sub-samples after opening the PVC film. Color determinations were taken from different locations on each forequarter muscle sample, and the mean readings of lightness (L*), redness (a*), and yellowness (b*) are shown. The experiments were performed in triplicate with replicates at a different position.

Drip loss

Drip loss was determined according to modified methods described previously (Honikel and Hamm, 1994). Drip loss was measured as the weight loss of freshly cut muscle (100 g) over 96 h at 2°C. Subsamples of 2.5-cm thickness were removed from each joint and suspended in an expander bag so that the meat did not come in contact with the bag. Each cube was weighed and suspended in an airtight container. Drip loss was expressed as a percentage of original weight. The experiments were performed in triplicate with replicates.

Water-holding capacity

WHC was measured in individual muscle samples to investigate the degree of muscle protein denaturation using a centrifugation procedure. Subsamples of approximately 10 g were weighed into a glass jar, and the jars were placed in a water bath (model no. Y-38; Grant Instruments, Ltd., UK) for 10 min at 90°C. After heating, each sample was removed carefully from the jar using forceps, wrapped in cheesecloth, and placed in a 30-mL centrifuge tube (model. 3118-0030, Nalgene Brand Products, USA) containing cotton wool in the bottom. The samples were centrifuged (Sigma SK 10; MSE Scientific Instruments, UK) at 1000 rpm for 10 min at 4°C. The cheesecloth was removed from the samples, and the samples were reweighed. Percent WHC was calculated as follows (Lianji and Chen, 1989):

$$\text{WHC (\%)} = 1 - (B - A) \times 100 / M_1$$
$$= 1 - (B - A) \times 100 / (M_2 \times B),$$

Where B is sample weight before heating, A is sample weight after heating and centrifugation, M_1 is total water content in the meat sample, and M_2 is percent moisture in the sample. The experiments were performed in quadruplicate with replicates.

Warner-Bratzler shear force

Shear force was expressed in Newtons (N); values <50 N indicate acceptable tenderness. Tenderness was measured on cooked samples as the force required to shear through a sample. The steak samples were cooked in a water bath to 70°C and tempered at 4°C overnight for ease of coring. Round core samples (70-mm length × 12.5-mm diameter) were cut parallel to the muscle fibers. The cores were sheared with a Warner-Bratzler shear device attached to an Instron Universal Testing Machine (model 5543, Instron Corp., USA). A static load cell (500 N) detected the force required to shear through the sample core at a crosshead speed of 50 mm/min (Shackelford *et al.,* 1991). Peak shear force (N) is reported. The experiments were performed in quadruplicate with replicates.

Statistical analysis

The data are expressed as means standard deviations. Muscle characteristics and quality analysis for variations in the forequarter muscles were evaluated using Tukey's multiple comparison and SAS software (SAS Institute, USA). P-values < 0.05 were considered significant. All experiments were performed in triplicate or quadruplicate.

Result and Discussion

Muscle weight measurements

The carcass weights of the nine Holstein steers are shown in Table 1. The heaviest muscle was the M. *serratus ventralis* (SERV) among the 15 forequarters, followed in order by the M. *pectoralis profundus* (PECP) > M. *triceps brachii caput longum* (TRLO) > M. *infraspinatus* (INFR) > M. *longissimus dorsi thoracis* (LDT) > M. *latissimus dorsi* (LATD) > M. *semispanitus capitus* (SEMC) > M. *supraspinatus* (SUPR) > M. *rhomboideus* (RHOM) > M. *pectoralis superficialis* (PECS) > M. *brachiocephalicus* (BRAC) > M. *subscapularis* (SUBS) > M. *triceps brachii caput laterale* (TRLA) > M. *omotransversarius* (OMOT) > M. *teres major* (TERM). Here, the quantity of muscle differed according to muscle type. Thus, carcass weights were different in muscles, and these differences were in accordance with differences in the oxidative (isocitric dehydrogenase) and glycolytic (lactic dehydrogenase) enzyme activity ratios (Chriki *et al.,* 2012). For example, 3-hydroxyacyl-CoA dehydrogenase (HADH), creatine kinase (CK), cytochrome-c oxidase (COX), and citrate synthase (CS) activities of skeletal muscle enzymes were changed in 24 h energy metabolism after weight loss (Doucet *et al.,* 2003). Therefore, muscle mass and size can be affected by muscle fiber type via energy metabolisms.

Table 1. Identification and carcass weights of the forequarter muscles

Muscle name	Commercial name	Muscle code	Weight, kg	S.E[1]	CV (%)[2]
M. brachiocephalicus	Clod	BRAC	1.01	0.07	28.30
M. infraspinatus	Feather blade	INFR	2.28	0.09	17.09
M. latissimus dorsi	Short rib (Flank)	LATD	1.68	0.08	21.00
M. longissimus dorsi thoracis	Rib eye	LDT	1.86	0.10	24.12
M. omotransversarius	Clod	OMOT	0.45	0.03	28.99
M. pectoralis profundus	Brisket	PECP	3.39	0.16	20.46
M. pectoralis superficialis	Brisket (top)	PECS	1.18	0.07	27.25
M. rhomboideus	Neck muscle	RHOM	1.20	0.09	32.29
M. semispanitus capitus	Neck muscle	SEMC	1.48	0.11	30.92
M. serratus ventralis	Jacobs ladder	SERV	4.00	0.15	17.44
M. subscapularis	Sous d'epaule	SUBS	0.86	0.06	30.32
M. supraspinatus	Chuck tender	SUPR	1.38	0.05	15.83
M. teres major	Shoulder tender	TERM	0.40	0.01	14.29
M. triceps brachii (caput laterale)	Arm roast - top	TRLA	0.52	0.02	17.67
M. triceps brachii (caput longum)	Leg of mutton cut - centre	TRLO	3.05	0.13	18.24

[1]Standard error.
[2]Coefficients of variation.
CV(%) = standard deviation / mean.

Table 2. Color value rank for the forequarter muscles

Rank	Muscle code	L*	Muscle	a*	Muscle	b*
1	OMOT	49.4^{a}	SEMC	17.26^{a}	SEMC	14.0^{a}
2	BRAC	46.6^{ab}	PECS	17.00^{ab}	PECS	13.9^{a}
3	RHOM	44.6^{abc}	PECP	16.6^{abc}	PECP	13.9^{a}
4	LDT	43.8^{abc}	LDT	15.5^{abc}	LDT	13.7^{a}
5	PECS	43.5^{abc}	SERV	15.2^{abcd}	BRAC	12.9^{ab}
6	SEMC	42.9^{abc}	TRLO	14.8^{abcde}	OMOT	12.5^{ab}
7	PECP	42.00^{abcd}	RHOM	14.8^{abcde}	RHOM	12.5^{ab}
8	SERV	40.7^{bcd}	SUPR	14.3^{abcde}	SERV	11.9^{ab}
9	LATD	38.9^{bcd}	BRAC	14.0^{abcde}	SUPR	10.7^{abc}
10	SUPR	38.7^{cd}	INFR	13.6^{bcde}	TRLO	10.5^{abc}
11	SUBS	38.4^{cd}	OMOT	13.2^{cde}	LATD	10.2^{abc}
12	TRLO	37.8^{cd}	LATD	13.2^{cde}	INFR	9.8^{abc}
13	INFR	37.00^{cd}	SUBS	11.7^{def}	SUBS	9.47^{bc}
14	TERM	35.0^{d}	TRLA	11.3^{ef}	TRLA	7.6^{c}
15	TRLA	34.8^{d}	TERM	9.35^{f}	TERM	7.1^{c}
s.e.d[1]		2.45		1.08		1.28
CV(%)[2]		10.3		13.5		19.9

[1]Standard error of the difference.
[2]Coefficients of variation.
[a-f]Means in the same column with different letters are different ($p<0.05$).
L*: lightness, a*: redness, b*: yellowness.

Color evaluation

Values for lightness (ranged from 34.8 to 49.4), redness (ranged from 9.35 to 17.26), and yellowness (ranged from 7.1 to 14.0) were assessed in the forequarter muscles of Holstein steers (Table 2). The lightness value was highest in OMOT among the 15 muscles, and this value was not significantly different from those for BRAC, RHOM, LDT, SEMC, and PECS. TERM and TRLA had the lowest lightness values. These results are similar to those reported previously by Von Seggern *et al.* (2005), who found OMOT had the highest lightness value of chuck muscle. They also reported that the external location and the visibly dense connective tissue in the animal explained this result. The redness value was highest for the SEMC, which is a neck muscle, and was lowest for TERM. LDT, SERV, TRLO, RHOM, and SUPR are characterized by high redness values (Von Seggern *et al.,* 2005). Here, SEMC, PECS, PECP, and LDT had the highest yellowness values

among the subsamples. TRLA and TERM were ranked lower than the other samples for yellowness.

Our findings are similar to those of previous studies on steer muscles (McKenna *et al.,* 2005; Von Seggern *et al.,* 2005). OKeeffe and Hood (1982) observed that beef color is related to muscle type. Various muscles discolor at different rates, and the shelf life of a multiple-muscle meat cut, such as beef chuck steak, is determined by the least color-stable muscle within the cut (Faustman and Cassens, 1990). The differences among muscles can be explained by the muscle's biological and biochemical properties (Von Seggern *et al.,* 2005).

Consumers traditionally demand acceptable meat color and unexpected bewitching taster. In particular, meat color is a major factor in consumer's purchasing decisions because it is assumed to be an indicator of meat quality and freshness (Arroyo et *al.,* 2015).

Drip loss

Drip loss was highest for LDT (p<0.05), and this value was significantly different from that for TRLO. The lowest values were found for INFR, SUPR, BRAC, and PECS (Fig. 1). These results are similar to those of a study by Jeremiah *et al.* (2003b), who reported that LDT had higher thaw-drip loss than did other forequarter muscles. They also reported that total muscle hydroxyproline content was negatively correlated with drip loss and positively correlated with total cooking loss. Hydroxyproline is majority amino acid in animal collagen. Consequently, meat collagen content can be measured by measuring hydroxyproline (Dugan *et al.,* 2000). Collagen is primary the connective tissue in muscle tissue. The degree of non- and cross-linked between collagen can be separated owing to difference of solubility. Non-cross-linked collagen is more soluble than those of cross-linked (Hill, 1966). Collagen is significantly less cross-linked and degraded more easily when heated (Bracho and Haard, 1990). Namely, the collagen solubility increased by heating time. Collagen also can be prevented from being released water. The shrinkage of collagen might be the main reason for the transverse shrinkage, resulting in affecting drip loss. In this study, LDT (5.40 mg/g) had the lowest (p<0.01) collagen content of the forequarter muscles, whereas OMOT (22.44 mg/g) and RHOM (11.85 mg/g) had the highest (data not shown).

Water-holding capacity

The WHC of OMOT, LATD, RHOM, PECS, and TRLO was higher (p<0.05) than that of others among the 15 fore-

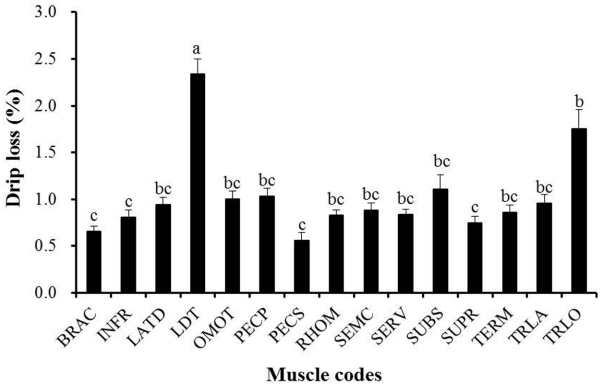

Fig. 1. Drip loss rank of the forequarter muscles. All values are means±standard deviations (SDs). Different superscript letters indicate significant among-group differences (p< 0.05). Refer to Table 1 for the muscle abbreviations.

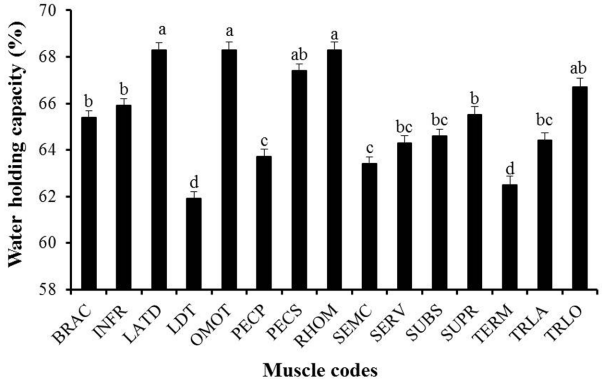

Fig. 2. Water-holding capacity rank of the forequarter muscles. All values are means±standard deviations (SDs). Different superscript letters indicate significant among-group differences (p<0.05). Refer to Table 1 for the muscle abbreviations.

quarter muscles (Fig. 2). LDT and TERM showed the lowest (p<0.05) WHC values among the 15 forequarter muscles. These results agree with the findings of Von Seggern, who reported that OMOT, LDT, and RHOM had higher WHC values than did LCT. Jeremiah *et al.* (2003c) reported that total cooking losses associated with WHC were higher for neck muscles, such as OMOT and RHOM, and lower for LDT when compared with other forequarter muscles. In the present study, the variation in WHC results was congruent with findings by Hamm (1960), who observed that differences in WHC occurred even within the same muscle. Water holding capacity is usually regarded as meat quality parameters and attributed to the changes of collagen content. The variation of pH, ionic strength, oxidation, and temperature of storage related to myo-

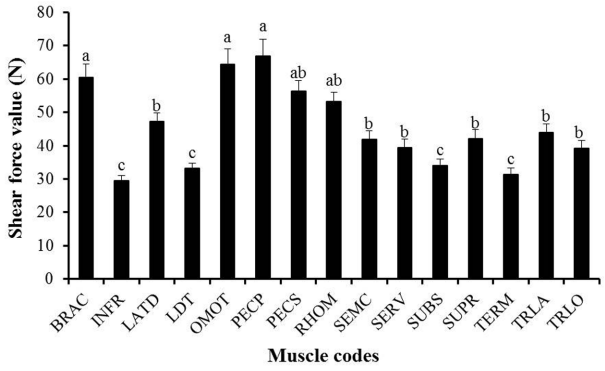

Fig. 3. Warner-Bratzler shear force rank of the forequarter muscles. All values are means±standard deviations (SDs). Different superscript letters indicate significant among-group differences (p<0.05). Refer to Table 1 for the muscle abbreviations.

fibrillar also affect proteolysis of cytoskeletal proteins in post-mortem muscle, resulting in muscle shrinkage and water mobilization. Therefore, the structural changes are associated with water holding capacity (Huff-Lonergan and Lonergan, 2005).

Warner-Bratzler shear force

The Warner-Bratzler shear force results showed that PECP, OMOT, BRAC, PECS, and RHOM were the tougher (p<0.05) musclethan those of muscle types, whereas SUBS, LDT, TERM, and INFR were the most tender (p< 0.05) (Fig. 3). These results are similar to those of a study by Von Seggern *et al.* (2005), who found that PECP, OMOT, BRAC, and PECS were the toughest of the forequarter muscles as assessed by Warner-Bratzler shear force, whereas LDT, TERM, and INFR were the most tender. Generally, aging, breed, sex, pre-slaughter treatments, electric stunning, freeze-thaw cycles, and pH have relatively influences on tenderness due to breaking muscle fibers. Stress is one of effects on meat tenderness at slaughter. For example, perimysium is consist of 90% of intramuscular tissue and is believed to be the main factor for the contribution of connective tissue to toughness (Tornberg, 2005). These results correspond with those of Carmack *et al.* (1995), who reported that LDT, TERM, and INFR had higher sensory panel tenderness scores compared with PECP.

Conclusion

Previous studies have characterized muscle size, color, and palatability profiles of hindquarter muscles, although forequarter muscles comprise approximately 52% of total carcass weight. However, limited information is available on processing techniques to improve the economic potential of forequarter beef muscles. Meat color was ranked highest in OMOT (L*), SEMC (a*), SEMC, PECS, PECP, and LDT (b*) compared with the other forequarter muscles. OMOT, LATD, and RHOM had the highest WHC, and drip loss was highest in LDT. PECP, OMOT, and BRAC had the highest shear force values among the 15 forequarter muscles. An evaluation of the forequarter would be worthwhile for purchasing decisions and to compare muscle properties of the hindquarter. Thus, our findings suggest that meat color and physiochemical characteristics can be applied to develop value-added products from forequarter muscles.

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Conflict of interest statement

No conflict of interest was declared.

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