Agronomy Research **17**(S2), 1472–1484, 2019
https://doi.org/10.15159/AR.19.069

The effect of ageing on chosen quality characteristics of skeletal muscles of Aberdeen Angus bulls

R. Soidla[1], K. Kerner[1], M. Tepper[1], A. Tänavots[1,2,*], T. Kaart[2] and I. Jõudu[1]

[1]Estonian University of Life Sciences, Institute of Veterinary Medicine and Animal Sciences, Chair of Food Science and Technology, Fr.R. Kreutzwaldi 56/5, EE51006 Tartu, Estonia
[2]Estonian University of Life Sciences, Institute of Veterinary Medicine and Animal Sciences, Chair of Animal Breeding and Biotechnology, Fr.R. Kreutzwaldi 62, EE51006 Tartu, Estonia
[*]Correspondence: alo.tanavots@emu.ee

Abstract. The objective of the trial was to study the qualitative parameters of two muscles of Aberdeen Angus bulls with 250–300 kg carcass weight. After slaughter, *longissimus thoracis et lumborum* (LD) muscle and unseparated *semimembranosus* and *adductor femoris* (SMA) muscles were removed from the chilled carcasses. Muscles were vacuum-packed and wet aged at +2 °C for 10, 14, 18 and 20 days. Meat pH, electrical conductivity, shear force and colour were measured in all ageing times. Two thermal treatment methods (sous-vide (SV) and grilling) were used to determine cooking losses. The effects of muscles, ageing times and muscles by ageing times interaction was found with two-factorial analysis of variance. The effects of muscles, ageing times and muscle groups by ageing time interaction for raw and SV treated meat shear force was significant. Ageing decreased SV treated meat shear force from day 10 (40.8 N) to 18 (29.7 N). Fresh and SV treated LD muscle was tougher compared to the SMA muscle group, but SM showed a better response to the tenderness within 20 days of ageing. Redness and yellowness value was higher in the SM group in comparison to LD. Muscles showed good colour (lightness, redness and yellowness) stability within ageing for 20 days. No interactions were found between muscle groups and ageing times for SV treated and grilled beef cooking losses. However, SV treated meat lost more weight than grilled meat slices. The present study suggests that the optimal ageing time for meat is 18 days when the grilled meat cooking loss is the lowest.

Key words: beef cattle, *semimembranosus*, *adductor femoris, longissimus,* muscle, colour, shear force, cooking loss, Aberdeen Angus.

INTRODUCTION

Aberdeen Angus is one of the most numerous beef cattle breed raised in Estonia. The interest in the quality of the beef is increasing with its growing popularity. Within the finishing period, local beef production based on the system where animals were reared extensively in the pastures. Tenderness is one of the challenging factors that affect the consumer's satisfaction in beef (Egan et al., 2001; Cassens et al., 2018). Meat ageing under controlled refrigerated conditions is the most common method used by meat retailers to increase the tenderness of the beef (Guelker et al., 2013; Piao et al., 2015).

Meat tenderness increases within the ageing period because of the enzyme activities, which lead to myofibrillar degradation (Guerrero et al., 2013). Changes in the biochemical and microbiological characteristics take place during this process – meat colour, flavour, texture are altered – all these improve meat quality (Wicklund et al., 2005). Wet-aging of the beef is one of the cheapest methods to improve meat tenderness (Sitz et al., 2006). To improve meat tenderness, beef should age at least 14 days (Hanzelková et al., 2011). However, the tenderness of the aged meat depends also on the location of the muscle as some of them have greater physical activity than others (Simonetti et al., 2015). Monson et al. (2005) concluded that the various muscles need different time for ageing. Most of the active muscles myoglobin content is higher because of the increased oxygen requirement, which contains more pigments (Mancini & Hunt, 2005). Oxygenation of the myoglobin (blooming) takes place as the meat exposed to the oxygen (AMSA, 2012) and this process affects meat colour (Lee et al., 2008).

Most of the beef offered for retail sale are vacuum-packed fresh or thermally treated meat. Meat loses water during the ageing and processing because of the changes in the charges and structure of the myofibrillar protein. Production yield is associated with the level of weight loss during meat processing and affect an economic outcome. The level of water holding capacity of fresh meat is usually estimated through the time and labour consuming analyses. However, a limited number of studies are using other time efficient and real-time analyses. For example, Florek et al. (2007) used electrical conductivity measurements to determine the tenderness of the beef. The electrical conductivity characterizes the concentration and mobility of ions (Shi et al., 2014) and therefore, shows the level of destruction in the cell membranes. Increased conductivity point to the leaked water in the intra- and extracellular space (Byrne et al., 2000).

As consumers are using less and less time for food preparation, then the retailers are demanding more ready-to-eat products. Thermally treated meat products are offered usually as boiled, grilled or roasted. An aim of the meat processing industry is to improve processing to decrease weight loss of the product during cooking. Schellekens (1996) defines sous-vide as cooking of the raw products inside vacuum bags under controlled temperature and time. Several authors have been found that meat cooked this way have better textural properties (Christensen et al., 2012; Mortensen, 2012) and popular among consumers (Bañón et al., 2007). However, grilling involves direct, radiant heat and can be used for cooking meat quickly. Hotplate direct contact to the meat surface closes the space between the muscle fibres because of crust formation (Sánchez-Muniz & Bastida, 2006) and this help to keep the moisture inside the meat. Grilling and frying resulted in the lowest cooking losses compared to the various cooking methods in the Serrano et al. (2007), Alfaia et al. (2010) and Domínguez et al. (2014) studies. Contrary to these findings, Juárez et al. (2010) discovered that frying and grilling showed the highest moisture loss compared to boiling.

Therefore, final product quality and meat processing economic output depends on the skills to find optimal ageing time for muscles and thermal treatment method. Considering this, the objective of this study was to evaluate some physicochemical and textural properties of beef of Aberdeen Angus. The effects of different ageing times and cooking methods on the quality traits of the two muscle groups were studied. The emphasis of the study was to find optimal ageing time for the grass-fed beef muscles by analyzing muscle and ageing time interaction.

MATERIALS AND METHODS

The **carcasses** were obtained from free-ranged Aberdeen Angus bulls that had been slaughtered at a commercial abattoir in Arke Lihatööstus Ltd. The animal's transport time from the farm to the slaughterhouse was 1–2 h and the pre-slaughter resting duration in the lairage pens was approximately 3 h. Slaughtering was carried out to the accordance with good animal welfare practices and slaughtering procedures followed the Veterinary and Food Board of Estonia. The electrical stimulation was not used in the slaughterhouse to tenderize meat. Three randomly selected carcasses from the different batches were used. The age of the animals were 20–24 months and weight of the carcasses 250–330 kg.

After the dressing, carcasses were split by sawing centrally down the vertebral column, weighed and transported to the cold store to cool down at 0 °C for approximately 24 h. After the chill period, carcasses were deboned in accordance with the scheme used by the abattoir, whereas no primal cuts removed prior deboning. During this process, samples of the *longissimus thoracis et lumborum* (LD) muscle (loin) and a group of unseparated muscles, *semimembranosus* and *adductor femoris* (SMA) (round), were removed. The intramuscular fat content of the samples was 0.7–1.7%. Four samples were taken from each muscle group and vacuum-packed to determine changes in the meat quality within a 20-day ageing period. Bags were marked with a permanent marker with muscle name and packing date. The samples were wet aged at +2 °C for 10, 14, 18 and 20 days in the Memmert climate chamber ICH110 (Memmert GmbH, Schwabach, Germany). The climate chamber was equipped with two PT100 platinum resistance thermometers (Pico Technology, Cambridgeshire, UK) for mutual monitoring, which allows temperature stability ± 0.3 °C.

Two **cooking methods**, sous-vide and electric contact grill, were used for the preparation of samples. The muscles were cooked in the rotated order within the study period. For the sous-vide cooking, steaks with 2 cm thickness were vacuum-packed and submerged immediately in the water bath for 180 min at 65 °C. The bags were removed from the water bath and cooled down in icy water (2 °C) for 1 h. The meat samples were removed from the bags afterwards and used for the analyses.

The raw meat samples were removed from the bags and let shortly stay in the room temperature. Steaks (2 cm) were grilled in an electric contact grill Sage Smart Grill™ Pro BGR840 (Sage Appliances GmbH, Düsseldorf, Germany) preheated at 230 °C. The steaks core temperature were monitored by thermocouples attached with a digital monitor. Before the removal from the grill, an internal temperature of the meat samples was allowed to reach 65 °C (medium).

The **pH** was determined to the accordance with reference method ISO 2917:1999 on the all aged muscles using a pH-meter Mettler Toledo Seven Excellence (Mettler-Toledo LLC, Columbus, Ohio, USA). A device was equipped with an electrode Inlab Expert Pro-ISM with a built-in temperature sensor for temperature compensation during the measurement. Five grams of grounded meat was homogenized in 50 mL of 0.1 M KCL solution. The device was calibrated before use in the standard solutions pH 4.0 and 7.0 at the 23 °C. The calibration procedure and measuring samples were carried through at the room temperature (23 °C). The pH-meter probe was cleaned with distilled water and paper tissue between the measurements.

Electrical conductivity was measured respectively to the method from Yao et al. (2011). Five grams of beef sample was ground by blender and homogenized with 50 mL distilled water for 1 minute (6,000 revolutions per minute). The electrical conductivity of the beef sample was measured with a temperature compensated electrode Inlab 731-ISM attached to a device Mettler Toledo Seven Excellence (Mettler-Toledo LLC, Columbus, Ohio, USA). An electrical conductivity meter probe calibration procedure was performed with the potassium chloride standard buffer at 1413 μS cm^{-1} and 12880 μS cm^{-1}.

Shear force analysis on raw meat and sous-vide treated samples was performed using a TA.XTplus Texture Analyser (Stable Micro System Ltd., Surrey, UK) equipped with Warner-Bratzler blade. Fresh meat slices were held for 120 min at –18 °C in the freezer and sous-vide cooked steaks were chilled for 24 h at 4 °C (AMSA, 2016). Freezing of the raw meat was necessary to ensure the uniformity of the drilled samples. Ten round cores with the 11 mm diameter were drilled parallel to the muscle fibres from each steak. Meat cores were held on the room temperature and sheared through the centre, perpendicular to the fibre direction at the constant speed 120 mm min^{-1} and with the 50 N force.

The determination of meat surface **colour** measurements was carried through with a handheld spectrophotometer X-Rite 964 (X-Rite Inc., Grand Rapids, Michigan, USA). An assessment was conducted in the CIE L* (lightness) a* (redness) b* (yellowness) colour model using measurement geometry 0°/45°, D65 illuminant and 10° observer. The spectrophotometer was calibrated before the usage in accordance with the standard reference with a ceramic disk for white calibration measurements and a trap opening for black. 2 cm meat slices were cut perpendicular to the muscle fibres and hold in the open plastic bags at +2 °C for 2 h (blooming time) to ensure optimal myoglobin oxygenation (Lee et al., 2008; AMSA, 2012). Colour measurements were taken from the three different locations at the cutting surface of the meat steaks.

Sous-vide treated and grilled meat samples **cooking losses** were estimated to determine the loss of water and soluble substances of meat during thermal treatment. Sous-vide treated meat slices were cooled down in the ice slurry to stop the temperature increase, then removed from the bags and blotted with the paper towel to remove excessive moisture. Grilled steaks were let to cool down for 5 minutes under the foil to stop movements of water. All thermally treated samples were reweighed, wherein two cooking losses measurements (hot and cooled) were obtained for the grilled steaks. The total cooking loss was calculated in accordance with Eq. 1:

$$Cooking\ loss, \% = \frac{(ra\quad weight, g\ -\ cooked\ weight, g)}{raw\ weight, g} \times 100 \qquad (1)$$

Statistical analysis. Analysis of variance was used to test the effects of muscles, ageing times and muscles by ageing time interaction, the fixed blocking effect of bull and the random effect of the muscle portion assigned to each ageing duration were also considered. The least square means corresponding to factors' levels were estimated and compared with the *Tukey* method in SAS 9.4. Relationships between variables are reported as Pearson correlation coefficients.

RESULTS AND DISCUSSION

No significant differences ($P > 0.05$) in pH mean values were found between muscles and ageing times, either interaction between ageing times and muscles was not detected (Table 1). However, the pH-value of LD muscles was slightly higher (5.55) than in SMA group of muscles (5.47) and effect of the muscle as a factor was found close to the statistical significance ($P = 0.114$). The ageing increased the pH-values of beef ($P > 0.05$) from day 10 (5.46) to day 18 (5.45), dropped slightly afterwards on the day 20 (5.52). The LD muscle acted a similar way regarding the interaction between the muscles and ageing times ($P > 0.05$). SMA muscle group pH decreased on day 14 (5.43) and showed an increase again on day 18, reached to the same level as on day 10 (5.46) and gained to the level of 5.52 on day 20.

Table 1. The effects of muscle groups, ageing times and muscle groups by ageing times interaction on technological parameters of beef

Factor / Levels	Technological parameters			
	pH (raw)	Electrical conductivity, μS cm^{-1} (raw)	Shear force, N (raw thawed)	Shear force, N (sous-vide)
Muscles (M)	$P = 0.114$	$P = 0.074$	$P < 0.001$	$P = 0.538$
LD	5.55	1081.6	27.6 [a]	38.7
SMA	5.47	1103.7	23.1 [b]	30.7
SE	0.051	16.2	2.24	9.68
Ageing time (AT)	$P = 0.398$	$P = 0.305$	$P = 0.094$	$P < 0.001$
Day 10	5.46	1087.6	27.9	40.8 [a]
Day 14	5.50	1110.1	24.1	34.7 [b]
Day 18	5.54	1081.3	25.1	29.7 [b]
Day 20	5.52	1091.6	24.3	33.7 [b]
SE	0.033	10.20	1.20	6.80
Interaction M x AT	$P = 0.302$	$P = 0.857$	$P = 0.002$	$P < 0.001$
LD				
Day 10	5.47	1069.9	29.0 [a]	41.5 [ab]
Day 14	5.56	1098.3	23.0 [ab]	37.9 [abc]
Day 18	5.62	1076.0	30.0 [a]	32.3 [acd]
Day 20	5.53	1082.3	28.2 [a]	43.2 [b]
SM				
Day 10	5.46	1105.2	26.8 [ab]	40.0 [abc]
Day 14	5.43	1121.9	25.1 [ab]	31.5 [cd]
Day 18	5.46	1086.7	20.2 [b]	27.1 [d]
Day 20	5.52	1101.0	20.4 [b]	24.2 [d]
SE	0.048	15.50	1.72	9.61

LD – *longissimus thoracis et lumborum* muscle, SMA – *semimembranosus* and *adductor femoris* muscle group; Factors' *P*-values and levels' least square means (*LSM*) with standard errors (*SE*) are presented; *LSM* of the same factor's levels without common superscript letter are statistically significantly different ($P < 0.05$, pairwise comparison of *LSM* followed by multiple comparison adjustment with *Tukey* method).

Meat pH-value is often related to technological and visual quality indicators, such as tenderness, colour, water holding capacity (Valero et al., 2014; Khan et al., 2016). Muscle pH in the living animal is around 7.0, but after the slaughter, it drops and 18–40 h later remains between 5.30–5.80 in the normal meat (Savell et al., 2005; Farmer

& Farell, 2018; Zhang et al., 2018). Muscles pHs has not exceeded values that correspond to the normal meat pH within the ageing period, which indicates an absence of the defective muscles. Small standard error value point to the limited variability of the pH-values. Over 80% of the carcasses pH fell into the narrow range (5.40–5.59) in Page et al. (2001) study. Simonetti et al. (2015) found that the pH of the Nellore bulls four muscles not differed significantly and was between 5.48–5.55. However, only *Trapezius thoracis* muscle showed significantly higher pH-value (5.66) compared to other muscles. They justified the existence of such difference with the lower glycogen level in the muscle, which was induced by the muscle extensive physical activity and shorter rest period.

Although ageing of the beef was performed in the vacuum-sealed bags, which promotes the growth of lactic bacteria due to anaerobic conditions and presumably increases acidity, the pH was not significantly affected by ageing time. Li et al. (2014) observed no changes in the muscle pH despite the significant increase in the count of the lactic acid bacteria between ageing day 8 and day 19 in the bag and vacuum ageing study. Contrary, Simonetti et al. (2015) found that the pH of the meat drops significantly on day 7 and increases on day 14. They inferred that the lower pH was observed especially due to the growth of the lactic bacteria, however, the microbial count was not observed. Tänavots et al. (2013) found a significant pH decrease after 28 days of ageing in the *longissimus* and *teres major* muscles. Constant pH within ageing may refer to the proper processing of the fresh meat, where the contamination with the bacteria is minimal (Jones, 2004). Therefore, a low count of lactic acid bacteria was not able to increase meat pH during a short ageing period, despite the favourable conditions in chill-stored and vacuum-packaged meat (low temperature and absence of oxygen).

Protein degradation intensifies in the lower pH conditions and free water augments in the muscle during this process. Dissolved substances hold charges that increases conductivity in meat (Schmitten et al., 1987). However, the present study showed that a relationship between pH and electrical conductivity was weak and non-significant (Table 4). The similar weak relationship between impedance and pH was found also by Page et al. (2001). As defective muscles were not detected, the pH-values remained in a narrow range and influenced the relationship between pH and electrical conductivity. Another reason for a weak relationship could be explained by the uneven moisture distribution and concentration inside the muscles.

Electrical conductivity not differed between muscles and ageing times and no interactions were found between muscles and ageing times (Table 1). However, the tendency to the lower electrical conductivity was observed in LD muscle, which indicates that the LD steaks contained less free fluid.

The fresh LD exhibited significantly ($P < 0.05$) higher value in the shear force assessment (27.6 N), compared to the SMA (23.1 N) (Table 1). The tenderness of the fresh steaks increased notably from day 10 to 14, but the change was not significant. However, a significant interaction was found between muscles and ageing times for the raw meat shear force ($P = 0.002$). LD muscle did not show a notable change in the shear force within 20 days of ageing, on the other hand, SMA tenderness improved from day 14 to 18 ($P > 0.05$). Raw LD muscle was significantly tougher on day 18 and 20, compared to the SMA at the same ageing times. Tänavots et al. (2013) observed tenderness escalation in LD muscle from day 14 to 28. Baldwin (2012) referred that the toughness of the muscle is related to the presence of the intramuscular connective tissue

and the myofibrillar component. Muscles with higher activity contain more connective tissue and are therefore tougher. Either increased α-white fibres in these muscles makes them less tender (Calkins et al., 1981). Kirchofer et al. (2002) classified *longissimus dorsi, semimembranosus* and *adductor* muscles as 'white', which indicate to their increased toughness. The results from the present study reflect their findings that LD muscle red and white fibres diameter and area is larger. Hence, more force was needed to cut through LD muscle.

The meat slices were heated up to 65 °C at which point proteins aggregate and makes cutting easier (Tornberg, 2005). Thermal treatment with the sous-vide method turned both muscles tougher compared to the fresh meat (Table 1). Slightly more force ($P > 0.05$) was applied to cut LD muscle (38.7 N), whereas the SMA group was tenderer (30.7 N). The significant effect of the muscles to the shear force was observed in Simonetti et al. (2015) and Cho et al. (2016) study.

Sullivan and Calkins (2011) classified LD muscle in their review article the toughest (WBSF > 46 N) and *semimembranosus* and *adductor* muscles tenderness were intermediate (WBSF > 39 N). However, they referred that some differences related to the toughness of the various muscles may exist among the authors. Stolowski et al. (2006) characterized LD muscle as 'tender with slow but continued response to ageing up to 42 d' and SMA as 'slightly tender with ageing response up to 14 d'. An interaction between the muscles and ageing times corresponded to the previous categories as the sous-vide treated SMA muscle group shear force was dropped notably since ageing day 14 (Table 1). LD response to ageing was modest and agreed with the Simonetti et al. (2015) results where they did not found a significant decrease in shear force from day 7 to 14. Tänavots et al. (2013) observed significant gain in LD tenderness from day 14 to 28 and later from day 35 to 60, which confirms that longer ageing period is necessary to improve this muscle tenderness. According to Shackelford et al. (1991), the beef is tender if its shear force remains below 45 N. The present study showed that both muscle groups could be considered as tender already on the tenth day of ageing so that the further ageing is not necessary. However, the shear force decline significantly from day 10 (40.8 N) to 18 (29.7 N) (Table 1).

Muscles, ageing times and their interaction did not show a difference in L* values (Table 2). Simonetti et al. (2015) found no interaction between ageing times and muscles and a difference was not existed in ageing from day 7 to 14, whereas only *Semitendinosus* muscle lightness was significantly higher from four others. Kadim et al. (2013) claimed that light diffusion properties during the ageing were related to the level of protein degradation due to the changes in the meat pH. This process intensifies the release of the free water, which flows to the surface of the meat through the spaces between the muscle fibres. The presence of excessive fluid on the surfaces leads to an increase in L* (Pereira et al., 2008). The previous finding was not confirmed in the present study, probably due to constant pH value within ageing time. Contrary, Sosin-Bzducha & Puchała (2017) found that beef lightness decreased within the ageing period up to 14 days. A relationship between meat L* and pH was not found either in the present study (Table 4). However, Page et al. (2001) found that L* is moderately related to pH ($r = –0.40$). At the same time, the negative relationship confirms previous claims that meat with lower acidity is lighter.

'White' muscles are less red as the myoglobin concentration in these muscles is lower (Cezar & Sousa, 2007). Myoglobin degradation is responsible for the red appearance of the meat, whereas darker colour is less favourable for consumers (Bass et al., 2008), while lipid peroxidation turns the colour of meat yellower (Sosin-Bzducha & Puchała, 2017). The a* (redness) and b* (yellowness) intensities showed the difference between muscles (Table 2). The highest values for both variables were found in SMA (a* = 20.3; b* = 19.1) and lowest in LD (a* = 14.3; b* = 15.4) ($P < 0.05$). Bass et al. (2008) observed also that high a* value was related to *semimembranosus* and *adductor* muscles, but a* value appeared to be lower in *longissimus*.

Table 2. The effects of muscle groups, ageing times and muscle groups by ageing times interaction on colour values of beef

Factor / Levels	Colour		
	L* (lightness)	a* (redness)	b* (yellowness)
Muscles (M)	$P = 0.644$	$P = 0.029$	$P = 0.021$
LD	38.0	14.3 [a]	15.4 [a]
SMA	39.8	20.3 [b]	19.1 [b]
SE	2.61	1.47	0.85
Ageing time (AT)	$P = 0.213$	$P = 0.214$	$P = 0.642$
Day 10	37.4	18.1	17.6
Day 14	38.3	17.8	18.0
Day 18	38.5	17.4	17.1
Day 20	41.3	15.9	16.4
SE	2.11	1.20	0.97
Interaction M x AT	$P = 0.298$	$P = 0.140$	$P = 0.319$
LD			
Day 10	37.4	15.3	15.8
Day 14	36.7	16.2	17.4
Day 18	39.1	13.0	13.9
Day 20	38.5	12.9	14.4
SMA			
Day 10	37.3	20.9	19.3
Day 14	39.9	19.4	18.5
Day 18	38.0	21.7	20.3
Day 20	43.9	18.9	18.4
SE	2.98	1.70	1.37

LD – *longissimus thoracis et lumborum* muscle, SM – *semimembranosus* and *adductor femoris* muscle group; Factors' *P*-values and levels' least square means *(LSM)* with standard errors (*SE*) are presented; *LSM* of the same factor's levels without common superscript letter are statistically significantly different ($P < 0.05$, pairwise comparison of *LSM* followed by multiple comparison adjustment with *Tukey* method).

Ageing decreased slightly intensities of the redness (a*) and yellowness (b*) colour ($P > 0.05$), which corresponds to the findings in *gluteus medius* steaks used in Lee et al. (2008) study. Contrary, in the research conducted by Simonetti et al. (2015) and Sosin-Bzducha & Puchała (2017), the a* and b* increased within the 14 days ageing period. Differences in the results can be explained by the longer blooming time in the present study. Lee et al. (2008) proved that blooming development related deoxygenation and pigment reduction processes (AMSA, 2012), were not fully stabilized on 120 min. They indicated also that the differences in the extent of the blooming might exist between

various muscle types. An absence of oxygen in the vacuum bags may also slow down the process of discolouration.

Strong positive correlation was found between a* and b* value ($r = 0.69$; $P = 0.003$) in the present study (Table 4) and even stronger relationship ($r = 0.95$) was observed for *longissimus* muscle by Page et al. (2001) and Giaretta et al. (2018), showing that discolouration processes are related to the same direction. A negative moderate relationship between colour measurements and pH ($r_{a^*;pH} = –0.59$; $P_{a^*;pH} = 0.016$ and $r_{b^*;pH} = –0.46$; $P_{b^*;pH} = 0.071$) indicate that acidity of the muscle plays important role in muscle colour by altering hue.

Table 3. The effects of muscle groups, ageing times and muscle groups by ageing times interaction on cooking losses

Factor / Levels	Cooking losses related to the treatment methods		
	Sous-vide	Grilled (hot)	Grilled (cooled)
Muscles (M)	$P = 0.995$	$P = 0.908$	$P = 0.977$
LD	28.2	14.1	19.0
SMA	28.1	14.5	18.8
SE	3.88	2.41	2.64
Ageing time (AT)	$P = 0.646$	$P = 0.105$	$P = 0.058$
Day 10	29.3	18.9	25.7
Day 14	27.8	15.5	19.7
Day 18	28.1	11.5	14.8
Day 20	27.4	11.3	15.3
SE	2.90	2.46	2.73
Interaction M x AT	$P = 0.754$	$P = 0.445$	$P = 0.313$
LD			
Day 10	29.0	21.6	29.9
Day 14	27.0	15.5	19.1
Day 18	28.9	10.2	13.5
Day 20	27.9	9.2	13.4
SMA			
Day 10	29.6	16.3	21.5
Day 14	28.6	15.6	20.4
Day 18	27.4	12.8	16.2
Day 20	27.0	13.4	17.3
SE	4.10	3.47	3.86

LD – *longissimus thoracis et lumborum* muscle, SMA – *semimembranosus* and *adductor femoris* muscle group; Factors' *P*-values and levels' least square means (*LSM*) with standard errors (*SE*) are presented.

No interaction was detected between muscles and ageing times for cooking losses, both factors, muscles and ageing times, was not significant. Sous-vide treated and grilled muscle groups showed relatively equal weight losses. Grilling is the preferred thermal treatment method compared to the sous-vide, as the LD muscle lost 14.1% and the SMA group 13.6% less weight. A relatively big difference could be explained by circumstances that the longitudinal muscle fibres shrinking as muscle temperature increases above 60–65 °C and this causes substantial water loss (Baldwin, 2012). Ismail et al. (2019) confirmed that beef *Semitendinosus* muscle water loss was significantly smaller at a lower temperature (45 °C), compared to sous-vide treated meat slices at 65 °C. On the other hand, grill hotplate direct contact with the meat slice helps crust formation (Sánchez-Muniz & Bastida, 2006) and prevents the release of the fluids from

the meat. Fabre et al. (2018) observed a significant difference between *longissimus* and *semimembranosus* muscle cooking losses by using oven and griddle plate treatment, but there was no difference in water bath cooking.

Grilled meat (hot and cooled) cooking loss decreased within the ageing period from day 10 to day 14 and day 14 to day 18 (Table 3) probably due to increased proteolytic activity, which caused swelling of myofibrils due to the uptake of water. Grilled meat tend to hold moisture better, which makes it juicier and more acceptable to consumers.

Table 4. Correlations between beef quality properties

	Traits	1.	2.	3.	4.	5.	6.	7.	8.	9.
1.	SF (raw), N	1.00	–0.33	–0.18	–0.38	0.01	–0.22	0.33	0.18	0.22
2.	pH	–0.33	1.00	0.16	–0.13	–0.59*	–0.46$^{\#}$	–0.48$^{\#}$	–0.58*	–0.50$^{\#}$
3.	EC, µS/cm (raw)	–0.18	0.16	1.00	0.11	0.24	0.44$^{\#}$	–0.35	–0.21	–0.20
4.	L* (lightness)	–0.38	–0.13	0.11	1.00	–0.09	0.39	0.24	0.04	0.01
5.	a* (redness)	0.01	–0.59*	0.24	–0.09	1.00	0.69**	–0.05	0.21	0.13
6.	b* (yellowness)	–0.22	–0.46$^{\#}$	0.44$^{\#}$	0.39	0.69**	1.00	0.05	0.21	0.16
7.	CL (sous-vide), %	0.33	–0.48$^{\#}$	–0.35	0.24	–0.05	0.05	1.00	0.453$^{\#}$	0.40
8.	CL (grilled, hot), %	0.18	–0.58*	–0.21	0.04	0.21	0.21	0.45$^{\#}$	1.00	0.97***
9.	CL (grilled, cooled), %	0.22	–0.50$^{\#}$	–0.20	0.01	0.13	0.16	0.40	0.97***	1.00

SF – shear force, EC – electrical conductivity, CL – cooking loss; # indicates that the correlation is different at level 0.1; * indicates that the correlation is significantly different at the level 0.05; ** indicates that the correlation is significantly different at the level 0.01; *** indicates that the correlation is significantly different at the level 0.001.

CONCLUSIONS

Ageing time has an effect on the technological and qualitative parameter of beef, by improving tenderness and colour. Muscle effect in ageing must consider as *longissimus thoracis et lumborum* muscle was tougher than *semimembranosus* and *adductor femoris* muscle group and therefore need longer ageing. Although both muscle groups were tender on the ageing day 10, the optimal ageing time for the vacuum-packed *semimembranosus* and *adductor femoris* muscle group is 18 days.

The *semimembranosus* and *adductor femoris* muscle group has a higher colour value, which attracts consumers more, compared to the *longissimus thoracis et lumborum* muscle. Muscles showed good colour (lightness, redness and yellowness) stability within ageing for 20 days.

Ageing has a slight positive effect on the grilled beef cooking loss, but there are no changes in sous-vide treated meat.

ACKNOWLEDGEMENTS. This study was supported by Enterprise Estonia (EAS) under the innovation voucher grant L180043VLTQ. The authors would like to express their sincere gratitude to the Arke Lihatööstus Ltd. for the cooperation.

REFERENCES

Alfaia, C.P.M., Alves, S.P., Lopes, A.F., Fernandes, M.F.E., Costa, A.S.H., Fontes, C.M.G.A., Castro, M.L.F., Bessa, R.J.B. & Prates, J.A.M. 2010. Effect of cooking methods on fatty acids, conjugated isomers of linoleic acid and nutritional quality of beef intramuscular fat. *Meat Science* **84**, 769–777.

AMSA. 2012. Meat Color Measurement Guidelines. In AMSA. (Ed.), *American Meat Science Association*, Illinois USA, 124 pp.

AMSA. 2016. Research Guidelines for Cookery, Sensory Evaluation, and Instrumental Tenderness Measurements of Meat. In AMSA. (Ed.), *American Meat Science Association,* Illinois USA, 105 pp.

Baldwin, D.E. 2012. Sous vide cooking: A review. *International Journal of Gastronomy and Food Science* **1**, 15–30.

Bañón, S., Nieto, G. & Díaz, P. 2007. Applications of sous vide technology in the elaboration of prepared meat dishes for catering. *Eurocarne* **17**(155) 109–115 (in Spanish).

Bass, P.D., Scanga, J.A., Chapman, P.L., Smith, G.C., Tatum, J.D. & Belk, K.E. 2008. Recovering value from beef carcasses classified as dark cutters by United States Department of Agriculture graders. *Journal of Animal Science* **86**(7), 1658–1668.

Byrne, C.E., Troy, D.J. & Buckley, D.J. 2000. Postmortem changes in muscle electrical properties of bovine M. longissimus dorsi and their relationship to meat quality attributes and pH fall. *Meat Science* **54**, 23–34.

Calkins, C.R., Dutson, T.R., Smith, G.C., Carpenter, Z.L. & Davis, G.W. 1981. Relationship of fiber type composition to marbling and tenderness of bovine muscle. *Journal of Food Science* **46**, 708–710.

Cassens, A.M., Arnold, A.N., Miller, R.K., Gehring, K.B. & Savell, J.W. 2018. Impact of elevated aging temperatures on retail display, tenderness, and consumer acceptability of beef. *Meat Science* **146**, 1–8.

Cezar, M. & Sousa, W. 2007. *Sheep and goat carcasses: Obtaining, evaluating and classifying*. Uberaba: Editora Agropecuária Tropical, Brasil, 232 pp. (in Portuguese)

Cho, S, Kang, S.M., Seong, P., Kang, G., Kim, Y., Kim, J., Lee, S. & Kim, S. 2016. Effect of aging time on physicochemical meat quality and sensory property of Hanwoo bull beef. *Korean Journal of Food Science and Animal Resources* **36**, 68–76.

Christensen, L., Gunvig, A., Tørngren, M.A., Aaslyng, M.D., Knøchel, S. & Christensen, M. 2012. Sensory characteristics of meat cooked for prolonged times at low temperature. *Meat Science* **90**, 485–489.

Domínguez, R., Gómez, M., Fonseca, S. & Lorenzo, J.M. 2014. Effect of different cooking methods on lipid oxidation and formation of volatile compounds in foal meat. *Meat Science* **97**(2), 223–230.

Egan, A.F., Ferguson, D.M. & Thompson, J.M. 2001. Consumer sensory requirements for beef and their implications for the Australian beef industry. *Australian Journal of Experimental Agriculture* **41**, 855–859.

Fabre, R., Dalzotto, G., Perlo, F., Bonato, P., Teira, G. & Tisocco, O. 2018. Cooking method effect on Warner-Bratzler shear force of different beef muscles. *Meat Science* **138**, 10–14.

Farmer, L. & Farrell, D. 2018. Review: Beef-eating quality: A European journey. *Animal*, 1–10.

Florek, M., Litwińczuk, A., Skałecki, P., Ryszkowska-Siwko, M. 2007. Changes of physicochemical properties of bullocks and heifers meat during 14 days of ageing under vacuum. *Polish Journal of Food and Nutrition Sciences* **57**(3), 281–288.

Giaretta, E., Mordenti, A.L., Canestrari, G., Brogna, N., Palmonari, A. & Formigoni, A. 2018. Assessment of muscle *Longissimus thoracis et lumborum* marbling by image analysis and relationships between meat quality parameters. *PLoS ONE* **13**(8), e0202535.

Guelker, M., Haneklaus, A., Brooks, J., Carr, C., Delmore, R., Griffin, D., Hale, D.S, Harris, K.B., Mafi, G.G., Johnson, D.D., Lorenzen, C.L., Maddock, R.J., Martin, J.N., Miller, R.K., Raines, C.R., VanOverbeke, D.L., Vedral, L.L., Wasser, B.E. & Savell, J.W. 2013. National Beef Tenderness Survey-2010: Warner-Bratzler shear force values and sensory panel ratings for beef steaks from United States retail and food service establishments. *Journal of Animal Science* **91**(2), 1005–1014.

Guerrero, A., Velandia Valero, M., Campo, M.M. & Sañudo, C. 2013. Some factors that affect ruminant meat quality: from the farm to the fork. Review. *Acta Scientiarum*. *Animal Sciences* **35**(4), 335–347.

Hanzelková, Š., Simeonovová, J., Hampel, D., Dufek, A. & Šubrt, J. 2011. The effect of breed, sex and aging time on tenderness of beef meat. Acta Veterinaria Brno **80**, 191–196.

Ismail, I., Hwang, Y.-H., Bakhsh, A. & Joo, S.-T. 2019 The alternative approach of low temperature-long time cooking on bovine semitendinosus meat quality. *Asian-Australasian Journal of Animal Sciences* **32**(2) 282–289.

Jones, R.J. 2004. Observations on the succession dynamics of lactic acid bacteria 441 populations in chill-stored vacuum packaged beef. *International Journal of Food Microbiology* **90**, 273–282.

Juárez, M., Failla, S., Ficco, A., Peña, F., Avilés, C. & Polvillo, O. 2010. Buffalo meat composition as affected by different cooking methods. *Food and Bioproducts Processing* **88**, 145–148.

Kadim, I.T., Al-Karousi, A., Mahgoub, O., Al-Marzooqi, W., Khalaf, S.K., Al-Maqbali, R.S., Al-Sinani, S.S. & Raiymbek, G. 2013. Chemical composition, quality and histochemical characteristics of individual dromedary camel (*Camelus dromedarius*) muscles. *Meat Science* **93**(3), 564–571.

Khan, M.I., Jung, S., Nam, K.C. & Jo, C. 2016. Postmortem Aging of Beef with a Special Reference to the Dry Aging. *Korean Journal for Food Science of Animal Resources* **36**(2), 159–619.

Kirchofer, K.S., Calkins, C.B. & Gwartney, B.L. 2002. Fiber-type composition of muscles of the beef chuck and round. *Journal of Animal Science* **80**(11), 2872–2878.

Lee, M.S., Apple, J.K., Yancey, J.W.S., Sawyer, J.T. & Johnson, Z.B. 2008. Influence of vacuum-aging period on bloom development of the beef gluteus medius from top sirloin butts. *Meat Science* **80**(3), 592–598.

Li, X., Babol, J., Bredie, W.L.P., Nielsen, B., Tománková, J. & Lundström, K. 2014. A comparative study of beef quality after ageing longissimus muscle using a dry ageing bag, traditional dry ageing or vacuum package ageing. *Meat Science* **97**(4), 433–442.

Mancini, R.A. & Hunt, M.C. 2005. Current research in meat color. *Meat Science* **71**(1), 100–121.

Monson, F., Sanudo, C. & Sierra, I. 2005. Influence of breed and ageing time on the sensory meat quality and consumer acceptability in intensively reared beef. *Meat Sci*ence **71**, 471–479.

Mortensen, L.M., Frøst, M.B., Skibsted, L.H. & Risbo, J. 2012. Effect of time and temperature on sensory properties in low-temperature long-time sous-vide cooking of beef. *Journal of Culinary Science & Technology* **10**, 75–90.

Page, J.K., Wulf, D.M. & Schwotzer, T.R. 2001. A survey of beef muscle color and pH. *Journal of Animal Science* **79**(3), 678–687.

Pereira, A.S.C., Sobral, P.J.A., Leme, P.R. & Silva, S.L. 2008. Physical and chemical characteristics of frozen ground beef and aged beef meat from *Bos indicus* steers supplemented with α-tocopherol acetate. *Italian Journal of Food Science* **20**(3), 419–425.

Piao, M.Y., Jo, C., Kim, H.J., Lee, H.J., Kim, H.J., Ko, J.Y. & Baik, M. 2015 Comparison of carcass and sensory traits and free amino acid contents among quality grades in loin and rump of Korean cattle steer. *Asian-Australasian Journal of Animal Sciences* **28**, 1629–1640.

Sánchez-Muniz, F.J. & Bastida, S. 2006. Effect of frying and thermal oxidation on olive oil and food quality. *Olive Oil and Health*. Wallingford, United Kingdom: CABI Publishing, pp. 74–108.

Savell, J.W., Mueller, S.L. & Baird, B.E. 2005. The chilling of carcasses. *Meat Science* **70**(3), 449–459.

Schellekens, M. 1996. New research issues in sous-vide cooking. *Trends in Food Science & Technology* **7**(8), 256–262.

Schmitten, F., Schepers, K.H. & Festerling, A. 1987. Evaluation of meat quality by measurement of electrical conductivity. In P.V. Eikelenboom, G. Eikelenboom & G. Monin. *Evaluation and control of meat quality in pigs.* Dordrecht: Martinus Nijho. pp. 191–200.

Shi, C., Lu, H., Cui, J., Shen, H. & Luo, Y. 2014. Study on the predictive models of the quality of silver carp (*Hypophthalmichthys molitrix*) fillets stored under variable temperature conditions. *Journal of Food Processing and Preservation* **38**, 356–363.

Sitz, B.M., Calkins, C.R., Feuz, D.M., Umberger, W.J. & Eskridge, K.M. 2006. Consumer sensory acceptance and value of wet-aged and dry-aged beef steaks. *Journal of Animal Science* **84**(5), 1221–1226.

Simonetti, L.R., Lage, J.F., Berchielli, T.T., Oliveira, E.A., Dallantonia, E.E. & Delevatti, L.M. 2015. Aging time of five muscles from carcass of Nellore young bulls. *Acta Scientiarum. Animal Sciences* **37**(4), 397–404.

Serrano, A., Librelotto, J., Cofrades, S., Saánchez-Muniz, F.J. & Jiménez-Colmenero, F. 2007. Composition and physicochemical characteristics of restructured beef steaks containing walnuts as affected by cooking method. *Meat Science* **77**, 304–313.

Shackelford, S.D., Morgan, J.B., Cross, H.R. & Savell, J.W. 1991. Identification of threshold levels for Warner-Bratzler shear force in beef top loin steaks. *Journal of Muscle Foods* **2**, 289−296.

Sosin-Bzducha, E. & Puchała, M. 2017. Effect of breed and aging time on physicochemical and organoleptic quality of beef and its oxidative stability. *Archives Animal Breeding* **60**, 191–198.

Stolowski, G.D., Baird, B.E., Miller, R.K., Savell, J.W., Sams, A.R., Taylor, J.F., Sanders, J.O. & Smith, S.B. 2006. Factors influencing the variation in tenderness of seven major beef muscles from three Angus and Brahman breed crosses. *Meat Science* **73**, 475–483.

Sullivan, G.A. & Calkins, C.R. 2011. Ranking beef muscles for Warner-Bratzler shear force and trained sensory panel ratings from published literature. Journal of Food Quality 34, 195–203.

Tornberg, E. 2005. Effect of heat on meat proteins – implications on structure and quality of meat products. *Meat Science* **70**, 493–508.

Tänavots, A., Põldvere, A., Lepasalu, L. & Soidla, R. 2013. Effect of long ageing time on beef quality of Aberdeen Angus. *Agraarteadus* **24**(2), 86–94.

Valero, M.V., Torrecilhas, J.A., Zawadzki, F., Bonafé, E.G., Madrona, G.S., Prado, R.M., Passetti, R.A.C., Rivaroli, D.C., Visentainer, J.V. & Prado, I.N. 2014. Propolis or cashew and castor oils effects on composition of Longissimus muscle of crossbred bulls finished in feedlot. *Chilean Journal of Agricultural and Research* **74**(4), 445–451.

Wicklund, S.E., Stetzer, A.J., Tucker, E.M., Nicolalde, C.L. & Brewer, M.S. 2005. Microbiological characteristics of enhancement solutions. *Journal of Food Science* **70**, 296–300.

Yao, L., Luo, Y., Sun, Y. & Shen, H. 2011. Establishment of kinetic models based on electrical conductivity and freshness indictors for the forecasting of crucian carp (*Carassius carassius*) freshness. *Journal of Food Engineering* **107**, 145–151.

Zhang, Y., Hopkins, D.L., van de Ven, R.J., Zhao, X., Mao, Y., Zhu, l., Han, G. & Luo, X. 2018. Characterisation of pH decline and meat color development of beef carcasses during the early post-mortem period in a Chinese beef cattle abattoir. *Journal of Integrative Agriculture* **17,** 1691–1695.