Physical and chemical properties of selected beef muscles infused with a phosphate and lactate blend

L.C. Hoffman[1#], A. Vermaak[1,2] & N. Muller[2]

[1] Department of Animal Sciences, Stellenbosch University, Private Bag X1, Matieland, Stellenbosch, 7602, South Africa

[2] University of Stellenbosch, Department of Food Science, Private Bag X1, Matieland 7602, South Africa

Abstract

The consumer demands a beef product of consistent and acceptable tenderness. The infusion of beef muscles with a blend containing sodium and potassium salts, various phosphates and lactates has the potential to improve the current status of low meat consumption and inconsistent tenderness of fresh beef products in South Africa. In the present investigation, the *biceps femoris* (BF, silverside), *rectus femoris* muscle (RF), *semitendinosus* muscle (ST, eye of the silverside), *supraspinatus* muscle (SS, scotch fillet) and *longissimus et lumborum* muscles from the left side of beef carcasses were infused, 3 d post mortem, with a blend consisting of various sodium and potassium salts, di- and triphosphates and lactates, while the corresponding muscles from the right side were untreated and served as the control. The changes in beef quality over a 19-d period and the initial proximate and mineral composition of the muscles were also determined. The general findings suggest that an increase in tenderness concurrent with an acceptable beef colour resulted from the infusion with this blend. The chemical composition of the treated muscles was not negatively affected by the infusion and the mineral content of the treated muscles was increased, accordingly.

Keywords: Alkaline infusion, pH, water-binding capacity, instrumental tenderness, beef colour, proximate composition, mineral composition

Corresponding author: lch@sun.ac.za

Introduction

Attending to the consumer demand for fresh meat products of consistent quality is of great importance in achieving success in the meat industry and increasing beef consumption. A major weakness in the modern beef industry is the variability of beef quality, and in particular tenderness (Morgan *et al*., 1991b; Smith *et al*., 1992). Several studies on meat acceptability have indicated that consumers consider tenderness the most important attribute (Whipple *et al*., 1990) and surely the most desirable when meat is consumed, whether at home or in a restaurant (Huffman *et al*., 1996). Other important qualities that consumers consider when buying meat are freshness, juiciness and the nutrients provided by the product (Boleman *et al*., 1995; Grunert, 1997).

Meat tenderness varies among species, animals within the same species, and among muscles (Polidori *et al*., 2000).

Beef colour is another important beef quality trait that has shown variation during retail display (Got *et al*., 1999). Even though colour is considered a poor guide to eating quality, consumers base their purchase decisions on colour display (Young *et al*., 1999).

Over the years, several techniques and processes have been researched and applied in search of a solution to the problem of meat-quality variation and in particular tenderness. These include electrical stimulation (Dransfield *et al*., 1992; Simmons *et al*., 2008), carcass suspension (Sørheim & Hildrum, 2002) and muscle stretching (Toohey *et al*., 2012a; b), natural ageing (Lawrie, 1998), blade tenderisation (Benito-Delgado *et al*., 1994; Pietrasik & Shand, 2011), marination (Scanga *et al*., 2000), injection (McGee *et al*.,

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2003) and explosion (Solomon *et al*., 1997). Meat-enhancing agents such as phosphates and salts have been investigated and their successes have been documented (Kerth *et al*., 1995; Morris *et al*., 1997; Holmer *et al*., 2009). Enhancing the flavour, tenderness and consumer acceptance of retail beef products and the ability to produce value-added and water-added beef products creates a growing market opportunity in the beef industry (Scanga *et al*., 2000). Several injection/infusion solutions that consist mainly of calcium and sodium salts have been developed. Examples include sodium lactate, known for its flavour-enhancing and shelf-life-extension properties (Duxbury, 1988; Maca *et al*., 1999), and sodium phosphate, used to increase protein solubility and water-binding ability (Hellendoorn, 1962; Trout & Schmidt, 1984). A solution of calcium chloride ($CaCl_2$) infused into meat has been demonstrated to be successful in enhancing and accelerating post-mortem tenderisation (Koohmaraie *et al*., 1988; 1989; 1990; Koohmaraie & Shackelford, 1991; Morgan *et al*., 1991a; Wheeler *et al*., 1991).

Phosphates are typically a component of enhancement solutions in the modern beef industry, because of their ability to increase the functionality of meat products, particularly via water binding (Hamm, 1970; Trout & Schmidt, 1983). Water retention in fresh muscles is based on a buffered (with phosphates) water solution with a pH that is more alkaline and further away from the isoelectric point of the meat. This action increases the water-holding capacity of the meat (Mandigo, 2002).

Phosphates and sodium chloride (NaCl) increase functionality via protein swelling (Paterson *et al*., 1988), ionic strength and pH (Trout & Schmidt, 1984). This increased functionality leads to increased water retention (Trout & Schmidt, 1983) and improved tenderness and juiciness (Prestat *et al*., 2002). Therefore, the inclusion of salt and phosphate improves the yield and palatability characteristics and affects the colour and shelf-life. Contradictory colour results have been reported with the use of a phosphate and NaCl blend. Meat colour is either improved (Lee *et al*., 1998) or diminished (Chen & Trout, 1991) with the infusion of such a blend.

The post-mortem storage (ageing) of beef at chill temperatures has been the practice for many years, and remains an important procedure for producing tender meat in the modern meat industry (Koohmaraie *et al*., 1988). It is known that different muscles from one carcass react differently to post-mortem storage (Koohmaraie *et al*., 1988; Rhee *et al*., 2004). A possible solution is the infusion of a blend containing salts, phosphates and lactates. Our laboratory have shown that this technology is suitable for decreasing the time required for ageing meat, even when applied to old and tough muscles (Hoffman, 2006). However, muscles respond to the same extent when infused (Molina *et al*., 2005). The study by Molina *et al*. found that brine injection reduced the percentage cook loss in seven of the eight beef shoulder muscles evaluated. However, it had no significant effect on Warner-Bratzler shear force (WBSF) values and sensory tenderness ratings of five and four muscles, respectively. It is postulated that the increase in tenderness is the result of physical damage caused by the injecting needles as well as the improved water-binding capacity owing to the infused phosphate and lactate salts. The improved water-binding capacity also causes a diluting effect on the protein responsible for meat texture.

The present study investigates a commercially available basting (Freddy Hirsch Tenderbite # 802539) consisting of sodium and potassium salts, various phosphates and lactates. This brine was used to infuse *biceps femoris* (BF, silverside), *rectus femoris* (RF), *semitendinosus* (ST, eye of the silverside), *supraspinatus* (SS, scotch fillet) and *longissimus et lumborum* (LL, striploin) beef muscles. Previous research (Hoffman, 2006) has indicated that this specific blend increases the tenderness of meat significantly. However, the effect of the blend on beef qualities, with post-mortem ageing, has not yet been determined. Therefore, the first aim of this study is to ascertain the effect of a phosphate and lactate blend on the physical (pH, water-binding capacity, beef colour and shear force) and chemical properties (proximate and mineral composition) of selected beef muscles. A secondary aim is to establish whether the blend has any significant effect on the physical properties over a given time.

Materials and Methods

Beef carcasses representing South African beef breeds (Brahman × Simmentaler cross; n = 3, average mass = 301 kg and Charolais × Hereford cross; n = 3, average mass = 298 kg) finished in a feedlot, were sourced from a commercial abattoir in Paarl, Western Cape, South Africa. At the abattoir, the animals were slaughtered, dressed and processed according to standard South African techniques and conditions. No electrical stimulation was applied to the carcasses. The animals were selected to represent steers from a typical commercial scenario, representative of the South African market. The carcasses were classified as A2

according to the South African classification system (Government Notice No R. 1748, 26 June 1992). An A2 animal is a young animal of the A age group (no permanent incisors) with a fat code of 2, representing a lean fat cover (1 - 3 mm thick subcutaneous fat depth measured between the 10th and 11th ribs, 50 mm from the midline of the cold unquartered carcass). The whole intact carcasses were chilled at *ca.* 2 °C for 24 h in a cooling chamber before being weighed and quartered at the abattoir (Day 1). Twenty-four hours (Day 2) post mortem (pm) the beef quarters were moved into a mobile cooling unit (set at 4 °C) and transported to the Meat Science Laboratory at Stellenbosch University, where the carcasses were stored in the cooling facility at 4 °C. On the same day (Day 2; 24 h pm) the left- and right-side B, RF, ST, SS and LL muscles were removed from the carcasses, trimmed of all visible subcutaneous fat and superficial collagen, weighed, labelled, vacuum packed and stored in a cooler at *ca.* 4 °C until further processing.

On Day 3 (48 h pm) all the muscles were transported to the Freddy Hirsch Processing Plant, where they were removed from their packaging, demembraned, reweighed to determine the pre-infusion weight and the pH was measured. Muscles from the right side of the carcass were left untreated and stored in a cooler at 2 °C to be used as the control. The muscles from the left side were infused with a salt mixture containing sodium and potassium di- and triphosphates, sodium lactate and sodium chloride (Freddy Hirsch Tenderbite; PO Box 2554, Cape Town, 8000) at a pressure of 2.4 bar at 30 strokes per min on a Rühle Curing Centre IR56 (Rühle GmbH, D·79865, Grafenhausen, Germany) to give a calculated pumped gain of 15% with a retention of 12%. The basting mixture gave a calculated chemical composition of 75.8% water, 5.21% Na^+, 2.53% K^+, 3.45% P_2O_5 and 12.4% lactate. The treated muscle samples were weighed immediately after infusion and after a resting (equilibration) period of 2 h to calculate the retained pumped gain. After 2 h the 10 muscles from both sides were divided into six equal portions by cutting across the length of the muscles. Each portion was randomly allocated to each time point.

The six time intervals reflected six successive post-mortem periods of measurements: days 4, 7, 10, 13, 16 and 19. Meat cuts were cut cross-sectionally to the muscle fibre to determine pH, purge loss, drip loss, cooking loss, colour and shear force of fresh beef muscle (4 °C). The same muscle segments of the left and right were compared experimentally. After the division, the muscles (sub-samples) were weighed, labelled, vacuum packed, stored in crates, transported back to the Meat Science Laboratory, and stored in the cooler at 4 ºC until collected for analysis on the pre-assigned day.

On the sampling date the samples allocated to the time interval were removed from the cooler for analyses. On analysing the physical characteristics of the muscle, the sample surfaces were dried with absorbent paper and reweighed to calculate purge loss (exudate collected in the vacuum bag). Meat slices of approximately 1.5 cm thick were cut cross-sectionally to the muscle fibre to determine the instrumental colour (CIE Lab) of the raw (after a blooming period of 30 min) (Wulf & Wise, 1999) and cooked muscles, drip loss, cooking loss and instrumental tenderness of the cooked muscles.

On sampling day 4, the remainder of the samples were homogenised, vacuum packed and stored at -18 °C until proximate chemical and mineral analyses could be conducted.

The physical characteristics determined from the deboned muscles consisted of the pH before and after infusion, the pumped gain and purge loss. The data collected from the sub-samples over the 19-d period were pH, purge loss, drip loss, cooking loss, raw and cooked colour and instrumental tenderness (WBSF). The pH measurements were conducted with a penetrating glass electrode on a hand-held Crison pH/mV-507 meter with an automatic temperature compensator.

The left-side muscles were weighed before and immediately after infusion to calculate the pumped gain, as well as 2 h after infusion (stored at 2 °C) to calculate the retained pumped gain. The purge losses of the undivided infused muscles were calculated from the pumped gain measurements.

Purge loss, drip loss and cooking loss, and colour were determined by the methods described by Honikel (1998). L*, a* and b* colour measurements were taken using a Colour-guide 45°/0° colorimeter (Catalog No 6805; BYK-Gardner, USA). These ordinates were used to calculate hue angle and chroma (Honikel, 1998) using the following equations (CIE, 1978):

Chroma: $C^* = \sqrt{(a^*)^2 + (b^*)^2}$ Hue angle: $h_{ab} = \tan^{-1}\left\{\frac{b^*}{a^*}\right\}$

After measuring the cooking loss, the same samples were stored overnight in a refrigerator (4 ºC) and used for instrumental determination of tenderness the next morning. The shear force values of the cooked meat samples were obtained with a Warner-Bratzler shear (WBS) attachment (Voisey, 1976), fitted to an

Instron Universal Testing Machine (Model 4444). Tenderness was measured as the maximum force (Newton) required to shear a 1.27 cm diameter cylindrical core of cooked meat (perpendicular to the grain) at a crosshead speed of 200 mm/min.

The total percentage of moisture, protein, fat and ash of the raw beef muscle samples was determined according to AOAC methods (AOAC, 2002). The total lipid content was determined by extracting the fat with a 1 : 2 mixture of chloroform and methanol (Lee *et al*., 1996). The moisture content was analysed by drying a 2.5 g sample at 100 ºC for a period of 24 h (method 934.01, AOAC, 2002) and ashing by cremating the samples at 500 °C for 6 h. The protein content was determined by the Dumas combustion method (Method 968.06, AOAC, 2002) on the defatted samples using a FP528 nitrogen analyser.

The mineral composition of the meat was determined after ashing defatted meat samples. These samples (1 - 3 g) were air-dried and ground to pass through a 0.5 mm to 1.0 mm sieve. After this the samples were ashed overnight in a muffle furnace at 550 °C. A 6 N hydrochloric acid (HCI) solution was prepared by diluting 500 mL of a 36% (m/m) HCI solution to 1 litre. After ashing, 5 mL of a 6 M HCI was added to dissolve the cooled sample. After cooling, a 5 mL 6 N nitric acid (HNO_3) solution was added to the samples. The 6 N HNO_3 solution was prepared by diluting 429 mL of a 65% (m/m) solution to 1 L. After adding this solution, the samples were heated in a water bath and removed after boiling point was reached. The solution was subsequently filtered through filter paper into a 100 mL volumetric flask and diluted to volume with deionised water (Giron, 1973).

The concentrations of calcium (Ca), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), sodium (Na), phosphorus (P), lead (Pb) and zinc (Zn) of the digestates were determined by using the inductively coupled plasma spectrometry (ICP) detection method (Method No AgriLASA 6.1.1) (Handbook of Feed & Plant Analysis, Volume 2).

The experimental design for the deboned whole muscles was a randomised complete block design with 10 treatment combinations replicated in six blocks (animals/carcasses). The treatment design was a 2 × 5 factorial with the factors, two treatments (control and infused) and five muscles (BF, RF, ST, SS and LL). The pH and pumped data were measured before infusion and after 2 h equilibration (resting period) and differences were calculated. All these data were subjected to an analysis of variance using SAS Statistical Software Version 9.1 (SAS, 2003). The Shapiro-Wilk test was performed to test for non-normality (Shapiro & Wilk, 1965). Student's t-least significant difference (t-LSD) was calculated at the 5% confidence level to compare treatment means of significant source effects (Ott, 1998).

A further statistical analysis was conducted on the muscles to test the effect of the infusion solution with a storage period of 19 d on the physical parameters (pH, purge loss, drip loss, cooking loss, shear force, and raw and cooked colour). The treatment design was a 2 × 6 factorial experiment replicated in six blocks (animals/carcasses). The factors were two treatments (control & infused), and six time periods (days 4, 7, 10, 13, 16, 19) determined for the five individual muscles (BF, RF, ST, SS and LL). Analyses of variance were performed for all of these variables using SAS Statistical Software Version 9.1 (SAS, 2003). The Shapiro-Wilk test was performed to test for non-normality (Shapiro & Wilk, 1965). Student's t-LSD was calculated at the 5% confidence level to compare treatment means of significant source effects (Ott, 1998).

Another statistical analysis was conducted on the muscles to test for the effect of the infusion on the chemical parameters (proximate and mineral composition). The design was a 2 × 5 factorial experiment replicated in six blocks (animals/carcasses) with factors two treatments (control & infused) and five muscles (BF, RF, ST, SS and LL). Factorial analysis of variance were performed on the chemical constituents measured, using SAS Statistical Software Version 9.1 (SAS, 2003). The Shapiro-Wilk test was performed to test for non-normality (Shapiro & Wilk, 1965). Student's t-LSD was calculated at the 5% confidence level to compare treatment means of significant source effects (Ott, 1998).

Results and Discussion

For all the parameters tested, there were no interaction among the main effects and thus they are discussed in more detail. The results from the deboned muscles infused with the phosphate and lactate blend on Day 3 (pre- and post-infusion pH, pumped gain) are depicted in Table 1. In Table 2 the mean values for the physical meat quality parameters of pH, water-binding properties and shear force resistance of the BF, RF, ST, SS, and LL sub-samples are displayed. In Table 3 the data for the quality measurements of the muscles over the 19 d were pooled and the muscles means are compared within and between treatments.

Several studies have shown that in order to improve the WHC of processed meat, the pH should be increased to a desired point (Young *et al*., 2005). This is achieved by adding an alkalinising agent to the meat product, such as alkaline polyphosphates (Shults *et al*., 1972; Puolanne *et al*., 2001). This agent aids the salt-induced solubilisation of myosin and augments water binding by increasing the pH (Young *et al*., 2005).

From Table 1 it is clear that the samples of both pre-infusion treatments were reasonably similar in initial pH values on the third day post mortem. Before infusion of the blend (Day 3; 72 h pm), the pH of the control samples ranged from 5.45 ± 0.043 (LL) to 5.52 ± 0.055 (RF), and the pH of the samples earmarked for infusion ranged from 5.38 ± 0.035 (LL) to 5.53 ± 0.064 (SS). After infusion the pH of the infused muscles increased substantially to a pH range of 5.55 ± 0.189 for LL to 5.77 ± 0.232 for SS (Table 1). This increase in pH was expected and is supported by many studies, in which the effect of an alkaline solution containing polyphosphates on muscle pH is researched (Baublits *et al*., 2005). The pH difference of the control and infused muscles (Table 1) illustrated differences before infusion ($P \leq 0.05$) for the LL muscle, whereas after infusion there were no differences in pH between pre- and post-infusion muscles ($P > 0.05$), illustrating that infusion decreased pH differences between muscles.

Bendall (1967) reported that phosphates increased the volume of uncooked muscles. This statement is supported by the present investigation, with an increase in muscle volume after infusion. The percentage fluid retained (pumped gain) directly after the muscles were infused ranged from 18.05 ± 2.299 (BF) to 22.93 ± 3.312 (SS) at 0 h and then decreased to 13.73 ± 2.916 (LL) to 17.59 ± 3.928 (RF) after a 2 h stabilisation period (Table 1). Previous studies reported similar pumped gain values (Hoffman, 2006).

The results pertaining to the specific change of the pH in each muscle over time are given in Table 2. The pH of the infused samples differed ($P \leq 0.05$) from that of the control over the 19 d, indicating that the phosphate blend increased the muscle pH of the infused samples substantially. The pH of the samples also changed ($P \leq 0.05$) over the 19-d period. The general trend in both the control and infused muscles was that of an initial increase from Day 4 to 13, and then the pH started to decrease ($P \leq 0.05$) from Day 13 to 16. Several authors reported that the alkalinity of the muscles, and thus the pH, is increased when muscles were treated with a blend containing phosphates (Boles & Shand, 2001; Baublits *et al*., 2005) and with the infusion of sodium lactate (Maca *et al*., 1999). All the muscles showed a decrease in pH towards the end of the shelf-life study – the reason for this phenomenon is not clear although it is speculated that it could be linked to bacterial growth – unfortunately this aspect was not evaluated.

The significant effect of the phosphate blend on the muscle pH illustrated in Table 2 should result in a significant effect on the water-binding abilities of the muscle (Honikel, 1987; Scanga *et al*., 2000; Baublits *et al*., 2005) and more specifically purge loss, drip loss and cooking loss (Briskey *et al*., 1960; Crouse *et al*., 1984). Several studies reported that steaks marinated in a solution of higher pH and strong buffering capacity have increased water-binding ability compared with steaks left untreated or marinated in solutions with a pH close to, or below, the isoelectric point of meat (Trout & Schmidt, 1986; Boles & Shand, 2001; McGee *et al*., 2003; Baublits *et al*., 2005).

In the present investigation the fluid-loss measurements consisted of the determination of purge loss (collected in vacuum bags over time), drip and cooking loss observed within the infused and control muscles. The control gives an indication of the normal fluid loss and of the water-holding capacity (WHC) of the meat under these circumstances, where fresh meat is stored in vacuum bags at a chill temperature. The WHC of muscles treated with a phosphate and lactate blend is known as the water-binding capacity (WBC) of the infused meat, which is the ability of the meat to bind added water (Boleman *et al*., 1995).

In the present investigation (Table 2) there was no difference ($P > 0.05$) in purge loss between the infused and control muscles. Lawrence *et al*. (2003) found similar results, that is, a slightly higher, but not significant purge loss in muscles treated with a salt solution. The addition of salt to a solution increases the ionic strength of the solution, thereby increasing the number of hydrophilic protein interactions, which causes an increase in the binding of free water (Lawrence *et al*., 2003). In the present investigation the amount of drip loss was higher for the infused samples than for the control samples, with differences for BF, ST and SS ($P \leq 0.05$) (Table 3). Several other studies reported this effect, with a consistent increase in WHC associated with an increase in salt content (Hamm, 1960; Sherman, 1962; Wheeler *et al*., 1993; Lennon *et al*., 2006).

Several authors reported a significant reduction in cooking loss when treating muscle with a salt solution similar to that of the present study (Bouton *et al*., 1982; Sheard *et al*., 1999; Walsh *et al*., 2010). Most of the infused muscles in the current investigation (Table 2) did not have higher cooking loss values

than the untreated muscles (P >0.05). The relatively similar cooking loss values of the control and infused muscles indicate that infusion did not have a negative effect on cooking loss in this investigation. However, there were differences within some of the muscles over storage time. For example, the BF and RF control and infused muscles differed ($P \leq 0.05$) from Day 4 to 13, after which both treatments stabilised and showed similar cooking losses (P >0.05). Generally, the cooking loss of the LL, ST and SS control and infused samples (Table 2) followed a similar pattern (P >0.05). Other authors also reported results of infused muscles indicating numerically higher cooking loss, but similar to the untreated muscles (P >0.05) (Baublits *et al*., 2006).

Table 3 illustrates the overall effect between treatments and between muscles for pH and water-binding capacity. The pH, purge, drip and cooking loss increased ($P \leq 0.05$) with infusion in most of the muscles. The WBSF values of the various muscles measured over time are given in Table 2. A treatment effect ($P \leq 0.05$) was achieved in the present study when a phosphate and salt solution was used to infuse the beef muscles, with reduced WBSF values obtained for all the infused samples on the designated days. This result illustrates that infusion has a substantial and positive effect on meat tenderness. Vote *et al*. (2000) report significant treatment differences between control and infused samples. Stites *et al*. (1989) found that when beef roasts were injected with a solution containing sodium tripolyphosphate and sodium chloride the WBSF values were significantly lowered when compared with those of the control samples. Authors such as McGee *et al*. (2003) have shown that the injection of a sodium lactate-phosphate-chloride brine in beef inside round roasts resulted in decreased instrumental tenderness.

The time effect showed that all the muscles illustrated differences in tenderness ($P \leq 0.05$) over time (Table 2). Both the control and infused muscles showed a pattern of decreased shear force with time from Day 7 to 19. Therefore, over time a fair amount of conditioning (ageing and tenderisation) took place in both treatments. The initial shear force of some of the untreated and infused muscles was low on Day 4 and then increased to Day 7. No clear explanation could be found to support this result. Reports on the effect of ageing on tenderness are contradictory. Some studies reported no influence of ageing on WBSF, whereas others found a significant decrease in WBSF values throughout the ageing period, thus a significant improvement in tenderness over time (French *et al*., 2001; Maria *et al*., 2003).

Table 3 illustrates the overall effect between treatments and between muscles for WBSF values. The shear force decreased substantially ($P \leq 0.05$) with infusion in all the muscles. This trend illustrates the positive effect of infusion on meat tenderness. Support muscles are reported to be more tender than locomotive muscles (Belew *et al*., 2003). However, with infusion this factor is not relevant, suggesting that the blend tenderised all the muscles to an acceptable level (Hoffman *et al*., 2008). In this investigation the infused muscles BF (38.90 N), RF (36.06 N) and LL (41.08 N) had significantly lower WBSF values than ST (47.63 N) and SS (47.26 N). The relatively high pH of the latter two samples could be ascribed to the initial high pH of the untreated samples.

Table 1 Means (± s.d.)[#] for infusion data on Day 3 of beef muscles infused with a phosphate and lactate blend

Muscle	Pre-infusion pH		pH difference (control[d] vs. infused[e])	Post-infusion pH[f]	pH difference (pre[e] vs. post[f] infusion)	Pumped gain (%) 0 h[g]	Pumped gain (%) 2h[h]	Pumped gain difference (%)[g-h]
	Control[d]	Infused[e]		Infused		Infused	Infused	Infused
BF	$5.45^{b} \pm 0.022$	$5.42^{bc} \pm 0.038$	$-0.03^{ab} \pm 0.027$	$5.72^{a} \pm 0.266$	$0.31^{a} \pm 0.286$	$18.05^{b} \pm 2.299$	$14.81^{b} \pm 2.152$	$3.24^{b} \pm 1.824$
RF	$5.52^{a} \pm 0.055$	$5.47^{b} \pm 0.045$	$-0.06^{b} \pm 0.031$	$5.68^{a} \pm 0.144$	$0.21^{a} \pm 0.164$	$22.14^{a} \pm 3.601$	$17.59^{a} \pm 3.928$	$4.55^{b} \pm 1.005$
ST	$5.45^{b} \pm 0.034$	$5.40^{c} \pm 0.025$	$-0.05^{ab} \pm 0.050$	$5.68^{a} \pm 0.272$	$0.28^{a} \pm 0.264$	$19.43^{ab} \pm 4.881$	$15.72^{ab} \pm 4.797$	$3.71^{b} \pm 1.894$
SS	$5.51^{a} \pm 0.055$	$5.53^{a} \pm 0.064$	$0.02^{a} \pm 0.091$	$5.77^{a} \pm 0.232$	$0.24^{a} \pm 0.249$	$22.93^{a} \pm 3.312$	$16.12^{ab} \pm 2.407$	$6.81^{a} \pm 1.245$
LL	$5.45^{b} \pm 0.043$	$5.38^{c} \pm 0.035$	$-0.07^{b} \pm 0.031$	$5.55^{a} \pm 0.189$	$0.17^{a} \pm 0.208$	$20.53^{ab} \pm 4.126$	$13.73^{b} \pm 2.916$	$6.80^{a} \pm 1.578$
LSD ($P = 0.05$)	0.047	0.054	0.066	0.265	0.279	3.577	2.695	1.891

[#] s.d.: Standard deviation.

BF: *biceps femoris*; RF: *rectus femoris*; ST: *semitendinosus*; SS: *supraspinatus*; LL: *longissimus lumborum.*

[a, b, c] Column means within a treatment and between muscles with common superscripts do not differ ($P \leq 0.05$).

[d,e] Pre-infusion pH: pH measured of both the control[d] and the infused[e] muscles before infusion.

pH difference[e-d] (control[d] vs. injected[e]): the difference between the control and infused muscles before infusion.

[f] Post-infusion pH: pH measured of the infused muscles directly after infusion.

pH difference[f-e] (pre[e] vs. post[f] infusion): the difference in pH between the infused muscles before and after infusion.

[g] Pumped gain (%) 0 h[g]: the amount of blend retained within the muscles directly after infusion.

[h] Pumped gain (%) 2 h[h]: the amount of blend retained within the muscles 2 h (resting period) after infusion.

Pumped gain difference[g-h]: the difference in pumped gain between the infused muscles before and after infusion.

LSD: Least significant difference ($P = 0.05$).

The parameters used in this investigation to evaluate the colour of the raw meat, as well as the cooked samples are the L*, a*, b* and chroma values, as well as hue angle. The L* value gives an indication of lightness (Papadopoulos *et al*., 1991). Overall there was no interaction between treatment and storage time ($P > 0.05$). Although the L* values fluctuated during storage ($P < 0.05$), there was no noticeable pattern (Table 4). Pooled over time and processing days (Table 5), L* values for the raw infused muscles ranged from 38.5 ± 2.36 (SS) to 43.0 ± 3.33 (RF). These results are supported by other studies, where a similar blend was used for infusion (Papadopoulos *et al*., 1991). From Table 4 it is clear that the L* values of the infused and untreated samples differed ($P \leq 0.05$) in only a limited number of cases. However, according to Table 5 (illustrating the overall effect), four of the infused samples had lower ($P \leq 0.05$) L* values than the control samples, indicating a darker meat colour for the BF, RF, SS and LL infused samples. Lawrence *et al*. (2004) reported contradictory results to those of the present investigation. Lawrence *et al*. (2004) found that beef samples treated with either a lactate or chloride solution showed similar L* values to those of the control. Conversely, Baublits *et al*. (2005) reported that the treated samples had higher L* values, thus were lighter in colour than the control samples. However, this result was obtained with the inclusion only of phosphates (Baublits *et al*., 2005). With the addition of sodium chloride (NaCl) to the blend, as in the present investigation, the overall colour becomes darker (Baublits *et al*., 2005a; b; 2006; Hoffman, 2006).

The a* value measures the red-green range of meat with greater a* values indicating a redder meat sample, whereas similar a* and b* values indicate a purple meat colour. In this investigation (Table 4) there was no interaction ($P < 0.05$) between the infusion and storage time. However, there was a tendency for both the infused and control samples to increase in redness (higher a* values) with time, indicating a deterioration as the muscles became darker. With the addition of a salt solution, the redness of muscle samples has been observed to decrease and therefore a darker sample colour is obtained (Baublits *et al*., 2006). And the well-documented deterioration of fresh meat with storage, even under vacuum packaging, is the logical explanation of the decreasing meat colour. Pooled over time (Table 5), redness (a*) was ($P \leq 0.05$) lower in all the treated samples with means for the raw muscles ranging from 13.67 ± 1.958 (RF) to 15.79 ± 1.772 (BF). Again, the results are supported by other studies in which a similar blend was used for infusion and the effect on colour parameters determined (Papadopoulos *et al*., 1991). Baublits *et al*. (2005b) also reported control muscles to have a redder colour (higher a* values) than the treated muscles. According to Baublits *et al*. (2005a), limited differences were observed between the control and muscles treated with phosphates and NaCl. However, there was a tendency for the phosphate and salt enhanced samples to have lower a* values, suggesting the deleterious effects of salt on meat colour (Baublits *et al*., 2006). In the present investigation much lower a* values were observed than reported by Baublits *et al*. (2005a).

The b* value measures the blue-yellow range of meat with a b* value of 0 (zero) indicating a grey appearance. With meat, greater b* values indicate a visual description of brown (Carpenter *et al*., 2001). In this investigation (Table 4) there was no consistent treatment effect. However, there was a tendency for the b* values to be lower in the treated samples. Furthermore, there was no interaction ($P < 0.05$) between the phosphate and lactate blend and storage time, and therefore the b* value did not change consistently during storage. The report by Papadopoulos *et al*. (1991), where a similar blend was used for infusion, showed comparable colour results. Pooled over time (Table 5) the means of the raw muscles treated with the blend ranged from 12.71 ± 1.612 (SS) to 14.90 ± 1.995 (ST). All the infused muscles had lower b* values ($P \leq 0.05$), indicating a lower degree of brownness. Baublits *et al*. (2005b) also reported control muscles to have a yellower colour (higher b* values) than the treated muscles.

The saturation index is defined by higher chroma values, indicating greater saturation or vividness of colour (Baublits *et al*., 2005b). As illustrated in Table 4, as well as the pooled data in Table 5, the treatment had an effect ($P \leq 0.05$) on all the muscles, with the infused muscles having lower chroma values, that is, degree of saturation. Lawrence *et al*. (2003) reported control muscles to have more intense red colour (higher chroma values) than the treated muscles. Baublits *et al*. (2005a) reported similar degrees of vividness for treated and untreated samples. This result suggests that phosphates can maintain or increase vividness. However, in combination with NaCl the vividness is hindered. In the present investigation, NaCl formed part of the blend and resulted in a poorer and less saturated raw colour. This again illustrates the negative effect of NaCl on beef colour (Baublits *et al*., 2005a). The colour change over time (Table 4) was inconsistent and no change ($P > 0.05$) in any of the muscles was observed within treatments and over time.

Table 2 Interaction means (± s.d.)[#] for physical attributes of beef muscles infused with a phosphate and lactate blend and aged for 19 days

Day	pH		Purge loss (%)		Drip loss (%)		Cooking loss (%)		WBSF (N)	
	Control	Infused	Control	Infused	Control	Infused	Control	Infused	Control	Infused
Biceps femoris (BF)										
4	$5.45_{ab}{}^{b} \pm 0.039$	$5.67_{bc}{}^{a} \pm 0.046$	$1.53_{b}{}^{a} \pm 0.487$	$2.93_{b}{}^{a} \pm 0.398$	$0.99_{ab}{}^{b} \pm 0.314$	$1.69_{a}{}^{a} \pm 0.334$	$34.22_{b}{}^{a} \pm 0.796$	$35.42_{c}{}^{a} \pm 1.854$	$46.26_{c}{}^{a} \pm 5.536$	$33.78_{b}{}^{b} \pm 5.110$
7	$5.45_{ab}{}^{b} \pm 0.044$	$5.65_{bc}{}^{a} \pm 0.011$	$2.80_{ab}{}^{a} \pm 0.886$	$4.36_{ab}{}^{a} \pm 1.463$	$1.10_{a}{}^{a} \pm 0.390$	$1.27_{b}{}^{a} \pm 0.407$	$41.55_{a}{}^{b} \pm 1.017$	$44.46_{a}{}^{a} \pm 1.818$	$60.86_{ab}{}^{a} \pm 6.246$	$47.19_{a}{}^{b} \pm 7.804$
10	$5.46_{ab}{}^{b} \pm 0.035$	$5.77_{a}{}^{a} \pm 0.100$	$3.53_{a}{}^{a} \pm 1.425$	$4.72_{a}{}^{a} \pm 1.825$	$0.98_{ab}{}^{a} \pm 0.120$	$1.12_{bc}{}^{a} \pm 0.303$	$41.12_{a}{}^{b} \pm 2.263$	$42.93_{ab}{}^{a} \pm 2.013$	$56.05_{abc}{}^{a} \pm 5.497$	$40.37_{ab}{}^{b} \pm 9.840$
13	$5.52_{a}{}^{b} \pm 0.029$	$5.72_{ab}{}^{a} \pm 0.064$	$2.92_{ab}{}^{b} \pm 1.844$	$4.56_{a}{}^{a} \pm 0.870$	$1.26_{a}{}^{b} \pm 0.191$	$1.61_{a}{}^{a} \pm 0.502$	$41.13_{a}{}^{b} \pm 0.940$	$44.35_{a}{}^{a} \pm 1.704$	$61.73_{a}{}^{a} \pm 13.64$	$45.95_{a}{}^{b} \pm 8.260$
16	$5.43_{b}{}^{b} \pm 0.046$	$5.63_{c}{}^{a} \pm 0.095$	$4.25_{a}{}^{a} \pm 1.591$	$5.37_{a}{}^{a} \pm 1.097$	$0.70_{b}{}^{a} \pm 0.121$	$0.81_{c}{}^{a} \pm 0.122$	$40.65_{a}{}^{a} \pm 0.796$	$42.00_{b}{}^{a} \pm 2.706$	$51.44_{bc}{}^{a} \pm 11.23$	$33.69_{b}{}^{b} \pm 7.859$
19	$5.34_{c}{}^{b} \pm 0.038$	$5.66_{bc}{}^{a} \pm 0.079$	$3.99_{a}{}^{a} \pm 1.184$	$4.03_{ab}{}^{a} \pm 1.054$	$1.13_{a}{}^{a} \pm 0.160$	$1.10_{bc}{}^{a} \pm 0.213$	$40.86_{a}{}^{a} \pm 1.483$	$41.45_{b}{}^{a} \pm 2.142$	$47.04_{c}{}^{a} \pm 12.05$	$32.42_{b}{}^{b} \pm 4.560$
Rectus femoris (RF)										
4	$5.42_{bc}{}^{b} \pm 0.034$	$5.65_{b}{}^{a} \pm 0.081$	$4.54_{a}{}^{a} \pm 2.089$	$5.87_{a}{}^{a} \pm 1.496$	$1.39_{ab}{}^{b} \pm 0.290$	$2.06_{a}{}^{a} \pm 0.339$	$37.32_{c}{}^{b} \pm 2.275$	$40.13_{b}{}^{a} \pm 2.162$	$58.68_{ab}{}^{a} \pm 11.82$	$41.53_{ab}{}^{b} \pm 5.809$
7	$5.46_{b}{}^{b} \pm 0.063$	$5.79_{a}{}^{a} \pm 0.116$	$3.92_{a}{}^{a} \pm 2.007$	$5.47_{a}{}^{a} \pm 1.650$	$1.24_{b}{}^{b} \pm 0.216$	$1.57_{b}{}^{a} \pm 0.275$	$40.36_{b}{}^{b} \pm 1.739$	$42.75_{a}{}^{a} \pm 2.617$	$61.00_{a}{}^{a} \pm 13.36$	$42.61_{a}{}^{b} \pm 8.977$
10	$5.50_{ab}{}^{b} \pm 0.058$	$5.78_{a}{}^{a} \pm 0.087$	$4.44_{a}{}^{a} \pm 1.195$	$5.43_{a}{}^{a} \pm 1.453$	$1.23_{b}{}^{a} \pm 0.117$	$1.21_{c}{}^{a} \pm 0.152$	$40.33_{b}{}^{b} \pm 1.003$	$42.06_{a}{}^{a} \pm 1.502$	$52.96_{abc}{}^{a} \pm 4.048$	$36.72_{abc}{}^{b} \pm 7.977$
13	$5.58_{a}{}^{b} \pm 0.082$	$5.79_{a}{}^{a} \pm 0.116$	$3.72_{a}{}^{b} \pm 1.308$	$6.64_{a}{}^{a} \pm 1.705$	$1.60_{a}{}^{a} \pm 0.190$	$1.41_{bc}{}^{a} \pm 0.220$	$40.03_{b}{}^{b} \pm 1.557$	$41.79_{a}{}^{a} \pm 1.697$	$50.08_{bc}{}^{a} \pm 8.457$	$32.72_{abc}{}^{b} \pm 2.489$
16	$5.47_{b}{}^{b} \pm 0.045$	$5.77_{a}{}^{a} \pm 0.099$	$4.55_{a}{}^{a} \pm 1.126$	$5.80_{a}{}^{a} \pm 1.466$	$1.16_{b}{}^{a} \pm 0.137$	$1.11_{c}{}^{a} \pm 0.315$	$42.44_{a}{}^{a} \pm 1.658$	$43.39_{a}{}^{a} \pm 2.615$	$51.52_{abc}{}^{a} \pm 8.748$	$27.44_{c}{}^{b} \pm 7.322$
19	$5.36_{c}{}^{b} \pm 0.058$	$5.63_{b}{}^{a} \pm 0.090$	$4.26_{a}{}^{b} \pm 0.871$	$6.50_{a}{}^{a} \pm 1.156$	$1.18_{b}{}^{a} \pm 0.290$	$1.27_{bc}{}^{a} \pm 0.187$	$40.84_{ab}{}^{a} \pm 2.471$	$42.05_{a}{}^{a} \pm 2.261$	$48.44_{c}{}^{a} \pm 9.766$	$35.32_{abc}{}^{b} \pm 8.998$
Semitendinosus (ST)										
4	$5.45_{b}{}^{b} \pm 0.030$	$5.73_{a}{}^{a} \pm 0.112$	$2.67_{b}{}^{b} \pm 1.100$	$6.61_{a}{}^{a} \pm 1.040$	$0.98_{ab}{}^{b} \pm 0.507$	$2.75_{a}{}^{a} \pm 0.392$	$39.02_{c}{}^{b} \pm 1.330$	$41.74_{bc}{}^{a} \pm 2.277$	$86.23_{ab}{}^{a} \pm 11.88$	$51.48_{a}{}^{b} \pm 9.642$
7	$5.43_{b}{}^{b} \pm 0.028$	$5.65_{ab}{}^{a} \pm 0.135$	$4.47_{a}{}^{b} \pm 1.27$	$7.77_{a}{}^{a} \pm 1.224$	$0.85_{b}{}^{b} \pm 0.327$	$1.42_{b}{}^{a} \pm 0.358$	$42.11_{a}{}^{a} \pm 0.914$	$43.64_{a}{}^{a} \pm 1.845$	$92.64_{a}{}^{a} \pm 14.43$	$48.56_{ab}{}^{b} \pm 8.630$
10	$5.48_{ab}{}^{b} \pm 0.053$	$5.65_{ab}{}^{a} \pm 0.084$	$3.72_{ab}{}^{b} \pm 1.486$	$8.08_{a}{}^{a} \pm 1.633$	$0.79_{b}{}^{a} \pm 0.297$	$0.84_{c}{}^{a} \pm 0.168$	$40.17_{bc}{}^{a} \pm 1.384$	$40.42_{c}{}^{a} \pm 2.894$	$79.10_{bc}{}^{a} \pm 19.42$	$48.99_{a}{}^{b} \pm 15.88$
13	$5.55_{a}{}^{b} \pm 0.041$	$5.72_{a}{}^{a} \pm 0.102$	$3.65_{ab}{}^{b} \pm 1.805$	$6.88_{a}{}^{a} \pm 1.312$	$1.27_{a}{}^{a} \pm 0.233$	$1.58_{b}{}^{a} \pm 0.481$	$41.70_{ab}{}^{a} \pm 0.845$	$42.66_{ab}{}^{a} \pm 1.542$	$82.35_{b}{}^{a} \pm 11.85$	$47.68_{ab}{}^{b} \pm 13.18$
16	$5.41_{bc}{}^{b} \pm 0.050$	$5.63_{b}{}^{a} \pm 0.126$	$5.16_{a}{}^{b} \pm 1.866$	$6.93_{a}{}^{a} \pm 1.648$	$0.73_{b}{}^{a} \pm 0.116$	$0.96_{c}{}^{a} \pm 0.298$	$40.69_{ab}{}^{a} \pm 1.100$	$41.45_{bc}{}^{a} \pm 2.340$	$80.09_{bc}{}^{a} \pm 19.82$	$50.46_{a}{}^{b} \pm 14.99$
19	$5.33_{c}{}^{b} \pm 0.053$	$5.58_{b}{}^{a} \pm 0.092$	$5.21_{a}{}^{b} \pm 2.634$	$7.97_{a}{}^{a} \pm 2.118$	$0.90_{b}{}^{a} \pm 0.076$	$1.04_{c}{}^{a} \pm 0.118$	$41.11_{ab}{}^{a} \pm 0.966$	$42.60_{ab}{}^{a} \pm 1.633$	$70.93_{c}{}^{a} \pm 7.007$	$38.77_{b}{}^{b} \pm 4.275$

Table 2 (continued) Interaction means (± s.d.)[#] for physical attributes of beef muscles infused with a phosphate and lactate blend and aged for 19 days

Day	pH		Purge loss (%)		Drip loss (%)		Cooking loss (%)		WBSF (N)	
	Control	Infused	Control	Infused	Control	Infused	Control	Infused	Control	Infused
Supraspinatus (SS)										
4	$5.51_{bc}^{b} \pm 0.026$	$5.81_{bc}^{a} \pm 0.097$	$2.16_{b}^{b} \pm 0.572$	$5.09_{b}^{a} \pm 1.282$	$0.72_{b}^{b} \pm 0.116$	$1.26_{ab}^{a} \pm 0.402$	$40.45_{c}^{b} \pm 1.087$	$42.11_{c}^{a} \pm 1.785$	$69.71_{ab}^{a} \pm 8.950$	$54.21_{a}^{b} \pm 7.283$
7	$5.60_{a}^{b} \pm 0.051$	$5.88_{ab}^{a} \pm 0.065$	$3.17_{ab}^{b} \pm 0.663$	$5.28_{ab}^{a} \pm 1.134$	$0.79_{b}^{b} \pm 0.172$	$1.15_{ab}^{a} \pm 0.393$	$45.64_{a}^{a} \pm 1.739$	$46.39_{a}^{a} \pm 2.201$	$77.37_{a}^{a} \pm 10.87$	$47.23_{ab}^{b} \pm 3.842$
10	$5.64_{a}^{b} \pm 0.033$	$5.95_{a}^{a} \pm 0.119$	$3.45_{ab}^{b} \pm 0.800$	$6.11_{ab}^{a} \pm 1.572$	$0.85_{b}^{a} \pm 0.100$	$0.95_{b}^{a} \pm 0.292$	$45.04_{ab}^{a} \pm 0.559$	$45.11_{ab}^{a} \pm 1.423$	$70.80_{ab}^{a} \pm 9.375$	$48.11_{ab}^{b} \pm 3.219$
13	$5.59_{ab}^{b} \pm 0.079$	$5.84_{bc}^{a} \pm 0.118$	$3.15_{ab}^{b} \pm 1.151$	$6.20_{ab}^{a} \pm 1.500$	$1.52_{a}^{a} \pm 0.222$	$1.47_{a}^{a} \pm 0.534$	$43.72_{b}^{a} \pm 1.182$	$44.46_{b}^{a} \pm 1.194$	$63.57_{b}^{a} \pm 8.859$	$47.03_{ab}^{b} \pm 5.649$
16	$5.60_{a}^{b} \pm 0.047$	$5.86_{bc}^{a} \pm 0.080$	$3.64_{ab}^{b} \pm 1.660$	$6.25_{ab}^{a} \pm 1.395$	$0.86_{b}^{a} \pm 0.195$	$1.03_{b}^{a} \pm 0.214$	$44.55_{ab}^{a} \pm 1.459$	$43.83_{b}^{a} \pm 1.633$	$65.22_{b}^{a} \pm 3.509$	$45.95_{ab}^{b} \pm 8.342$
19	$5.48_{c}^{b} \pm 0.067$	$5.78_{c}^{a} \pm 0.076$	$4.15_{a}^{b} \pm 1.753$	$6.83_{a}^{a} \pm 1.955$	$0.96_{b}^{a} \pm 0.137$	$1.15_{ab}^{a} \pm 0.143$	$43.83_{b}^{a} \pm 2.138$	$44.14_{b}^{a} \pm 1.585$	$66.11_{b}^{a} \pm 6.237$	$41.04_{b}^{b} \pm 4.975$
Longissimus lumborum (LL)										
4	$5.40_{bc}^{b} \pm 0.026$	$5.55_{c}^{a} \pm 0.077$	$2.90_{b}^{b} \pm 0.781$	$4.96_{b}^{a} \pm 1.013$	$1.19_{b}^{a} \pm 0.171$	$1.22_{b}^{a} \pm 0.385$	$40.11_{abc}^{a} \pm 1.138$	$40.02_{bc}^{a} \pm 2.043$	$79.04_{a}^{a} \pm 16.67$	$54.73_{a}^{b} \pm 9.705$
7	$5.47_{ab}^{b} \pm 0.018$	$5.63_{bc}^{a} \pm 0.077$	$6.04_{a}^{a} \pm 1.128$	$6.39_{ab}^{a} \pm 1.434$	$1.91_{a}^{a} \pm 0.450$	$1.94_{a}^{a} \pm 0.349$	$40.90_{ab}^{a} \pm 1.436$	$41.71_{a}^{a} \pm 2.567$	$75.78_{a}^{a} \pm 20.17$	$49.21_{ab}^{b} \pm 19.90$
10	$5.45_{ab}^{b} \pm 0.057$	$5.70_{ab}^{a} \pm 0.071$	$5.76_{a}^{a} \pm 1.296$	$7.01_{a}^{a} \pm 0.893$	$1.01_{b}^{a} \pm 0.438$	$1.14_{b}^{a} \pm 0.454$	$39.83_{bc}^{a} \pm 1.249$	$39.74_{bc}^{a} \pm 1.769$	$63.96_{b}^{a} \pm 10.56$	$39.29_{bc}^{b} \pm 17.44$
13	$5.52_{a}^{b} \pm 0.046$	$5.73_{a}^{a} \pm 0.091$	$5.28_{a}^{a} \pm 1.256$	$6.15_{ab}^{a} \pm 0.819$	$1.28_{b}^{a} \pm 0.224$	$1.40_{b}^{a} \pm 0.249$	$38.54_{c}^{a} \pm 1.528$	$39.38_{c}^{a} \pm 2.604$	$54.93_{b}^{a} \pm 11.22$	$39.12_{c}^{b} \pm 17.98$
16	$5.42_{b}^{b} \pm 0.018$	$5.57_{c}^{a} \pm 0.088$	$5.62_{a}^{a} \pm 1.748$	$7.12_{a}^{a} \pm 1.845$	$1.06_{b}^{a} \pm 0.218$	$1.34_{b}^{a} \pm 0.373$	$41.14_{ab}^{a} \pm 1.261$	$41.14_{ab}^{a} \pm 1.862$	$58.69_{b}^{a} \pm 11.44$	$33.65_{c}^{b} \pm 12.44$
19	$5.33_{c}^{b} \pm 0.058$	$5.57_{c}^{a} \pm 0.073$	$5.37_{a}^{a} \pm 1.097$	$6.20_{ab}^{a} \pm 1.726$	$0.97_{b}^{a} \pm 0.164$	$1.16_{b}^{a} \pm 0.242$	$41.68_{a}^{a} \pm 1.155$	$41.36_{ab}^{a} \pm 0.958$	$58.56_{b}^{a} \pm 15.25$	$30.47_{c}^{b} \pm 8.662$
LSD $P = 0.05$	1.968		1.568		0.324		1.654		10.01	

[#] s.d.: standard deviation.

[a, b, c] Column means between days within a treatment and within a muscle with common subscripts do not differ ($P \leq 0.05$).

[a, b] Row means between treatments within an attribute with common superscripts do not differ ($P \leq 0.05$).

LSD: least significant difference ($P = 0.05$).

Table 3 Summary of means (± s.d.)[#] for physical attributes of different beef muscles (pooled) infused with a phosphate and lactate blend and aged for 19 days

Muscle	pH		Purge loss (%)		Drip loss (%)		Cooking loss (%)		WBSF (N)	
	Control	Infused	Control	Infused	Control	Infused	Control	Infused	Control	Infused
BF	$5.44_{b}^{b} \pm 0.065$	$5.68_{c}^{a} \pm 0.083$	$3.17_{c}^{b} \pm 1.523$	$4.33_{c}^{a} \pm 1.347$	$1.03_{b}^{b} \pm 0.288$	$1.24_{bc}^{a} \pm 0.428$	$39.92_{c}^{b} \pm 2.876$	$41.77_{b}^{a} \pm 3.634$	$53.90_{c}^{a} \pm 10.88$	$38.90_{bc}^{b} \pm 9.21$
RF	$5.46_{b}^{b} \pm 0.088$	$5.73_{b}^{a} \pm 0.113$	$4.24_{b}^{b} \pm 1.428$	$5.95_{b}^{a} \pm 1.465$	$1.30_{a}^{a} \pm 0.254$	$1.42_{a}^{a} \pm 0.390$	$40.22_{bc}^{b} \pm 2.302$	$42.03_{b}^{a} \pm 2.263$	$53.78_{c}^{a} \pm 10.19$	$36.06_{c}^{b} \pm 8.53$
ST	$5.44_{b}^{b} \pm 0.079$	$5.66_{c}^{a} \pm 0.115$	$4.16_{b}^{b} \pm 1.882$	$7.37_{a}^{a} \pm 1.541$	$0.92_{b}^{b} \pm 0.321$	$1.43_{a}^{a} \pm 0.728$	$40.80_{b}^{b} \pm 1.454$	$42.09_{b}^{a} \pm 2.238$	$82.20_{a}^{a} \pm 15.31$	$47.63_{a}^{b} \pm 11.79$
SS	$5.57_{a}^{b} \pm 0.075$	$5.86_{a}^{a} \pm 0.103$	$3.29_{c}^{b} \pm 1.279$	$5.96_{b}^{a} \pm 1.511$	$0.95_{b}^{b} \pm 0.307$	$1.17_{c}^{a} \pm 0.376$	$43.72_{a}^{a} \pm 2.241$	$44.34_{a}^{a} \pm 2.028$	$68.79_{b}^{a} \pm 9.00$	$47.26_{a}^{b} \pm 6.67$
LL	$5.43_{b}^{b} \pm 0.073$	$5.62_{d}^{a} \pm 0.102$	$5.16_{a}^{b} \pm 1.569$	$6.31_{b}^{a} \pm 1.446$	$1.22_{a}^{a} \pm 0.412$	$1.35_{ab}^{a} \pm 0.416$	$40.35_{bc}^{a} \pm 1.593$	$40.56_{c}^{a} \pm 2.093$	$65.70_{b}^{a} \pm 16.66$	$41.08_{b}^{b} \pm 16.30$
LSD $P = 0.05$	0.033		0.640		0.132		0.668		4.083	

[#] s.d.: standard deviation.

BF: *biceps femoris*; RF: *rectus femoris*; ST: *semitendinosus*; SS: *supraspinatus*; LL: *longissimus lumborum.*

[a, b, c] Column means within a treatment with common subscripts do not differ ($P \leq 0.05$).

[a, b] Row means within an attribute and between treatments with common superscripts do not differ ($P \leq 0.05$).

LSD: least significant difference ($P = 0.05$).

According to Baublits *et al*. (2005a), the inclusion of phosphate-based solutions increases or results in similar hue angles to those of the control samples. However, with the addition of NaCl the hue angle decreased, indicating a deterioration of redness when NaCl is included. In the present investigation the infusion had no (P >0.05) effect on the hue angle (Tables 4 and 5) and with time the pattern was inconsistent in both the control and infused samples. According to the pooled data (Table 5), four of the five muscles had similar hue angles (P >0.05). Only the infused ST had a higher hue angle. This is supported by other research studies, which reported higher hue angles for infused muscles (Baublits *et al*., 2005b; Lawrence *et al*., 2003).

The results on the instrumental colour of the cooked samples are illustrated in Table 6. In general, the blend did not affect the muscle lightness (L*) of the cooked muscles significantly (Table 6). Overall, however, the L* values of the infused samples were higher ($P \leq 0.05$) and the infused samples were therefore slightly lighter in appearance (Table 7). No pattern (P >0.05) over time with regard to lightness was visible within treatments (Table 6).

The a* value showed no (P >0.05) effect with regard to the treatment (Table 6). The change within treatment over time indicated no pattern and suggests no (P >0.05) change over time (Table 6). Overall the infused samples were generally ($P \leq 0.05$) lower in cooked a* colour (Table 7). The b* and chroma values followed similar patterns, that is, lower ($P \leq 0.05$) values in the infused muscles.

With the hue angle calculations (Table 7), the infused muscles had slightly higher values than the control samples. However, only the infused ST and LL samples were higher ($P \leq 0.05$). Thus, overall the infused cooked samples appeared redder. Other research reported higher hue angles for infused muscles (Lawrence *et al*., 2003; Baublits *et al*., 2005a; b; 2006).

Lactate has been described as a 'colour-stabilizer' in fresh beef, minimizing surface colour change by producing a dark-coloured pigment that is stable during retailing (Lawrence *et al*., 2004). Maca *et al*. (1999) concluded that NaLac had a protective effect on the meat colour and acted as a stabiliser. This was observed in the treated muscles of this investigation, that is, they had a slightly redder colour than the control sample. Research into the mechanism of lactate-induced beef colour stability indicates that added lactate promotes maintenance of ferrous Mb redox forms (Kim *et al*., 2006; Mancini & Ramanathan, 2007; Suman *et al*., 2009). In conclusion, colour values fluctuated during the storage of raw and cooked beef over the 19 days and no clear pattern could be found.

The proximate chemical composition values were determined using the muscles samples taken from Day 4 and the results are presented in Table 8. The mineral content of the muscles is shown in Table 9.

The selected beef muscles were compared for percentage moisture, protein, lipid and ash content (Table 8). The proximate chemical composition of the control sample of this investigation is similar to that reported for beef (Sayed *et al*., 1999; Hoffman, 2006). The results of the infused muscles presented in Table 8 are in agreement with what is expected when a solution of water and several minerals, such as phosphates, potassium and sodium is infused, into beef muscle, that is, an increase in moisture and ash content and a decrease in protein and lipid content (Hoffman, 2006).

The percentage moisture was influenced ($P \leq 0.05$) by the infusion of the phosphate and lactate blend – three of the five muscles had increased moisture content. The protein content of the infused BF and RF muscles was lower ($P \leq 0.05$) than that of the control samples. The control and infused muscles were very similar in fat content, except for the BF muscles, where the expected lower fat content of enhanced meat was obtained (Hoffman, 2006) with the addition of a water-based solution. Because the infusion blend contained several minerals such as potassium and sodium, differences ($P \leq 0.05$) in the ash content between the treated and control muscles were expected, as shown in Table 8.

The muscles differed in proximate composition in this investigation (Table 8). However, the differences between muscles within treatments showed no definite pattern. It was observed that the BF muscle had the lowest moisture content and highest fat content compared with the other beef muscles. Other studies have reported this inverse relationship (Delgado *et al*., 2005).

The results of this investigation indicated differences ($P \leq 0.05$) in the mineral composition (Table 9) between muscles. Several other studies indicated differences in mineral content among various muscles (Schönfeldt & Welgemoed, 1996; Hoffman, 2006).

Table 4 Means (± s.d.)[#] for colour attributes of the raw beef muscles infused with a phosphate and lactate blend and aged for 19 days

Day	Raw L*		Raw a*		Raw b*		Raw chroma		Raw hue angle	
	Control	Infused	Control	Infused	Control	Infused	Control	Infused	Control	Infused
Biceps femoris (BF)										
4	$39.29_{a}^{a} \pm 1.758$	$39.90_{a}^{a} \pm 1.741$	$15.33_{e}^{a} \pm 1.470$	$14.19_{d}^{a} \pm 1.297$	$13.57_{bc}^{a} \pm 1.585$	$12.70_{c}^{a} \pm 1.535$	$20.50_{c}^{a} \pm 2.053$	$19.08_{c}^{a} \pm 1.823$	$41.46_{a}^{a} \pm 1.940$	$41.46_{a}^{a} \pm 2.577$
7	$39.78_{a}^{a} \pm 1.903$	$39.35_{a}^{a} \pm 1.387$	$16.06_{de}^{a} \pm 1.814$	$15.65_{bc}^{a} \pm 1.742$	$13.17_{c}^{a} \pm 2.674$	$14.46_{ab}^{a} \pm 1.643$	$20.87_{c}^{a} \pm 2.834$	$21.36_{ab}^{a} \pm 2.260$	$38.88_{a}^{b} \pm 4.039$	$42.61_{a}^{a} \pm 2.193$
10	$39.94_{a}^{a} \pm 2.637$	$38.51_{ab}^{a} \pm 2.285$	$16.95_{cd}^{a} \pm 2.006$	$14.97_{cd}^{b} \pm 0.778$	$15.05_{ab}^{a} \pm 2.173$	$13.03_{bc}^{b} \pm 1.817$	$22.69_{b}^{a} \pm 2.874$	$19.91_{bc}^{b} \pm 1.440$	$41.53_{a}^{a} \pm 1.605$	$40.88_{a}^{a} \pm 3.796$
13	$40.93_{a}^{a} \pm 2.601$	$39.02_{ab}^{a} \pm 1.950$	$18.34_{ab}^{a} \pm 1.377$	$16.26_{ab}^{b} \pm 1.432$	$16.35_{a}^{a} \pm 1.080$	$14.39_{ab}^{b} \pm 1.575$	$24.58_{a}^{a} \pm 1.637$	$21.75_{a}^{b} \pm 1.899$	$41.71_{a}^{a} \pm 1.445$	$41.61_{a}^{a} \pm 2.781$
16	$40.60_{a}^{a} \pm 1.796$	$40.52_{a}^{a} \pm 2.036$	$19.48_{a}^{a} \pm 1.206$	$17.44_{a}^{b} \pm 2.325$	$15.95_{a}^{a} \pm 1.047$	$14.66_{a}^{a} \pm 1.439$	$25.20_{a}^{a} \pm 1.356$	$22.80_{a}^{b} \pm 2.610$	$39.29_{a}^{a} \pm 1.939$	$40.11_{a}^{a} \pm 2.022$
19	$39.43_{a}^{a} \pm 1.157$	$36.94_{b}^{b} \pm 2.049$	$18.10_{bc}^{a} \pm 0.987$	$16.26_{ab}^{b} \pm 1.223$	$16.16_{a}^{a} \pm 1.236$	$14.35_{ab}^{b} \pm 1.777$	$24.30_{ab}^{a} \pm 1.444$	$21.76_{a}^{b} \pm 1.780$	$41.66_{a}^{a} \pm 1.565$	$41.34_{a}^{a} \pm 3.188$
Rectus femoris (RF)										
4	$49.74_{a}^{a} \pm 4.205$	$48.01_{a}^{a} \pm 1.868$	$13.19_{d}^{a} \pm 1.131$	$12.51_{d}^{a} \pm 0.766$	$15.43_{ab}^{a} \pm 1.392$	$14.75_{a}^{a} \pm 1.045$	$20.33_{c}^{a} \pm 1.502$	$19.38_{b}^{a} \pm 1.181$	$49.44_{a}^{a} \pm 2.767$	$49.65_{a}^{a} \pm 1.518$
7	$43.48_{b}^{a} \pm 2.746$	$41.07_{b}^{b} \pm 2.747$	$14.41_{cd}^{a} \pm 1.587$	$12.72_{cd}^{b} \pm 2.129$	$14.71_{b}^{a} \pm 1.538$	$12.06_{b}^{b} \pm 2.102$	$20.68_{c}^{a} \pm 1.800$	$17.65_{c}^{b} \pm 2.602$	$45.56_{b}^{a} \pm 3.479$	$43.32_{b}^{a} \pm 4.634$
10	$42.95_{b}^{a} \pm 1.749$	$42.04_{b}^{a} \pm 1.487$	$15.06_{bc}^{a} \pm 1.666$	$13.84_{abc}^{a} \pm 2.803$	$15.54_{ab}^{a} \pm 1.164$	$13.20_{b}^{b} \pm 1.594$	$21.67_{bc}^{a} \pm 1.797$	$19.19_{bc}^{b} \pm 2.958$	$45.99_{b}^{a} \pm 2.560$	$44.40_{b}^{a} \pm 4.230$
13	$44.66_{b}^{a} \pm 3.087$	$42.75_{b}^{a} \pm 3.189$	$16.32_{ab}^{a} \pm 1.371$	$14.25_{ab}^{b} \pm 1.916$	$15.59_{ab}^{a} \pm 1.137$	$13.43_{ab}^{b} \pm 1.896$	$22.61_{ab}^{a} \pm 1.187$	$19.64_{ab}^{b} \pm 2.513$	$43.73_{b}^{a} \pm 3.291$	$43.21_{b}^{a} \pm 2.737$
16	$45.21_{b}^{a} \pm 3.239$	$42.19_{b}^{b} \pm 2.175$	$16.01_{ab}^{a} \pm 1.229$	$13.64_{bcd}^{b} \pm 1.280$	$15.87_{ab}^{a} \pm 1.190$	$13.34_{ab}^{b} \pm 1.705$	$22.61_{ab}^{a} \pm 0.805$	$19.14_{bc}^{b} \pm 1.886$	$44.79_{b}^{a} \pm 3.822$	$44.33_{b}^{a} \pm 2.869$
19	$43.73_{b}^{a} \pm 2.959$	$41.52_{b}^{a} \pm 3.235$	$16.89_{a}^{a} \pm 1.296$	$15.05_{a}^{b} \pm 1.772$	$16.51_{a}^{a} \pm 1.790$	$14.78_{a}^{b} \pm 1.564$	$23.72_{a}^{a} \pm 1.276$	$21.16_{a}^{b} \pm 2.031$	$44.25_{b}^{a} \pm 4.327$	$44.44_{b}^{a} \pm 3.071$
Semitendinosus (ST)										
4	$44.06_{a}^{a} \pm 3.166$	$42.28_{a}^{a} \pm 2.814$	$15.06_{b}^{a} \pm 1.434$	$13.07_{b}^{b} \pm 1.655$	$15.25_{c}^{a} \pm 1.107$	$13.16_{c}^{b} \pm 1.321$	$21.46_{b}^{a} \pm 1.612$	$18.64_{c}^{b} \pm 1.488$	$45.46_{a}^{a} \pm 2.172$	$45.47_{bc}^{a} \pm 4.541$
7	$44.82_{a}^{a} \pm 4.364$	$44.07_{a}^{a} \pm 4.205$	$15.11_{b}^{a} \pm 1.569$	$12.80_{b}^{b} \pm 1.511$	$16.09_{abc}^{a} \pm 1.560$	$15.14_{ab}^{a} \pm 2.298$	$22.16_{ab}^{a} \pm 1.117$	$19.91_{bc}^{b} \pm 2.133$	$46.87_{a}^{a} \pm 4.935$	$49.60_{a}^{a} \pm 4.865$
10	$41.24_{b}^{a} \pm 1.759$	$42.15_{a}^{a} \pm 1.917$	$16.74_{a}^{a} \pm 1.530$	$13.75_{ab}^{b} \pm 2.335$	$16.80_{ab}^{a} \pm 1.252$	$15.47_{a}^{a} \pm 1.777$	$23.78_{a}^{a} \pm 0.905$	$20.78_{ab}^{b} \pm 2.311$	$45.17_{a}^{b} \pm 4.323$	$48.59_{a}^{a} \pm 4.984$
13	$43.34_{ab}^{a} \pm 2.814$	$42.80_{a}^{a} \pm 2.745$	$16.79_{a}^{a} \pm 1.319$	$14.83_{a}^{b} \pm 1.681$	$16.58_{abc}^{a} \pm 1.849$	$16.08_{a}^{a} \pm 2.064$	$23.65_{a}^{a} \pm 1.775$	$21.90_{a}^{b} \pm 2.509$	$44.68_{ab}^{a} \pm 3.501$	$47.36_{ab}^{a} \pm 2.227$
16	$45.35_{a}^{a} \pm 3.366$	$43.99_{a}^{a} \pm 3.024$	$16.01_{ab}^{a} \pm 1.675$	$14.42_{a}^{b} \pm 1.671$	$17.22_{a}^{a} \pm 0.464$	$15.93_{a}^{a} \pm 0.968$	$23.55_{a}^{a} \pm 1.268$	$21.55_{a}^{b} \pm 1.264$	$47.22_{a}^{a} \pm 2.901$	$48.05_{ab}^{a} \pm 3.987$
19	$43.56_{ab}^{a} \pm 3.893$	$43.62_{a}^{a} \pm 3.970$	$17.28_{a}^{a} \pm 1.874$	$14.02_{ab}^{b} \pm 1.095$	$15.37_{bc}^{a} \pm 1.077$	$13.63_{bc}^{b} \pm 1.873$	$23.19_{a}^{a} \pm 1.497$	$19.61_{bc}^{b} \pm 1.556$	$41.83_{b}^{a} \pm 3.833$	$44.09_{c}^{a} \pm 4.487$

Table 4 (continued) Means (± s.d.)[#] for colour attributes of the raw beef muscles infused with a phosphate and lactate blend and aged for 19 days

Day	Raw L*		Raw a*		Raw b*		Raw chroma		Raw hue angle	
	Control	Infused	Control	Infused	Control	Infused	Control	Infused	Control	Infused
Supraspinatus (SS)										
4	$39.99_{a}^{a} \pm 0.989$	$38.93_{a}^{a} \pm 1.928$	$14.76_{b}^{a} \pm 0.556$	$13.74_{b}^{a} \pm 1.365$	$12.88_{b}^{a} \pm 0.811$	$12.09_{ab}^{a} \pm 0.843$	$19.65_{b}^{a} \pm 0.793$	$18.42_{b}^{a} \pm 1.403$	$40.97_{a}^{a} \pm 1.895$	$41.40_{a}^{a} \pm 2.233$
7	$40.17_{a}^{a} \pm 3.023$	$37.09_{a}^{b} \pm 2.607$	$15.87_{b}^{a} \pm 1.062$	$13.93_{b}^{b} \pm 1.206$	$12.92_{b}^{a} \pm 1.076$	$11.53_{b}^{a} \pm 0.852$	$20.51_{b}^{a} \pm 0.875$	$18.14_{b}^{b} \pm 1.233$	$39.11_{a}^{a} \pm 3.446$	$39.66_{a}^{a} \pm 2.610$
10	$40.67_{a}^{a} \pm 1.377$	$38.61_{a}^{a} \pm 1.803$	$18.26_{a}^{a} \pm 0.993$	$15.87_{a}^{b} \pm 0.938$	$15.83_{a}^{a} \pm 1.048$	$12.58_{ab}^{b} \pm 1.439$	$24.18_{a}^{a} \pm 1.352$	$20.27_{a}^{b} \pm 1.508$	$40.90_{a}^{a} \pm 1.184$	$38.32_{a}^{a} \pm 2.216$
13	$40.73_{a}^{a} \pm 2.051$	$39.14_{a}^{a} \pm 3.873$	$18.77_{a}^{a} \pm 1.753$	$15.74_{a}^{b} \pm 1.631$	$15.88_{a}^{a} \pm 1.400$	$13.60_{a}^{b} \pm 2.657$	$24.59_{a}^{a} \pm 2.204$	$20.84_{a}^{b} \pm 2.888$	$40.24_{a}^{a} \pm 0.979$	$40.49_{a}^{a} \pm 3.130$
16	$41.13_{a}^{a} \pm 2.218$	$38.58_{a}^{b} \pm 2.092$	$17.83_{a}^{a} \pm 0.677$	$15.68_{a}^{b} \pm 0.973$	$14.95_{a}^{a} \pm 1.067$	$13.53_{a}^{a} \pm 1.256$	$23.34_{a}^{a} \pm 0.928$	$20.74_{a}^{b} \pm 1.403$	$39.80_{a}^{a} \pm 2.166$	$40.70_{a}^{a} \pm 2.016$
19	$42.28_{a}^{a} \pm 1.687$	$38.77_{a}^{b} \pm 1.631$	$17.84_{a}^{a} \pm 0.561$	$14.79_{ab}^{b} \pm 0.848$	$15.68_{a}^{a} \pm 0.730$	$12.94_{ab}^{b} \pm 1.448$	$23.79_{a}^{a} \pm 0.594$	$19.69_{ab}^{b} \pm 1.485$	$41.32_{a}^{a} \pm 4.686$	$41.06_{a}^{a} \pm 2.147$
Longissimus lumborum (LL)										
4	$38.72_{c}^{a} \pm 1.417$	$38.16_{b}^{a} \pm 1.723$	$13.82_{c}^{a} \pm 1.048$	$13.58_{cd}^{b} \pm 1.004$	$12.32_{c}^{a} \pm 0.900$	$12.08_{b}^{a} \pm 0.775$	$18.57_{c}^{a} \pm 1.103$	$18.23_{c}^{a} \pm 0.770$	$41.62_{ab}^{a} \pm 2.409$	$41.67_{ab}^{a} \pm 3.150$
7	$40.56_{abc}^{a} \pm 1.725$	$39.42_{ab}^{a} \pm 1.141$	$16.54_{b}^{a} \pm 0.906$	$14.36_{bcd}^{b} \pm 1.205$	$14.15_{b}^{a} \pm 1.415$	$12.73_{ab}^{a} \pm 1.633$	$21.87_{b}^{a} \pm 1.342$	$19.23_{bc}^{b} \pm 1.904$	$40.56_{ab}^{a} \pm 2.101$	$41.37_{ab}^{a} \pm 2.159$
10	$39.39_{bc}^{a} \pm 2.107$	$38.59_{ab}^{a} \pm 1.899$	$16.04_{b}^{a} \pm 0.948$	$13.44_{d}^{b} \pm 1.494$	$14.80_{ab}^{a} \pm 0.334$	$13.09_{ab}^{b} \pm 0.894$	$21.86_{b}^{a} \pm 0.756$	$18.89_{bc}^{b} \pm 1.022$	$42.75_{a}^{a} \pm 1.711$	$44.32_{a}^{a} \pm 4.357$
13	$41.24_{ab}^{a} \pm 2.026$	$39.67_{ab}^{a} \pm 2.186$	$17.25_{ab}^{a} \pm 0.887$	$14.83_{bc}^{b} \pm 1.423$	$15.87_{a}^{a} \pm 0.658$	$13.93_{a}^{b} \pm 0.341$	$23.47_{ab}^{a} \pm 0.891$	$20.39_{ab}^{b} \pm 1.224$	$42.58_{a}^{a} \pm 1.553$	$43.29_{a}^{a} \pm 2.311$
16	$40.17_{abc}^{a} \pm 1.630$	$39.62_{ab}^{a} \pm 1.178$	$16.31_{b}^{a} \pm 1.370$	$15.09_{b}^{a} \pm 0.914$	$14.55_{ab}^{a} \pm 0.932$	$13.34_{ab}^{a} \pm 0.767$	$21.90_{b}^{a} \pm 1.265$	$20.20_{ab}^{b} \pm 0.559$	$41.74_{ab}^{a} \pm 2.742$	$41.49_{ab}^{a} \pm 2.988$
19	$41.91_{a}^{a} \pm 1.248$	$40.74_{a}^{a} \pm 1.064$	$18.38_{a}^{a} \pm 0.456$	$16.79_{a}^{b} \pm 0.903$	$15.02_{ab}^{a} \pm 0.835$	$13.81_{a}^{a} \pm 1.278$	$23.76_{a}^{a} \pm 0.471$	$21.76_{a}^{b} \pm 1.333$	$39.25_{b}^{a} \pm 1.896$	$39.37_{b}^{a} \pm 2.205$
LSD $P = 0.05$	2.336		1.277		1.528		1.631		3.108	

[#] s.d.: standard deviation.

$^{a, b, c, d, e}$ Column means between days within a treatment and within a muscle with common subscripts do not differ ($P \leq 0.05$).

$^{a, b}$ Row means between treatments within an attribute with common superscripts do not differ ($P \leq 0.05$).

LSD: Least significant difference ($P = 0.05$).

Table 5 Summary of means (± s.d.)[#] for colour attributes of the raw beef muscles infused with a phosphate and lactate blend and aged for 19 days

Muscle	Raw L*		Raw a*		Raw b*		Raw chroma		Raw hue angle	
	Control	Infused	Control	Infused	Control	Infused	Control	Infused	Control	Infused
BF	$40.0_{c}^{a} \pm 1.982$	$39.04_{b}^{b} \pm 2.124$	$17.38_{a}^{a} \pm 2.005$	$15.79_{a}^{b} \pm 1.772$	$15.04_{bc}^{a} \pm 2.053$	$13.93_{b}^{b} \pm 1.703$	$23.02_{a}^{a} \pm 2.699$	$21.11_{a}^{b} \pm 2.245$	$40.75_{b}^{a} \pm 2.424$	$41.33_{cd}^{a} \pm 2.724$
RF	$45.0_{a}^{a} \pm 3.677$	$42.97_{a}^{b} \pm 3.326$	$15.31_{c}^{a} \pm 1.809$	$13.67_{c}^{b} \pm 1.958$	$15.61_{ab}^{a} \pm 1.400$	$13.59_{bc}^{b} \pm 1.830$	$21.94_{b}^{a} \pm 1.789$	$19.36_{c}^{b} \pm 2.346$	$45.63_{a}^{a} \pm 3.693$	$44.89_{b}^{a} \pm 3.805$
ST	$43.8_{b}^{a} \pm 3.367$	$43.15_{a}^{a} \pm 3.18$	$16.16_{b}^{a} \pm 1.694$	$13.81_{c}^{b} \pm 1.728$	$16.22_{a}^{a} \pm 1.404$	$14.90_{a}^{b} \pm 1.995$	$22.96_{a}^{a} \pm 1.558$	$20.40_{b}^{b} \pm 2.127$	$45.20_{a}^{b} \pm 3.881$	$47.19_{a}^{a} \pm 4.398$
SS	$40.83_{c}^{a} \pm 2.001$	$38.52_{b}^{b} \pm 2.361$	$17.22_{a}^{a} \pm 1.724$	$14.96_{b}^{b} \pm 1.412$	$14.69_{c}^{a} \pm 1.637$	$12.71_{d}^{b} \pm 1.612$	$22.68_{a}^{a} \pm 2.236$	$19.68_{c}^{b} \pm 1.942$	$40.39_{b}^{a} \pm 2.054$	$40.27_{d}^{a} \pm 2.471$
LL	$40.33_{c}^{a} \pm 1.928$	$39.36_{b}^{b} \pm 1.694$	$16.39_{b}^{a} \pm 1.666$	$14.68_{b}^{b} \pm 1.575$	$14.45_{c}^{a} \pm 1.386$	$13.16_{cd}^{b} \pm 1.151$	$21.91_{b}^{a} \pm 1.950$	$19.78_{bc}^{b} \pm 1.624$	$41.41_{b}^{a} \pm 2.313$	$41.92_{c}^{a} \pm 3.169$
LSD $P = 0.05$	0.953		0.521		0.624		0.666		1.269	

[#] s.d.: standard deviation.
BF: *biceps femoris*; RF: *rectus femoris*; ST: *semitendinosus*; SS: *supraspinatus*; LL: *longissimus lumborum.*
$^{a, b, c, d}$ Column means within a treatment and between muscles with common subscripts do not differ ($P \leq 0.05$).
$^{a, b}$ Row means within an attribute and between treatments with common superscripts do not differ ($P \leq 0.05$).
LSD: least significant difference ($P = 0.05$).

Table 6 Means (± s.d.)[#] for colour attributes of the cooked beef muscles infused with a phosphate and lactate blend and aged for 19 days

Day	Cooked L*		Cooked a*		Cooked b*		Cooked chroma		Cooked hue angle	
	Control	Infused	Control	Infused	Control	Infused	Control	Infused	Control	Infused
Biceps femoris (BF)										
4	$38.88_{ab}{}^{a} \pm 2.800$	$42.00_{a}{}^{a} \pm 2.129$	$5.74_{bc}{}^{a} \pm 0.896$	$5.72_{a}{}^{a} \pm 0.501$	$13.11_{c}{}^{a} \pm 0.785$	$12.55_{c}{}^{a} \pm 0.417$	$14.34_{d}{}^{a} \pm 0.629$	$13.82_{c}{}^{a} \pm 0.439$	$66.30_{bc}{}^{a} \pm 3.998$	$65.44_{b}{}^{a} \pm 1.911$
7	$39.67_{ab}{}^{a} \pm 3.208$	$40.92_{a}{}^{a} \pm 2.515$	$5.91_{bc}{}^{a} \pm 1.186$	$6.18_{a}{}^{a} \pm 0.703$	$15.35_{a}{}^{a} \pm 0.805$	$14.69_{ab}{}^{a} \pm 0.610$	$16.50_{bc}{}^{a} \pm 0.889$	$15.96_{a}{}^{a} \pm 0.627$	$68.96_{ab}{}^{a} \pm 3.896$	$67.14_{ab}{}^{a} \pm 2.458$
10	$41.36_{a}{}^{a} \pm 1.374$	$42.51_{a}{}^{a} \pm 3.431$	$5.48_{c}{}^{a} \pm 0.711$	$5.25_{a}{}^{a} \pm 0.538$	$15.87_{a}{}^{a} \pm 0.338$	$14.64_{ab}{}^{b} \pm 0.457$	$16.82_{ab}{}^{a} \pm 0.201$	$15.58_{ab}{}^{b} \pm 0.470$	$70.95_{a}{}^{a} \pm 2.608$	$70.28_{a}{}^{a} \pm 1.874$
13	$41.75_{a}{}^{a} \pm 4.417$	$41.80_{a}{}^{a} \pm 4.710$	$5.92_{bc}{}^{a} \pm 1.217$	$5.83_{a}{}^{a} \pm 0.809$	$15.99_{a}{}^{a} \pm 0.853$	$14.98_{a}{}^{b} \pm 0.891$	$17.10_{ab}{}^{a} \pm 0.794$	$16.10_{a}{}^{b} \pm 0.837$	$69.67_{a}{}^{a} \pm 4.221$	$68.70_{ab}{}^{a} \pm 3.049$
16	$36.90_{b}{}^{b} \pm 3.529$	$40.56_{a}{}^{a} \pm 3.779$	$6.86_{a}{}^{a} \pm 0.865$	$5.61_{a}{}^{b} \pm 0.631$	$14.36_{b}{}^{a} \pm 1.052$	$14.12_{b}{}^{a} \pm 0.863$	$15.94_{c}{}^{a} \pm 0.889$	$15.22_{b}{}^{a} \pm 0.719$	$64.40_{c}{}^{b} \pm 3.625$	$68.27_{ab}{}^{a} \pm 2.972$
19	$41.48_{a}{}^{a} \pm 1.580$	$41.80_{a}{}^{a} \pm 1.824$	$6.51_{ab}{}^{a} \pm 0.847$	$5.76_{a}{}^{a} \pm 0.685$	$15.97_{a}{}^{a} \pm 0.793$	$15.23_{a}{}^{a} \pm 0.728$	$17.27_{a}{}^{a} \pm 0.993$	$16.29_{a}{}^{b} \pm 0.801$	$67.85_{ab}{}^{a} \pm 1.975$	$69.27_{a}{}^{a} \pm 2.117$
Rectus femoris (RF)										
4	$50.52_{a}{}^{a} \pm 2.709$	$50.78_{a}{}^{a} \pm 2.992$	$4.15_{b}{}^{a} \pm 0.531$	$3.99_{a}{}^{a} \pm 1.562$	$16.47_{b}{}^{a} \pm 0.505$	$16.65_{a}{}^{a} \pm 0.734$	$17.01_{b}{}^{a} \pm 0.536$	$17.19_{a}{}^{a} \pm 0.878$	$75.77_{ab}{}^{a} \pm 1.727$	$76.58_{a}{}^{a} \pm 4.853$
7	$46.21_{b}{}^{a} \pm 4.447$	$47.03_{b}{}^{a} \pm 3.365$	$4.87_{ab}{}^{a} \pm 0.984$	$4.09_{a}{}^{a} \pm 0.576$	$17.06_{ab}{}^{a} \pm 0.446$	$15.72_{b}{}^{b} \pm 0.769$	$17.85_{a}{}^{a} \pm 0.391$	$16.32_{b}{}^{b} \pm 0.631$	$73.95_{abc}{}^{a} \pm 3.324$	$75.05_{ab}{}^{a} \pm 2.473$
10	$45.82_{b}{}^{a} \pm 3.681$	$45.46_{b}{}^{a} \pm 3.368$	$5.12_{a}{}^{a} \pm 0.801$	$4.31_{a}{}^{a} \pm 0.920$	$16.69_{b}{}^{a} \pm 0.398$	$15.75_{b}{}^{b} \pm 0.663$	$17.56_{ab}{}^{a} \pm 0.250$	$16.39_{b}{}^{b} \pm 0.533$	$72.72_{bc}{}^{a} \pm 3.008$	$74.53_{ab}{}^{a} \pm 3.536$
13	$45.21_{b}{}^{a} \pm 3.854$	$44.84_{b}{}^{a} \pm 3.427$	$5.22_{a}{}^{a} \pm 0.548$	$4.74_{a}{}^{a} \pm 0.818$	$16.90_{ab}{}^{a} \pm 0.868$	$16.22_{ab}{}^{a} \pm 0.959$	$17.80_{a}{}^{a} \pm 0.652$	$16.99_{ab}{}^{b} \pm 0.722$	$72.33_{c}{}^{a} \pm 2.875$	$73.38_{ab}{}^{a} \pm 3.579$
16	$45.62_{b}{}^{a} \pm 2.936$	$47.53_{b}{}^{a} \pm 3.174$	$5.18_{a}{}^{a} \pm 1.054$	$4.00_{a}{}^{b} \pm 0.888$	$16.67_{b}{}^{a} \pm 0.741$	$16.24_{ab}{}^{a} \pm 0.685$	$17.50_{ab}{}^{a} \pm 0.490$	$16.79_{ab}{}^{a} \pm 0.527$	$72.64_{bc}{}^{b} \pm 3.898$	$76.07_{ab}{}^{a} \pm 3.436$
19	$49.69_{a}{}^{a} \pm 4.273$	$46.95_{b}{}^{a} \pm 3.265$	$3.98_{b}{}^{a} \pm 1.232$	$4.83_{a}{}^{a} \pm 0.551$	$17.53_{a}{}^{a} \pm 0.611$	$15.81_{b}{}^{b} \pm 0.395$	$18.04_{a}{}^{a} \pm 0.606$	$16.59_{ab}{}^{b} \pm 0.436$	$77.21_{a}{}^{a} \pm 3.890$	$72.91_{b}{}^{b} \pm 1.789$
Semitendinosus (ST)										
4	$42.42_{a}{}^{a} \pm 3.653$	$45.34_{a}{}^{a} \pm 4.337$	$7.06_{a}{}^{a} \pm 0.764$	$6.54_{a}{}^{a} \pm 1.242$	$15.67_{c}{}^{b} \pm 0.773$	$16.96_{a}{}^{a} \pm 0.585$	$17.23_{ab}{}^{b} \pm 0.504$	$18.23_{a}{}^{a} \pm 0.475$	$65.72_{c}{}^{a} \pm 3.246$	$68.90_{b}{}^{a} \pm 4.081$
7	$42.11_{a}{}^{a} \pm 4.049$	$44.70_{a}{}^{a} \pm 3.410$	$6.16_{ab}{}^{a} \pm 1.032$	$5.35_{b}{}^{a} \pm 1.235$	$15.76_{bc}{}^{a} \pm 0.945$	$15.86_{bc}{}^{a} \pm 0.998$	$16.97_{b}{}^{a} \pm 0.573$	$16.81_{bc}{}^{a} \pm 0.829$	$68.56_{bc}{}^{a} \pm 4.411$	$71.25_{ab}{}^{a} \pm 4.586$
10	$42.34_{a}{}^{b} \pm 4.46$	$46.39_{a}{}^{a} \pm 4.948$	$5.12_{c}{}^{a} \pm 0.887$	$4.70_{b}{}^{a} \pm 1.158$	$16.13_{abc}{}^{a} \pm 0.931$	$16.21_{abc}{}^{a} \pm 0.595$	$16.98_{b}{}^{a} \pm 0.707$	$16.93_{bc}{}^{a} \pm 0.565$	$72.24_{a}{}^{a} \pm 3.658$	$73.87_{a}{}^{a} \pm 4.004$
13	$43.35_{a}{}^{a} \pm 4.59$	$46.19_{a}{}^{a} \pm 2.608$	$5.76_{bc}{}^{a} \pm 1.264$	$5.15_{b}{}^{a} \pm 0.634$	$16.68_{a}{}^{a} \pm 0.930$	$16.46_{ab}{}^{a} \pm 0.618$	$17.71_{a}{}^{a} \pm 0.629$	$17.28_{b}{}^{a} \pm 0.718$	$70.91_{ab}{}^{a} \pm 4.464$	$72.74_{a}{}^{a} \pm 1.735$
16	$43.13_{a}{}^{a} \pm 5.54$	$45.79_{a}{}^{a} \pm 4.481$	$5.44_{bc}{}^{a} \pm 1.357$	$4.75_{b}{}^{a} \pm 0.775$	$15.91_{abc}{}^{a} \pm 0.897$	$15.54_{c}{}^{a} \pm 0.632$	$16.89_{b}{}^{a} \pm 0.521$	$16.29_{c}{}^{a} \pm 0.493$	$71.01_{ab}{}^{a} \pm 5.332$	$72.97_{a}{}^{a} \pm 3.092$
19	$45.25_{a}{}^{a} \pm 4.698$	$47.10_{a}{}^{a} \pm 2.316$	$5.26_{bc}{}^{a} \pm 1.019$	$5.11_{b}{}^{a} \pm 0.334$	$16.52_{ab}{}^{a} \pm 0.808$	$15.62_{c}{}^{b} \pm 0.658$	$17.38_{ab}{}^{a} \pm 0.641$	$16.46_{c}{}^{b} \pm 0.562$	$72.24_{a}{}^{a} \pm 3.756$	$71.87_{ab}{}^{a} \pm 1.656$

Table 6 (continued) Means (±s.d.)[#] for colour attributes of the cooked beef muscles infused with a phosphate and lactate blend and aged for 19 days

Day	Cooked L*		Cooked a*		Cooked b*		Cooked chroma		Cooked hue angle	
	Control	Infused	Control	Infused	Control	Infused	Control	Infused	Control	Infused
Supraspinatus (SS)										
4	$39.87_{a}^{a} \pm 2.658$	$39.90_{a}^{a} \pm 3.997$	$6.90_{a}^{a} \pm 0.754$	$6.27_{a}^{a} \pm 0.690$	$15.30_{b}^{a} \pm 0.525$	$14.76_{abc}^{a} \pm 0.998$	$16.82_{b}^{a} \pm 0.639$	$16.08_{a}^{b} \pm 0.882$	$65.69_{b}^{a} \pm 2.121$	$66.95_{b}^{a} \pm 3.037$
7	$38.50_{a}^{a} \pm 3.002$	$38.47_{a}^{a} \pm 2.632$	$7.04_{a}^{a} \pm 0.965$	$6.23_{a}^{a} \pm 0.403$	$15.92_{ab}^{a} \pm 0.682$	$14.58_{c}^{b} \pm 0.940$	$17.45_{ab}^{a} \pm 0.532$	$15.90_{a}^{b} \pm 0.956$	$66.13_{b}^{a} \pm 3.478$	$66.74_{b}^{a} \pm 1.316$
10	$39.32_{a}^{a} \pm 2.388$	$38.81_{a}^{a} \pm 2.827$	$7.09_{a}^{a} \pm 0.725$	$6.38_{a}^{a} \pm 0.610$	$15.96_{ab}^{a} \pm 0.898$	$14.65_{bc}^{b} \pm 0.769$	$17.55_{a}^{a} \pm 0.642$	$16.02_{a}^{b} \pm 0.532$	$65.83_{b}^{a} \pm 3.275$	$66.36_{b}^{a} \pm 2.908$
13	$38.86_{a}^{a} \pm 3.452$	$39.42_{a}^{a} \pm 2.790$	$5.93_{b}^{a} \pm 0.931$	$5.11_{b}^{a} \pm 0.678$	$16.22_{a}^{a} \pm 0.806$	$15.48_{a}^{a} \pm 0.968$	$17.32_{ab}^{a} \pm 0.495$	$16.34_{a}^{b} \pm 0.716$	$69.80_{a}^{a} \pm 3.802$	$71.57_{a}^{a} \pm 3.278$
16	$37.36_{a}^{a} \pm 2.029$	$39.00_{a}^{a} \pm 2.367$	$6.67_{ab}^{a} \pm 0.673$	$5.98_{ab}^{a} \pm 0.652$	$16.30_{a}^{a} \pm 0.516$	$15.42_{ab}^{b} \pm 0.629$	$17.65_{a}^{a} \pm 0.578$	$16.59_{a}^{b} \pm 0.449$	$67.74_{ab}^{a} \pm 2.099$	$68.75_{ab}^{a} \pm 2.761$
19	$39.04_{a}^{a} \pm 3.757$	$40.29_{a}^{a} \pm 2.353$	$6.69_{ab}^{a} \pm 0.701$	$6.31_{a}^{a} \pm 0.665$	$16.11_{a}^{a} \pm 1.044$	$15.30_{abc}^{b} \pm 0.796$	$17.49_{ab}^{a} \pm 0.911$	$16.59_{a}^{b} \pm 0.695$	$67.38_{ab}^{a} \pm 2.814$	$67.55_{b}^{a} \pm 2.670$
Longissimus lumborum (LL)										
4	$49.39_{a}^{a} \pm 3.395$	$48.19_{a}^{a} \pm 4.910$	$5.33_{a}^{a} \pm 1.296$	$4.37_{a}^{b} \pm 1.124$	$17.56_{a}^{a} \pm 1.235$	$15.29_{a}^{b} \pm 0.792$	$18.42_{a}^{a} \pm 1.382$	$15.94_{a}^{b} \pm 0.779$	$73.31_{ab}^{a} \pm 3.482$	$74.07_{c}^{a} \pm 4.082$
7	$46.97_{ab}^{a} \pm 4.089$	$49.31_{a}^{a} \pm 2.596$	$5.41_{a}^{a} \pm 0.797$	$4.22_{ab}^{b} \pm 0.692$	$15.81_{b}^{a} \pm 0.504$	$15.59_{a}^{a} \pm 0.363$	$16.74_{c}^{a} \pm 0.510$	$16.17_{a}^{a} \pm 0.406$	$71.08_{b}^{b} \pm 2.776$	$74.90_{bc}^{a} \pm 2.367$
10	$48.27_{ab}^{a} \pm 3.973$	$51.06_{a}^{a} \pm 4.337$	$4.34_{b}^{a} \pm 1.204$	$3.41_{bc}^{b} \pm 1.584$	$16.99_{a}^{a} \pm 0.542$	$15.54_{a}^{b} \pm 0.359$	$17.59_{b}^{a} \pm 0.330$	$15.99_{a}^{b} \pm 0.325$	$75.62_{a}^{a} \pm 4.176$	$77.62_{ab}^{a} \pm 5.739$
13	$49.62_{a}^{a} \pm 4.821$	$50.70_{a}^{a} \pm 3.901$	$4.28_{b}^{a} \pm 0.795$	$3.74_{abc}^{a} \pm 0.997$	$17.04_{a}^{a} \pm 0.068$	$15.79_{a}^{b} \pm 0.691$	$17.59_{b}^{a} \pm 0.174$	$16.26_{a}^{b} \pm 0.785$	$75.92_{a}^{a} \pm 2.527$	$76.70_{abc}^{a} \pm 3.340$
16	$45.42_{b}^{b} \pm 4.012$	$49.57_{a}^{a} \pm 2.193$	$4.21_{b}^{a} \pm 0.645$	$3.15_{c}^{b} \pm 0.524$	$16.77_{a}^{a} \pm 0.724$	$15.80_{a}^{b} \pm 0.426$	$17.31_{bc}^{a} \pm 0.543$	$16.13_{a}^{b} \pm 0.485$	$75.83_{a}^{a} \pm 2.708$	$78.69_{a}^{a} \pm 1.728$
19	$46.74_{ab}^{b} \pm 3.275$	$50.07_{a}^{a} \pm 2.738$	$4.30_{b}^{a} \pm 0.895$	$3.17_{c}^{b} \pm 0.618$	$16.82_{a}^{a} \pm 0.651$	$15.54_{a}^{b} \pm 0.398$	$17.40_{bc}^{a} \pm 0.636$	$15.90_{a}^{b} \pm 0.430$	$75.61_{a}^{a} \pm 3.035$	$78.39_{a}^{a} \pm 2.236$
LSD $P = 0.05$	3.178		0.930		0.795		0.722		3.350	

[#] s.d.: standard deviation.

[a, b, c, d] Column means between days within a treatment and within a muscle with common subscripts do not differ ($P \leq 0.05$).

[a, b] Row means between treatments within an attribute with common superscripts do not differ ($P \leq 0.05$).

LSD: least significant difference ($P = 0.05$).

Table 7 Summary of means (±s.d.)[#] for colour attributes of the cooked beef muscles infused with a phosphate and lactate blend and aged for 19 days

Muscle	Cooked L*		Cooked a*		Cooked b*		Cooked chroma		Cooked hue angle	
	Control	Infused	Control	Infused	Control	Infused	Control	Infused	Control	Infused
BF	$40.00_{c}^{b} \pm 3.298$	$41.60_{c}^{a} \pm 3.060$	$6.07_{b}^{a} \pm 1.018$	$5.72_{a}^{a} \pm 0.666$	$15.11_{c}^{a} \pm 1.306$	$14.37_{d}^{b} \pm 1.097$	$16.33_{c}^{a} \pm 1.233$	$15.49_{c}^{b} \pm 1.043$	$68.02_{c}^{a} \pm 3.905$	$68.18_{d}^{a} \pm 2.757$
RF	$47.18_{a}^{a} \pm 4.040$	$47.10_{b}^{a} \pm 3.585$	$4.75_{c}^{a} \pm 0.974$	$4.33_{c}^{b} \pm 0.943$	$16.89_{a}^{a} \pm 0.671$	$16.07_{a}^{b} \pm 0.750$	$17.62_{a}^{a} \pm 0.575$	$16.71_{a}^{b} \pm 0.670$	$74.10_{a}^{a} \pm 3.490$	$74.75_{b}^{a} \pm 3.434$
ST	$43.10_{b}^{b} \pm 4.334$	$45.92_{b}^{a} \pm 3.614$	$5.80_{b}^{a} \pm 1.197$	$5.27_{b}^{b} \pm 1.084$	$16.11_{b}^{a} \pm 0.888$	$16.11_{a}^{a} \pm 0.819$	$17.19_{b}^{a} \pm 0.627$	$17.00_{a}^{a} \pm 0.864$	$70.12_{b}^{b} \pm 4.543$	$71.93_{c}^{a} \pm 3.530$
SS	$38.83_{c}^{a} \pm 2.836$	$39.31_{d}^{a} \pm 2.743$	$6.72_{a}^{a} \pm 0.837$	$6.05_{a}^{b} \pm 0.728$	$15.97_{b}^{a} \pm 0.790$	$15.03_{c}^{b} \pm 0.883$	$17.83_{ab}^{a} \pm 0.659$	$16.25_{b}^{b} \pm 0.728$	$67.09_{c}^{a} \pm 3.138$	$67.99_{d}^{a} \pm 3.108$
LL	$47.73_{a}^{b} \pm 3.970$	$49.82_{a}^{a} \pm 3.456$	$4.64_{c}^{a} \pm 1.037$	$3.67_{d}^{b} \pm 1.039$	$16.83_{a}^{a} \pm 0.845$	$15.59_{b}^{b} \pm 0.524$	$17.51_{a}^{a} \pm 0.826$	$16.07_{b}^{b} \pm 0.539$	$74.56_{a}^{b} \pm 3.452$	$76.73_{a}^{a} \pm 3.698$
LSD $P = 0.05$	1.2975		0.3797		0.3246		0.2947		1.3677	

[#] s.d.: standard deviation.
BF: *biceps femoris*; RF: *rectus femoris*; ST: *semitendinosus*; SS: *supraspinatus*; LL: *longissimus lumborum.*
[a, b, c, d] Column means within a treatment and between muscles with common subscripts do not differ ($P \leq 0.05$).
[a, b] Row means within an attribute and between treatments with common superscripts do not differ ($P \leq 0.05$). LSD: least significant difference ($P = 0.05$).

Table 8 Means (±s.d.)[#] for proximate chemical composition of beef muscles infused with a phosphate and lactate blend

Muscle	Moisture (%)		Protein (%)		Lipid (%)		Ash (%)	
	Control	Infused	Control	Infused	Control	Infused	Control	Infused
BF	$73.17_{b}^{a} \pm 1.548$	$73.61_{c}^{a} \pm 1.489$	$20.21_{a}^{a} \pm 1.203$	$18.13_{bc}^{b} \pm 0.814$	$3.04_{a}^{b} \pm 0.971$	$3.71_{a}^{a} \pm 0.726$	$1.13_{ab}^{b} \pm 0.081$	$1.73_{b}^{a} \pm 0.121$
RF	$74.18_{ab}^{b} \pm 0.747$	$75.84_{ab}^{a} \pm 1.325$	$20.28_{a}^{a} \pm 0.955$	$17.19_{c}^{b} \pm 2.140$	$2.54_{ab}^{a} \pm 0.523$	$2.54_{b}^{a} \pm 0.783$	$1.15_{ab}^{b} \pm 0.020$	$1.91_{a}^{a} \pm 0.087$
ST	$75.10_{a}^{b} \pm 0.936$	$76.99_{a}^{a} \pm 1.250$	$20.71_{a}^{a} \pm 0.800$	$19.25_{ab}^{a} \pm 1.214$	$2.10_{b}^{a} \pm 0.435$	$1.70_{c}^{a} \pm 0.261$	$1.14_{ab}^{b} \pm 0.094$	$1.89_{a}^{a} \pm 0.094$
SS	$75.22_{a}^{b} \pm 0.931$	$76.84_{a}^{a} \pm 1.191$	$20.28_{a}^{a} \pm 0.942$	$18.82_{abc}^{a} \pm 1.043$	$2.95_{a}^{a} \pm 0.617$	$2.47_{b}^{a} \pm 0.378$	$1.06_{b}^{b} \pm 0.144$	$1.74_{b}^{a} \pm 0.122$
LL	$73.84_{b}^{a} \pm 0.685$	$74.62_{bc}^{a} \pm 1.160$	$19.78_{a}^{a} \pm 2.538$	$20.16_{a}^{a} \pm 1.190$	$2.28_{b}^{a} \pm 0.335$	$2.51_{b}^{a} \pm 0.780$	$1.25_{a}^{b} \pm 0.098$	$1.72_{b}^{a} \pm 0.106$
LSD $P = 0.05$	1.260		1.681		0.582		0.116	

[#] s.d.: Standard deviation.
BF: *biceps femoris*; RF: *rectus femoris*; ST: *semitendinosus*; SS: *supraspinatus* ; LL: *longissimus lumborum.*
[a, b, c] Column means within a treatment and between muscles with common subscripts do not ($P \leq 0.05$).
[a, b] Row means within a component and between treatments with common superscripts do not differ ($P \leq 0.05$). LSD: least significant difference ($P = 0.05$).

Table 9 Means (±s.d.)[#] for mineral composition (mg/100 g) of beef muscles infused with a phosphate and lactate blend

Mineral component (mg/100 g)	Muscle										LSD (P =0.05)
	Biceps femoris (BF)		*Rectus femoris (RF)*		*Semitendinosus (ST)*		*Supraspinatus (SS)*		*Longissimus lumborum (LL)*		
	Control	Infused	Control	Infused	Control	Infused	Control	Infused	Control	Infused	
Phosphorus	$180.0_{ab}{}^{a}$±9.928	$157.9_{b}{}^{a}$±29.78	$196.3_{a}{}^{a}$±8.138	$178.5_{ab}{}^{a}$±25.04	$164.1_{bc}{}^{a}$±5.198	$184.0_{a}{}^{a}$ ±35.53	$154.6_{c}{}^{a}$±9.572	$172.8_{ab}{}^{a}$±14.57	$189.8_{a}{}^{a}$±7.922	$158.8_{b}{}^{b}$±25.42	23.58
Potassium	$166.8_{ab}{}^{b}$±16.28	$191.7_{b}{}^{a}$ ±28.93	$163.6_{ab}{}^{b}$±3.209	$199.7_{ab}{}^{a}$±26.53	$161.5_{ab}{}^{b}$±7.329	$215.4_{a}{}^{a}$±35.92	$145.5_{b}{}^{b}$±8.043	$196.6_{ab}{}^{a}$±20.06	$169.9_{a}{}^{a}$± 5.086	$187.5_{b}{}^{a}$± 12.40	22.56
Calcium	$6.35_{a}{}^{a}$±1.301	$4.94_{b}{}^{b}$±1.167	$6.98_{a}{}^{a}$±0.199	$4.73_{b}{}^{b}$±0.889	$6.46_{a}{}^{a}$±0.984	$5.64_{b}{}^{a}$± 0.878	$6.89_{a}{}^{a}$ ± 0.622	$7.89_{a}{}^{a}$ ± 1.813	$7.17_{a}{}^{a}$ ± 0.164	$4.94_{b}{}^{b}$ ± 0.809	1.126
Magnesium	$21.78_{a}{}^{a}$±0.795	$16.29_{ab}{}^{b}$±1.130	$22.49_{a}{}^{a}$±1.126	$15.35_{b}{}^{b}$±2.093	$22.80_{a}{}^{a}$± 0.845	$16.34_{ab}{}^{b}$±1.491	$21.85_{a}{}^{a}$ ±1.885	$17.56_{a}{}^{b}$± 0.922	$21.88_{a}{}^{a}$± 1.706	$16.41_{ab}{}^{b}$±1.943	1.895
Sodium	$12.05_{a}{}^{b}$ ±1.442	$24.43_{bc}{}^{a}$±5.879	$11.15_{a}{}^{b}$ ±0.454	$25.74_{b}{}^{a}$ ±4.298	$10.91_{a}{}^{b}$ ±0.316	$26.27_{b}{}^{a}$ ±3.537	$12.59_{a}{}^{b}$ ±0.974	$30.99_{a}{}^{a}$ ± 5.358	$11.49_{a}{}^{b}$± 0.569	$21.30_{c}{}^{a}$± 3.108	3.968
Iron	$2.73_{a}{}^{a}$ ± 0.608	$1.99_{b}{}^{b}$ ± 0.561	$1.91_{b}{}^{a}$ ± 0.390	$1.73_{b}{}^{a}$ ± 0.346	$2.11_{b}{}^{a}$ ± 0.326	$1.58_{b}{}^{b}$ ± 0.232	$2.95_{a}{}^{a}$ ± 0.350	$2.68_{a}{}^{a}$ ± 0.368	$2.15_{b}{}^{a}$ ± 0.323	$1.63_{b}{}^{b}$ ± 0.201	0.454
Copper	$0.018_{ab}{}^{a}$±0.008	$0.025_{ab}{}^{a}$±0.005	$0.022_{a}{}^{a}$ ±0.004	$0.023_{b}{}^{a}$ ±0.005	$0.017_{ab}{}^{b}$±0.005	$0.032_{a}{}^{a}$ ± 0.004	$0.013_{b}{}^{b}$ ±0.008	$0.027_{ab}{}^{a}$±0.008	$0.016_{ab}{}^{a}$±0.005	$0.022_{b}{}^{a}$ ±0.008	0.008
Zinc	$3.48_{a}{}^{a}$ ± 0.610	$2.28_{d}{}^{b}$ ± 0.628	$4.49_{b}{}^{a}$ ± 0.554	$3.37_{b}{}^{b}$ ± 0.187	$3.54_{cd}{}^{a}$ ± 0.637	$2.45_{cd}{}^{b}$ ± 0.772	$6.03_{a}{}^{a}$ ± 0.638	$4.74_{a}{}^{b}$ ± 0.433	$4.05_{bc}{}^{a}$ ± 0.627	$2.91_{bc}{}^{b}$ ±0.768[f]	0.540
Manganese	$0.028_{a}{}^{a}$ ±0.004	$0.027_{a}{}^{a}$ ±0.005	$0.028_{a}{}^{a}$ ±0.008	$0.020_{b}{}^{b}$ ±0.000	$0.010_{b}{}^{b}$ ±0.000	$0.020_{b}{}^{a}$ ± 0.009	$0.015_{b}{}^{a}$± 0.005	$0.015_{b}{}^{a}$± 0.005	$0.033_{a}{}^{a}$ ± 0.008	$0.030_{a}{}^{a}$ ± 0.000	0.006

[#] s.d.: standard deviation.

$^{a, b, c, d}$ Column means between days within a treatment and within a muscle with common subscripts do not differ ($P \leq 0.05$).

$^{a, b}$ Row means between treatments within an attribute with common superscripts do not differ ($P \leq 0.05$).

LSD: least significant difference (P = 0.05).

The ash content of the infused samples (Table 9) indicated an increase in mineral composition as a result of the blend. Therefore, significant differences in mineral content between treatments are expected. The infused muscle had higher concentrations for K, Na, and Cu, which is expected, because both K and Na are present in the blend infused into the beef muscles. The levels of P were high only in the infused SS muscle – the reason is unknown as it would have been expected that the added phosphate would have accumulated within the infused muscle. The role of the P used in the phosphate blends needs further elucidation. The effect of the infusion on the various muscles is in accord with previous data (Hoffman, 2006).

Conclusions

One of the main objectives of the beef industry is to produce a product of consistent quality, which complies with consumer needs and satisfies the demand for a high-quality beef product (Kerth *et al*., 1995). In the present study the effect of a blend containing sodium and potassium salts, di- and triphosphates and lactates on the pH, water-binding capacity, instrumental meat colour and instrumental tenderness during post-mortem ageing were investigated. The initial proximate and mineral composition of the treated muscles was also determined. The general findings suggest than an increase in tenderness concurrent with minimal changes in beef colour resulted from the infusion with a blend containing sodium and potassium salts, di- and triphosphates and lactates. Thus, infusion with this blend is one of the methods that can be used by South African meat processors to improve traditionally less tender beef cuts. Several corrective actions that are referred to in this study have been investigated by researchers to overcome toughness problems, reduce tenderness variability and increase consumer satisfaction in beef quality (Scanga *et al*., 2000; Baublits *et al*., 2005a; b; Hoffman, 2006). The similarities of the brine solutions applied within these studies and the success achieved by other reported studies give an indication of the success that the blend used in the present investigation could accomplish in the South African beef industry. In conclusion, the infusion of beef muscles with a commercial basting mixture containing sodium and potassium salts, di- and triphosphates and lactates is an effective means of lowering shear force values, without negatively affecting the colour and water-binding abilities. Therefore, this blend could be implemented in current industry practice as a feasible and effective means of improving the tenderness of beef with no detrimental effects to other physical and chemical properties.

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