Influence of $CaCl_2$ and NaCl injections on the texture and flavour of beef

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Summary The present study compares the effects of pre- and post-rigor injections of 0.1 M $CaCl_2$ or 0.15 M NaCl on sensory characteristics (appearance, texture and flavour) and on physical measurements (sarcomere length, drip loss and mechanical resistance of raw myofibres) of beef meat at 2, 6 and 14 days of ageing. An injection of $CaCl_2$ 1 h post-mortem (pH ≈6.8) greatly decreased sarcomere length and myofibrillar resistance, increased drip loss, contracted appearance and brightness, and induced abnormal flavour, mainly bitterness, whatever the ageing time. $CaCl_2$-treatment 1 h post-mortem produced little effect on tenderness during ageing; it was slightly higher at day 2 and lower at day 14 than controls. $CaCl_2$-injection at 24 h post-mortem did not change the sarcomere length but produced a smaller increase in drip loss and a decrease in the resistance of raw myofibres. Improved meat tenderness compared to controls occurred mainly at days 2 and 6 but, during ageing, abnormal flavour appeared by day 6. NaCl-injection had no effect on either sarcomere length or resistance of raw myofibres, but produced higher drip loss and saltier taste at day 14 only. Thus pre-rigor injection of $CaCl_2$ is not recommended because of adverse effects on flavour and appearance of meat. Post-rigor injection of $CaCl_2$ has a beneficial effect on tenderness in the first part of the ageing period, but after complete ageing, the only overall benefit is a decrease in the variability between animals.

Keywords Ageing, calcium and sodium treatments, drip loss, myofibrillar resistance, off-flavour, sensory quality.

Introduction

Many studies have been undertaken with the aim of reducing the ageing time of meat and variability in meat tenderness between animals. In particular, salt solutions containing calcium ions ($CaCl_2$) used in infusion, injection or marination of meat have a positive effect on tenderness (Koohmaraie *et al*., 1990; Morgan *et al*., 1991; Wheeler *et al*., 1992; Whipple & Koohmaraie, 1993; Boleman *et al*., 1995). According to Wheeler *et al.* (1991) and Morgan *et al.* (1991), when carcasses are infused or meat injected with 10% $CaCl_2$ (0.3 M) solutions in the pre-rigor stage, a maximum tenderization can occur as soon as 1 day post-mortem. This tenderizing effect has been attributed to the activation of calpains, the Ca^{++}-dependant proteases, involved in the ageing of meat (Koohmaraie, 1994; Geesink *et al*., 1994) and also to the increase in the intracellular ionic strength inducing protein solubilization (Taylor & Etherington, 1991; Takahashi, 1992). Other salts such as NaCl, $MgCl_2$ and KCl have also been shown to have positive effects on preservation and decreasing toughness, but they were less efficient than $CaCl_2$ (Koohmaraie *et al*., 1988; Alarcón-Rojo & Dransfield, 1995).

Among the various factors which can influence the efficiency of calcium tenderization of meat, the time (pre- or post-rigor) of injection of

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the salt plays an important role, although no agreement on its actual effect on meat tenderness could be reached between authors. When $CaCl_2$ (0.3 M, 10% w/w) was injected post-rigor, Wheeler *et al.* (1992) obtained a tenderization similar to that induced by pre-rigor injection. However, Wheeler *et al.* (1993) showed that $CaCl_2$ (0.175 M, 10% w/w) injection at 24 h post-mortem resulted in a greater reduction in shear force than when $CaCl_2$ was injected at 30 min post-mortem. A detrimental effect of pre-rigor $CaCl_2$ (0.3 M, 10% w/w) injections on tenderness was even obtained after a 7-day-ageing period by Benito-Delgado *et al.* (1994). In contrast, Boleman *et al.* (1995) found that the greatest degree of tenderization was achieved after pre-rigor injection of the same amount of $CaCl_2$. The mechanisms involved in the modification of texture induced by calcium injection are especially due to the actions of calpains. Indeed, when treatment occurred in the pre-rigor period, Got *et al.* (1994) and Geesink *et al.* (1994) observed a very strong contraction, drastic changes in meat structure and great drip losses which did not occur in meat injected post-rigor; this might have a stronger influence on texture than the activation of calpains and the increase in ionic strength. Wheeler *et al.* (1993) and Eilers *et al.* (1994) noted that sour, bitter and livery flavours were present in $CaCl_2$ injected meat, more especially when the amount of calcium was high (> 0.2 M, 5% w/w). However, Landsell *et al.* (1995) showed that post-rigor $CaCl_2$ injection (0.2 M, 5% w/w) improved beef steak tenderness and reduced tenderness variation. In recent studies, supermarket consumers (Miller *et al.*, 1995) and restaurant consumers (Hoover *et al.*, 1995) well accepted and even preferred such treated steaks. However, these authors did not report tenderness values beyond 7 days of storage.

Most of these earlier works evaluated texture by measuring shear force. The present study was carried out in order to determine the influence of pre- or post-rigor treatments of calcium chloride or sodium chloride on the sensory attributes of texture and the flavour of meat after 3 different ageing stages (2, 6 and 14 days). Sarcomere length, drip loss and ageing index were also measured.

Materials and methods

Animals

Three Friesian cull cows (3, 5 and 6 years old), of 269, 258 and 270 kg carcass weights, were conventionally slaughtered without electrical stimulation. *Longissimus* muscles were excised 1 h after slaughter and cut into 2.5 cm-thick steaks (about 150 g).

Treatments

Samples from each animal were injected with an eight needle (0.6 × 25 mm) multi-pipette at various and regular locations to ensure a homogeneous distribution of solution. Controls consisted of non-treated samples. After the injection, the samples were weighed, vacuum-packed and stored at 15°C until rigor mortis and then at 4°C until analysis. All treated samples and controls were analysed after 2, 6 and 14 days of ageing.

Some of our previous experiments (non-published data) showed that, at day 14, samples treated with 0.3 M $CaCl_2$ (pre-rigor or post-rigor) were unacceptable because of a bitter taste and strange flavours. Samples injected with 0.6 M NaCl were also distinguished by their much saltier taste. In contrast, other treatments such as injection of water or piercing with the needles used for the injection did not have any effect on sensory characteristics. We chose to eliminate treated samples which were either too different from or too similar to the control. Thus, the treatments used were: 10% of cut weight of solution of 0.1 M $CaCl_2$ and 10% of cut weight of solution of 0.15 M NaCl, with approximately the same theoretical ionic concentration (40 mg Ca per 100 g of meat; 34.5 mg Na per 100 g of meat). The injections were performed either at 1 h post-mortem (pre-rigor, pH 6.8 ± 0.1) or 24 h post-mortem (post-rigor, pH 5.5 ± 0.1). Four different treatments were compared to the controls (CONT): $CaCl_2$-injected pre-rigor (Ca0), $CaCl_2$-injected post-rigor (Ca1), NaCl-injected pre-rigor (Na0) and NaCl-injected post-rigor (Na1).

Cooking and sensory analysis

Fresh meat was grilled at 310°C for 2 min to reach a core temperature of 55°C using a sand-

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wich contact grill (Turmix Sofraca). Samples were served immediately to 12 trained assessors who, during a session, monadically tested samples of meat from the same animal subjected to each treatment and at a given ageing stage (i.e. 5 samples in all per session). The same assessors participated in all the sessions.

Eleven sensory attributes of appearance (contracted, bright), texture (tender, fibrous, elastic, juicy), taste (salty, bitter) and flavour (meaty, abnormal, and persistence of abnormal flavour) were selected by the panel to describe the meat sample; each was evaluated by the assessors on non-structured scales (15 cm long) by placing a cursor on the scale at the point which best described the intensity of each.

Physical measurements

Twenty-four sarcomere lengths (μm) were measured on each glutaraldehyde-fixed sample at day 6 by diffraction of a laser beam (Cross *et al.*, 1980–81).

Drip losses (% w/w) were determined at 2, 6 and 14 days post-mortem by weighing samples before and after storage.

Myofibrillar mechanical resistance (Ncm^{-2}) of raw meat was analysed at 2, 6 and 14 days post-mortem according to Lepetit *et al.* (1986). A linear compression (50 mm min^{-1}) was performed on raw meat samples, perpendicularly to the myofibre axis, using a universal testing machine with a cell equipped with 2 lateral walls. In these conditions, the stress reached at a 0.2 strain is characteristic of the mechanical resistance of myofibres and can be used as an ageing index (Lepetit & Buffière, 1995).

Statistical analysis

The effect of treatment on sarcomere length at day 6 was analysed with 2-way ANOVA with treatment as a fixed effect and the animal as a random effect.

Several measurements of drip loss, myofibrillar resistance and sensory data were recorded on the same meat samples during ageing. Repeated measures analysis of variance was used for drip loss and myofibrillar resistance, and multivariate analysis of variance (MANOVA models) for the sensory data; both are especially designed for the analysis of repeated measurements. The first one is more appropriate when the hypothesis of sphericity holds, i.e. correlation between times are all equal, and the second one is used when the sphericity criterion does not occur (Schlich, 1993). Two-way models of the factor treatment (fixed effect) and animal (random effect) were performed with the instrumental and sensory data. These models showed if there was a treatment effect on sensory analysis, drip loss and myofibrillar resistance over time, an ageing time effect over treatments and an interaction treatment × ageing time. In the case of MANOVA, the statistic of Wilks' Lambda approximated by the *F*-value of Fisher with a special degree of freedom, was used to test the factor effects. When the treatment effect was significant ($P < 5\%$), Dunnett's test of multiple mean comparisons was performed at each ageing stage to compare the controls with the treated samples (Dunnett, 1964).

Principal component analysis (PCA) was carried out on the panel mean sensory data. The data matrix has 45 lines (5 treatments × 3 ageing stages × 3 animals) and 11 columns for the sensory variables recorded. The samples are represented by a configuration of points in an 11-dimensional space. The purpose of PCA is to successively find the line, the plane and the 3-dimensional space which give the most informative representation of the whole configuration. The principal components are given by the first eigenvectors of the correlation matrix, which are linear combinations of the variables. The percentage of information explained by the first principal plane is obtained by summing the first two eigenvalues. Correlations between principal components and variables determine the sample location on the principal plane in terms of initial variables (Caillez & Pages, 1976).

Results and discussion

Analysis of variance and multiple comparison test on physical variables

The effect of all the treatments together was highly significant ($P < 0.001$) for sarcomere length at day 6 (Table 1). The multiple comparison test (Table 2) showed that the pre-rigor injection of $CaCl_2$ (Ca0) produced much shorter sarcomere

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Table 1 Influence of treatment on physical variables. Results of univariate analysis of variance for sarcomere length. Results of repeated measures analysis of variance for drip loss and myofibrillar resistance

	Factors					
	Treatment		**Ageing time**		**Treatment × Time**	
Degrees of freedom	(4, 8)		(2, 16)		(8, 16)	
Physical variables	F	p⁺	F	p⁺	F	p⁺
Sarcomere length	16.9	***	—		—	
Drip loss	202.6	***	168.3	***	4.8	**
Myofibrillar resistance	6.3	*	28.4	***	2.4	NS

⁺: Level of significance (NS: not significant, *: $P < 0.05$, **: $P < 0.01$, ***: $P < 0.001$).

length than the controls, findings in agreement with the results of Morgan *et al.* (1991) and Geesink *et al.* (1994). This strong contraction has also been obtained by Got *et al.* (1994), who observed drastic changes in the myofibrillar structure of pre-rigor treated meat, in particular, disappearance of the Z-line and partial solubilization of the thick filament. Post-rigor $CaCl_2$ or NaCl injections had no effect on sarcomere length.

A significant effect of treatment, of ageing time and a significant interaction treatment × ageing time was observed for drip loss (Table 1). The treated samples were separated from the controls by multiple comparison tests at day 2, 6 and 14 (Table 2). Controls exhibited less drip loss than all other treatments at each ageing time. Although pre- and post-rigor sodium (Na0 and Na1) and post-rigor calcium (Ca1) treated samples exuded some 5% more than controls by day 14, they lost only about the 10% that accounted for the volume of injected solution. In contrast, Ca0 samples had an almost immediate drip loss of 26% (i.e. more than twice the injected volume) with little further loss, whereas drip from the other samples continued to increase. The pre-rigor $CaCl_2$-injection caused drastic contraction and myofibrillar disorganization which were responsible for this enormous drip loss. Diles *et al.* (1994) and Geesink *et al.* (1994) have also shown that the drip loss was much higher with pre- rather than post-rigor $CaCl_2$ injection**.** However**,** Boleman *et al.* (1995) did not find any difference in drip loss when $CaCl_2$ injection was performed pre- or post-rigor. Their different results could have been the result of either the injection method (single-needle) or the large size of samples (*semimembranosus* cut in four segments). The difference in methodology could have led to different penetration and much less diffusion of $CaCl_2$ solutions throughout the sample.

The effect of treatments on myofibrillar mechanical resistance over time was significant (Table 1), but only $CaCl_2$-treated samples at day 2 were significantly reduced from those of the controls (Table 2); this has been systematically observed previously (Got *et al.*, 1994). Our results confirmed those of Wheeler *et al.* (1993) who

Table 2 Means and standard deviations of physical variables for the meat samples at different ageing times (day 2, 6 and 14). Results of Dunnett's test for multiple comparisons with the controls for sarcomere length, drip loss and myofibrillar resistance

Treatment	**Sarcomere length (μm)**	**Drip loss (%)**			**Myofibrillar resistance (N cm⁻²)**		
	D6	**D2**	**D6**	**D14**	**D2**	**D6**	**D14**
Control	2.02 ± 0.04	2.65 ± 0.32	3.43 ± 0.61	5.69 ± 1.89	14.76 ± 5.06	8.32 ± 5.56	6.18 ± 4.58
Na0	1.96 ± 0.09	5.54 ± 0.75*	6.52 ± 0.86*	9.78 ± 1.24*	9.87 ± 0.60	6.81 ± 5.52	4.02 ± 1.31
Na1	2.08 ± 0.09	4.95 ± 1.36*	6.81 ± 0.65*	9.64 ± 0.51*	9.36 ± 4.81	6.35 ± 4.53	4.30 ± 1.63
Ca0	1.36 ± 0.24*	24.42 ± 2.49*	25.78 ± 2.96*	26.46 ± 3.23*	4.34 ± 1.57*	4.16 ± 1.21	3.47 ± 0.37
Ca1	2.01 ± 0.06	4.74 ± 0.97*	7.05 ± 0.64*	10.15 ± 1.25*	6.85 ± 3.51*	4.64 ± 2.28	3.75 ± 1.05

Na0: samples injected with NaCl at 1 h *post-mortem*, Na1: samples injected with NaCl at 24 h *post-mortem*.
Ca0: samples injected with $CaCl_2$ at 1 h *post-mortem*, Ca1: samples injected with $CaCl_2$ at 24 h *post-mortem*.
In a column, treatments with * significantly differ from the controls ($P < 0.05$).

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found that shear force was reduced in $CaCl_2$-treated muscle. Myofibrillar resistances of Na0 and Na1 were lower but not significantly than that of the controls. Geesink *et al.* (1994) found that pre- or post-rigor treatment with $CaCl_2$ or NaCl improved tenderization in muscle.

Differences in myofibrillar resistance between treated samples and controls were probably not significant at day 6 and 14 because of the large variations within some treatments (CONT, Na0 and Na1) because of the inter-animal differences (Table 2). Touraille *et al.* (1990) have also shown that standard deviations measured in untreated meat after 14-day ageing are high because of the variability of ageing rate among animals.

Ageing time was a significant factor for the resistance of raw myofibres: for all the treatments, myofibrillar resistance decreased over time. The final raw myofibre resistance (at day 14) of all the treated samples was about 50% lower than those at day 2 except for Ca0 samples which practically did not age after day 2, being already lower than the controls aged 14 days. These results are in agreement with those of Lepetit & Buffière (1995).

Analysis of variance on sensory characteristics of grilled beef

Treatment, ageing and interaction effects

All the sensory attributes except elasticity and fibrousness were influenced by the various treatments over time (Table 3), with the most significant results obtained for brightness, saltiness and persistency of abnormal flavour.

Ageing time was very highly significant for perceived meat tenderness, and significant also for persistency of abnormal flavour, contracted appearance, meat flavour and bitterness (Table 3).

The effects of ageing time on contracted appearance, brightness, meat flavour and abnormal flavour were different for the five treatments studied, as shown by the significant interactions treatment × ageing time for these attributes. Indeed, the contracted appearance of $CaCl_2$-treated samples increased more with ageing time than that of the NaCl-treated samples (Tables 4, 5 and 6). Also, the brightness of the $CaCl_2$-treated samples increased with ageing time while that of the NaCl-treated samples did not. The intensity of meat flavour of Ca0 was low and decreased with time as persistency and level of abnormal flavour increased dramatically; Cal only increased in both abnormal flavour attributes at 14 days, whilst the controls and NaCl-treated samples varied little over time. These observations explain the significant interaction treatment × ageing time for the meat flavour and persistency attributes.

Multiple comparison tests

Day 2 (Table 4)

Ca0 samples were significantly brighter, saltier, more bitter and had a more intense and persistent abnormal flavour than the controls. Tenderness

Table 3 Influence of treatment over ageing time, of ageing time and of the interaction treatment × ageing time on sensory characteristics. Results of multivariate analysis of variance

	Factors					
	Treatment		**Ageing time**		**Treatment × Time**	
Degrees of freedom	(12, 16.2)		(2, 7)		(8, 14)	
Attributes	F	p⁺	F	p⁺	F	p⁺
Contracted appearance	5.2	**	6.3	*	4.0	*
Brightness	14.4	***	4.3	NS	7.6	***
Tenderness	2.9	*	32.7	***	2.4	NS
Fibrousness	1.1	NS	1.8	NS	0.8	NS
Elasticity	0.6	NS	0.8	NS	0.3	NS
Juiciness	4.6	**	2.2	NS	0.7	NS
Meat flavour	5.2	**	5.9	*	3.5	*
Abnormal flavour	4.0	**	3.4	NS	2.1	NS
Saltiness	5.8	***	0.6	NS	1.7	NS
Bitterness	3.5	**	8.2	*	1.0	NS
Persistency of abnormal flavour	8.6	***	10.1	**	6.4	**

⁺: Level of significance (NS: not significant, *: $P < 0.05$, **: $P < 0.01$, ***: $P < 0.001$).

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Table 4 Means of the sensory attributes (ageing: day 2). Results of Dunnett's test for multiple comparisons with the controls

Code	**Cont**	**Ca0**	**Cal**	**Na0**	**Nal**
	Control	**0.1 M $CaCl_2$**	**0.1 M $CaCl_2$**	**0.15 M NaCl**	**0.15 M NaCl**
Meat pH at injection		**pH 6.8**	**pH 5.5**	**pH 6.8**	**pH 5.5**
Attributes					
Contracted appearance	10.4	12.2	7.9	9.1	10.3
Brightness	10.1	13.1*	8.8*	9.7	9.5
Tenderness	7.1	8.3	10.0*	7.3	7.5
Fibrousness	11.7	12.0	11.3	11.5	11.3
Elasticity	11.6	10.8	11.4	11.9	11.3
Juiciness	11.0	9.9	12.5	11.9	11.8
Meat flavour	10.9	8.7*	10.6	10.8	11.0
Abnormal flavour	4.1	7.2*	4.7	4.1	4.4
Saltiness	4.9	6.5*	5.7	5.5	4.8
Bitterness	2.9	3.8*	3.2	2.9	3.0
Persistency of abnormal flavour	3.7	6.3*	4.4	4.0	4.0

In a row, treatments with * significantly differ from the controls ($P < 0.05$).

of Ca0 was not significantly different from that of the controls. However, Morgan *et al.* (1991) and Geesink *et al.* (1994) found that meat samples injected pre-rigor with $CaCl_2$ were significantly more tender than the controls after 1 or 2 days of ageing. This difference could be explained by the higher concentration of $CaCl_2$ (0.3 M) they used.

Samples injected post-rigor with $CaCl_2$ were significantly less bright and much more tender than controls.

Tenderness scores of Ca0 were not in exact agreement with the mechanical resistances of raw myofibres: pre-rigor treated samples exhibited a much lower physical resistance than the controls while they were not rated significantly tender. This phenomenon has already been observed whenever sarcomeres were very shortened because of cold- or thaw-shortening or pre-rigor cooking (Hericher & Culioli, 1988; Hericher *et al.*, 1988). In that case, the behaviour of raw meat did not parallel that found in the cooked case.

Samples treated with 0.15 M NaCl were not distinguished with regard to appearance, texture or flavour attributes from the controls whereas

Table 5 Means of the sensory attributes (ageing: day 6). Results of Dunnett's test for multiple comparisons with the controls

Code	**Cont**	**Ca0**	**Ca1**	**Na0**	**Na1**
	Control	**0.1 M $CaCl_2$**	**0.1 M $CaCl_2$**	**0.15 M NaCl**	**0.15 M NaCl**
Meat pH at injection		**pH 6.8**	**pH 5.5**	**pH 6.8**	**pH 5.5**
Attributes					
Contracted appearance	9.4	13.2*	8.5	9.5	8.9
Brightness	8.8	15.0*	9.4	9.7	9.1
Tenderness	9.0	9.4	12.6*	10.2	10.7
Fibrousness	10.7	12.1	10.1	10.0	11.2
Elasticity	11.6	10.1	10.9	11.1	10.3
Juiciness	11.1	9.5	13.0	11.5	12.3
Meat flavour	12.3	7.4*	10.7*	11.6	12.0
Abnormal flavour	3.4	9.1*	5.3	4.1	3.4
Saltiness	4.3	6.8*	6.0*	5.4	5.3
Bitterness	2.8	4.2*	4.0*	3.0	3.0
Persistency of abnormal flavour	3.1	7.9*	4.0	3.8	3.1

In a row, treatments with * significantly differ from the controls ($P < 0.05$).

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Geesink *et al.* (1994) found that pre- or post-rigor 0.6 M NaCl treatment improved tenderness at 2 days post-mortem.

Day 6 (Table 5)

As at day 2, Ca0 samples were perceived brighter, saltier, more bitter than the controls and with an abnormal flavour. In addition, they were distinguished by a more contracted appearance. No difference in tenderness could be observed.

Ca1 samples were more tender than the controls in agreement with the findings of Wheeler *et al.* (1993); they appeared saltier, more bitter and with less meat flavour than the controls. Wheeler *et al.* (1993) and Eilers *et al.* (1994) also found some off-flavours in the $CaCl_2$ treated samples, but at concentrations greater than 0.2 M (5% w/w). The other samples treated with 0.15 M NaCl were not distinguished from the controls, as at day 2.

Day 14 (Table 6)

The same sensory attributes were significantly affected at day 14 by Ca0 treatment as at day 6. Tenderness of Ca0 samples barely increased (8.3, 9.4 and 9.4 at day 2, 6 and 14, respectively), and were never significantly different from the controls aged 14 days (7.1, 9.0 and 10.4). The typical meat flavour of Ca0 decreased with ageing (8.7, 7.4 and 6.5 at day 2, 6 and 14, respectively) whilst persistency of abnormal flavour increased. Other studies (Morgan *et al.*, 1991; Eilers *et al.*, 1993) also found that $CaCl_2$ injection can lead to bitter and salty flavour notes. Morgan *et al.* (1991) reported that 0.3 M $CaCl_2$-injected strip loin resulted in bitter and metallic off-flavours; flavour increased in intensity during storage (1, 7 and 14 days) but as they did not specify the nature of this flavour, no direct comparison can be made with the present results.

Ca1 samples showed the same differences from the controls as above, except that tenderness was no longer significantly different, although still higher than that of the controls. While tenderness of the control increased regularly with ageing, that of the samples treated post-rigor with $CaCl_2$ increased but then did not change between day 6 and 14 (12.6 and 11.8, respectively). There was no difference in juiciness between the controls and the $CaCl_2$ injected samples, in agreement with Morgan *et al.* (1991) and Wheeler *et al.* (1993). The persistency of abnormal flavour of Ca1 became significantly different from that of the controls between 6 and 14 days (4.0 and 6.2, respectively); it was always less than in Ca0.

Samples injected with 0.15 M NaCl were always similar to the controls except for saltiness: samples treated post-rigor were significantly saltier. NaCl treatment never improved tenderization, whereas Geesink *et al.* (1994) found a positive effect of pre- and post-rigor injection of beef *longissimus M.* with a much higher concentration of NaCl (0.6 M).

Table 6 Means of the sensory attributes (ageing: day 14). Results of Dunnett's test for multiple comparisons with the controls

Code Meat pH at injection	Cont Control	Ca0 0.1 M $CaCl_2$ pH 6.8	Ca1 0.1 M $CaCl_2$ pH 5.5	Na0 0.15 M NaCl pH 6.8	Na1 0.15 M NaCl pH 5.5
Attributes					
Contracted appearance	10.5	13.5*	11.4	10.0	9.5
Brightness	9.2	14.5*	10.0	10.2	9.3
Tenderness	10.4	9.4	11.8	11.3	10.5
Fibrousness	11.0	12.9	10.6	11.0	10.4
Elasticity	11.4	10.9	10.5	11.0	10.6
Juiciness	9.8	8.7	10.5	11.9	12.2
Meat flavour	11.7	6.5*	9.6*	11.6	12.5
Abnormal flavour	3.7	10.2*	6.6*	4.0	3.8
Saltiness	4.1	6.7*	5.1	4.7	5.9*
Bitterness	3.2	4.9*	4.4	3.2	3.4
Persistency of abnormal flavour	3.2	8.9*	6.2*	3.4	3.4

In a row, treatments with * significantly differ from the controls ($P < 0.05$).

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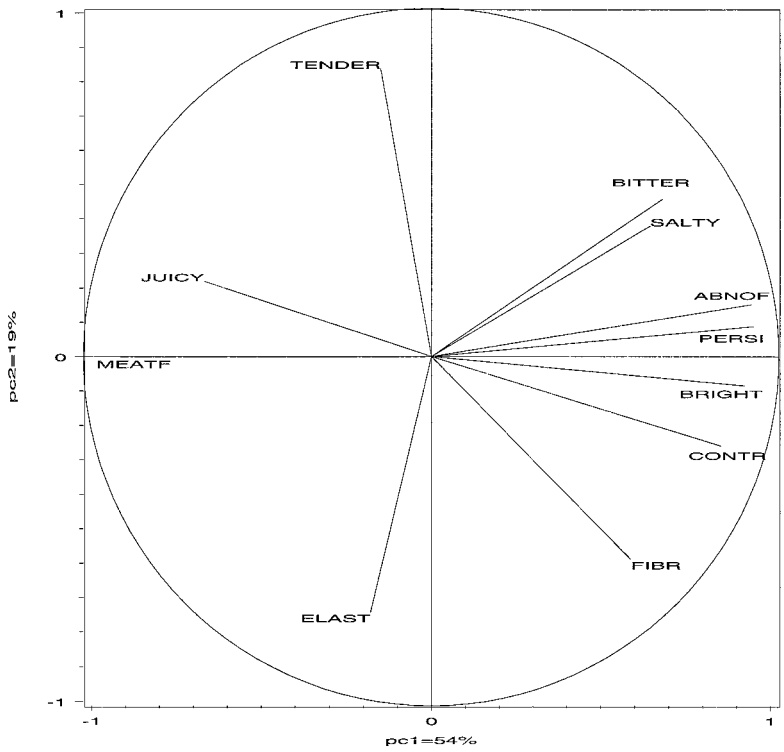

Figure 1 Correlation circle. CONTR: contracted appearance, BRIGHT: brightness, TENDER: tenderness, FIBR: fibrousness, ELAST: elasticity, JUICY: juiciness, MEATF: meat flavour, ABNOF: abnormal flavour, SALTY: saltiness, BITTER: bitterness, PERSI: persistency of abnormal flavour.

Principal component analysis (PCA)

The first two components of the PCA accounted for 73% of the variations in the sensory properties of the different meat samples. The third and following ones are not described because they accounted for too low a percentage of variance (8% for the third and 6% for the fourth). In Fig. 1, the end of the line variables define the directions for the corresponding variables. The longer a line, the better the variable explains the sample plot. The first principal component (PC1) showed an opposing relationship between the positively correlated abnormal flavour, persistency of abnormal flavour, contracted appearance, brightness, saltiness, bitterness and the negatively correlated typical meat flavour and juiciness (Fig. 1). The second principal component (PC2) showed a good positive correlation with tenderness and a negative correlation with elasticity and fibrousness.

The effect of ageing (day 2, 6 and 14) and of treatments (NaCl and $CaCl_2$) is shown in Fig. 2. The triangles correspond to the same treatment and the same ageing time for the three animals. On the one hand, nearly all the samples at day 2 were located at the bottom of the figure because of their toughness. Moreover, the control samples taken from animal 'b' were also located in this area, whatever the ageing state. Meat from this animal did not age like the others and assessors clearly perceived differences in toughness. On the other hand, the samples injected with $CaCl_2$ in the pre-rigor stage were located in the right quadrants of the plot and were associated with the characteristics of abnormal flavour, bitterness, brightness and contracted appearance. Ageing further increased the perception of these characteristics. At day 2, two out of three samples (animals 'a' and 'c') injected post-rigor with $CaCl_2$ were located in the top left quadrant and were associated with perception of a high tenderness. The third one (animal 'b') located beside the controls, was perceived as tough as the control sample of the same animal. The variation in sensory characteristics with ageing was also noticeable: tenderness increased between day 2 and 6, while saltiness and abnormal flavour tended to rise between day 6 and 14. Samples injected with NaCl were located close to the controls, at each stage of ageing. For these samples, as for the con-

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trols, we mainly observed a change in texture, i.e. an increase in tenderness between day 2 and day 6. It can also be seen from the PCA plots that the triangles corresponding to the pre- or post-rigor $CaCl_2$ treatments were smaller than those of the controls, especially at day 14, which means that the treatments tended to reduce the inter-animal sensory differences.

Conclusion

Injection of $CaCl_2$ (0.1 M) and NaCl (0.15 M) solutions (10% dose w/w) modified the sensory properties of meat but the changes were different depending on the time of treatment post-mortem (pre-rigor or post-rigor) and the ageing time (2, 6 and 14 days). Samples injected with $CaCl_2$ in the pre-rigor state were always distinguished from the controls by their abnormal taste and flavour which increased with ageing time. Moreover, no significant improvement in tenderness could be noted.

Samples injected post-rigor with $CaCl_2$ had a completely different behaviour from samples treated pre-rigor. Tenderness was improved over that of the controls, but only at the beginning of the ageing process. An abnormal and bitter flavour appeared after some days of ageing and then increased with subsequent storage. Injection with NaCl did not modify tenderness but sometimes increased the salty taste.

In the experimental set-up used here (injection of meat slices), we can conclude that pre-rigor injection of calcium has to be avoided as it presents too many deleterious effects on the appearance and flavour of meat and has no advantages over meat that is allowed to age normally (no cold-shortening, no β-agonist treatment, storage time long enough). The positive aspects of calcium treatments performed post-rigor are a reduction of the variability in meat quality among animals and an acceleration of the tenderization in the first few days of storage.

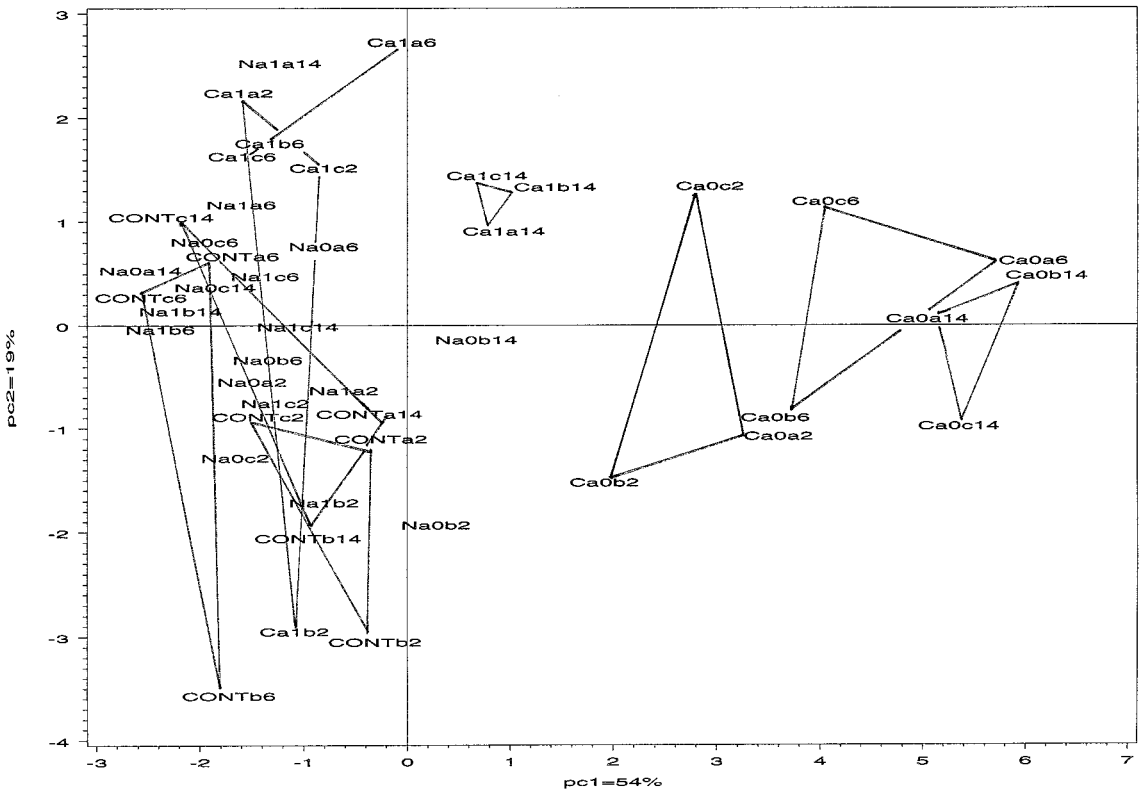

Figure 2 Sample plot. Samples are identified by the treatment: CONT (control), Na (0.15 M NaCl) or Ca (0.1 M $CaCl_2$) followed by the time of injection: 0 (1 h *post mortem*, pH 6.8) or 1 (24 h *post mortem*, pH 5.5) followed by the code of animal: a (animal a), b (animal b) or c (animal c) followed by the ageing time: 2 (day 2), 6 (day 6) or 14 (day 14).

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