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Shelf life of beef from local Spanish cattle breeds stored under modified atmosphere

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Abstract

Beef steaks from six Spanish cattle breeds (Asturiana de los Valles, Morucha, Parda Alpina, Pirenaica, Rubia Gallega and Retinta) were packaged under modified atmosphere (60% O_2, 30% CO_2 and 10% N_2). Water loss, pH, thiobarbituric acid values (TBA), aerobic plate counts, lactic acid bacteria and *Enterobacteriaceae* counts, CIE $L^*a^*b^*$ colour values and the sensory properties of odour and colour were recorded before packaging (day 0) and after 5, 10 and 15 days of storage. A significant interaction ($P < 0.05$) between breed and storage time was found for all variables, except water loss. Values of pH were between 5.3 and 5.6; maximum water loss (2.64%) was reached after 10 days of storage; aerobic plate counts, lactic acid bacteria and *Enterobacteriacea* counts were lower than 10^7 CFU/g, and L^* increased with storage time while a^* decreased ($P < 0.05$). The maximum shelf life of beef assessed by sensory evaluation (regarding colour and odour degradation) was between days 5 and 10 in meat from Retinta breed and between days 10 and 15 in meat from the other breeds, shelf life was probably limited by lipid oxidation. © 2000 Published by Elsevier Science Ltd.

Keywords: Packaging; Breed; Beef; Quality; Shelf life

1. Introduction

Although in the past, livestock systems have usually intensified to increase production, more recently interest has focused on meat quality. There is also an increasing trend to centralised cutting and packaging of meat.

There are many factors that influence meat quality before and after slaughter. One of the main factors is breed because it influences the growth and development of the animal and the quality of meat, mainly due to genetic differences and productive purpose (dairy or beef). With the aim of improving the profitability of farms that rear local cattle breeds, policy has moved to guaranteeing meat quality using the European Union Regulation 2081/92 to establish regional and quality assurance labels.

After slaughter, there are many factors that determine meat quality, including temperature and time of ageing (Lochner, Kauffman & Marsh, 1980) and packaging (Beriain & Lizaso, 1997; Young, Reviere & Cole, 1988). Packaging is the last step in the production process and needs to be standardised if high quality meat is to be obtained. In packing red meat, one of the most common methods is the use of modified atmospheres, usually mixtures of carbon dioxide, oxygen and nitrogen. More information is needed on the effect of these gases on meat quality. An important variable that must be considered is the initial pH of the meat. For example, dark, firm and dry meat (DFD) with a pH > 6.0 should not be stored under modified atmosphere since spoilage occurs more readily than in beef of normal pH (Foegeding, Naumann & Stringer, 1983). Water holding capacity, texture, tenderness (Dutson, 1983), and meat colour (Guignot, Tourraille, Quali, Renerre & Monin, 1994) are also influenced by pH.

A main objective of packaging meat is to delay the growth of aerobic gram negative bacteria, especially *Pseudomonas*, which are responsible for spoilage and are the predominant flora in the presence of oxygen. In

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modified atmospheres this flora is replaced by lactic acid bacteria (Lee, Simard, Layele & Holley, 1983), that develop a homolactic metabolism. This does not have an off-odour if the concentration of glucose in the meat is adequate (Lee, Sebranek & Parrish, 1996). When spoilage by micro-organisms is prevented, other factors, such as lipid oxidation, cause deterioration.

The hydration properties of meat determine its ability to retain water during packing and processing (Boakye & Mittal, 1993). These properties also influence the tenderness, juiciness, firmness and appearance of meat (Offer & Knight, 1989). Water loss is of economic concern because it affects weight loss along the distribution chain and during cooking.

Colour is the most important factor for consumers when purchasing meat (Kropf, 1980). It depends on the concentration of myoglobin at the meat surface, its chemical state and the structure of the muscle surface, which is directly related to pH (Agullo, Centurrion, Ramos & Bianchi, 1990). Myoglobin has a purple colour when it is in the reduced state; it oxygenates in the presence of oxygen giving a brilliant red colour, but can oxidise to metmyoglobin to give the meat a brownish colour (Rosset & Roussel-Ciquard, 1978). The proportion of the different states of myoglobin at the meat surface changes with storage and the atmosphere around the meat and may determine the shelf life of the meat.

Due to the importance of packaging in the production chain of high quality meat and to the relative small number of studies on the effect of breed on the quality of meat packaged under modified atmosphere, the aim of this work was to study the differences in meat quality parameters in meat from six Spanish cattle breeds packaged in a commonly used commercial modified atmosphere.

2. Material and methods

36 young entire bulls from six different Spanish cattle breeds (six animals/breed) were used: Retinta, Morucha, Parda Alpina, Pirenaica, Rubia Gallega and Asturiana de los Valles. These are all breeds reared for meat production, except for Parda Alpina, which is a dual purpose breed and was introduced into Spain from Switzerland at the end of the last century (MAPA, 1986). Morucha and Retinta cattle are kept in extensive systems from the West and South of Spain, whereas Rubia Gallega, Pirenaica and Asturiana de los Valles are larger, have lower fat contents at typical Spanish slaughter weights and produce carcasses of higher value.

After weaning, when the bulls weighed 220–260 kg at 6–8 months, they were managed in groups of six at the Agricultural Research Service (Dirección General de Agricultura, Zaragoza, Spain). They were fed commercial concentrate and barley straw, ad libitum.

Animals were slaughtered in a commercial abattoir when the group mean live weight was approximately 470 kg, in order to eliminate the effect of live weight.

After 24 h postmortem, carcasses were graded for fatness (grades 1–5) and conformation (EUROP, EU Regulation No. 2930/81). The *longissimus dorsi* muscle was removed from the left carcass side and cut into 2–3 cm thick steaks. Initial measurements (day 0) were made and steaks were placed in plastic foam trays and packed in pouches of polyamide/polyethylene (120 μm and 1 cc/m^2/24 h O_2 permeability, 3 cc/m^2/24 h CO_2 permeability and 0.5 cc/m^2/24h N_2 permeability measured at 5°C and 75% relative humidity; water vapour transmission rate (WVTR) was 3 g/m^2/24h at 38°C and 100% RH; the vicat softening point of sealing was reached at 97°C and it had a dart drop strength of 1,300 g; Vaessen Schoemaker Ind., Barcelona, Spain) before flushing with 60% O_2, 30% CO_2 and 10% N_2 (Extendapack 52) with an EGARVAC machine.

Samples were kept at 2±1°C in the dark and 90–95% relative humidity until analysed at (5, 10 and 15 days). Measurements were made on fresh samples, except for lipid oxidation which was carried out on samples that were vacuum packaged and stored at −20°C after modified atmospheric storage.

2.1. Physical variables

An Orion Research potentiometer for solid samples was used to measure pH (ISO, 1974) of the samples in water homogenates.

Water loss was estimated by weighing the empty pack (W_p) and the pack with meat (W_{p+m}) on day 0. After storage the meat was removed from the pack and the weight of the pack plus the juice (W_{p+j}) was recorded. Water loss was expressed as a percentage of the initial weight of the meat:

$$\%\ \text{water loss:}\frac{(W_{p+j})-(W_p)}{(W_{p+m})-(W_p)}\times 100$$

2.2. Lipid oxidation

Thiobarbituric acid values (TBA) as described by Tarladgis, Watts and Younathan (1960) were determined in duplicate for each batch×time×breed combination. Absorbancies at 532 nm, measured with a Shimadzu spectrophotometer (model UV-2101 PC), were converted to mg malonaldehyde/kg meat and are reported as TBA values.

2.3. Microbiological evaluation

The meat samples were removed from the pouches using sterile scalpels and forceps. Two cores, of 10±0.1 g, were aseptically removed from each sample and

blended with a 90 ml of 1% tryptone solution (w/v) for 60 s in a Stomacher (Lab Blender 400; Seward Medical, London, UK). Additional dilutions were made in 1% tryptone (w/v). Then 1 ml of the undiluted homogenate and of each dilution were spread on duplicate plates. Bacterial numbers were determined from plates bearing 30–300 colonies. Counts were obtained as follows: Aerobic plate counts on Plate Count Agar (Difco®), incubated at 32°C for 48 h; *Enterobacteriaceae* on Violet Red Bile Glucose Agar (Difco®) overlaid with the same medium and incubated at 37°C for 24 h, and Lactic acid bacteria on *Lactobacilli* MRS Broth (Difco®) + Bacto Agar (Difco®) and glacial acetic acid (Panreac), incubated at 32°C for 48 h in a Heraeus electronic chamber with 5% CO_2. Although this medium is specific for *Lactobacilli*, Ledda, Floris, Mannu and Santu (1996) in studies carried out on cheese, found that other lactic acid bacteria can also grow in this medium.

2.4. Colour evaluation

CIE (1976) $L^*a^*b^*$ colour values were measured using a Minolta CM2002 spectrophotometer with a D65 illuminant and a 10° standard observer. Measurements were averaged over five non-overlapped zones of each steak, changing the instrument orientation each time. They were made directly on the meat surface immediately after opening the pouches. More detailed information about colour evaluation of these samples was reported previously (Insausti, Beriain, Purroy, Alberti, Lizaso & Hernandez, 1999).

2.5. Sensory evaluation

Quantitative descriptive analysis (Stone, Sides, Oliver, Wolsey & Singleton, 1974) was used to assess beef odour and colour degradation by a trained sensory panel. Batches were assessed for colour before opening the pouches and for odour just after opening. Panellists rated odour and colour using a 150 mm line anchored at each end with the terms: on the left side ''non detectable off-odour'', ''bright fresh red meat'' and on the right side ''extreme off-odour'', ''brown, greenish, discoloured meat'', respectively. The acceptability limit was anchored in the middle of the line (75 mm from each end). The results were quantified by measuring the distance in millimetres of the panellists mark from the left side.

2.6. Statistical analysis

All statistical analyses were performed using the computer package SPSS 8.0 (1998). To obtain a normal distribution logarithmic transformations were made of water loss, aerobic plate counts and lactic acid bacteria counts and square transformation of TBA. A two way analysis of variance was used to examine the interaction between breed and days of storage. The model used was the following:

$$y_{ijk} = \mu + B_i + D_j + B \times D_{ij} + e_{ijk}$$

where y_{ijk} = represents each of the studied variables (pH; water loss; TBA value; aerobic plate, *Enterobacteriaceae* and lactic acid bacteria counts; L^*, a^* and b^*; and sensory evaluation of odour and colour); μ = least square mean; B_i = fixed effect due to breed ($i=1$, Asturiana de los Valles, $i=2$, Morucha; $i=3$, Parda Alpina; $i=4$, Pirenaica; $i=5$, Rubia Gallega; $i=6$, Retinta); D_j = fixed effect due to days of storage ($j=1$, 0 days; $j=2$ 5, days; $j=3$, 10 days; $j=4$, 15 days); $B \times D_{ij}$ = effect due to interaction between breed and days of storage; e_{ijk} = random residual effect.

All significance tests were conducted at the 5% level. Correlation and linear regression analysis were also applied to the data.

3. Results and discussion

3.1. Physical variables

The meat samples had normal pH values of between 5.3 and 5.6 (MacDougall & Rhodes, 1972; Renerre & Valin, 1979) at day 0, 24 h post mortem (Insausti et al., 1999), thus no DFD meat was found. Although there was an interaction between breed and days of storage ($P < 0.001$), pH did not exceed 5.6 during 15 days. This might be related to buffering caused by the production of lactic acid by the population of lactic acid bacteria during storage (Foegeding et al., 1983). Clark and Lentz (1973) also found that pH was not significantly affected by the O_2 or CO_2 content of the atmosphere.

During the ageing process, losses of water originate from volume changes of myofibrils caused by rigor (Honikel, 1997). Gill (1996) reported that exudate losses of about 5% of the primal cut weight at the packing plant must be expected. In the present study, water loss increased to a maximum of 2.64% at day 10 ($P < 0.05$) and then remained constant until day 15. Boakye and Mittal (1993) also found maximum press juice or minimum retained water on day 12 in beef aged under both vacuum and on the carcass. However, water holding values are method dependent (Hamm, 1986), and values obtained with one method may not correlate well with values obtained with another (Kauffman, Eikeleboom, Van der Wal, Engel & Zaar, 1986).

Guignot et al. (1994) and Price and Schweigert (1994) found that the pH of meat has a direct influence on the charged groups of the myofibrils and, thus, on water holding capacity. Nevertheless, in this study, there was no correlation (Table 1) between water loss and pH,

which though, only varied within a narrow range (5.3–5.6). The changes in the myofibrils in the different breeds may not be sufficient to significantly affect water loss, which did not differ significantly between breeds. Kemp (1994) also found little evidence of significant genetic effects in juiciness scores.

Water holding capacity may influence consumers choice, when purchasing packaged meat, as too much exudate around the meat is not appealing. In fact, in this study there was a positive correlation (Table 1) between water loss and the sensory assessment of odour and colour deterioration.

3.2. Lipid oxidation

Rancidity, expressed as the TBA value, increased during ageing ($P < 0.05$) (Fig. 1). Only meat from Parda Alpina and Pirenaica showed TBA values lower than 5 ppm after 15 days of storage. This is the concentration at which Brewer and Harbers (1991) found that rancidity is detectable. Retinta meat reached this value after 5 days of storage. This may be due to the fact that Retinta is a less improved breed that would tend to accumulate more fat in internal depots than improved breeds (Kempster, 1980–1981). In this sense, Bhattacharya, Hanna and Mandigo (1988) found that ground beef patties having more fat had higher TBA values during the first 12 weeks of frozen storage than those containing less fat. Morucha breed is similar to the Retinta breed (Mendizabal, Alberti, Equinoa, Arana, Sret & Purroy, 1999) and thus, similar fatness and TBA values would be expected. However, meat from Morucha showed lower TBA values than meat from Retinta ($P < 0.05$) (Fig. 1). The higher TBA values in Retinta meat may be related to its lower pigment stability. Since the colour of Retinta meat deteriorated faster than in the other breeds (Fig. 2), Liu, Lanari and Schaefer (1995) have related pigment and lipid oxidation in meat, although the basis for the relationship is not understood.

3.3. Microbiological evaluation

Microbial spoilage of food occurs when total aerobic counts and/or *Enterobacteriaceae* counts reach 10^7 CFU/g (ICMSF, 1984) and when lactic acid bacteria reach 10^7 CFU/cm^2 (Nortjé & Shaw, 1989). In the present work, aerobic plate counts and lactic acid bacteria and *Enterobacteriaceae* counts increased during storage ($P < 0.05$) (Tables 2 and 3) but not to this level. Although microbial load was not the major cause of spoilage in this study, it may have contributed to spoilage as microbial counts were positively correlated to loss of meat quality as assessed by sensory evaluation (Table 1). Robach and Costillow (1961) and Nortjé and Shaw (1989) reported that bacteria can produce colour changes in beef stored in air due to a reduction in the oxygen concentration at the surface tissue due to microbial respiration.

During storage, lactic acid bacteria counts were lower than aerobic plate counts (Table 2) probably because in atmospheres containing sufficient oxygen competition from aerobic bacteria is high (Bartkowsky, Dryden & Marchello, 1982), and because oxygen plays a major role in determining the types of micro-organisms present on stored beef (Ali, Abdullah & Babji, 1987). Daun, Solberg, Franke and Giebert (1971) reported that microbial growth on fresh meat stored in oxygen enriched atmospheres was similar to that of meat stored in air. Generally, in anoxic packs only *Lactobacilli* are found (Christopher, Seideman, Carpenter, Smith & Vanderzant, 1979; Gill, 1996). Under aerobic conditions, the dominant spoilage organisms are the strictly aerobic *Pseudomonas* (Gill) although Clark and Lentz (1973) found an inhibitory effect of oxygen concentration

Table 1
Correlation analysis: Pearson coefficients[a]

	pH	% wl	TBA	Ent.	APC	LAB	L^*	a^*	b^*	Odour	Colour
pH											
% wl	0.08										
TBA	0.25**	0.61**									
Ent.	0.01	0.57**	0.65**								
APC	0.02	0.43**	0.67**	0.69**							
LAB	0.01	0.41**	0.64**	0.64**	0.83**						
L^*	−0.05	0.67**	0.55**	0.54**	0.39**	0.35**					
a^*	−0.13	−0.31**	−0.57**	−0.43**	−0.53**	−0.49**	−0.59**				
b^*	−0.06	0.59**	0.36**	0.33**	0.18*	0.13	0.56**	0.06			
Odour	0.07	0.78**	0.82**	0.65**	0.63**	0.61**	0.68**	−0.50**	0.55**		
Colour	0.11	0.75**	0.82**	0.65**	0.66**	0.62**	0.67**	−0.63**	0.43**	0.93**	

[a] % wl: percentage water loss; Ent.: *Enterobacteriaceae* counts; APC: aerobic plate counts; LAB: lactic acid bacteria counts; L^*, lightness; a^*, redness; b^*, yellowness; Odour and Colour, Odour and Colour deterioration assessed at the sensory evaluation). **Significant correlation at $P < 0.01$; *significant correlation at $P < 0.05$.

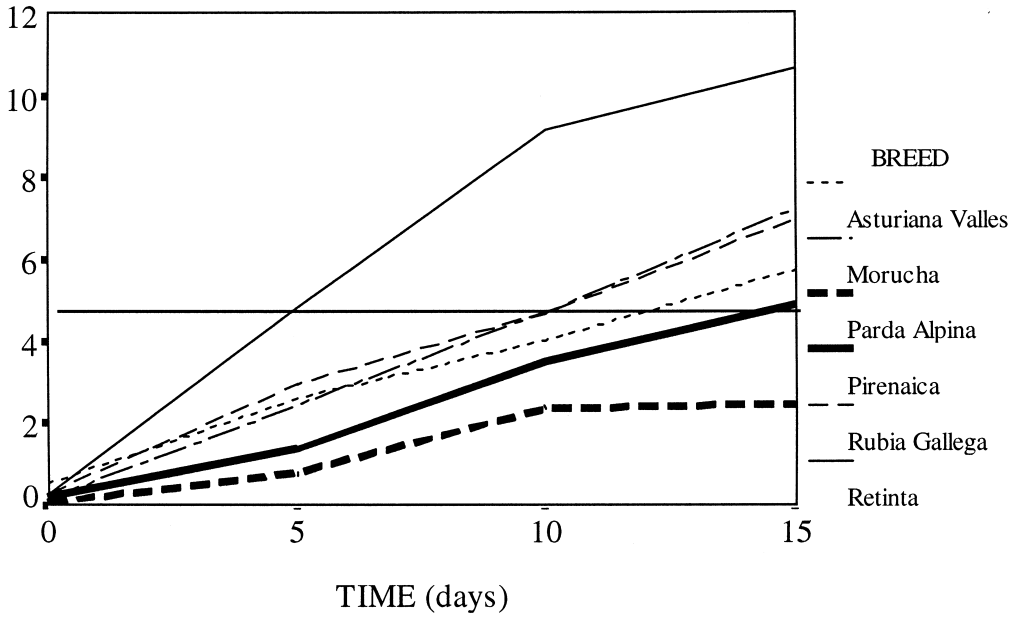

Fig. 1. Rancidity (TBA: mg malonaldehyde/kg meat) in beef stored under modified atmosphere (5 ppm: detectable rancidity).

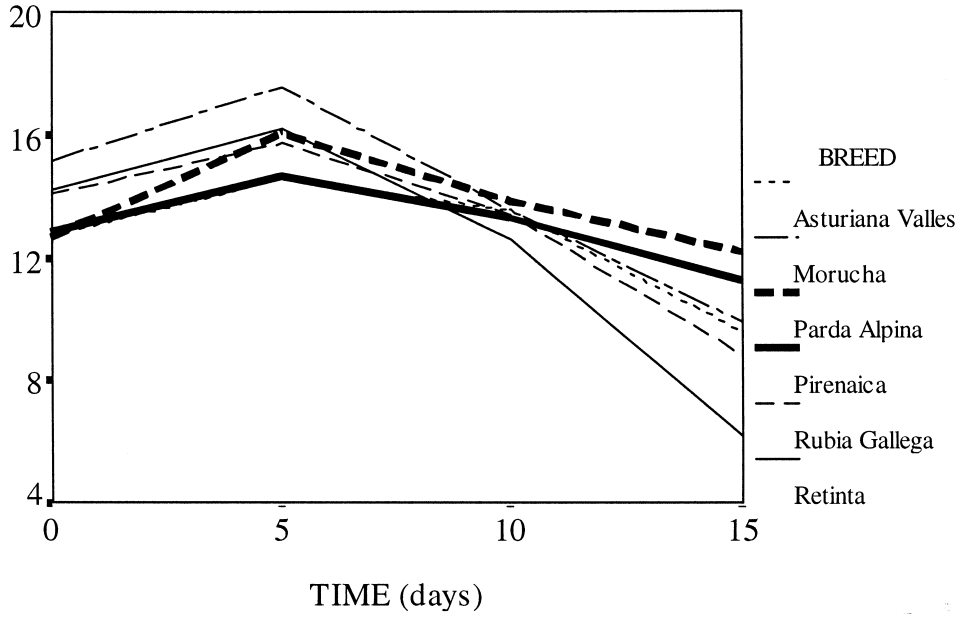

Fig. 2. Redness (a*) of beef stored under modified atmosphere (from Insausti et al., 1999 plus this study).

on the growth of *Pseudomonas* and *Moraxella acinetobacter* in oxygen enriched atmospheres.

Although total aerobic counts and lactic acid bacterial counts did not differ significantly between breeds ($P > 0.05$), there was significant effect ($P < 0.05$) on *Enterobacteriaceae* counts (Table 3). These were similar in all samples at day 0 ($P > 0.05$), but then increased, reaching significantly ($P < 0.05$) higher values on Pirenaica and Retinta meat than on the other breeds at day 15. There is a growing recognition of the role of proteolytic *Enterobacteriaceae* in the spoilage of refrigerated meats packaged under vacuum or modified atmosphere (Dainty, Edwards, Hibbard & Ramantanis, 1986) and in the development of a putrid ammoniacal odour (Nortjé & Shaw, 1989). The higher *Enterobacteriaceae* counts in the Pirenaica and Retinta meat show high correlation (Table 1) with sensory evaluation for unacceptable odour. These two breeds, together with Rubia Gallega, reached unacceptable odour values earlier than the other breeds. The bacterial counts at which meat can be considered to be spoiled (10^7 CFU/g) did not coincide with the panellists rejection of meat (75 mm)

Table 2
Microbial counts (log_{10} CFU/g) (mean values + standard error) of beef stored under modified atmosphere[a,b]

	0 days	5 days	10 days	15 days
APC	4.57±0.63a	4.82±0.69a	5.24±0.75b	6.38±0.87c
LAB	4.00±0.93a	4.27±0.66a	4.88±0.97b	5.76±0.92c

[a] APC, aerobic plate counts; LAB, lactic acid bacteria.
[b] Means within a row lacking a common letter differ ($P < 0.05$)

Table 3
Enterobacteriaceae counts (log_{10} CFU/g) (mean values + standard error) of beef stored under modified atmosphere[a,b,c]

Breed	0 days	5 days	10 days	15 days
AT	3.11±0.451ab	2.40±0.471b	4.47±0.3213a	4.42±0.231a
MO	2.58±0.231a	4.70±0.193b	5.35±0.2823b	4.91±0.141b
PA	2.52±0.211a	2.87±0.3712a	3.40±0.491ab	4.39±0.371b
PI	3.57±0.321a	3.14±0.1812a	5.89±0.042b	6.47±0.132b
RG	2.88±0.161a	3.61±0.25123ab	4.43±0.203b	5.50±0.4012c
RE	3.12±0.131a	4.03±0.3223a	5.58±0.192b	6.22±0.452b

[a] Interaction breed×days of storage: $P < 0.001$.
[b] AT: Asturiana de los Valles, MO: Morucha, PA: Parda Alpina, PI: Pirenaica, RG: Rubia Gallega, RE: Retinta).
[c] Means within a row lacking a common letter differ ($P < 0.05$); Means within a column lacking a common number differ ($P < 0.05$).

Table 4
Colour lightness (L^*) and yellowness (b^*) (mean values + standard error) of beef stored 15 days under modified atmosphere[a]

	0 days	5 days	10 days	15 days
L^*	36.22±3.07[a]	39.53±2.38b	41.05±2.25c	42.69±2.52d
b^*	7.45±1.78a	10.76±0.65b	10.05±1.00c	9.95±0.83c

[a] Means within a row lacking a common letter differ ($P < 0.05$).

Table 5
Colour lightness (L^*) and yellowness (b^*) (mean values + standard error) of beef from different local Spanish cattle breeds stored under modified atmosphere[ab]

	L^*	b^*
AT	41.73±3.08a	10.09±1.31a
MO	37.60±3.23b	8.75±1.82b
PA	37.82±3.63b	8.95±2.08bc
PI	41.39±2.74a	9.82±1.79ac
RG	40.01±2.56ab	9.76±0.86ac
RE	40.35±3.66a	9.81±1.85ac

[a] AT: Asturiana de los Valles, MO: Morucha, PA: Parda Alpina, PI: Pirenaica, RG: Rubia Gallega, RE: Retinta
[b] Means within a column lacking a common letter differ ($P < 0.05$).

on the basis of colour because all counts were less than 10^7 CFU/g. This is probably related to the bacteriostatic effect of CO_2 (Young et al., 1988).

3.4. Colour evaluation

Breed affected L^*, a^* and b^* values. L^* and b^* changed similarly in all breeds. Table 4 shows L^* and b^* mean values during storage, irrespective of breed, because breed×days of storage interaction was not significant ($P > 0.05$). Similarly, Table 5 shows L^* and b^* mean values, irrespective of time. Nevertheless, there was significant interaction ($P < 0.001$) between breed and days of storage for a^* values (Fig. 2).

During storage, yellowness (b^*) increased during the first 5 days ($P < 0.05$) and then decreased slightly (Table 4). L^* (Table 4), increased progressively during storage. Redness (a^*) increased from day 0 to day 5 ($P < 0.05$) but then decreased to day 15 ($P < 0.05$) (Fig. 2).

Little has been published on the factors affecting b^*. Wulf, O'Conner, Tatum and Smith (1997) found that final muscle pH was highly correlated with b^* value. In the present work, however, the correlation between pH and b^* was very low (Table 1). Variations in L^* values have been attributed to the changes that take place in the structure of meat during ageing, especially protein denaturation, which result in greater dispersion and, thus, increased lightness (MacDougall, 1982). These results were obtained in meat aged for at least 3 weeks and may not be entirely applicable to the present study. L^* may be affected by water loss as these variables were positively correlated (Table 1). The decrease in redness or a^* values (Fig. 2) after 5 days of storage may result from the gradual formation of metmyoglobin on the meat surface, because they have been reported to be negatively correlated (Demos & Mandigo, 1995; Insausti et al., 1999; Renerre, Dumont & Gatellier, 1996).

Morucha and Parda Alpina meat showed the lowest L^* values ($P < 0.05$) during storage (Table 5), and Morucha meat also showed the lowest b^* values. Retinta meat showed the lowest a^* values at day 15 ($P < 0.05$). This may be due to the high TBA value of Retinta meat, as Yin and Faustman (1993) reported that the oxidation of fat is related to the formation of precursors of oxymyoglobin oxidation and thus to the formation of metmyoglobin and the decrease in a^*. Insausti et al. (1999) found that metmyoglobin percentages increased to 40–70% at day 15 and this increase was directly related to the decrease in a^*.

As all animals were handled identically and slaughtered at the same live weight, differences in meat colour could be attributed to the composition of meat, as related to age at slaughter and breed. Boccard and Bordes (1986) found that meat colour was affected by breed, due to differences in type of muscle fibres and pigment content.

3.5. Sensory evaluation

Odour and colour deteriorated similarly during storage (Figs. 3 and 4), and were highly and positively correlated (Table 1), so it was not clear which was the limiting factor in the shelf life of the beef. Clark and Lentz (1973) also found that changes in both odour and colour shelf life, when packed in oxygen concentrations above 50%, occurred at similar times, although the former was related to microbial growth and the latter to metmyoglobin formation.

The shelf life of fresh beef under modified atmosphere (60% O_2, 30% CO_2 and 30% N_2) at 2±1°C was between days 5 and 10 for Retinta meat and between days 10 and 15 for meat from the other breeds. Shelf life of beef was not determined by the hygienic quality, as there were no counts above 10^7 CFU/g, probably due to the inhibitory effect of CO_2 (Ordóñez, Blanco & De la Hoz, 1996).

The correlation analysis (Table 1) showed that fat oxidation (TBA value) was positively correlated to the deterioration in odour and colour as measured by sensory evaluation. Similar results were reported by Hwang, Browers and Kropf (1990). This may result from the oxygen enriched atmosphere enhancing lipid oxidation, giving rise to off-odours (Brewer, William & Harters, 1992), or the atmosphere may have increased myoglobin oxidation (Brewer et al., 1992).

Stepwise multiple regression analysis, confirmed that TBA contributed to the deterioration of odour and colour:

$$\text{Predicted deterioration of odour} = 19.61 + 110.01\ \text{TBA};\quad R^2 = 0.68\ (P < 0.001).$$

$$\text{Predicted deterioration of colour} = 14.19 + 12.71\ \text{TBA},\quad R^2 = 0.67\ (P < 0.001).$$

Greene and Cumuze (1982) reported that the TBA test could serve as an indicator of oxidised odour or flavour in meat.

The next variables to enter the regression model were water loss, (wl) in both cases and then, b^* because of its relationship to odour and a^* for colour deterioration.

$$\text{Predicted degradation of odour} = -22.88 + 7.52\ \text{TBA} + 10.82\ \text{wl\%} + 3.58\ b^*;\ R^2 = 0.81\ (P < 0.001).$$

$$\text{Predicted degradation of colour} = 65.64 + 6.32\ \text{TBA} + 15.40\ \text{wl\%} - 4.42\ a^*;\ R^2 = 0.82\ (P < 0.001).$$

The role of water loss in meat acceptability was also shown by the correlation analysis (Table 1). This supports the results of Forrest, Aberle, Hedrick, Judge and Merkel (1979) who found that, when water accumulates around meat, it becomes wet and unattractive to consumers.

The relation between a^* and the deterioration of colour has already been discussed. The relation between b^* and the deterioration of odour was possibly influenced by the biochemical changes that took place in the meat during the first 5 days of storage. Insausti et al. (1999) also found that b^* had an important impact on the shelf

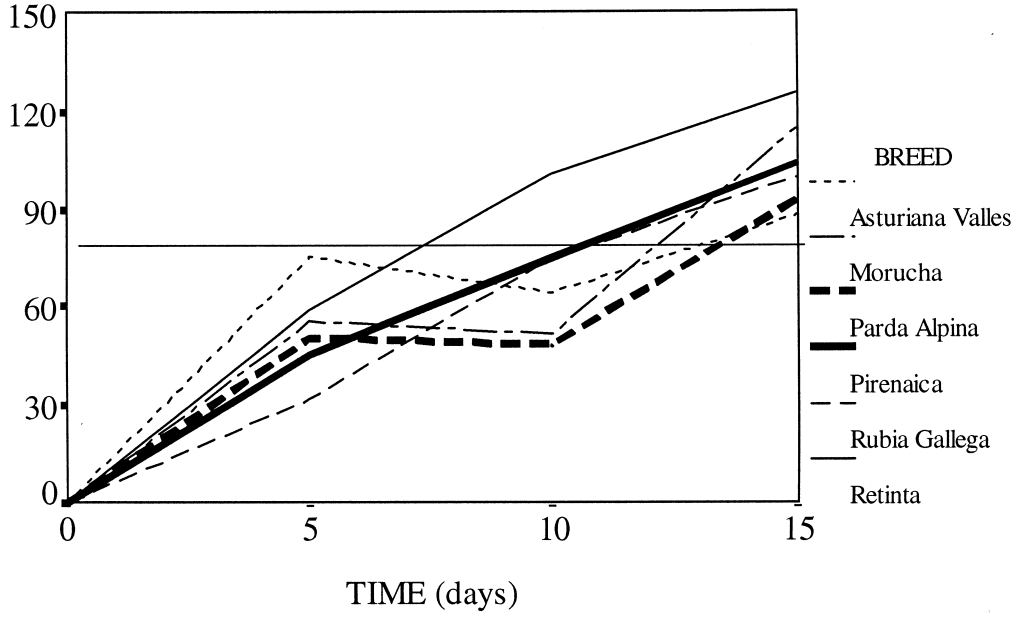

Fig. 3. Sensory evaluation: odour of beef stored under modified atmosphere (75 mm: acceptability limit).

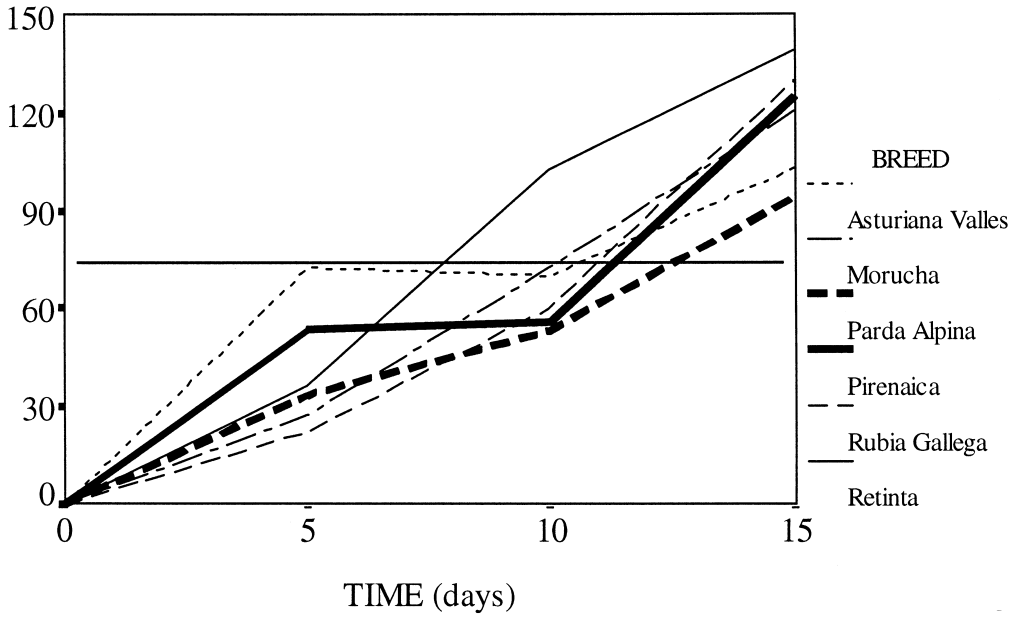

Fig. 4. Sensory evaluation: colour of beef stored under modified atmosphere (75 mm: acceptability limit).

life as assessed by beef colour. Further research is needed on these aspects.

In conclusion, the limiting factor in quality in this study was odour and colour spoilage by lipid oxidation. Water loss and myoglobin instability also influenced shelf life. Beef samples showed differences in shelf life between breeds, probably due to different initial colour and chemical composition. Thus, if storage in such gas mixtures is to be used in central pre-packaging operations, meat packaging systems should be standardised for each meat.

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