Available online at www.sciencedirect.com
ScienceDirect
Meat Science 79 (2008) 408–422
MEAT SCIENCE
www.elsevier.com/locate/meatsci

Review

Nutritional and eating quality of Argentinean beef: A review

Alejandro Schor [a], María E. Cossu [a], Alejandra Picallo [a], Jorge Martínez Ferrer [b], Juan J. Grigera Naón [a,*], Darío Colombatto [a,c]

[a] *Departamento de Producción Animal, Facultad de Agronomía, Universidad de Buenos Aires, Argentina, Av. San Martín 4453, C1417DSE Ciudad de Buenos Aires, Argentina*
[b] *EEA Manfredi INTA, Ruta 9 km 636, 5988 Manfredi, Córdoba, Argentina*
[c] *CONICET, Argentina*

Abstract

This review deals with distinctive aspects of quality of Argentinean beef in terms of tenderness, flavour, colour, juiciness, taste, acceptability, lipid content and composition and its resultant nutraceutical characteristics. Differences are due to beef production systems based on temperate or tropical grasslands aimed at shortening the fattening phase as far as possible, with limited or null use of concentrates. However, the effect of limited supplemental feeding is also discussed as well as the responses arising from the use of beef cattle genotypes, including British, Continental, Dairy, Zebu breeds and their crosses, adapted to the various environments and systems found in the country.

Keywords: Beef; Argentina; CLA; Quality attributes; Review

Contents

1. Introduction

Traditionally, the beef sector in Argentina has been instrumental in the country's economy. Argentina possesses one of the world's highest levels of beef consumption per capita, as well as an established reputation as a supplier of high quality beef around the globe. Nowadays, consum-

* Corresponding author. Tel.: +54 11 4524 8000x8183; fax +54 11 4514 8735.
E-mail address: grigeran@agro.uba.ar (J.J.G. Naón).

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doi:10.1016/j.meatsci.2007.10.011

ers are increasingly aware of the fact that beef quality is not unique, and that there are several aspects that should be taken into account in order to enhance the nutritional quality of the human diet. As mentioned, Argentinean beef is well known globally, but objective measures of the quality of its beef are seldom reported in the literature. Therefore, to be able to compete on the international stage, Argentinean beef should be characterized accurately in terms of its nutritional quality and safety for consumption. Knowledge about the origin, sensorial characteristics, chemical, nutritional and nutraceutical components of beef are important tools to enhance business competitiveness.

The perspectives for Argentinean beef exports are promising, mainly due to the country's recent advances in sanitary status. Argentina has obtained a declaration as free of foot and mouth disease with vaccination, and also the best possible status for a low BSE risk. These achievements, together with the fertile soil and climate characteristics for beef production, are leading forces for the increase in the country's beef exports.

The present review discusses important aspects related to the nutritional and eating quality of Argentinean beef. It summarizes data published from the year 2000 onwards in Argentinean and international sources, with an emphasis on the effect of *ante-mortem* (breed and diet: grazing, supplementation to grazing or feedlot finishing) and *post-mortem* (ageing) factors, on physical, chemical and sensorial parameters of beef quality.

2. Diet effects on physical parameters of Argentinean beef quality

Colour, tenderness, juiciness and flavour are among the most important meat quality traits influencing the consumer's decision over purchasing beef. However, only colour can be appreciated by the naked human eye. Colour is therefore used to establish the acceptability of meat and meat products. In Argentina, as in several other countries as well, it appears that tenderness is the most important component of meat quality taken into account by consumers. As it is clearly a trait that cannot be detected at the time of purchase, it is very important to certify this quality trait in order to assure consumers of what they are buying.

In Argentina, factors associated with tenderness are of utmost importance, as most beef is consumed fresh (i.e., without ageing), and traditionally comes from two-year-old steers of British (pure and crosses) breeds finished on high quality pastures. A lack of consistency in tenderness has driven consumers to pay more money for very small cuts from young animals fed on concentrates. In this category of young animals one can include heifers, young steers and the "bolita" calves which are usually finished when they reach 260 kg live weight (around 140 kg hot carcass weight). The "bolita" calves category presents the advantage that animals are very efficient in converting feed into meat, and the meat tenderness is almost guaranteed.

2.1. Feeding systems

Teira et al. (2004a,2004b,2004c,2004d) examined the effect of different finishing strategies on physical aspects of beef quality of Hereford steers grown on pasture from 157 kg live weight until finished at 380–400 kg (all pasture), or grown on pasture until reaching 320 kg and then finished on a high grain diet in feedlot for 40, 60 or 80 days. Warner Bratzler shear force values in *Longissimus dorsi* were 57.23, 51.06, 53.12 and 42.43 N for the all pasture, 40, 60, and 80 days in feedlot steers, respectively, with differences ($P < 0.05$) only between the all pasture and the 80 days in feedlot. This difference in shear force values would be relevant when working with not-aged beef. According to Miller, Carr, Ramsey, Crockett, and Hoover (2001), shear force values between 42.14 and 48.02 N would satisfy 86% of the consumers, whereas higher values would only result in a 25% of the consumers satisfied. In addition, these authors indicated that the standard deviation in shear force was reduced in the 80 days feedlot treatment when compared to the rest of the treatments (±4.11 vs. ±8.53 N, respectively). The latter is very important as consumers tend not to buy "averages" but buy "small variations". Regarding the beef and fat colour, they showed only minor differences among treatments (Teira et al., 2004b). Only the b^* parameter differed, but within a small range (4.8–5.9). Subcutaneous fat colour showed a higher ($P < 0.05$) b^* value in the pasture-finished animals compared to the feedlot-finished ones (16.06 vs. 11.7, respectively). Cooking losses were reduced ($P < 0.05$) by the longest feedlot period (Teira et al., 2004c) with respect to the other treatments (7.5% vs. 12.7–15.7% for the 80 days and the rest of treatments, respectively). This parameter is highly desirable for the processing industries and restaurants. In addition, evaporation and dripping losses were lowest ($P < 0.05$) with the longest feedlot period.

In another study, Schindler de Avila, Pruzzo, Arieu, and de Santa Coloma (2003) used 228 Hereford steers of small (1.5) and medium (3.5) frame and assigned them to different finishing strategies: (a) all pasture, (b) pasture with grain supplementation at the beginning, (c) pasture followed by feedlot finishing or (d) feedlot throughout the cycle. These authors found little influence on shear force values when animals were slaughtered at an equal finishing degree (subcutaneous fat depth of 5 mm on *Longissimus dorsi*) but different ages and final weights. Furthermore, frame-adjusted shear force did not differ ($P > 0.05$) (average of 26.07 N for 15 days ageing) for pasture or feedlot finished animals. According to Latimori et al. (2003), shear force value was not greatly affected by diet (mean = 30.18 N, $P > 0.05$) when pasture diets (based on alfalfa and tall fescue), with or without corn grain supplementation (0.7% of live weight in DM basis, added strategically, or 1% permanently), or a feedlot system were evaluated with steers. Fattening period was 394 days long in the pasture system (with a shear force value of 31.75 N), or 378, 346 and 194 days for the 0.7% supplementation

(29.79 N), 1% supplementation (30.18 N) and feedlot (28.62 N), respectively. Latimori et al. (2005) analyzed two production cycles of the same treatments described above and did not find effects of feeding system on shear force (31.16 N) or marbling score (1.79), although marked differences in intramuscular fat content were observed (2.9c, 3.6b, 4.2a y 3.9b g/100 g for all pasture, 0.7% supplementation, 1% supplementation and feedlot, respectively).

Martínez Ferrer et al. (2006a) used 70 steers from British breeds and of medium frame (230 kg initial live weight), to evaluate the effect of five pasture-based feeding systems (control, two stocking rates and two corn grain supplementation levels) and two feedlot systems (based on corn grain or whole-crop sorghum silage). At slaughter, live weight and subcutaneous fat depth were 443.6 kg and 10.4 mm, respectively. No differences ($P > 0.05$) were detected on beef pH (5.65) or the L^* parameter (36.5). Steers finished on feedlot with corn grain showed marginally lower a^* values (14.7 vs. 16.9–18.4), with a whiter fat (b^* values of 8.2 vs. an average of 11.0 for the rest of the treatments). As expected, feedlot finishing produced a higher marbling score (7.3 vs. 4.7), but shear forces were higher for feedlot than for pasture-finished animals (57.82 vs. 75.46 N, $P < 0.05$). The latter was very surprising and could be attributed to the fact that animals were slaughtered as they reached the finishing point. Thus, these differences in slaughter dates might have masked the results, as animals could have been under different pre-slaughter stress levels, temperature, humidity, etc. In another study, Pensel et al. (2000) examined the impact of finishing strategies (pasture or feedlot) on the antioxidant contents and colour stability of *Psoas major* muscle of crossbred steers, stored for 1, 3, 5 and 7 days simulating retail conditions. As expected, antioxidant contents in meat samples from pasture were higher than those coming from feedlot ($P < 0.05$). Metmyoglobin levels did not differ among treatments ($P > 0.05$) but metmyoglobin levels increased ($P < 0.05$) with storage time. The L^* parameter was higher for the feedlot-finished animals, but was not affected by display period. In turn, b^* was not altered by treatment but was decreased by ageing time ($P < 0.05$). Higher levels of antioxidants in the meat of pasture-finished improved colour stability, but antioxidants had no effect on surface metmyoglobin formation.

Together with colour and tenderness, flavour is one of the main sensory attributes considered by consumers to assess meat quality. Human panel assessments and gas chromatography/mass spectrometry have traditionally been used to evaluate beef meat flavour. Recently, the use of an electronic nose device has allowed researchers to create an odour descriptor based on the response to volatile compounds present in a headspace above a sample. Grigioni, Descalzo, Insani, Pensel, and Margaría (2000) and Descalzo et al. (2007) determined the differences in raw meat odour derived from animals under different feeding strategies using an electronic nose (Aroma Scan™). Four treatments, namely pasture, pasture plus vitamin E supplementation (500 IU/animal/day), grain and grain plus vitamin E supplementation (500 IU/animal/day) were used, and the *Psoas major* of those animals were evaluated. Aroma intensity was decreased ($P < 0.05$) as the α-tocopherol content increased, suggesting a reduced formation of volatile oxidation products due to the α-tocopherol antioxidant activity. Vitamin E supplementation failed ($P > 0.05$) to produce differences. An addition outcome of this research was that it was possible to describe a relationship between raw meat odour profile and the antioxidant power of that sample.

2.2. Types, levels and duration of supplementation at pasture

Grigera Naón, Schor, Cossu, Schindler de Avila, & Panella (2003) did not find differences on the shear force values of *Longissimus dorsi* (75.46 N) and *Semitendinosus* (107.8 N) when Angus steers (21 months of age) were fed on pasture (118 days, no supplement added), pasture plus supplementation with soybean grain by-products (1.1% of live weight in a DM basis, for 74 days), or supplementation as above but with a finishing period on pasture from 74 to 144 days. Villarreal et al. (2003) finished Angus steers from contrasting frames using whole-crop corn silage (2.0–2.4 kg DM/animal/day) or high moisture corn grain (1.7–1.9 kg DM/animal/day) as a winter supplement to pasture during the growing season (176 d), with a finishing period on pasture alone. They found beef from the whole-crop corn silage treatment to be marginally tenderer than the corn grain treatment (59.78 vs. 71.54 N, $P < 0.07$, $n = 30$) after the winter supplementation, with none of the other physical parameters affected.

In a recent study, Chicatún, Santini, Depetris, Faverín, and Villarreal (2006) finished Angus steers on mixed pastures, unsupplemented or supplemented with corn silage (1.5% of live weight, on a DM basis) during background, and supplemented with three levels of corn grain (0%, 1%, and 2% of live weight, on a DM basis) at finishing (final live weight = 394 kg). They did not find any effects on physical parameters evaluated (mean values were pH 5.62; $L^* = 36.0$; $a^* = 20.4$; $b^* = 10.2$; Warner Bratzler shear force = 80.36 N ($P > 0.05$). In contrast, Davies and Méndez (2005) evaluated corn grain supplementation (1% live weight in a DM basis) strategies at pasture (no supplementation, supplementation at the beginning of the finishing period, at the end or throughout the finishing period), and reported that shear force values decreased with constant supplementation (24.79 N) compared to those that supplemented at the beginning (30.48 N). In agreement to Teira et al. (2004a), supplementation at the end of the finishing process was associated with a reduced variability in shear force (12.7%) and a lower pH value (5.60 ± 0.07) than the steers that did not receive grain at the end of the finishing period (18.5% and pH 5.75 ± 0.08, respectively).

Depetris et al. (2005) used heifers to evaluate effects of pasture type (grass – GR or legumes – LG) and length of supplementation (at 1.3% of live weight, DM basis) on the LG pasture (14, 28 or 42 days prior to slaughter), and did not find effects ($P > 0.05$) on shear force (48.1–60.6 N), pH (5.39–5.50), L^* (33.2–36.5), a^* (15.4–17.6), and b^* (16.5–18.9). The findings could be attributed to the short duration of the trial and the low live weight gain rate.

2.3. Feedlot diets

Villarreal, Santini, Faverín, Depetris, Paván, et al. (2005) reported that animals finished on feedlot and fed on a corn silage based diet showed a slightly redder meat ($a^* = 24.5$ vs. 23.3; $P < 0.05$) and a higher pH (5.60 vs. 5.55; $P < 0.05$), than those fed on a high moisture corn grain, but no differences on shear force were detected (58.02 vs. 58.51 N respectively). When dry corn instead of high moisture was used, Villarreal, Santini, Faverín, Depetris, Grigera, et al. (2005) found no effects on red color intensity, pH or shear force, but reported higher L^* and b^* values with silage. Furthermore, Picallo et al. (2002) did not find differences in *Longissimus dorsi* color of "bolita" calves (231 kg final weight) using diets containing chicken oil vs. tallow, with or without antioxidants. Depetris, Santini, Pavan, Villarreal, and Rearte (2003) and Depetris et al. (2003a) fed "bolita" heifers with corn grain (75% of the diet, DM basis) using high oil or standard (7.6% or 4.3% ether extract, respectively) corn varieties and reported that at slaughter (240 kg final live weight) those receiving a high oil corn grain showed larger subcutaneous fat depth (6.10 vs. 5.28 mm, $P = 0.09$), lower pH (5.56 vs. 5.97, $P < 0.01$), and higher L^* and a^* values (37.0 and 15.6 vs. 35.4 and 14.1 for high oil and standard and for L^* and a^*, respectively). Animals receiving high oil corn showed a lower marbling score and a higher shear force.

Navarro, Santini, Depetris, Villarreal, and Rearte (2005) fed animals with whole sunflower or soybean seeds and found that no physical parameter was affected, except for a decrease in the rib eye area in the treatments receiving oil-rich seeds compared to the unsupplemented controls. Pordomingo, Volpi Lagreca, García, Grigioni, and Carduza (2005) fed three levels of condensed tannins to heifers (170 kg initial live weight) and two levels of corn grain (45% or 70%) and found no effects on meat quality attributes.

As a general conclusion from these research activities, it is clear that a high variability exists, which may be attributable to several factors such as different breeds, diets, pre-slaughter treatments, methodologies employed, sample numbers, etc. In general, it can be said that when animals are slaughtered at the same finishing degree, differences in shear force values between pasture-finished and animals receiving supplementation are small. In terms of beef color, the general agreement is that finishing strategy had small influence on *Longissimus dorsi*. When *Psoas major* was used as a model muscle, feedlot finished animals showed higher L^* values than pasture finished ones. The most important difference was found on fat colour, which as expected was whiter for the feedlot finished animals. One important aspect in beef quality studies is the colour stability, as it is related to product shelf life and consumer's acceptance. Animals finished on pastures showed higher beef colour stability, which has been linked to a greater antioxidant concentration present in pastures. Finally, only one study regarding flavour was found in this review. Pasture-fed animals showed lower flavour intensity when compared to those receiving supplementation to grazing, which can be attributed to the antioxidant activity of α-tocopherol present in pastures, which very likely prevented production of volatile compounds coming from oxidation.

3. Diet effects on chemical and nutritional aspects of Argentinean beef quality

Beef chemical composition, and in particular type and amount of fatty acids present, are very important due to their possible influence on human health. Consumers are increasingly aware about how meat consumption can affect their health. Argentinean beef in general is lean, and only exceptionally can they contain more than 5% intramuscular fat. However, these low values might negatively affect some meat quality attributes (i.e., juiciness and flavour). In some cases, beef fat consumption is considered as negative for human health, given its high content of saturated fatty acids. However, it must be taken into account that not all saturated fatty acids are similar in terms of their biological effects. For instance, stearic acid ($C_{18:0}$) is considered as neutral, whereas myristic ($C_{14:0}$) and palmitic ($C_{16:0}$) can be dangerous as higher consumption of these fatty acids tend to increase plasmatic levels of low density lipoproteins (LDL). Production systems are therefore a key factor affecting nutritional attributes of meat. In general, beef coming from steers finished on pasture has lower fat and cholesterol concentrations, and more polyunsaturated fatty acids (PUFA) than beef coming from feedlot-finished animals. Pasture beef contains more ω-3 fatty acids metabolized from linolenic acid ($C_{18:3}$), which is a major component of pasture lipids. In addition, natural antioxidants like Vitamin E and β-carotene are also present in pastures and incorporated into beef.

An important quality trait in Argentinean beef is its high content of conjugated linoeic acid isomers (CLA), mainly the *cis* 9, *trans* 11 isomer. This isomer is incorporated into beef both by direct (ruminal escape) or indirect (endogenous synthesis) pathways, and it is produced as a result of the biohydrogenation process occurring in the rumen where unsaturated fatty acids (mainly linoleic ($C_{18:2}$) and linolenic acids) from feedstuffs are first isomerized and partially saturated later. It has been established that some of these CLA isomers possess anticarcinogenic and immunostimulant properties. The ω6:ω3 ratio is also important as immunostimulant and to prevent cardiovascular diseases. García (2000) concluded that pasture-fed beef offers unique conditions to be accepted for both human nutritionists and consumers. However, as mentioned before, one of the major problems in beef coming from pasture-finished animals lies in its relative inconsistency with respect to feedlot-finished beef. Over the last decade, there has been a great deal of efforts done by Argentinean researchers to characterize and improve beef quality and consistency. Results discussed in this review reflect the effects of finishing strategies on beef fat content and composition.

Rosso, García, and Machado (1998) evaluated the effects of production system (all pasture, grain supplemention – strategic or permanent – or feedlot) on nutritional quality of beef. Pasture produced beef had lower fat content than feedlot beef (2.3% vs. 3.2% in *Semitendinosus*; 2.6% vs. 4.7% in *Longissimus dorsi*) and also lower cholesterol concentrations in *Longissimus dorsi* (45.8 mg/100 g in the pasture fed animals compared to 52.8 mg/100 g in the feedlot finished ones). In addition, α-linolenic acid concentrations were higher ($P < 0.05$) for pasture fed animals compared to the feedlot treatment (1.22% vs. 0.19%, respectively). In contrast, Davies and Méndez (2005) supplemented steers using different strategies (no supplement, supplementation during backgrounding, supplementation only during finishing phase, or permanently) and found no substantial effects on chemical composition of beef. In turn, Schindler, Cossu et al. (2000) evaluated the effect of four fattening strategies (pasture, pasture plus grain at 1.5% live weight post-weaning, pasture plus feedlot for the last 90 days and feedlot) on intramuscular fat and cholesterol contents of *Longissimus dorsi*. Beef coming from feedlot-finished steers had the highest ($P < 0.01$) cholesterol content (56.6 mg/100 g vs. an average of 38.7 mg/100 g for the other three treatments), which agreed with data from Rosso et al. (1998). Intramuscular fat contents were highest ($P < 0.05$) for pasture, intermediate for pasture + grain or pasture + feedlot and lowest for feedlot. These data appear to contradict most of other research in the area (Latimori et al., 2005; Martínez Ferrer, Ustarroz, Ferrayoli, & Turco, 2006; Rosso et al., 1998). This contradiction may be due to the fact that the feedlot steers were in most cases finished at an earlier age than those coming from pastures (113 vs. 363 days in the work of Schindler et al., 2000), which might have created a confounding effect of age on this particular quality trait.

Latimori et al. (2003) and Latimori et al. (2005) carried out two consecutive trials with steers from different breeds subjected to different feeding strategies (pasture, supplementation or feedlot). Latimori et al. (2003) reported that in the first year of study, intramuscular fat and cholesterol levels were lower ($P < 0.05$) in the all pasture treatment (2.86 vs. 3.85 g/100 g, and 40.8 vs. 45.0 mg/100 g for intramuscular fat and cholesterol in pasture fed and the rest of treatments, respectively). Saturated fatty acids were lower in feedlot finished animals (35.0 vs. 37.6%, $P < 0.05$) with a larger ω6:ω3 ratio (21.6 vs. 3.7, $P < 0.05$) than in the pasture fed or the supplemented steers. Concentration of CLA was higher when animals were kept on pasture compared to those supplemented or fed in the feedlot (0.71%, 0.59% and 0.29% for pasture, supplementation and feedlot treatment, respectively, $P < 0.05$). When data from two fattening cycles were considered, Latimori et al. (2005) found similar results, except for an absence of differences in saturated fatty acid contents.

In another series of studies, Martínez Ferrer et al. (2004), Martínez Ferrer, Ustarroz, Ferrayoli, and Alomar (2005) and Martínez Ferrer, Ustarroz, Ferrayoli, et al. (2006) examined the effect of several feeding regimens on the amount and composition of fatty acids present in *Longissimus dorsi* on 6 months feeding Angus steers ($n = 70$ per year). Five pasture treatments differing in herbage allowance and supplementation level, and two feedlot treatments (one based on grain (GRA = 73% corn) or silage (SIL =

Table 1
Fatty acid profile (g/100 g methyl esterified fatty acids, FAME) on *Longissimus dorsi* of steers subjected to different feeding regimes (average of 2 years of evaluation) adapted from Martínez Ferrer (2005)

Feeding regimes[a]								
Fatty acid profile (g/100 g FAME)	GRA	SIL	LA-HS	LA-LS	MA-HS	MA-LS	HA-NS	s.e.[b]
$C_{16:0}$	25.9	26.5	26.5	25.5	27.0	26.7	27.0	0.407
$C_{18:0}$[c]	14.6a	14.9ab	15.1ab	16.2bc	15.7abc	15.7abc	17.0c	0.221
$_{c\,9}C_{18:1}$	37.6c	39.8d	37.3bc	35.8bc	37.4c	35.3ab[b]	33.5[a]	0.552
$C_{18:2}$ω6	4.70	4.36	4.17	5.29	4.11	4.74	4.04	0.208
$_{c\,9,\,t\,11}$CLA	0.37a	0.34a	0.69b	0.68b	0.65b	0.65b	0.80c	0.033
$C_{18:3}$ ω3	0.47a	0.55a	1.36b	1.85c	1.73bc	1.86c	3.10d	0.171
SFA	44.5	44.9	45.0	45.0	46.0	46.0	47.8	0.471
MUFA	46.2d	46.2d	44.8cd	42.0ab	43.8bc	41.9ab	40.1[a]	0.479
PUFA	8.6a	8.8a	10.2ab	13.1c	10.2ab	12.1bc	12.1bc	0.482
PUFA ω6	7.1	7.1	6.7	8.6	6.4	7.7	6.3	0.311
PUFA ω3	1.2a	1.4a	2.8b	3.8c	3.2bc	3.7c	5.0d	0.271
PUFA/SFA	0.20a	0.20a	0.23ab	0.29c	0.23ab	0.26bc	0.26bc	0.012
ω6/ω3	6.26bc	5.37b	2.39a	2.33a	2.05a	2.06a	1.27a	0.401

[a] GRA = feedlot finishing based on corn grain (73% diet DM); SIL = feedlot finishing based on BMR sorghum silage (65% diet DM); LA-HS = low forage allowance, high supplementation level; LA-LS = low forage allowance, low supplementation level; MA-HS = medium forage allowance, high supplementation level; MA-LS = medium forage allowance, low supplementation level; HA-NS = high forage allowance, no supplement.

[b] s.e. = standard error.

[c] Within files, numbers followed by different letters differ significantly ($P < 0.05$).

65% BMR sorghum). Animals were slaughtered when they reached a subcutaneous fat depth of 10 mm. Results from two years of studies are presented in Table 1 (Martínez Ferrer, 2005). There was a trend ($P = 0.11$) towards a higher proportion of saturated fatty acids in pasture based diets, which was due to a larger extent to an increase in $C_{18:0}$ ($P = 0.047$) and to a lesser extent to an increase in $C_{14:0}$ ($P = 0.121$) and $C_{16:0}$ ($P = 0.373$). These findings are in agreement with what was reported by Latimori et al. (2003), Latimori et al. (2005) and García et al. (2005). As expected, the highest PUFA and $_{c9,t11}$CLA, concentrations were observed in those animals fed solely on pasture. It is noteworthy the wide range in PUFA ω3 and CLA concentrations that existed between the pasture fed and the feedlot finished animals (Table 1). Concentration of $_{c9,t11}$ CLA (mg/100 g tissue) as a result of ingested fresh forage (FF; g forage/g total intake) for the first year was: y (mg $_{c9,t11}$ CLA/100 g tissue) = 8.02(±1.04) + 7.06(±1.71) * FF (R^2: 0.585; $P = 0.0014$; $n = 14$), while for the second year was: $y = 6.72(\pm1.34) + 11.44(\pm3.80)$ * FF (R^2: 0.678; $P = 0.0003$; $n = 14$).

Fig. 1a shows the $_{c9,t11}$CLA, eicosapentaeonic (EPA, $C_{20:5}$), docosahexaeonic (DHA, $C_{22:6}$) contents (mg), whereas Fig. 1b shows the PUFA ω3 and PUFA ω6 per 100 g lean beef. Values are means, adjusted by methyl esterified fatty acid contents for the 2 years. The highest contents (mg/100 g tissue) of $_{c9,t11}$CLA ($P = 0.0002$), EPA ($P = 0.0053$) and PUFA ω3 were obtained with pasture fed animals, whereas no differences were observed in DHA ($P = 0.77$) and PUFA ω6 ($P = 0.24$).

These findings can have significant implications for human nutritionists, and they could be in the position of calculating how much beneficial fatty acids a given quantity of lean Argentinean beef could supply to consumers.

With the objective of evaluating the direct and carry over effects of short term supplementation with by-products of soybean harvest on fatty acid composition of meat from grazing steers, Grigera Naón et al. (2003) used 41 Angus steers (21 months of age, 390 kg live weight), assigned to two treatments: pasture only (PO, $n = 20$) or pasture supplemented with by-products at 1.1% live weight (SP, $n = 21$). Carry-over effects were assessed by removing 11 steers from the SP treatment after 74 days and finishing them on pasture only (COS). The remaining 10 steers from the SP group were slaughtered after 74 days of fattening. End point was visually determined by the same trained abattoir official in each case. Supplemented steers (SP and COS) had lower oleic acid ($C_{18:1}$) and higher $C_{16:0}$ acids contents (Table 2). Monounsaturated fatty acids (MUFA) decreased with supplementation, whereas ω6 acids increased; which resulted in higher ω6:ω3 values (>4) for the supplemented animals (SP), however the values did not differ ($P > 0.05$) from the PO treatment (Table 2).

In another experiment studying carry over effects, Villarreal et al. (2003) finished Angus steers from contrasting frames using whole-crop corn silage (2.0–2.4 kg DM/animal/day) or high moisture corn grain (1.7–1.9 kg MS/animal/day) as a winter supplement to pasture during the growing season (176 days), with a finishing period on pasture alone. They found at the end of the supplementation period that smaller frame animals receiving whole crop silage had higher CLA content than those receiving high moisture grain (1.08% vs. 0.82% total fatty acids); while higher frame steers were not affected by supplement type. There were no other effects of type of supplement on fatty acid composition during the growing period, and those found on CLA disappeared after the pasture fattening period.

Depetris, Santini, Pavan, Villarreal, and García (2005) evaluated the effects of type of pasture (grasses vs. legumes) and supplementation length (on legumes) with corn grain at 1.3% live weight for 14, 28 or 42 days prior to slaughter

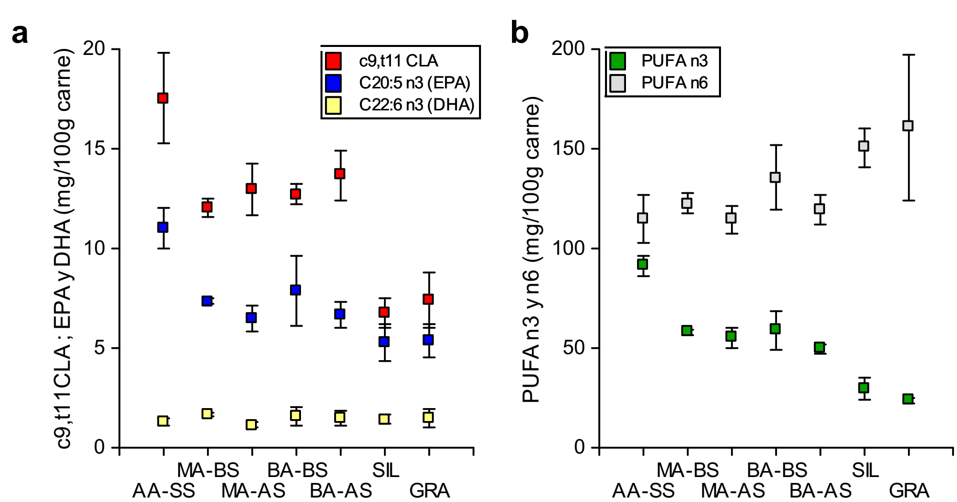

Fig. 1. Contents of $_{c9,t11}$CLA, EPA, and DHA (a) and PUFA ω3 and PUFA ω6 (b) (mg/100 g tissue) in *Longissimus dorsi* of steers subjected to different feeding regimes. Values are averages of two consecutive years of evaluation. Adapted from Martínez Ferrer (2005). For information on feeding regimes, see corresponding footnote Table 1.

Table 2
Fatty acid composition (%) of muscles from steers at pasture or supplemented with by products of soybean harvest

Treatment[a]	SP	COS	PO	s.d.[b]	SP	COS	PO	s.d.
Fatty acid	*Longissimus dorsi*				*Semitendinosus*			
$C_{16:0}$[c]	24.6a	25.5[a]	23.8b	0.84	25.4[a]	26.1a	23.5b	1.08
$C_{18:0}$	18.1	16.1	16.3	2.02	18.8	17.0	15.8	1.90
$C_{18:1}$ ω9	35.9a	38.1ab	40.8b	2.27	34.4[a]	37.2ab	40.4b	2.10
$C_{18:2}$ ω6	7.6a	5.7ab	4.7b	1.53	6.9	5.5	4.1	1.86
$C_{18:3}$ ω3	1.3	1.5	1.1	0.36	1.1	1.4	1.5	0.49
CLA	0.9a	1.3b	1.5b	0.17	1.3	1.3	1.5	0.25
$C_{20:5}$ ω3	0.6	0.7	0.6	0.29	0.6	0.6	0.7	0.30
$C_{22:6}$ ω3	0.1	0.1	0.1	0.05	<0.1	<0.1	<0.1	
MUFA	40.3a	42.7ab	46.0b	2.53	38.7[a]	41.8ab	45.1b	2.15
PUFA	13.0	11.6	9.6	2.71	12.7	10.9	11.3	3.15
ω6	10.9a	7.5b	6.7b	1.64	9.1	7.3	7.2	1.82
ω-3	2.1	2.2	1.7	0.65	1.8	2.1	2.2	0.76
ω6:ω3	5.4a	3.4b	4.2ab	0.83	5.0	3.8	3.5	1.00

Adapted from Grigera Naón et al. (2003).
[a] SP, steers on pasture and supplemented with by products of soybean harvest (1.1% live weight, DM basis) for 74 days; COS, steers on pasture supplemented with by products of soybean harvest (1.1% live weight, DM basis) for 74 days, then finished on pasture from day 74 to day 144; PO, steers finished on pasture without supplementation (118 days).
[b] s.d. = standard deviation.
[c] Within files, numbers followed by different letters differ significantly ($P < 0.05$).

on the fatty acid profile of meat from heifers finished at 285 kg live weight. Legume grazing resulted in higher CLA percentages (0.7% vs. 0.53% CLA, expressed as a proportion of total fatty acids) than grass grazing. Also, CLA concentrations were lineally reduced with supplementation length. Authors concluded that supplementation, even of limited duration, modified the fatty acid profile of beef. These findings agree with international data, as Enser et al. (2001) also found increased PUFA, ω6 and ω3 when legumes were included into a ryegrass pasture.

Kugler, Garcilazo, Barbarossa, García, and Loriente (2005) compared the nutritional quality of Hereford steers subjected to three diets: pasture only, pasture plus 3 h grazing on whole crop fresh corn per day, or sole grazing on whole crop corn plants from 285 kg until slaughtered at a same finishing degree. These authors found differences in MUFA (33.9% vs. 37.4%) and PUFA (8.6% vs. 3.9%) for pasture and treatments consuming whole crop fresh corn, respectively. In addition, α-linolenic acid and CLA contents were higher for the grazing animals, but the opposite held true for the ω6:ω3 ratio. Furthermore, Chicatún et al. (2006) evaluated the nutritional quality of beef from Angus steers grazing pastures, unsupplemented or supplemented with two levels of corn silage during the growing phase, and three levels of cracked corn grain during the finishing phase. Animals were slaughtered when they reached 350 kg live weight. Table 3 shows the results during the finishing phase and their interaction with the backgrounding treatments, as effects during backgrounding were not significant. Both CLA and ω3 fatty acids were reduced with grain intake, which is agreement with previous reports (Latimori et al., 2003; Martínez Ferrer, Ustarroz, Ferray-

Table 3
Fatty acid composition (%) of muscle lipid of steers, supplemented with corn silage during backgrounding phase, and cracked corn grain during the finishing phase

Backgrounding treatment[a]	Pasture			Pasture plus corn silage			Effect, $P <$ [c]	
Finishing treatment[b]	0%	1%.1	2%	0%	1%	2%	CG	CG × CS
CLA	0.79	0.44	0.47	0.78	0.41	0.35	Q	NS
SFA	42.3	45.8	49.9	41.9	48.8	49.4	–	*
MUFA	53.5	49.6	44.4	53.7	47.1	45.6	–	*
PUFA	4.2	4.6	5.7	4.5	4.0	5.1	L	NS
PUFA/SFA	0.10	0.10	0.12	0.11	0.08	0.10	NS	NS
ω6	2.4	3.5	4.6	2.6	2.9	4.1	L	NS
ω3	1.1	0.64	0.61	1.08	0.71	0.66	Q	NS
ω6:ω3	2.23	5.55	7.53	2.41	4.41	6.25	L	NS

Adapted from Chicatún et al. (2006).
[a] Backgrounding treatment consisted on pasture only (control) or pasture plus corn silage, supplemented at 1.5% live weight (DM basis).
[b] Finishing treatment consisted on pasture only (0%) or pasture supplemented with corn grain (1% or 2% live weight, DM basis).
[c] CG, corn grain effect; CG × CS, corn grain × corn silage interaction effect; *Significant effect ($P < 0.05$); NS, not significant; L, lineal effect; Q, quadratic effect.

oli, et al. 2006). In contrast, ω6-FA, ω6:ω3 ratio and PUFA were lineally increased with cracked grain intake. The results observed by Chicatún et al. (2006) would suggest that corn silage supplementation during the backgrounding phase would not affect fat composition, whereas corn grain supplementation during the finishing phase would significantly alter beef nutritional quality. On the contrary, Marinissen, Arelovich, Martínez, and Ombrosi (2006) fed incremental levels of oat grains (0%, 0.25% and 0.5% live weight) to steers grazing winter oats over a 130 day period, and found increased intramuscular fat (1.57, 1.90, and 2.03 for 0%, 0.25% and 0.5%, respectively) but without affecting statistically CLA contents (0.45%, 0.40%, 0.38%, respectively) probably because of the low levels of supplement used, the reduced number of animals, or both.

Kedzierski, Schindler de Ávila, Pruzzo, and Santa Coloma (2002) analyzed the effects of production system (pasture, supplementation during the backgrounding, feedlot during the finishing phase and feedlot) on fatty acid profile, cholesterol and intramuscular fat contents in *Longissimus dorsi* of Hereford steers differing in frames but slaughtered at the same finishing level. Cholesterol content and ω6:ω3 ratio were higher for the feedlot treatment ($P < 0.05$) than for the pasture based system. Grigera Grigera Naón, Schor, Cossu, Trinchero, and Parra (2000) studied the effects of grain supplementation (1.5% live weight in a DM basis) over a short period of time on cholesterol and fatty acid composition of Angus steers grazing pastures and slaughtered at a similar subcutaneous fat depth (7.25 mm). Cholesterol in both *Longissimus dorsi* and *Semitendinosus* were not affected by feeding strategy ($P > 0.05$). Feeding strategy also did not alter intramuscular fat and saturated fatty acid contents (Table 4). Only marginally higher levels of α-linolenic acid were found in the pasture fed animals, with the lack of differences likely being attributable to the limited duration of the supplementation. In this study, type of muscle was more important than feeding strategy to define intramuscular fat contents or fatty acid profiles.

Table 4
Effects of grain supplementation (1.5% live weight in a DM basis) over a short period of time on chemical characteristics of beef from Angus steers grazing pastures and slaughtered at a similar subcutaneous fat depth (7.25 mm)

Feeding system	$C_{18:2}$ ω6 (%)	Saturated fatty acids (%)	Cholesterol, mg/100 g	Intramuscular fat content (%)
Pasture				
Longissimus dorsi	6.7	47.4	38.1	4.2
Semitendinosus	10.0	43.1	37.9	2.6
Pasture + grain				
Longissimus dorsi	6.7	42.8	48.6	4.2
Semitendinosus	8.2	45.0	33.3	1.6
Feeding system effect[a]	NS	NS	NS	NS

Adapted from Grigera Naón et al. (2000).
[a] NS, not significant ($P > 0.05$).

Cossu et al. (2000) studied the effects of three fattening strategies (pasture, pasture plus corn grain at 1.5% live weight post weaning and feedlot) on intramuscular fat content of *Longissimus dorsi* muscles and fatty acid profiles of Hereford steers slaughtered at similar end point (5 mm subcutaneous fat depth). Feeding regimen did not affect ($P < 0.05$) fatty acid composition except for $C_{14:0}$, (3.13% vs. 3.72 for feedlot and pasture treatments, respectively, $P < 0.05$) and $C_{18:2}$ ω6, (4.09% vs. 2.64% for feedlot and pasture treatments, respectively, $P < 0.01$). Meat from grass fed steers (pasture and pasture plus grain) tended to have higher concentrations of $C_{18:3}$ ω3 (1.29% vs. 1.14% for feedlot). Differences among systems found in this particular study are smaller than in most other studies.

Santini et al. (2005) evaluated diets differing in metabolizable energy concentration (S: 2.4 and M: 2.7 Mcal ME/kg DM) on chemical characteristics of beef from Angus steers of contrasting frames: small (frame 1–2) and large (frame 4–5). In general, diet M had lower proportion of saturated fatty acids (SFA) (44.6% vs. 46.7%), larger PUFA contents (7.5% vs. 5.2%), ω6 (6.71% vs. 4.62%), ω3 (0.71% vs. 0.50%), and a larger PUFA:SFA (0.17 vs. 0.11) than the S diet.

Fiber content in the diet could potentially affect performance and quality attributes of beef. Volpi Lagreca, Pordomingo, Miranda, García, and Grigioni (2005) examined the effects of adding incremental fiber quantities (10%, 40% or 70% alfalfa hay) in heifers (189 kg initial live weight) fed on a corn grain based diet for 104 day ad libitum. Upon the fattening phase, authors observed a poorer performance, feed conversion, subcutaneous fat depth (11.0–7.4 mm), intramuscular fat content (3.7% vs. 2.7%), MUFA proportion (38.7% vs. 36.2%) and the ω6:ω3 ratio (4.62–1.89), with concurrent increases in PUFA ω3 (1.7–4.4%), CLA (0.30–0.39%) and the PUFA:SFA ratio (0.21–0.28). An additional group of heifers received diets consisting of 40%, 70% or 100% alfalfa hay during winter, and then were finished on pasture (132 d). The heifers did not show residual effects of the winter feeding, as no differences on fat composition were detected (Volpi Lagreca et al., 2005b).

Pordomingo et al. (2005) examined the effect of incremental levels of condensed tannins combined with two levels of corn grain in the diet of heifers at feedlot, and although they did not find effects of tannins on fatty acid profiles, the diet with higher energy concentration produced beef with higher intramuscular content (3.7% vs. 2.6%, $P = 0.027$), MUFA (38.7% vs. 36.2%, $P = 0.009$), and ω6:ω3 ratio (4.6 vs. 3.5, $P = 0.024$), and lower levels of PUFA ω3 (1.74% vs. 2.04%, $P = 0.037$) and CLA (0.30% vs. 0.41%, $P = 0.003$). Furthermore, Navarro et al. (2005) added whole sunflower or soybean seeds to a diet based on whole crop corn silage, corn grain and sunflower meal, in order to obtain diets with different levels of ether extract contents (control = 3.1%, low = 4.6–4.9%; medium = 5.5%, and high = 6.1%), and found reduced SFA (from 40.1% to 37.6–38.6%) and MUFA (from 40.6% to 34.8–38.4%), but higher PUFA (8.7% to 10.5–13.2%), ω6 (7.2% to 8.7–10.9%), ω3 (1.52% to 1.78–2.31%) and CLA (from 0.31% to 0.29–0.44%) for the higher levels of oilseeds inclusion. Therefore, adding oil rich seeds could alter the fatty acid profile of beef, enhancing its nutritional quality and the contents of potentially healthy components. Depetris et al. (2003b) found that "bolita" heifers fed with a high oil corn grain hybrid (7.6% total fat) instead of a standard one (4.3% total fat) at 75% of the diet (DM basis) presented at slaughter (240 kg final live weight) in their meat higher CLA (0.36 vs. 0.30%, $P = 0.08$), SFA (41.1 vs. 39.5%, $P = 0.02$), and SFA:UFA (unsaturated fatty acids) ratio (0.89 vs. 0.81, $P = 0.005$), and lower UFA (46.1 vs. 48.4, $P = 0.014$). Unfortunately, the intramuscular fat values were not reported in this study, which prevents the possibility of reaching definitive conclusions.

As it has been mentioned, Argentinean beef has a high content of antioxidants, mainly due to the fact that most animals are raised and finished on pasture. This is of particular importance given that it also has a high content of fatty acids that can easily be oxidized (e.g., PUFA ω3). Oxidation stability is important as it enhances shelf life, and can be explained by studying the pro-oxidants and antioxidants factors present in the beef. Descalzo et al. (2000,2002,2005) characterized the pro-oxidants to antioxidants ratio in beef from steers fed on different feeding strategies, in order to establish its influence on nutritional quality during storage. A pasture- or grain-based diets, alone or with addition of 500 IU/animal/d of Vitamin E, were used as diet models. Determinations made on fresh meat (24 h post-slaughter) indicated that only α-tocopherol content was affected (pasture = 3.5 mg/g tissue vs. grain = 1.62 mg/g tissue, $P < 0.05$), suggesting that the basal diet contribution to the antioxidant capacity was greater than the contribution coming from supplementation. In addition, lipid oxidation values were similar for both grain-based diets (0.28 and 0.26 mg malon-di-aldehyde/kg tissue respectively; $P > 0.05$) and pasture-based diets (0.095 mg MDA/kg tissue). In terms of pro-oxidants contents, the pasture-based diets showed higher double bonded PUFA contents (4.04% vs. 7.75% for pasture- and grain-based diets, respectively; $P < 0.05$). However, the contribution of natural antioxidants found in meat from pasture fed steers was enough to compensate the high pro-oxidant effect of double bonded PUFA. These findings led to the suggestion that antioxidant levels present in muscle would explain the stability of beef coming from grazing systems. Vitamin E supplementation contributed to a lesser extent to enhance fresh meat antioxidant status.

Insani, Eyherabide, Descalzo, Sancho, and Pensel (2000) determined the effects of intensive pasture systems compared to feedlot on lipid and protein oxidation during retail display storage (1, 3, 5, 7 and 9 days) of *Psoas major* of cross-bred steers. Meat samples from pasture presented lower levels and different lipid oxidation pattern than those from feedlot. After 3 days of display, feedlot samples showed a significant increase in lipid oxidation compared to pasture (0.56 vs. 0.21 mg MDA/kg tissue; $P < 0.01$), while pasture-based diets only showed an increase after 7 days of storage. Beta carotene levels were higher for meat coming from pasture, and although they decreased significantly after 9 days, the levels continued to be higher than those determined in the feedlot samples. In spite of similar initial levels for both pasture and feedlot, protein oxidation, measured as carbonyl content, was higher for feedlot ($P < 0.05$) after 9 days of storage, without a concomitant increase in protein oxidation in the pasture samples.

As a general conclusion for this section, it can be pointed out that variation in cholesterol and intramuscular fat percentages as a result of feeding systems are highly dependant on the age, live weight or finishing degree of the animal under study. When animals are evaluated at similar degree of finishing, there is a general agreement that animals coming from pasture showed lower cholesterol and intramuscular fat contents than their feedlot counterparts. These findings agree with previous data reported by García and Castro Almeyra (1992) and García and Casal (1992). Likewise, contents of ω3 (linolenic acid) were higher for pasture fed animals (or those receiving supplementation at low levels to pasture) than for feedlot (or animals receiving high supplementation levels to pasture). The ω6:ω3 ratio increases and CLA concentrations decrease as grain percentage in the diet increases up to reach extreme values in the feedlot diets. In general, supplementation to pasture failed to increase ω6:ω3 over the recommended levels for human consumption. Only long supplementation periods and/or very high supplementation levels resulted in fatty acid levels exceeded those recommended, but without reaching those observed for feedlot diets. The nutritional quality of meat produced in extensive systems shows advantages compared to that obtained under confinement and grain-based diets.

4. Diet effects on beef sensory characteristics

The sensorial quality of a given food is the combination of sensations experienced by a person when eating it, which are related to the food intrinsic characteristics such as colour, flavour, juiciness, aroma and texture. These attributes influence the consumer's decision over purchasing a determined product.

Teira, Perlo, Bonato, Monje, and Galli (2003) and Teira et al. (2004e) evaluated the sensory characteristics of beef produced by animals with a finishing period in tie stall housing in comparison to animals produced on grazing systems, with the objective of selecting the longest feedlot period without detrimental effects on meat quality. Steers were fed on pasture alone or with three final feedlot periods: 40, 60 or 80 days, and slaughtered at 380 kg live weight. Steaks were cooked to a final internal temperature of 80 °C using dry heat for sensory evaluation of flavour, taste, juiciness and acceptability on a 1–7 scale (1: non existent, very mild, very dry, poor; seven: intense, very strong, very juicy, very good). Flavour and acceptability were not affected ($P > 0.05$) by feeding system (see Table 5). However taste was higher for animals finished on feedlot for 80 days. It was concluded that a feedlot phase of up to 80 days could be used without any detrimental effect on beef sensory characteristics.

Martínez Ferrer et al. (2006b) used 70 steers from British breeds (230 kg initial live weight) and assigned them to five pasture systems (control, two pasture allowances and two supplementation levels) and two feedlot systems (grain- or silage-based. Animals were slaughtered when reaching 10 mm of subcutaneous fat depth. Global acceptability was not different among treatments, and no differences were detected for aroma, taste, juiciness and acceptability either. In terms of presence of off-flavors, values were extremely low, almost inexistent. In general, the authors concluded that the systems evaluated were unexpectedly similar in terms of the sensorial parameters evaluated, despite the fact that the fatty acid profiles differed markedly (Martínez Ferrer et al. (2006a)).

Picallo, Gállinger & Margaria (2002) characterized meat from steers of British breeds fed on pasture or feedlot. In agreement with other reports (Martínez Ferrer et al., 2006b; Pordomingo et al., 2005), the authors did not find differences in sensory characteristics, although a larger proportion of sweet, metallic and pork-like tastes appear in the feedlot meat.

Monje, Galli, Garciarena, Picallo, and Gallinger (2002) examined the impact of energy concentration and source of fat addition (chicken oil vs. tallow), with or without antioxidant supplementation on the sensory characteristics of meat from Zebu × Hereford calves (from weaning to slaughter at 231 live weight). In *Longissimus dorsi*, flavour and aroma did not show differences, but there was a trend ($P < 0.10$) towards juicier meat in animals fed on saturated fat (tallow, 4.3), vs. animals fed chicken oil without antioxidants in the ration (2.8).

Pasinato et al. (2006) fed Holstein calves from 80 to 360 kg live weight with iso-energetic diets but varying protein contents (12%, 14%, or 17%), and found no effects on performance (average LW gain: 1.32 kg/d) or meat sensory characteristics (aroma, taste, juiciness, off-flavours, collagen content).

Table 5
Effect of grazing and duration of feedlot phase (40, 60 or 80 days) on sensory characteristics of Argentinean beef

Sensory parameters	Pasture	Feedlot		
		40	60	80
Flavour[a]	4.35[a]	4.05[a]	4.29a	4.32a
Juiciness	4.80[a]	4.20b	4.38ab	4.50ab
Taste	3.80ab	3.87ab	3.64a	4.20b
Acceptability	4.59[a]	4.55[a]	4.43a	4.54a

Adapted from Teira et al. (2003) and Teira et al. (2004e).
[a] Within files, numbers followed by different letters differ significantly ($P < 0.05$).

González, Pazos, Salitto, García, and Lasta (2003) examined the shear force of pure Aberdeen Angus (A) and Hereford (H) steers, and their crosses with *Bos indicus* (B), (BA 1/4, BH 1/4, BA 3/8 and BH 3/8) fattened at pasture and slaughtered when they reached 4–8 mm subcutaneous fat depth. *Longissimus dorsi* samples were vacuum-packaged when still fresh (36 h post-mortem) or aged for 7 days at 1 °C. A 1–8 scale (8 = tender, nothing; 1 = hard, abundant) was used to evaluate global shear force and amount of connective tissue. Post-mortem ageing improved shear force in the A samples (4.93 vs. 5.82), BA 1/4 (4.74 vs. 5.59), BH 1/4 (5.01 vs. 5.73) and BH 3/8 (4.40 vs. 5.67), whereas no differences were detected for the other samples.

As a general conclusion, different feeding regimes did not markedly alter the sensory characteristics of beef. Taste of meat from feedlot finished animals would appear to present a higher intensity with respect to other systems, with occasional off flavours but without compromising the overall acceptability of the meat. More research is required to define the best conditions for beef storage prior to be subjected to tasting panel assessments in order to avoid diluting or masking sensations.

5. Breed effect on carcass physical parameters and physical, chemical and nutritional aspects of Argentinean beef

Fumagalli et al. (2005) carried out a trial to examine the effect of supplementing corn grain to steers from three racial types: Braford, Criollo and a cross between a *Bos indicus* and *Bos taurus*, fattened on irrigated pastures for 381 days. Cracked corn grain was added during the last 100 days of the trial at two levels 0.6% and 1.2% live weight. There was no effect ($P > 0.05$) of the diet × breed interaction for carcass yield, but breed type was significant ($P < 0.001$), with the Criollo showing the lowest yield (57.5% vs. 60.6%). Braford animals showed higher subcutaneous fat depth and a trend towards higher intramuscular fat content.

Altuve, Pourrain, Sampedro, Pizzio, and Carduza F.J. (2004) studied the differences in intramuscular fat content and Warner Bratzler shear force in Braford or Brahman × Hereford steers finished at pasture with 20 months of age (418 kg live weight) in two consecutive experiences. There was no difference in intramuscular fat content between breeds. Shear force values (5 days of ageing) were similar, suggesting that different proportions of *Bos indicus* would not affect the factors under study.

Latimori et al. (2003) and Latimori et al. (2005) used Aberdeen Angus (AA), Charolais × Angus crosses (CH × AA) or Holstein (HA) steers fed on pasture with or without supplementation (0%, 0.7% and 1% live weight) or in feedlot, to evaluate meat quality characteristics. Shear force values were not affected by breed (mean = 68.70 N, $P > 0.05$), but intramuscular fat content was higher for AA than CH × AA and HA. Cholesterol contents were higher ($P < 0.05$) for AA (45.3 mg/100 g) compared to

CH × AA and HA (mean = 43.2 mg/100 g). Saturated fatty acid proportion was lower in HA steers compared to AA and CH × AA (37.1% vs. 39.4% for HA and the mean of the other two, respectively), whereas the ω6:ω3 ratio did not show differences. Finally, CLA concentrations were lowest in AA (0.50%) compared to the other two breeds (mean = 0.57%). Latimori, Kloster, and Amigone (2001) examined five breed types of heavy steers (Red Angus, Charolais × Angus, Fleckvieh × Angus, Criollo × Angus, and Holstein) under grazing conditions with corn grain supplementation (0.7% live weight) all year round with the exception of the december–february period. All breed types exceeded 450 kg live weight at slaughter. Holstein steers showed the lowest yield (53.5% vs. 56.1–57.8% for the other treatments) and SFA proportion (37.7% vs. 40.1–42.5%). They also showed the lowest rib eye area (58.9 cm^2), with the Charolais × Angus being the highest (72.1 cm^2) and the rest of the treatments showing intermediate values (63.4–65.7 cm^2). With respect to shear force, Red Angus and Holstein were the most tender (30.18 N), whereas Fleckvieh × Angus resulted the toughest (38.22 N). Breed types evaluated did not differ in the rest of the quality parameters, which suggests that grazing conditions with moderate supplementation can generate high quality meat.

In another series of studies, Villarreal, Santini, Faverín, Depetris, Paván, et al. (2005) and Villarreal, Santini, Paván, et al. (2005) evaluated the effect of diets varying in energy densities (2.4 vs. 2.7 Mcal ME/kg DM) fed to Angus steers from contrasting frames (small = 1–2, and large = 4–5) from weaning (7 months of age) to slaughter (6 mm of subcutaneous fat depth, determined by ultrasound). Animals from large frame showed higher cooking losses (21.6% vs. 15.7%; $P < 0.05$), which were associated with their larger muscle content. Santini et al. (2005) analyzed the chemical characteristics of the meat from the animals used by Villarreal, Santini, Faverín, Depetris, Paván, et al. (2005) and Villarreal, Faverín, et al. (2005) found that those animals of small frame, fed on high energy diet showed the lowest levels of MUFA (45.9%), highest PUFA (9.0%), ω3 (0.84%), ω6 (8.1%) and the highest PUFA:SFA ratio (0.2) with respect to the rest of the treatments. Small frame combined with high energy diets produced the largest alterations in fatty acids profile.

In another work from the same group, Villarreal et al. (2003) evaluated the same frames as above unsupplemented or supplemented with whole crop corn silage or high moisture corn grain but finished on pasture. They found that animals of large frame showed the lowest pH values (5.62 vs. 5.51, $P < 0.01$), the most tender meat (74.09 vs. 99.96 N, $P < 0.01$), largest CLA and PUFA concentration (1.15% vs. 0.80% and 8.92% vs. 5.72% for CLA and PUFA for large and small frame animals, respectively), and a lower SFA content (46.0% vs. 53.2%, $P < 0.01$) and ω6:ω3 ratio (3.23 vs. 4.23, $P < 0.09$).

Pruzzo, Schindler, Abbiati, and Santa Coloma (2000) determined the relative importance of breed type (British, Continental, *Bos indicus* and Friesians crosses) on shear force of the *Longissimus dorsi* of steers and cows. Mean shear force values of *Bos indicus* (38.12 N) differed significantly from all others (32.14 N).

Latimori et al. (2000) evaluated the productive performance and meat quality of medium framed (4–6) steers from four genetic groups (Santa Gertrudis, SG; 3/4 Brangus × Aberdeen Angus cross, B × AA; Limousin × Aberdeen Angus cross, L × AA; and Fleckvieh × Hereford cross, F × H), grazing alfalfa and tall fescue pastures with strategic corn grain supplementation. Fattening phase (i.e., weaning to slaughter) lasted 12 months, and animals were slaughtered with an average of 466 kg live weight. No differences ($P > 0.05$) in Warner Bratzler shear force (mean = 27.66 N), colour parameters (mean of $L^* = 26.4$, saturation index = 17.43, Hunter Lab scale), intramuscular fat (mean = 2.87%) and cholesterol content (mean = 38.77 mg/100 g) were found in *Longissimus dorsi*. Cholesterol levels were low, which was attributed to the low relative values of intramuscular fat or other unexplained factors. Saturated fatty acids contents showed differences (46.7% vs. 43.4% for SG and F × H, respectively, $P < 0.05$), and so did MUFA contents (36.9% vs. 41.4% for B × AA and F × H, respectively), but no differences were detected for PUFA (mean = 7.65%).

Bonsmara is a 5/8:3/8 combination of the Afrikaner (*Bos taurus africanus*) and Shorthorn/Hereford (*Bos taurus taurus*) introduced in Argentina before the year 2000. García and Lundqvist (2000) studied the composition of intramuscular (*Longissimus dorsi*) and subcutaneous lipids from Bonsmara (25 months old, 450 kg live weight) steers fattened under a traditional grazing system. The average intramuscular fat content (1.9%) was similar or lower than British cattle fattened under similar conditions (García & Castro Almeyra, 1992). Cholesterol content was also low but typical of very lean beef (39 mg/100 g). Likewise, the fatty acid composition of Bonsmara (SFA = 43.0%; MUFA = 44.2%; PUFA = 8.4%) was similar to the fatty acid composition of Angus steers with low levels of intramuscular fat contents.

González et al. (2003) examined the shear force of pure Aberdeen Angus (A) and Hereford (H) steers, and their crosses with *Bos indicus* (B), (BA 1/4, BH 1/4, BA 3/8 and BH 3/8) fattened at pasture and slaughtered when they reached 4–8 mm subcutaneous fat depth. No differences were detected in WB shear force values from the pure breeds (A and H, mean = 82.32 N), the 1/4 crosses (mean = 79.38 N) and the 3/8 crosses (84.28 N).

As a general conclusion, breed type had a minor effect in terms of physical and nutritional parameters of meat. Different proportion of *Bos indicus* did not result in differences in intramuscular fat contents or shear force values, but when *Bos indicus* steers were compared to very different breed types (Pure British and Continental), their shear force values were higher. However this will depend on the proportion of *Bos indicus* in the cross. When pure British breeds were compared to British × Continental crosses, the former showed higher intramuscular fat contents, lower

CLA content and higher saturated fatty acid concentrations, without differences in the ω6:ω3 ratio and shear force values. When steers from contrasting frames were compared, only marginal, likely, non-biologically significant differences were observed.

6. Effect of animal and post-slaughter handling on physical parameters of Argentinean beef

Altuve et al. (2004) fed Braford or a Brahman × Hereford cross steers on grass until finished with 20 months of age, and found that regardless of breed type, ageing time (0, 7, and 14 days for the first trial, and 5, 12, and 19 days for the second trial, between 5 and 12 °C) was very important to obtain a "tender" product (less than 35.6 N, using the Warner Bratzler machine). The Warner Bratzler measurements were different ($P < 0.05$) between 0 and 7 days, but similar between 7 and 14 days in the first trial, whereas in the second trial, shear force values were different between 5 and 12 days, but not different between 12 and 19 days of ageing. To a similar conclusion arrived Schindler et al. (2003), who highlighted the importance of ageing time (3 or 15 days) in Hereford steers finished at pasture, at pasture with supplementation or at feedlot. Although production system did not influence final tenderness, meat cuts showed lower shear force values ($P < 0.05$) when they were subjected to ageing for 15 days (mean = 26.07 N) than those cuts aged for 3 days (30.0 N). In Argentina, the lack of infrastructure prevents ageing from being a standard practice in meat sold for internal market, which suggests that meat tenderness is determined to some extent in the production system itself.

Zamorano, Ramos, and Picallo (2002) evaluated the effect of two variants of the "tendercut" technique (cutting the carcass to the ischium and ilium bones level), with respect to a control (without tendercut) and ageing (1 or 5 days, 4 °C) on shear force values of several muscles: *Longissimus dorsi thoracis*, *Longissimus dorsi lumbarum*, *Bicipitis femoris*, *Glutaeous medius*, *Semimembranosus*, and *Semitendinosus*. The use of the tendercut technique cutting the carcass to the ilium bone level resulted in lower shear force values for beef, except in case of *Longissimus dorsi thoracis*. Whilst ageing showed a systematic effect in all muscles ($P < 0.05$), no interaction between tendercut and ageing was detected. It was concluded that tendercut and ageing improved meat tenderness.

Sager, Carduza, and Pensel (2002) evaluated the sensory characteristics of *Longissimus dorsi* from Angus steers (271 kg initial live weight) fed on feedlot with or without addition of grape pomace (40% of the ration) for three months. Three ageing times were also evaluated: 0, 7 and 21 days (2 ± 1 °C). As no differences ($P < 0.05$) were observed in terms of diet composition, a non-structured lineal scale was developed to determine effects of ageing. Flavour and aroma values were slightly decreased by ageing time, which was concurrent with a slight presence of off flavours and off aromas.

Grigera Naón, Schor, Cossu, and von Bernard (2004) studied the relationship between shear force value and age, assessed by dental status. Measurements were performed either 24 or 96 h post-slaughter on *Longissimus dorsi* muscles from Aberdeen Angus steers slaughtered according to 4–5 mm or 6–7 mm subcutaneous fat depth. Upon 24 h of cold storage, meat from steers with two incisors was more tender ($P < 0.05$) than that from those with no permanent incisors. No differences ($P < 0.05$) were detected between two and four incisors, and between four and no permanent incisors. However, after 96 h storage all aged meat showed decreased shear force values, with meat from steers with two and four permanent incisors showing lower shear force values than meat from less mature steers. Correlation between degree of fatness and shear force was significant (r = -0.34; $P < 0.05$). After a short ageing period, meat from steers with two and four permanent incisors proved to present less mechanical strength than meat from those animals showing no permanent incisors.

Pruzzo et al. (2000) determined the potential of several pre-slaughter factors such as sex, feeding system (feedlot or pasture), age, breed type and intramuscular fat content as on farm predictors of shear force. *Longissimus dorsi* was used as a model muscle. After a preliminary analysis, sex and chemical fats were excluded from the model since they were not significant ($P > 0.05$). Mean shear force values (7 days of ageing) between age groups was not different ($P > 0.05$), probably due to the fact that *Longissimus dorsi* has a low proportion of connective tissue, which is the tissue most affected by age. The authors concluded that a model to predict on farm effects on shear force could be used with reasonable precision by recording breed type, age group, feeding system and carcass weight at slaughter.

Picallo, Martínez, and Margaría (2000) examined the relationship between objective colour measurements of retail ready cuts and Warner Bratzler shear force using 10 cuts coming from steers. Shear force values showed significant differences ($P < 0.05$) among cuts, with *Psoas major* showing the lower (24.02 N) and *Pectoralis superficialis* the higher resistance (59.16 N). When data were classified by a trained assessment panel, the muscles *Longissimus dorsi*, *Gluteous medious*, *Quadriceps femoris*, *Psoas major*, and *Triceps bracchii* were classified as "tender"; whereas *Semitendinosus* and *Obliquus abdominalis* were classified as "somewhat tender". In contrast, muscles like *Semimembranosus* and *Biceps femoris* were "somewhat tough", while *Pectoralis superficialis* was "tough". Meat colour parameters did not show differences ($P < 0.05$) in terms of redness (a^*) score. The strongest correlation coefficients between Warner Bratzler and Hunter Lab parameters were found for *Gluteous medius* ($r = 0.78$ and $r = 0.86$ for a^* and b^* respectively; $P < 0.05$) and *Psoas major* ($r = 0.72$, $r = -0.72$, $r = -0.85$ for L^*, a^* and b^* respectively; $P < 0.05$).

González et al. (2003) found that post-mortem ageing was highly successful in assuring tenderness consistency in cattle with up to 1/4 of *Bos indicus*, whereas 3/8 cattle did not respond to ageing (82.32 vs. 49.98 N for fresh and aged beef in pure British breeds; 79.38 vs. 55.86 N for fresh and aged beef in 1/4 Bos indicus × British breeds crosses).

Gárriz, Picallo, and Martínez (2000) compared the shear force values of commercial cuts from Argentinean Criollo steers grown in Patagonia or the north-western region of the country. Animals were grown under extensive grazing conditions and slaughtered at three different ages: 18, 24, and 30 months, with an average live weight at slaughter of 410 kg. *Psoas major*, *Longissimus dorsi*, *Gluteus medius*, *Quadriceps femoris*, *Triceps brachii*, *Obliquus abdominalis*, *Semitendinosus*, *Semimembranosus*, *Biceps femoris* and *Pectoralis superficialis* were assessed. It was concluded that shear force value was more related to muscle type than to breed type, geographic origin, live weight, and slaughter age. On average, *Psoas major* was considered as "very tender", while *Longissimus dorsi*, *Gluteus medius*, *Quadriceps femoris* and *Triceps brachii* were considered as "tender", *Obliquus abdominalis* and *Semitendinosus* were assessed as "somewhat tender", *Semimembranosus* and *Biceps femoris* were classed as "somewhat tough" and *Pectoralis superficialis* was considered as "tough".

As a general conclusion, short ageing periods (7–12 days) decreased shear force values regardless of breed type and age. Although longer ageing times further improved tenderness, the magnitude of this improvement was not high enough so as to be economically justifiable. A further improvement in cuts from the hind quarter could be achieved by using the tendercut technique (ilium bone level). It was observed that shear force value was more related to the individual muscle under consideration than to other factors such as breed type, geographical origin, live weight and slaughter age of the animal. Moreover, ageing time would improve tenderness in all muscle types.

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