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**Article** *in* The Canadian veterinary journal. La revue veterinaire canadienne · September 1992

DOI: 10.4141/cjas92-065



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# The combined effects of time on feed, electrical stimulation and aging on beef quality

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*Red Meat and Beef Production Section, Agriculture Canada Research Station, Bag 5000, Lacombe, Alberta, Canada T0C 1S0.* *Contribution no. 708, received 10 Mar. 1992, accepted 13 May 1992.*



Aalhus, J. L., Jones, S. D. M., Tong, A. K. W., Jeremiah, L. E., Robertson, W. M. and Gibson, L. L. 1992. **The combined effects of time on feed, electrical stimulation and aging on beef quality.** Can. J. Anim. Sci. **72**: 525–535. Two experiments were conducted to determine the combined effects of time on feed, high-voltage electrical stimulation (HVES) and postmortem aging on beef quality and palatability. Increasing time on feed resulted in an increase in carcass fat thickness, dressed carcass weight and marbling and a decrease in carcass lean content, carcass shrinkage and shear values in both experiments. Steaks from longer-fed animals were rated more highly for juiciness, tenderness and overall palatability by the consumers polled. HVES lowered muscle pH (3 , 24 and 144 h), increased subjectively appraised marbling fat, gave brighter, redder muscle colour up to 6 d postmortem, and improved consumer ratings for flavour, juiciness, tenderness and overall palatability. HVES also resulted in a significant improvement in shear values (shear values were decreased by 27 and 35% in experiments 1 and 2, respectively). Aging for 6 d improved meat colour, decreased the amount of expressible juice and lowered the shear value of steaks by 11 and 9% respectively, in experiments 1 and 2. A consumer survey indicated that more than 20% of steaks were rated as unacceptable for tenderness when time on feed and postmortem aging were similar to Canadian beef-production practices. Incorporation of HVES as a means of quality control would reduce the proportion of unacceptable steaks to approximately 10%.

Key words: Beef quality, time on feed, electrical stimulation, aging

Aalhus, J. L., Jones, S. D. M., Tong, A. K. W., Jeremiah, L. E., Robertson, W. M. et Gibson, L. L. 1992. **Effets combinés de la durée d'engraissement, de la stimulation électrique et de la maturation sur la qualité de la viande bovine.** Can. J. Anim. Sci. **72**: 525–535. Deux expériences avaient pour objet de déterminer les effets réunis de la durée d'engraissement, de la stimulation électrique à haute tension (SEH) et de la maturation post-abattage sur la qualité et sur l'appétibilité de la viande bovine. Dans les deux expériences, l'allongement de la durée d'engraissement a donné lieu à un accroissement de l'épaisseur du gras de couverture, du poids de carcasse habillée et du persillé, mais aussi à une réduction de la teneur en muscle de la carcasse, des pertes de volume au ressuyage et des valeurs de cisaillement. Les steaks produits sur les animaux engraissés plus longtemps étaient mieux cotés par un jury de consommateurs pour la jutosité, la tendreté et les qualités gustatives générales. La SEHT a abaissé le pH du muscle (3 h, 24 h, 144 h) et amélioré l'appréciation subjective du gras de persillé. Elle donnait à la viande une couleur d'un rouge plus vif jusqu'à six jours après l'abattage et améliorait les cotes d'appréciation des consommateurs pour la jutosité, la tendreté et l'appétibilité générale. La stimulation électrique a également amélioré significativement les valeurs de cisaillement qui ont baissé de 27 et 35%, respectivement, dans les expériences 1 et 2. Une durée de maturation de six jours a amélioré la couleur, réduit la quantité de jus libre et abaissé les valeurs de cisaillement de 11 et 9% respectivement dans les expériences 1 et 2. Dans une enquête auprès des consommateurs, plus de 20% des steaks étaient cotés inacceptables pour la jutosité lorsque la durée d'engraissement et la durée de maturation correspondaient aux pratiques en usage dans le secteur des viandes au Canada. L'utilisation de le SEH comme outil de contrôle de la qualité ramènerait la proportion des steaks inacceptables à environ 10%.

Mots clés: Qualité de la viande, durée d'engraissement, stimulation électrique

A recent national survey conducted by the Beef Information Centre (McDonell 1988) indicated that variation in beef quality, particularly tenderness, was a concern for Canadian consumers. Although lack of consumer education in choosing and preparing cuts of meat may contribute to this finding, the increase in production of lean beef (A1 beef has increased from 40% of the A grade in 1972 to over 70% of the A grade in 1990: Agriculture Canada, Livestock Market Review 1972, 1990) and the advent of rapid methods of carcass chilling may also be contributing factors.

Research by Aberle et al. (1981), Rompala and Jones (1984) and Miller et al. (1987) indicated that time on feed and growth rate prior to slaughter can influence beef tenderness. Faster growth rates prior to slaughter have been associated with a higher collagen solubility, which leads to increased tenderness (Miller et al. 1987). Although Aberle et al. (1981) indicated that feeding a high-energy diet for a short period ($\sim$70 d) prior to slaughter improved beef palatability, little benefit was obtained from longer feeding periods.

Postmortem electrical stimulation and aging of the carcass are known to improve the palatability of beef. However, the effects of electrical stimulation and aging on carcasses that differ in fat cover as a result of differences in time on feed are not known. Thus the objective of the present study was to examine the combined effects of time on feed, electrical stimulation and aging on beef quality and palatability. Additionally, we examined the effects of time on feed on lean-meat yield and carcass grade.

## MATERIALS AND METHODS

### Experiment 1

Ninety crossbred steers and heifers (45 steers and 45 heifers) were blocked by weight within sex and assigned to one of 18 pens (five animals per pen) following weaning. In two extra pens (one with two steers and one with two heifers) spare animals were raised under conditions similar to those for the experimental animals. Initial pen weights ranged from 217 to 228 kg for the steers and from 213 to 225 kg for the heifers. Animals were fed ad libitum an on-test diet consisting of 20–25% cereal silage and 75–80% rolled barley concentrate mixture (dry matter (DM) basis) to which they had adapted in the pretest period. Average DM content of the silage was 28.5%; of the barley concentrate 87.2%. On a DM basis, the silage had a digestible energy (DE) content of 9.12 Mcal $kg^{-1}$; the barley concentrate, 4.00 Mcal $kg^{-1}$. Steers were implanted with Synovex-S; heifers, with Synovex-H (Syntex Animal Health, Calgary, Alberta). During the feedlot period, the animals were weighed at 28-d intervals. Pens were randomly allocated to one of three slaughter dates (143, 170 and 220 d after the start of the trial), with 30 animals to be slaughtered each date. Spare animals in one pen (steers) were shipped after 143 d; those in the other pen (heifers) were shipped after 220 d. These animals were included in the data set.

The day prior to slaughter, animals were removed from feed but given free access to water. Unshrunk and shrunk weights were recorded at the Beef Unit, prior to shipping to the Lacombe Research Station Meats Facility (5-min truck ride). A final live weight was recorded at the abattoir. All cattle were stunned with a captive bolt pistol, exsanguinated and dressed following commercial procedures (except the hides were removed with a rotary air-knife). After splitting, but prior to electrical stimulation (45 min post-slaughter), warm-carcass weights were recorded and pH and temperature values were determined on the longissimus thoracis (LT) with a Corning Model 4 pH–temperature meter (Corning Glass Works, Medfield, Massachusetts) equipped with an Ingold spear-type electrode (Ingold Messtechnik AG, Urdorf, Switzerland). Alternate carcass sides were electrically stimulated with a Koch-Britton Stimulator (Kansas City, Missouri; 470 V, 1.5 A, 60 Hz, 20 pulses/min) for 1 min. Post-stimulation pH and temperature were recorded for the stimulated sides. All sides were then washed, shrouded and chilled for 24 h at 1°C. Temperature and pH were measured on both sides 3 h post-stimulation.

Following chilling, the left and right sides were weighed and then ribbed between the 12th and 13th ribs. Two meat-colour measurements (CIE L* (brightness), a* (red–green axis) and b* (yellow–blue axis) values: Commission internationale de l'éclairage 1976) were made on the LT surface, following a 15–20 min bloom period, with a Chroma-Meter II (Minolta Canada Inc., Mississauga, Ontario). The results were then averaged. At 24 h post-slaughter, pH and temperature values were recorded on the LT at the 12th rib. Subjective marbling scores (using the United States Department

of Agriculture Grade Standards 10-point scale, where 1 = very abundant and 10 = devoid) were determined, and Canadian grades were assessed on both sides of the carcass by an Agriculture Canada grader.

All unstimulated sides were broken into primal cuts that were then separated into fat, lean and bone according to the procedure described by Rahnefeld et al. (1983). A portion of the LT, from the 4th thoracic vertebra to the 12th rib, was collected from both carcass sides and divided into two samples (anterior and posterior locations). These samples were then vacuum packaged and heat shrunk prior to storage at 2°C for either 3 or 6 d. Once the aging time was completed, the loins were frozen and stored at −30°C for a subsequent consumer survey. A portion of the longissimus lumborum (LL, 13th rib to 5th lumbar vertebra) was collected from both carcass sides and divided into two samples (anterior and posterior locations). These samples were then vacuum packaged and heat shrunk prior to storage at 2°C for either 3 or 6 d. Once the aging time was completed, a 20-mm-thick steak was cut from the anterior end of each muscle sample, and its ultimate pH was recorded. Final objective colour readings were recorded using a MacBeth Series 1500 colour-measurement system (Newberg, New York), after which the steak was cooked to an internal temperature of 75°C (monitored with an electronic temperature probe: Technoterm 1100, West Germany) in a Litton XLC-20 microwave oven (2000 W output). After the steaks were chilled to 2°C, three 20-mm cores (removed from the middle portions of lines dividing the steak into fourths) were sheared on an Ottawa texture-measuring system (OTMS) (Canners Machinery Ltd., Simcoe, Ontario) equipped with a Warner–Bratzler cell. The remaining uncooked portions of the anterior and posterior LL muscle samples were separately ground three times through a 3-mm grinding plate, and expressible juice was determined on 20 g of ground sample centrifuged for 60 min at 37 000 × $g$.

For the consumer survey, 20-mm steaks were cut from the 3-d and 6-d-aged frozen loins. The number of steaks cut from each portion of the loin varied with the length of the loin: the minimum was two steaks, and the maximum was nine. Each steak was identified with a numbered metal tag. With the aid of Central Alberta District home economists, participating consumers received a package containing two steaks (one stimulated steak and one unstimulated steak aged for either 3 or 6 d). Altogether, 1020 packages were sent out. Consumers were asked to prepare both steaks at the same time within 2 wk of delivery, using a method they would normally use for that type of beef. Cooking method and cooking time were recorded by the consumer, and each steak was rated for flavour, juiciness, tenderness, and overall palatability on a four-point scale (4 = acceptable; 3 = slightly acceptable; 2 = slightly unacceptable; and 1 = unacceptable).

### Experiment 2

Ninety crossbred steers were blocked by weight and randomly allocated to one of 18 pens (five animals per pen). The average pen weights ranged from 223 to 306 kg. Pens were randomly assigned to one of three slaughter dates: (1) after 140 d of backgrounding; (2) after 140 d of backgrounding and 55 d of high-energy feed (total of 195 d on feed); or (3) after 140 d of backgrounding and 86 d of high-energy feed (total of 226 d on feed). Animals were backgrounded on 85% cereal silage and 15% rolled barley concentrate (DM basis). The high-energy feed consisted of 60% rolled barley concentrate and 40% cereal silage (DM basis). The DM contents of the silage and barley concentrate were 33.4 and 87.7%, respectively. The average DE content (DM basis) was 2.59 Mcal $kg^{-1}$ for silage and 3.50 Mcal $kg^{-1}$ for barley concentrate. Slaughter procedures, meat-quality analysis and the consumer survey were identical to those outlined for exp. 1, except 958 packages of steaks were sent out for this survey.

### Statistical Analysis

All carcass and meat-quality data were analysed using the general linear model (GLM) procedure of the Statistical Analysis System Institute (1990). For exp. 1, feed-consumption data and weight gains were summarized for each pen and analysed using a model that included sex, time on feed and their interaction. Similarly, carcass data were analysed using a model that included sex, time on feed and their interaction as main effects. Data from all animals were used for the carcass and grading information; however, any carcasses that graded as dark cutters (Canada grade B2: five animals in exp. 1 and seven animals in exp. 2) were removed from the meat-quality analysis. Meat-quality data, obtained for both carcass sides but only one location (e.g., grading data), were analysed using a split-plot model that included sex, time on feed and their interaction in the main plot and electrical-stimulation treatment and its interactions in the subplot. Meat-quality consumer-survey data, which were obtained for both carcass sides and two aging treatments, were analysed

using a split-plot model that included sex, time on feed and their interaction in the main plot and electrical-stimulation treatment, aging treatment and their two-way interactions in the subplot. Since loin location (anterior and posterior) was partially confounded with aging, location was included in the subplot to remove its effects. Models similar to those used in exp. 1 were used for the respective data sets in exp. 2, except that sex was not included in any of the models. The among-animal error term was used to test the significance of factors in the main plot. Linear contrasts with one degree of freedom were used for means separation ($P \leq 0.05$).

## RESULTS AND DISCUSSION

### Feedlot Performance and Carcass Characteristics

Despite similar daily DM feed consumption, average daily gains decreased with time on 75–80% concentrate feed in exp. 1 (Table 1). However, in exp. 2, both DM feed consumption and average daily gain increased significantly with time on feed. These results reflect different maturities of the two groups: animals in exp. 1 were at a later stage of maturity (fattening more rapidly) than animals in exp. 2. Hence, the decreasing feed efficiency with time on feed in exp. 1 was accompanied by a decrease (from 87% to 82%) in the number of carcasses receiving Canada grade A1 (4–10 mm backfat) and an increase (from 3% to 14%) in the number of carcasses grading A2 (11–15 mm backfat). In exp. 2, cattle slaughtered after only 140 d of backgrounding, with no time on high-energy feed, graded 46% B1 (1–4 mm backfat) and 54% A1. On high-energy feed, the proportion of carcasses that graded A1 increased to 89% after 55 d and to 93% after 86 d.

The shift in Canada beef grades with increasing time on feed was reflected in the average grade fat (Table 1). In exp. 1, the average grade fat increased from 6.6 mm after 143 d on feed to 7.5 mm after 220 d on feed. Similarly for exp. 2, the average grade fat increased from 3.4 mm after 140 d of backgrounding on cereal silage to 7.0 mm after 86 d on high-energy feed. In both experiments, as the animals fattened, the dressing proportion — warm-carcass weight

Table 1. Summary of the feedlot performance and carcass characteristics of animals in exp. 1 and exp. 2

| | Experiment 1 | | | | Experiment 2 | | | |
|---|---|---|---|---|---|---|---|---|
| | Time on feed (d) | | | | Time on feed (d) | | | |
| | 0/143[z] | 0/170[z] | 0/220[z] | $P^y$ | 140/0[z] | 140/55[z] | 140/86[z] | $P^y$ |
| Dry matter (kg d$^{-1}$) | 7.2 ±0.15 | 6.9 ±0.15 | 7.1 ±0.15 | 0.2374 | 6.3 ±0.20*a* | 6.9 ±0.20*b* | 7.5 ±0.20*b* | 0.0026 |
| Digestible energy (Mcal d$^{-1}$) | 38.2 ±0.81 | 35.5 ±0.81 | 35.8 ±0.81 | 0.0643 | 18.1 ±0.58*a* | 21.0 ±0.58*b* | 23.1 ±0.58*c* | 0.0001 |
| Gain (kg d$^{-1}$) | 1.35±0.033*b* | 1.22±0.033*a* | 1.22±0.033*a* | 0.0243 | 0.97±0.029*a* | 1.13±0.029*b* | 1.25±0.029*c* | 0.0001 |
| Final live weight (kg) | 409 ±7.4*a* | 427 ±7.8*a* | 459 ±7.4*b* | 0.0001 | 367 ±6.9*a* | 436 ±6.9*b* | 493 ±7.1*c* | 0.0001 |
| Warm-carcass weight (kg) | 249.0 ±4.7*a* | 259.4 ±5.0*a* | 283.7 ±4.7*b* | 0.0001 | 214.9 ±4.4*a* | 259.7 ±4.4*a* | 295.6 ±4.4*b* | 0.0001 |
| Dressing proportion (g kg$^{-1}$)[x] | 608 ±3.6 | 608 ±3.8 | 618 ±3.6 | 0.1019 | 586 ±2.9*a* | 596 ±2.9*b* | 601 ±2.9*b* | 0.0017 |
| Grade fat (mm) | 6.6 ±0.33 | 7.6 ±0.35 | 7.5 ±0.33 | 0.0525 | 3.4 ±0.22*a* | 5.4 ±0.22*b* | 7.0 ±0.22*c* | 0.0001 |
| Carcass lean (g kg$^{-1}$) | 609.1 ±5.47*b* | 584.7 ±5.76*a* | 578.9 ±5.76*a* | 0.0005 | 622.8 ±5.62*c* | 591.8 ±5.62*b* | 568.5 ±5.62*a* | 0.0001 |

[z]Time on cereal-silage backgrounding followed by time on high-energy feed.
[y]Level of significance.
[x]Warm-carcass weight expressed as a proportion of final liveweight.
*a*–*c*Means in the same row followed by different letters are significantly different ($P < 0.05$) as determined by linear contrast with a single degree of freedom.

as a proportion of final liveweight — increased (by 1.6% in exp. 1 and by 2.6% in exp. 2) and the carcass lean content decreased (by 5% in exp. 1 and by 8.7% in exp. 2). These changes are consistent with reports in the literature on the effects of dietary energy and duration of feeding period on carcass characteristics (reviewed by Moody 1976).

**Meat-quality Measurements**

There were very few two-way or three-way interactions, and for the most part, interaction effects were not consistent between the two experiments; hence, only the main effects are discussed below.

Increasing the time on feed had little influence on pH values, except after 24 h postmortem, when the pH was significantly lower in the carcasses from longer fed animals in both experiments (Table 2). Slower cooling rates due to increased backfat depth likely contributed to these differences in pH, especially in exp. 2, where the temperature was significantly higher in the fatter carcasses at 40 min and 3 h. In addition, longer times on feed were associated with slightly lower objective colour scores, which were probably due to carcass fat cover and its influence on temperature and pH decline (Murray 1989). However, these differences in L*, a* and b* values were relatively minor and unlikely to be of any commercial significance. Subjective marbling scores were lower (indicating increased marbling) with increasing time on feed in both experiments, reflecting the normal pattern of increased intramuscular fat deposition as carcasses become higher in fat content. In addition, shorter times on feed (leaner carcasses) resulted in higher cooler shrink losses.

Shear values decreased significantly as time on feed increased in both exp. 1 and exp. 2 ($P = 0.0006$ and 0.0448, respectively; Table 2). However, the changes to the shear values were more pronounced in exp. 1, decreasing by 13% after 170 d on feed and by 19% after 220 d on feed. The corresponding changes in exp. 2 were only 5% after 55 d on high-energy feed and 10% after 86 d on high-energy feed. Previous studies (Zinn et al. 1970; Aberle et al. 1981) reported similar effects of feeding period on beef tenderness. However, the suggestion by Aberle et al. (1981) that an increased growth rate prior to slaughter may be more important than time on feed was not supported in the present study. In exp. 1, cattle fed for 170 or 220 d had lower growth rates than cattle fed for only 143 d, yet they had lower shear values. Aberle et al. also suggested that the improved tenderness as a result of feeding a high-energy diet occurred primarily during the first 70 d. In the present study, shear values of steaks from longer fed animals continued to decrease, even after 220 d on feed.

The mechanism contributing to the increase in tenderness with increasing time on feed was not investigated in the present study. Several researchers (Aberle et al. 1981; Rompala and Jones 1984; Miller et al. 1987) have suggested that increased collagen solubility as a result of reduced collagen synthesis and maturation may contribute to observed improvements in tenderness. Additionally, Aberle et al. (1981) hypothesized that variable amounts or activities of the calpains at slaughter (due to differences in live-animal growth rates or in carcass cooling rates) may contribute to increased tenderness through accelerated degradation of the myofibrillar proteins. Increasing time on feed was also associated with increasing levels of intramuscular fat, which has been demonstrated to have a small, but positive effect on tenderness (Savell et al. 1987). It is likely that the effects of time on feed on tenderness are complex, and one or more of the above mechanisms may contribute to the observed improvements in tenderness.

Electrical stimulation had a significant effect on almost all the objective measurements of meat quality in both experiments (Table 3). The pH of stimulated sides was significantly lower than the pH of non-stimulated sides; this effect persisted up to 6 d postmortem. As well, electrical stimulation led to greater amounts of subjectively appraised marbling fat and brighter, redder muscle colour (L*, a* and b* values). Similar findings had been reported previously by Savell et al. (1978a). The higher amounts of

Table 2. The effect of time on feed on postmortem quality measurements for exp. 1 and exp. 2

| | Experiment 1 | | | | Experiment 2 | | | |
|---|---|---|---|---|---|---|---|---|
| | Time on feed (d) | | | | Time on feed (d) | | | |
| | 0/143[z] | 0/170[z] | 0/220[z] | $P$[y] | 140/0[z] | 140/55[z] | 140/86[z] | $P$[y] |
| Pre-stimulation | | | | | | | | |
| pH | 6.76±0.012 | 6.80±0.012 | 6.80±0.013 | 0.2674 | 6.67±0.009 | 6.70±0.009 | 6.70±0.009 | 0.7714 |
| Temperature (°C) | 38.8 ±0.07 | 38.8 ±0.07 | 39.0 ±0.08 | 0.4336 | 38.6 ±0.03*c* | 39.0 ±0.03*a* | 39.3 ±0.03*b* | 0.0002 |
| Post-stimulation | | | | | | | | |
| pH | 6.63±0.016 | 6.69±0.016 | 6.65±0.018 | 0.0913 | 6.49±0.012 | 6.53±0.013 | 6.50±0.013 | 0.6534 |
| Temperature (°C) | 38.7 ±0.06 | 38.8±0.07 | 39.0 ±0.07 | 0.3642 | 38.6 ±0.04*a* | 39.1 ±0.04*b* | 39.4 ±0.04*c* | 0.0001 |
| 3 h | | | | | | | | |
| pH | 6.09±0.032 | 6.09±0.032 | 5.99±0.036 | 0.0985 | 6.20±0.022 | 6.14±0.023 | 6.09±0.023 | 0.1350 |
| Temperature (°C) | 21.3 ±0.15 | 21.9 ±0.15 | 21.8 ±0.17 | 0.2813 | 21.8 ±0.08*b* | 21.2 ±0.08*a* | 23.5 ±0.08*c* | 0.0001 |
| 24 h | | | | | | | | |
| pH | 5.76±0.008*b* | 5.76±0.008*b* | 5.70±0.008*a* | 0.0025 | 5.71±0.008*b* | 5.63±0.008*a* | 5.61±0.008*a* | 0.0001 |
| Subjective marbling | 8.60±0.052*b* | 8.71±0.053*b* | 7.23±0.058*a* | 0.0093 | 9.80±0.050*c* | 8.51±0.051*b* | 7.24±0.051*a* | 0.0001 |
| Minolta colour | | | | | | | | |
| CIE L* | 38.4 ±0.21*b* | 38.0 ±0.21*b* | 37.1 ±0.23*a* | 0.0415 | 36.9 ±0.27*c* | 35.0 ±0.27*a* | 35.9 ±0.27*b* | 0.0031 |
| CIE a* | 18.6 ±0.18 | 19.3 ±0.18 | 18.5 ±0.20 | 0.2370 | 19.6 ±0.16*b* | 16.5 ±0.16*a* | 16.6 ±0.16*a* | 0.0001 |
| CIE b* | 9.3 ±0.14 | 9.6 ±0.14 | 9.3 ±0.15 | 0.5497 | 9.0 ±0.11*b* | 4.3 ±0.11*a* | 4.6 ±0.11*a* | 0.0001 |
| Carcass shrink (g 100 $g^{-1}$) | 1.23±0.014*b* | 1.14±0.014*a* | 1.14±0.015*a* | 0.0057 | 1.62±0.028*b* | 1.37±0.028*a* | 1.37±0.028*a* | 0.0001 |
| Ultimate | | | | | | | | |
| pH | 5.73±0.003*b* | 5.64±0.003*a* | 5.65±0.004*a* | 0.0001 | 5.56±0.003 | 5.58±0.003 | 5.57±0.003 | 0.1868 |
| Shear (kg) | 7.70±0.110*c* | 6.71±0.112*b* | 6.27±0.123*a* | 0.0006 | 7.68±0.113*c* | 7.31±0.115*b* | 6.88±0.116*a* | 0.0448 |
| Expressible juice (g 100 $g^{-1}$) | 24.7 ±0.10 | 25.3 ±0.10 | 24.4 ±0.11 | 0.0597 | 25.8 ±0.11*b* | 24.7 ±0.11*a* | 24.8 ±0.11*a* | 0.0034 |
| MacBeth colour | | | | | | | | |
| CIE L* | 38.1 ±0.10*b* | 38.2 ±0.11*b* | 36.8 ±0.12*a* | 0.0102 | 34.1 ±0.11 | 34.3 ±0.11 | 33.9 ±0.11 | 0.6948 |
| CIE a* | 17.6 ±0.08*a* | 18.5 ±0.09*c* | 18.0 ±0.09*b* | 0.0097 | 18.2 ±0.07*a* | 18.3 ±0.08*a* | 18.9 ±0.08*b* | 0.0120 |
| CIE b* | 13.8 ±0.09*b* | 14.1 ±0.09*c* | 13.2 ±0.10*a* | 0.0258 | 15.0 ±0.08 | 14.7 ±0.08 | 15.2 ±0.08 | 0.1765 |

[z]Time on cereal-silage backgrounding followed by time on high-energy feed.
[y]Level of significance.
*a–c*Means in the same row followed by different letters are significantly different ($P < 0.05$) as determined by linear contrast with a single degree of freedom.

Table 3. The effect of electrical stimulation on postmortem quality measurements for exp. 1 and exp. 2

| | Experiment 1 | | | Experiment 2 | | |
|---|---|---|---|---|---|---|
| | HVES[z] | NHVES[z] | $P^y$ | HVES[z] | NHVES[z] | $P^y$ |
| Pre-stimulation | | | | | | |
| pH | 6.78±0.010 | 6.79±0.010 | 0.4880 | 6.69±0.007 | 6.69±0.008 | 0.5714 |
| Temperature (°C) | 38.8 ±0.06 | 38.9 ±0.06 | 0.2465 | 38.9 ±0.03 | 39.0 ±0.03 | 0.0599 |
| Post-stimulation | | | | | | |
| pH | 6.52±0.013 | 6.79±0.014 | 0.0001 | 6.33±0.010 | 6.69±0.010 | 0.0001 |
| Temperature (°C) | 38.7 ±0.06 | 38.9 ±0.06 | 0.0446 | 39.0 ±0.03 | 39.0 ±0.03 | 0.4016 |
| 3 h | | | | | | |
| pH | 5.72±0.027 | 6.39±0.028 | 0.0001 | 5.75±0.018 | 6.53±0.018 | 0.0001 |
| Temperature (°C) | 21.6 ±0.12 | 21.7 ±0.13 | 0.7982 | 22.2 ±0.07 | 22.1 ±0.07 | 0.1557 |
| 24 h | | | | | | |
| pH | 5.70±0.006 | 5.78±0.007 | 0.0001 | 5.59±0.007 | 5.71±0.007 | 0.0001 |
| Subjective marbling | 7.01±0.044 | 8.69±0.045 | 0.0001 | 8.68±0.041 | 8.35±0.042 | 0.0001 |
| Minolta colour | | | | | | |
| CIE L* | 39.0 ±0.18 | 36.7 ±0.18 | 0.0001 | 36.8 ±0.22 | 35.0 ±0.22 | 0.0001 |
| CIE a* | 20.1 ±0.15 | 17.6 ±0.16 | 0.0001 | 18.8 ±0.13 | 16.3 ±0.13 | 0.0001 |
| CIE b* | 10.3 ±0.12 | 8.5 ±0.12 | 0.0001 | 6.9 ±0.09 | 5.0 ±0.09 | 0.0001 |
| Carcass shrink (g 100 $g^{-1}$) | 1.20±0.012 | 1.13±0.012 | 0.0002 | 1.50±0.023 | 1.40±0.023 | 0.0017 |
| Ultimate | | | | | | |
| pH | 5.65±0.003 | 5.70±0.003 | 0.0001 | 5.55±0.003 | 5.58±0.003 | 0.0001 |
| Shear (kg) | 5.82±0.092 | 7.97±0.094 | 0.0001 | 5.75±0.093 | 8.82±0.094 | 0.0001 |
| Expressible juice (g 100 $g^{-1}$) | 25.4 ±0.08 | 24.1 ±0.08 | 0.0001 | 25.2 ±0.09 | 24.9 ±0.09 | 0.0178 |
| MacBeth colour | | | | | | |
| CIE L* | 38.4 ±0.09 | 36.9 ±0.09 | 0.0001 | 34.7 ±0.09 | 33.5 ±0.09 | 0.0001 |
| CIE a* | 18.7 ±0.07 | 17.4 ±0.07 | 0.0001 | 18.9 ±0.06 | 18.1 ±0.06 | 0.0001 |
| CIE b* | 14.4 ±0.07 | 13.0 ±0.07 | 0.0001 | 15.4 ±0.06 | 14.5 ±0.06 | 0.0001 |

[z]HVES, high-voltage electrical stimulation; NHVES, no high-voltage electrical stimulation.
[y]Level of significance.

subjectively appraised marbling fat are thought to be due to the faster rate of glycolysis in electrically stimulated carcasses (Pearson and Dutson 1985), which results in a more rapid conversion of muscle to meat. Hence, over an extended period (longer than 48 h) these differences resulting from electrical stimulation do not persist (Pearson and Dutson 1985). Our results agree with this information: there were no differences in subjective marbling scores between stimulated and non-stimulated sides after 3 d of chilling (data not shown). However, the improvement in marbling scores at 24 h postmortem (when most carcass grading takes place in Canada) could be important, especially in light of the re-introduction of marbling into the Canadian beef-grading system.

Over all treatments, electrical stimulation resulted in significantly lower shear forces in both exp. 1 and exp. 2 (27% and 35%, respectively). Although the improvement in tenderness associated with electrical stimulation is not a novel result, the magnitude of the changes in the present study are greater than those normally reported for high-voltage stimulation (~20%: Pearson and Dutson 1985). The nature of the mechanism(s) responsible for the increase in tenderness in electrically stimulated meat (both high and low voltage) is still not fully understood. However, three mechanisms have been postulated (Lee 1986): (1) lysosomal rupturing; (2) prevention of cold shortening; and (3) supercontraction resulting in tissue fracture.

The major mechanism contributing to the improved tenderness associated with high-voltage stimulation is thought to be supercontraction resulting in tissue fracture (Savell et al. 1978b). Since supercontraction requires a source of energy, glycogen-depleted carcasses (dark cutters) do not experience

the same improvements in tenderness as normal carcasses (Dutson et al. 1982). On the other hand, low-voltage stimulation is thought to improve tenderness, mainly by preventing cold shortening. However, some recent work at the Lacombe Research Station suggests that Canada Grade A1 carcasses (4–10 mm of backfat) are in little danger of experiencing cold shortening even under extreme chilling rates (blast chilled for 3 h at −20°C: Aalhus et al. 1991). Marsh (1983) has suggested that a rapid pH decline per se, without exposure of the carcass to cold shortening, can actually toughen meat; therefore, incorporation of low-voltage electrical stimulators in Canadian packing plants would appear to be of little benefit and may actually reduce tenderness. Clearly, the significant increases in tenderness that can accompany electrical stimulation (as in the present study) should be capitalized on by the packing industry. However, until the mechanisms underlying the increases in tenderness are fully understood for both high- and low-voltage electrical stimulation, anomalies (carcasses that experience either no improvement or a decrease in tenderness as a result of electrical stimulation) will persist. As well, there is little incentive for packers to adopt this technology, since they are trading in a commodity market and are not being paid for quality.

As expected, aging for 6 d rather than 3 d lowered the shear value of steaks by 11 and 9% in exp. 1 and exp. 2, respectively (Table 4). These decreases in shear value were similar to the decreases in shear value associated with time on feed and were approximately one-third the decrease in shear value realized by electrical stimulation. The effects of electrical stimulation and aging did not appear to be additive, as there was a tendency for steaks that had been stimulated to show less improvement with aging than non-stimulated steaks ($P = 0.02$ and 0.06 in exp. 1 and exp. 2, respectively). The effects of aging have been well documented in the literature (see Jeremiah 1978 for a review). As in the present study, the effects include improved colour and decreased expressible juice.

Table 4. The effect of 3-d or 6-d aging on postmortem quality measurements for exp. 1 and exp. 2

| | Experiment 1 | | | Experiment 2 | | |
|---|---|---|---|---|---|---|
| | 3 d | 6 d | $P^z$ | 3 d | 6 d | $P^z$ |
| Ultimate | | | | | | |
| pH | 5.66±0.003 | 5.69±0.003 | 0.0001 | 5.57±0.003 | 5.56±0.003 | 0.2600 |
| Shear (kg) | 7.29±0.093 | 6.50±0.094 | 0.0001 | 7.62±0.093 | 6.96±0.094 | 0.0001 |
| Expressible juice (%) | 25.4 ±0.08 | 24.2 ±0.08 | 0.0001 | 25.6 ±0.09 | 24.5 ±0.09 | 0.0001 |
| MacBeth colour | | | | | | |
| CIE L* | 37.2 ±0.09 | 38.1 ±0.09 | 0.0001 | 33.6 ±0.09 | 34.6 ±0.09 | 0.0001 |
| CIE a* | 17.4 ±0.07 | 18.7 ±0.07 | 0.0001 | 17.8 ±0.06 | 19.1 ±0.06 | 0.0001 |
| CIE b* | 13.1 ±0.07 | 14.4 ±0.07 | 0.0001 | 14.2 ±0.06 | 15.7 ±0.06 | 0.0001 |

[z]Level of significance.

Table 5. The effect of time on feed, electrical stimulation and aging on consumer ratings for flavour, juiciness, tenderness and overall palatability for exp. 1 and exp. 2[z]

| | Experiment 1 | | | Experiment 2 | | |
|---|---|---|---|---|---|---|
| | Time on feed | Electrical stimulation | Aging | Time on feed | Electrical stimulation | Aging |
| Flavour | NS | * | NS | NS | * | NS |
| Juiciness | * | * | NS | * | * | NS |
| Tenderness | * | * | * | * | * | * |
| Overall palatability | * | * | NS | * | * | NS |

[z] *, Significant ($P \leq 0.05$) main effect for the trait indicated; NS, non-significant ($P > 0.05$).

## Consumer Survey

In exp. 1, 84.2% of the consumers surveyed responded (859 packages were rated). In exp. 2, 98.4% of the consumers surveyed responded (943 packages were rated).

In both experiments, consumers found a significant improvement in juiciness and overall palatability with increasing time on feed (Table 5). Normally, differences in objective shear measurements of the order of 1 kg are on the borderline for consumers to detect. However, in agreement with the objective shear measurements (~1 kg difference), consumers consistently rated steaks from longer-fed animals as being more tender. Increasing amount of intramuscular fat associated with increasing time on feed is likely to contribute to improved consumer ratings (Savell et al. 1987). However, Aberle et al. (1981) and Miller et al. (1987) indicated that collagen solubility or calpain activity may also contribute to increased tenderness (as discussed previously).

As with the objective meat-quality measurements, steaks that had been electrically stimulated were rated significantly higher for flavour, juiciness, tenderness and overall palatability (Table 5). As well, the consumers rated 6-d-aged steaks as being more tender than 3-d-aged steaks, which was somewhat surprising, given that the differences in objective shear measurements were smaller than those normally detected by consumers.

Information collected by the Beef Information Centre (McDonell 1988) has indicated that tenderness is the major quality trait leading to consumer dissatisfaction with beef. As shown in Figs. 1 and 2, meat from animals that were on feed for a shorter period (143 d on 15% concentrate in exp. 1; 140 d of backgrounding on cereal silage in exp. 2) and received no postmortem treatment (electrical stimulation or aging) was rated as unacceptable for tenderness (scores of 1 or 2) more than 40% of the time. Even after tenderization was maximized through increased time on feed, electrical stimulation and aging, 10–15% of the steaks were still unacceptable to consumers. Most beef marketed in Canada

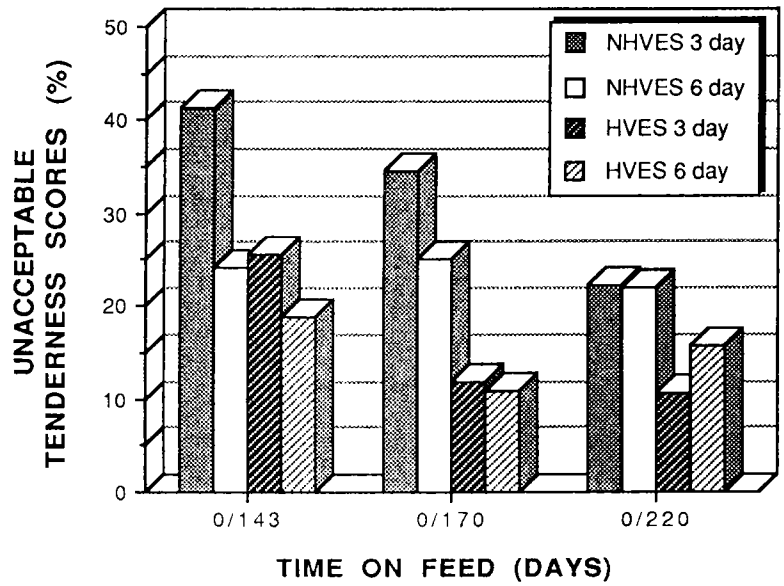


Fig. 1. Proportion of unacceptable tenderness scores (scores of 1 or 2) in exp. 1, as rated by consumers. HVES denotes high-voltage electrical stimulation, whereas NHVES denotes no high-voltage electrical stimulation. Aging was for 3 or 6 d. Time on feed: first number indicates time on cereal-silage backgrounding; second number, time on high-energy feed.

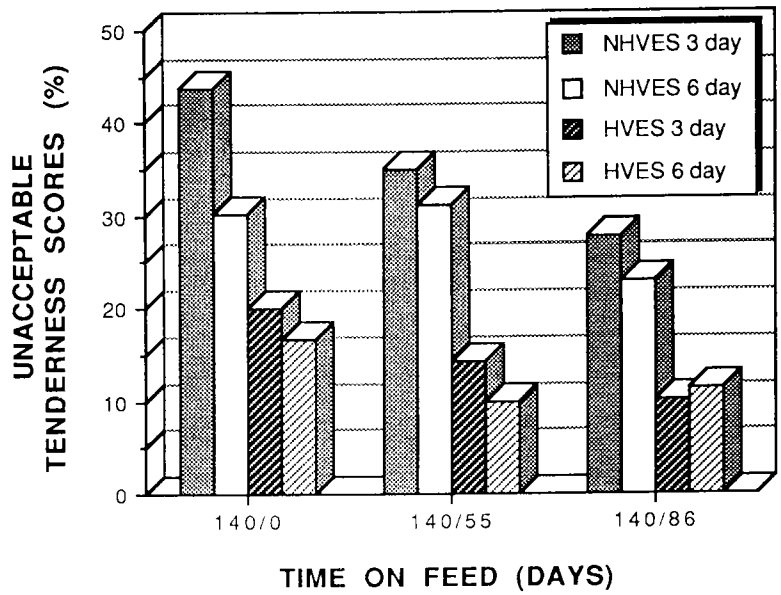


Fig. 2. Proportion of unacceptable tenderness scores (scores of 1 or 2) in exp. 2, as rated by consumers. HVES denotes high-voltage electrical stimulation, whereas NHVES denotes no high-voltage electrical stimulation. Aging was for 3 or 6 d. Time on feed: first number indicates time on cereal-silage backgrounding; second number, time on high-energy feed.

would experience some aging during distribution, since 6 d is normally required for beef to reach most retailers and/or consumers in North America (Jeremiah and Martin 1982). However, very few packing plants in Canada use high-voltage electrical stimulation as a means of quality control. Hence, on the basis of the present study, more than 20% of the steaks marketed in Canada would be rated as having unacceptable tenderness by the consumer.

## CONCLUSION

Of particular concern in the present study were the data indicating that more than 40% of steaks were rated by consumers as unacceptable for tenderness when time on feed was limited and electrical stimulation and aging were not used. Longer times on feed, electrical stimulation and aging all contributed to improvements in tenderness, although there was a tendency for stimulated steaks to show less improvement with aging than non-stimulated steaks. High-voltage electrical stimulation had the greatest effect, decreasing shear values by 27 and 35% in exp. 1 and exp. 2, respectively. These data indicate that routine use of high-voltage electrical stimulation by the Canadian packing industry would be useful for quality control. However, to maximize the benefits of electrical stimulation, a more complete understanding of the cellular mechanisms involved in tenderization associated with high- or low-voltage electrical stimulation must be sought.

## ACKNOWLEDGMENTS

The authors wish to thank the staff at the Beef Unit for the management of the animals and the staff at the Meat Centre for the slaughter and carcass cut-outs. The skilled technical assistance provided by Bernard Vincent and data management provided by Nancy Jensen are gratefully acknowledged. Thanks are also extended to the Central Alberta District Home Economists for their effort and cooperation in conducting the consumer survey.

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