Influence of concentrate composition and forage type on retail packaged beef quality

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ABSTRACT: The objective of this study was to determine the effect of type of conserved forage and concentrate composition on the quality of beef held in overwrapped (aerobic) or modified atmosphere packaging under simulated retail display for 17 d. Friesian steers (n = 45) were assigned randomly to one of five dietary treatments: 1) extensively fermented grass silage plus silage concentrate (EFS); 2) restricted fermented grass silage plus silage concentrate (RFS); 3) starch-based concentrate plus wheat straw (SC); 4) nonstarch-based concentrate plus wheat straw (NSC); or 5) zero-grazed perennial ryegrass plus grass concentrate (RYE). Meat quality was determined by measuring color, lipid oxidation (TBARS), α-tocopherol concentrations, and fatty acid composition. In aerobically packaged beef, there was a display day × diet interactive effect (P < 0.001) on Hunter a* values, with steaks from the EFS group having higher (P < 0.05) a* values than all other dietary groups from d 6 through d 17. Moreover, during the last 12 d of display, beef from the EFS group had the lowest (P < 0.01) proportion of metmyoglobin (display day × diet; P < 0.001). Under aerobic packaging, the SC and NSC groups produced steaks with higher (P < 0.05) TBARS values than RFS, EFS, and RYE groups, which did not differ from each other (display day × diet; P < 0.01). The SC and NSC groups had higher (P < 0.05) oxidation levels than RFS, EFS, and RYE groups, which did not differ from each other. Beef from the EFS group had (P < 0.05) higher concentrations of α-tocopherol than from the SC, NSC, and RYE groups. Beef from EFS-fed steers had a higher (P < 0.05) proportion of saturated fatty acids than the SC and NSC groups. It was concluded that the method of grass conservation influenced beef color, whereas concentrate composition did not. Color of aerobically packaged beef was improved by feeding animals silage that had undergone extensive fermentation. Conversely, oxidative stability was decreased by feeding animals starch- and non-starch-based concentrate diets.

Key Words: Beef Quality, Color, Concentrate, Fermented Silage, Polyunsaturated Fatty Acids, Vitamin E

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Introduction

Color is an extremely critical component of the appearance of fresh beef sold through retail, and among visual characteristics has substantial influence on purchase decisions. In red meats, consumers relate a bright-red color to freshness, but discriminate against meat that has turned brown (Morrissey et al., 1994). The feeding regimen of the animal can affect meat color, quality (O'Sullivan et al., 2002, 2003), flavor, and lipid oxidation (Gray et al., 1994). Diet formulation, therefore, may have an effect on meat quality, meat composition (Mitchell et al., 1991; Wood and Enser, 1997), and, ultimately, shelf life.

Today's consumer demands a more healthy diet; therefore, considerable effort has focused on the impact of natural diets, such as grass, silage, and grain, on the eating quality of red meats. Many studies have been carried out on the effect of forage (Baker et al., 1992; French et al., 2000, 2001) and concentrates (Schnell et al., 1997) on beef quality. Grass silage is the predominant forage of Irish beef cattle finished indoors. Silage is produced by controlled fermentation of crops of high moisture content (McDonald et al., 1995). Restricting fermentation of grass in the silo is likely to capture more available nutrients for conversion into animal product. Wilting is one such strategy that has been shown to have a dramatic effect on fatty acids. If restricting fermentation by acid addition influences the fatty acid composition of silage, this may have an impact on the stability of muscle lipids in animals consuming such silage. Similarly, if acid addition alters the concentration of antioxidants in silage, this might affect the color stability of meat. Limited research has been done on the
extent of silage fermentation effects on color, consumer perception, and overall beef quality. Therefore, the objective of this study was to determine the effect of grass conservation method and composition on retail packaged beef color stability.

Materials and Methods

Animals and Diets

The experiment was carried out at Teagasc, Grange Research Centre (Meath, Ireland). Animals were penned indoors in groups of five in a slatted-floor shed with 3 m² of space each. In a randomized block design, with blocks based on BW, groups of 15 2-yr-old Friesian steers (498 kg ± 29.3 initial BW) were individually offered (as-fed) 1) extensively fermented, unwilted grass silage with 25 kg of molasses per tonne of grass (EFS); 2) restricted-fermented, unwilted grass silage was treated with 48% formic acid and 16% ammonium tetraformate/L (RFS); 3) a starch-based (895 g of barley per kilogram) concentrate (SC); 4) a nonstarch-based fibrous (880 g of sugar beet pulp per kilogram) concentrate (NSC); or 5) zero-grazed perennial ryegrass (RYE). Silage was prepared from a regrowth of a predominantly perennial ryegrass sward, whereby alternative strips of grass were treated with the appropriate additive prior to pickup and removal to the silo. The perennial ryegrass sward available for zero-grazing was managed such that the grass offered was a 4-wk regrowth. Grass was harvested and offered to the cattle on the same day. Concentrate allowances were restricted and offered 1 kg (as-fed) of wheat straw per steer daily. The forages were supplemented with a common concentrate (formulated to balance for estimated metabolizable protein supply [Table 1]) to ensure similar carcass growth for all groups. After 140 d, steers were slaughtered in a commercial slaughter facility according to industry-accepted procedures.

Slaughter and Beef Sampling

After slaughter, carcasses were chilled for 24 h at 4°C. For the purpose of this study, nine carcasses from each dietary group were chosen at random, and the LM was excised from each carcass. Two 2.5-cm-thick steaks were cut from each carcass, vacuum-packaged, and frozen at −30°C for subsequent analysis. On the day before analysis, steaks were removed from the freezer and thawed at 2°C overnight. Then, duplicate 2.5-cm-diameter cores were removed from one steak for objective and subjective color measurements, whereas the other steak was used for all other data collection.

Packaging

Aerobic packaging consisted of placing duplicate meat cores and steaks on separate polystyrene/ethylvinylalcohol (EVOH)/polyethylene (PE) trays (203 × 146 × 47 mm), and over-wrapped with oxygen-permeable (6,000 to 8,000 cm³/[m²/24 h]) at standard temperature and pressure), PVC film (Wrap Film Systems Ltd., Shropshire, England). Additional duplicate meat cores and steaks were packed separately in polystyrene/EVOH/PE trays, gas flushed with a 80:20 mixture of O₂:CO₂, and heat-sealed using a low-oxygen-permeable (3 cm³/[m²/24 h]) lidding material composed of a laminate of 20-μm oriented polypropylene (OPP) and a co-extrusion layer (50-μm) of PE/EVOH/PE (Cryovac; W. R. Grace Europe Inc., Lausanne, Switzerland). Steaks and cores were packaged using a packaging machine (type VS 100 BS; Gustav Muller and Co., Bad Homburg, Germany).

Determination of Color

Both aerobic and modified atmosphere-packaged (MAP) samples were stored in a chest display case (Criossanc, Padova, Italy) under simulated retail conditions at 4°C (616 lux; Osram L36W/76 Natura de Luxe lighting) for 17 d. Hunter a* values of meat cores were measured using a Minolta chromameter CR-300 (Minolta Camera Co., Osaka, Japan). The proportion of the pigment metmyoglobin was also determined using the method of Krzywicki (1979). The same meat cores were analyzed on a spectrophotometer equipped with an integrating sphere Lambda 2 UV/Visible spectrophotometer (Perkin-Elmer, Beaconsfield, Bucks, U.K.).

Table 1. Chemical composition of dietary ingredients

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<td>38</td>
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<tr>
<td>Sugar, g/kg DM</td>
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</table>

³EFS = extensively fermented grass silage plus silage concentrate; RFS = restricted-fermentation grass silage plus silage concentrate; SC = starch-based concentrate plus wheat straw; NSC = nonstarch based-concentrate plus wheat straw; and RYE = zero-grazed perennial ryegrass plus grass concentrate.
method uses the reflex attenuation of incident light at the isosbestic points of 572, 525, 473, and 730 nm. From these absorbance values, the relative proportions of the pigment states were calculated and values were measured in duplicate on d 0, 2, 4, 6, 8, 10, 12, and 17 of retail display. On d 0, meat cores were allowed bloom for 3 h before color was determined.

Sensory Evaluation of Beef (Visual Assessment)

A semitrained panel of 15 people (consisting of departmental staff and postgraduate students) were asked to examine the meat color on the same days as objective color analysis. Two displays of meat, Display X (aerobically packaged) and Display Y (MAP), were shown to panelists. Within each display, there were five trays, with each tray \((203 \times 146 \times 47 \text{ mm})\) containing meat cores from the nine steaks per dietary group. Panelists were asked to evaluate each display separately and score the color of each tray of meat cores on a 10-point scale \((1 = \text{very poor color to 10 = excellent color})\). Panelists were also asked to indicate in terms of color their most preferred dietary group.

Determination of Oxidative Stability

The extent of lipid oxidation was determined by the 2-thiobarbituric acid assay using the distillation method of Tarladgis et al. (1960), as modified by Ke et al. (1977). Results were expressed as thiobarbituric acid–reactive substances \((\text{TBARS; milligrams of malonaldehyde per kilogram of meat})\). Lipid oxidation was measured in duplicate for each steak at d 0, 2, 4, 6, 8, 12, and 17 for both aerobic and MAP packed samples.

Determination of \(\alpha\)-Tocopherol from Muscle Tissue

The \(\alpha\)-tocopherol was extracted from duplicate 1-g samples of each LM steak using the method of Sheehy et al. (1993) and quantified by HPLC using a Waters model S10 pump, a Waters 717 autosampler, a Machery-Nagel Nucleosil 5 C18 \((250 \times 0.4 \text{ mm})\) reverse-phase column, and a Waters model 486 UV-visible wavelength detector (Millipore Corp., Milford, MA) set at 292 nm. The mobile phase was methanol:water \((97:3)\) at a flow rate of 2 mL/min. Data were recorded and integrated using the Millennium 32 Chromatography Manager (Millipore Corp.).

Fatty Acid Analysis of Beef

Total fat was extracted from duplicate, 1-g samples using the method of Polch et al. (1957). Fatty acid methyl esters were prepared according to the procedure of Slover and Lanza (1979), and analysis was carried out using a gas chromatograph (model GC-14A; Shimadzu, Kyoto, Japan) with flame ionization detection, equipped with an auto-injector (model AOC-17; Shimadzu). The column used was a DB-WAX fused-silica capillary column \((\text{i.d.} = 25 \text{ m} \times 0.32 \text{ mm} \text{ and film thickness} = 0.25 \text{ m})\); J&W Scientific, Folsom, CA). Carrier gas was N at a pressure of 1 kg/cm\(^2\). Oven temperature programming was as follows: 50 to 200°C at 10°C/min and held isothermally at 200°C for 37 min, and then increased to 230°C at 10°C/min and held isothermally for 38 min. The injector port and detector temperature was 250°C. Chromatograms were processed using the Millennium 32 Chromatography Manager (Millipore Corp.).

Chemical Composition of Dietary Ingredients

Dry matter concentration, CP, DM digestibility, and ash were measured as described by Moloney and O’Kiely (1999). Starch concentration was measured by polarimetry, oil by acid hydrolysis, and ether extract, and sugar concentration by the Luff-Schoorl method (ECMFR, 1984).

Statistical Analysis

A significant three-way interaction was obtained for diet, time, and packaging method. To investigate this further, a full, repeated measures ANOVA was conducted to investigate the effect of time and diet, and the interaction of time and diet within each packaging type. Diet represented the “between subjects,” where subjects were individual steers. The effect of day was measured “within subjects,” and multiple measurements were made for the same animal. Tukey’s test was used to assess the significance of difference within subjects (Neter et al. 1990). For muscle vitamin E and fatty acid concentrations, one-way ANOVA was used to test for the effect of diet. Tukey’s test was again used for multiple comparisons. Sensory data were analyzed using the \(\chi^2\) test. All analyses were carried out using SPSS 8.0 for Windows (SPSS, Chicago, IL) software.

Results

Daily DM intakes of forages were 7.9, 6.98, 0.84, 0.84, and 9.4 kg, whereas daily DMI of concentrates were 3.46, 3.46, 6.98, 7.60, and 1.79 kg, for steers in the EFS, RFS, SC, NSC, and RYE groups, respectively (results not shown). Dietary treatment had no \((P = 0.180)\) effect on carcass weight \((313, 318, 324, 313, \text{ and } 324 \text{ kg})\) or LM intramuscular fat content \((39.7, 40.0, 29.6, 37.2, \text{ and } 37.3 \text{ g/kg}; P = 3.392)\) of steers fed EFS, RFS, SC, NSC, and RYE, respectively.

The average pH, residual water-soluble carbohydrate, lactic acid concentration, and ammonia concentration were 4.01, 23.3 g/kg DM, 78.6 g/kg DM, and 2.1 g/kg DM, respectively, for EFS and 4.04, 28.5 g/kg DM, 59.0 g/kg DM, and 3.3 g/kg DM, respectively, for RFS (results not shown). The higher lactic acid and correspondingly lower residual carbohydrate in EFS compared with RFS indicated that in-the-silo fermentation was more extensive in EFS as planned. The higher ammonia concentration in RFS reflects the contribution
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Figure 1. Hunter a* values (mean + SEM) of A) aerobically packaged and B) modified atmosphere packaged longissimus muscle steaks during 17 d of display (display day × diet; \(P < 0.001\)). ◆ = extensively fermented grass silage plus silage concentrate, ■ = restricted-fermentation grass silage plus silage concentrate, ▲ = starch-based concentrate plus wheat straw, × = nonstarch-based concentrate plus wheat straw, and □ = zero-grazed, perennial ryegrass plus grass concentrate.

from the additive used because a more extensive fermentation would be expected to result in a higher concentration of ammonia.

Hunter a* Values

There was a display day × diet interaction \((P < 0.001)\) for a* values of steaks aerobically packaged (Figure 1a). On d 6 through 17 of display, beef from the EFS group had higher \((P < 0.05)\) a* values than beef from the SC, NSC, and RYE groups. The EFS group had higher \((P < 0.01)\) a* values than the RFS group on d 8, 10, and 17 of display; however, a* values were not \((P > 0.05)\) different among SC, NSC, and RYE beef. Redness (a*) values for aerobically packaged LM steaks decreased \((P < 0.001)\) as retail display increased from d 0 to 17, regardless of dietary treatment. Yet, under MAP packaging there was no difference \((P > 0.771)\) in a* values of beef among the five dietary groups, regardless of retail display day.

Metmyoglobin Formation

There was a display day × dietary treatment interactive effect \((P < 0.001)\) on metmyoglobin formation under aerobic packaging (Figure 2a). On d 4, 10, and 17 of display, steaks from the EFS group had a lower \((P < 0.01)\) proportion of metmyoglobin than the other four dietary groups. On d 6, steaks from the EFS group had a lower \((P < 0.01)\) proportion of metmyoglobin than beef from the SC and NSC groups, and, by d 12, beef from the EFS group had a lower \((P < 0.01)\) proportion of metmyoglobin than all other dietary groups, except RYE. There was no \((P > 0.092)\) difference in the proportion of metmyoglobin between SC and NSC beef. Moreover, in MAP samples, the only difference observed was on d 10 of display, when beef from the EFS group had
Figure 3. Subjective color scores (mean + SEM) of A) aerobically packaged and B) modified atmosphere packaged longissimus muscle steaks during 17d of display. Panelists scored fresh beef color based on a 10-point scale (1 = very poor color to 10 = excellent color). EFS = extensively fermented grass silage plus silage concentrate, RFS = restricted-fermentation grass silage plus silage concentrate, SC = starch-based concentrate plus wheat straw, NSC = nonstarch-based concentrate plus wheat straw, and RYE = zero-grazed, perennial ryegrass plus grass concentrate.

A lower (P < 0.05) proportion of metmyoglobin than beef from the NSC group. However, there was no difference (P > 0.092) in MAP samples among the dietary groups at any other display day.

**Sensory Analysis**

Panel scoring of dietary groups under aerobic packaging is shown in Figure 3a. A higher score indicates that the color level of excellence was higher. On d 0 and 2 of display, there was no (P > 0.05) difference in scores among the five dietary treatments; however, by d 6, cores from the EFS group received the highest (P < 0.001) color scores (mean = 7.33), whereas the RFS was scored next highest (mean = 4.5). On d 8, the EFS group was still the most preferred (P < 0.05; mean = 6.46), yet, after 12 d of display, there was no (P > 0.12) difference in the mean ranking of the five dietary groups. Panelists’ scoring of the dietary groups under MAP is presented in Figure 3b. On d 0 and 2 of display, no (P > 0.07) difference in the mean scoring of the five dietary groups was observed, but the EFS and RFS groups were most preferred (P < 0.001) on d 6 and 8 of display. By d 12, steaks from the EFS group were most preferred (P < 0.001, mean = 4.80), whereas the RFS beef was the second most preferred (P < 0.001, mean = 3.40).

**Oxidative Stability**

In aerobically packaged samples, there was display day × dietary treatment interaction (P < 0.01) for TBARS values (per gram of fresh tissue; Figure 4a). On d 4, beef from NSC-fed steers had higher (P < 0.05) TBARS values than beef from EFS-, RFS-, and RYE-fed steers. Furthermore, steaks from steers fed SC and NSC had higher (P < 0.05) TBARS values than steaks from the EFS, RFS, and RYE groups after 8 d of retail display. On d 12 of display, beef from the NSC group had higher (P < 0.05) TBARS values than the EFS, RFS, and RYE groups, whereas the SC beef had higher (P < 0.05) TBARS values than the EFS and RFS.

Differences among dietary treatments for TBARS were not as apparent for the MAP samples (Figure 4b) as those observed for the aerobically packed samples. On d 2, beef from the SC and NSC groups had higher (P < 0.05) TBARS values than beef from the EFS, RFS, and RYE groups, and, by d 4, TBARS for the SC group were higher (P < 0.01) than those of beef from EFS, RFS, and RYE. However, during the remaining days of display, there were no (P > 0.05) differences in TBARS values among the five dietary treatments.

**α-Tocopherol Content**

The EFS-fed steers had higher (P < 0.05) α-tocopherol concentrations per gram of fresh tissue (7.8 μg/g) than beef from the SC, NSC, and RYE treatment groups (3.3, 4.5, and 4.2 μg/g respectively; data not shown). Steaks from the EFS group also had numerically higher α-tocopherol concentrations than steaks from the RFS group (5.7 μg/g).

**Fatty Acid Composition**

Fatty acid composition of beef from the five dietary groups is shown in Table 2. There was a difference among the dietary groups in the proportion of saturated (P < 0.05) and polyunsaturated (P < 0.01) fatty acids, whereas there was no (P = 0.201) difference in the proportion of monounsaturated fatty acids. The EFS group had a higher (P < 0.05) proportion of saturated fatty acids than the SC and NSC groups, whereas the EFS...
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Figure 4. Thiobarbituric acid-reactive substances values (fresh-tissue basis; mean + SEM) in A) aerobically packaged and B) modified atmosphere packaged longissimus muscle steaks during 17 d of display (display day × diet; \( P < 0.001 \)).◆ = extensively fermented grass silage plus silage concentrate, ▼ = restricted-fermentation grass silage plus silage concentrate, ▲ = starch-based concentrate plus wheat straw, × = nonstarch-based concentrate plus wheat straw, and □ = zero-grazed, perennial rye-grass plus grass concentrate.

and RFS groups had lower \( (P < 0.05) \) proportions of polyunsaturated fatty acids than the NSC group.

Discussion

Several studies have been carried out to determine the effect of grass silage and/or concentrates on meat quality (French et al., 2000, 2001; O’Sullivan et al., 2002); however, in these studies, generally one type of silage and one type of concentrate have been examined. Smith (1990) discouraged forage finishing of beef owing to lower dressing percent, decreased quality grade, yellow fat color, darker muscle color, and decreased flavor relative to grain-fed beef. The results of the present study demonstrated that beef from forage-finished animals had greater color and lipid stability than beef from concentrate-fed steers, which concurs with the previous findings of O’Sullivan et al. (2002, 2003).

The type of silage fermentation was shown to have an effect on color stability, with beef from the EFS group having greater color stability than beef from the RFS group. Results of the subjective color panel showed that panelists preferred the color of beef from the EFS group most, followed by beef from the RFS group. Although there was a difference in color between the EFS and RFS, there was no difference in the level of lipid oxidation in beef from these two groups. Within concentrate-fed steers, there was no difference in color or lipid stability. Under MAP, differences between the dietary groups were not evident from objective color measurements; however, panelists did note differences during the later days (d 10 and 12) of retail display. This effect of packaging does not agree with previous studies carried out by O’Sullivan et al. (2002, 2003), who found that the effect of diet was more apparent in the MAP samples. This suggests that the packaging environment has a pronounced effect on beef quality but differs in its effect depending on the feeding system.

Metmyoglobin formation and lipid oxidation are the most important problems in maintaining a stable display of retail beef. Discoloration in retail meats during display conditions may be a combined function of muscle pigment oxidation and lipid oxidation in the membrane phospholipids (Sherbeck et al., 1995). Chan et al. (1997) reported that the process of oxymyoglobin oxidation was involved in catalyzing lipid oxidation. In the present study, beef from the SC and NSC groups had highest proportions of metmyoglobin and highest levels of lipid oxidation—supporting the hypothesis that pigment and lipid oxidation may be linked. Yin and Faustman (1993) reported that the formation of metmyoglobin from oxymyoglobin was positively correlated with lipid oxidation and seems to be dependent on the antioxidant status. In the present study, similar trends were observed under aerobic packaging for the proportion of metmyoglobin and extent of lipid oxidation (Figures 2a and 4a, respectively).

Several studies have shown that dietary vitamin E supplementation of steers causes accumulation of \( \alpha \)-tocopherol in muscle tissue, which delays oxymyoglobin and lipid oxidation and prolongs the color stability of beef (Arnold et al., 1992, 1993a; Liu et al., 1996), which agrees with results of the current study. The EFS group, which produced beef with the greatest color and lipid stability, also had highest \( \alpha \)-tocopherol concentrations. Arnold et al. (1993b) concluded that the target \( \alpha \)-tocopherol level in fresh muscle for optimum protection against discoloration was approximately 3.5 \( \mu \)g of \( \alpha \)-tocopherol per gram of meat, depending on the muscle. The level of \( \alpha \)-tocopherol in beef from the EFS group was almost twice the target level (7.8 \( \mu \)g of \( \alpha \)-tocopherol per gram).

Vitamin E in forage can be affected by a number of factors, including further processing, stage of maturity, composition at time of cutting, and dehydration time.
feeding systems. Effect on the quality attributes of beef from differing conservation has an influence on meat color stability, but concentrate composition of the diet had little to no effect on beef shelf life. The color of fresh beef may be improved by feeding animals grass silage that has undergone extensive fermentation. Moreover, results indicate that packaging environment has a pronounced effect on the quality attributes of beef from differing feeding systems.

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<tr>
<th>Fatty acid</th>
<th>EFS</th>
<th>RFS</th>
<th>SC</th>
<th>NSC</th>
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*aEFS = extensively fermented grass silage plus silage concentrate; RFS = restricted-fermentation grass silage plus silage concentrate; SC = starch-based concentrate plus wheat straw; NSC = nonstarch based-concentrate plus wheat straw; and RYE = zero-grazed perennial ryegrass plus grass concentrate.

**Results of this study imply that the method of grass conservation has an influence on meat color stability, but concentrate composition of the diet had little to no effect on beef shelf life. The color of fresh beef may be improved by feeding animals grass silage that has undergone extensive fermentation. Moreover, results indicate that packaging environment has a pronounced effect on the quality attributes of beef from differing feeding systems.**

**Literature Cited**


