Treatments for Prevention of Persistent Pinking in Dark-Cutting Beef Patties

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ABSTRACT

Food-grade oxidants and browning agents were compared for prevention of undesirable raw appearance of cooked dark-cutting (DC) beef patties. DC beef had higher pH (6.6 vs 5.7) and lower 24h oxidation-reduction potential (−190 vs −108 mV) than controls, with higher cooked yield and cohesiveness, but lower beef flavor intensity scores. DC patties with lactic acid (LA) had acceptable cooked appearance and increased myoglobin (Mb) denaturation during cooking (77%-LA; 63%-normal control; 41%-DC control), but a tangy off-flavor. Calcium peroxide increased Mb denaturation to 69%, but caused excessive oxidation. Caramel color eliminated undercooked appearance without increasing Mb denaturation, but raw and cooked patties were dark.

Key Words: dark-cutting, beef, myoglobin, browning, oxidation

INTRODUCTION

IN MIDWESTERN BEEF PROCESSING PLANTS, 1.1–1.4% of cattle slaughtered in August, September, and October were dark-cutters, with incidences of 0.4–0.7% during the other months (Kreikemeier et al., 1998). Most meat packers discount dark-cutters substantially (Wulf, 1998). The reason is two-fold: high pH, dark-cutting (DC) meat spoils more rapidly (Newton and Gill, 1981); and the unusually dark meat is not as marketable. Most DC beef is ground into hamburger or used for cooked items such as pre-cooked roast beef. However, high pH beef (pH>6.0) is also "hard-to-cook", exhibiting a persistent red, undercooked appearance even when cooked to internal temperatures adequate for browning of normal beef cuts (Mendenhall, 1989; Trout, 1989; Cornforth et al., 1991; Hague et al., 1994; Van Laack et al., 1996). Due to variable pH effects on cooked meat appearance, the USDA changed advice to consumers regarding ground beef cookery. They now recommend that consumers "use a meat thermometer when cooking hamburger, and do not rely on internal color to insure meat safety" (USDA, 1997). They also recommend that ground meats be cooked to 71°C, or equivalent (68°C internal for 15 sec).

Our objective was to determine the feasibility of using a food grade oxidant (calcium peroxide), acid (encapsulated lactic acid), or browning agents (glucose, caramel coloring) to prevent the uncooked appearance (pinking) problem in DC beef patties.

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MATERIALS AND METHODS

Experimental design and statistical analysis

The experiment was a 2 × 2 × 6 × 2 factorial design, with patties made at 2 meat pH levels (pH 5.7=normal beef; pH 6.6=extreme DC), 2 fat levels (3 and 20%), and 6 treatments; control patties with no additives; controls with 1% salt and 10% added water; and patties made with browning agents (glucose, caramel color), calcium peroxide (CaO_2), or encapsulated lactic acid, with 2 replicates of the entire experiment. Data were analyzed as a randomized block with the two replicates as blocks. The two meat pH values were whole plot treatments, with pattie fat level as subplot treatments. The 6 treatments (two controls + 4 types of browning agents) were sub-subplot treatments with 2 or 3 subsamples.

Treatment means were calculated by ANOVA, using the Statistical Analysis System program (SAS Institute, Inc., 1988). Differences between means were determined by calculation of multiple comparison Fisher's least significant difference (LSD) values, when appropriate. Significance was defined at $p<0.05$.

Pattie preparation and formulation

Frozen "A" maturity inside rounds of normal and DC beef were purchased from a local meat processor. Rounds were sorted into three pH groups: normal (pH<6.0), DC beef (pH 6.01–6.49), and extreme DC (pH 6.50–6.92). Oxidation-reduction potential (ORP) measurements were taken in samples from all three pH groups (Fig. 1). However, patties were prepared only from normal and extreme DC rounds, to compare effects of browning agents on cooked appearance of patties from the most extreme DC beef that was commercially available, vs normal controls. Selected rounds were trimmed, cut into 2.5 cm cubes, and mixed. Samples were taken from each group for pH, fat, and moisture measurements. To make lean (3% fat) patties, lean meat was passed through a fine (0.32 cm) meat grinder plate (Hobart Mfg. Co., Troy, OH). For 20% fat patties, fresh (3 day postmortem) beef intermuscular fat from young (A-maturity) steers was collected during carcass fabrication, and held overnight

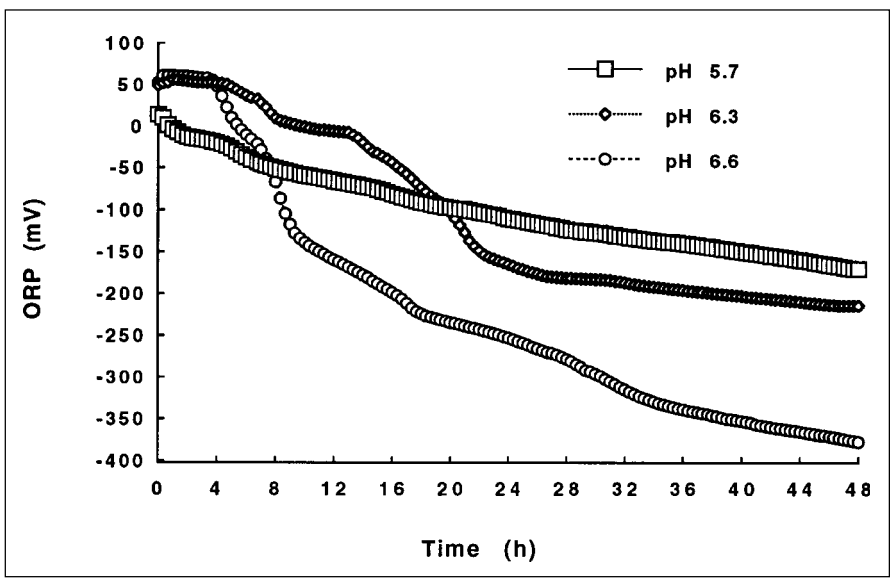

Fig. 1—Oxidation-reduction potential of extra lean ground beef during storage at 3°C (n=3).

at –29°C. An appropriate weight of finely ground (through a 0.32 cm plate) frozen beef fat was mixed (Hollymatic Corp., Park Forest, IL) for 3 min with finely ground lean (3% fat), then passed a second time through the fine grinder plate. The comminuted meat was then spread in a thin (8–10 mm) layer on plastic trays and held at 3–5°C for 1h to permit bloom. Appropriate amounts of non-meat ingredients were dissolved in cold tap water, sufficient to give 10% added water in patties, according to the following formulations: Control 1 (C1)-no additives; Control 2 (C2)-1% salt and 10% added water; C2 + 1% D-glucose (FMC Corp., Philadelphia, PA); C2 + 0.2% caramel color (Edgar A. Weber & Company, Wheeling, IL); C2 + 0.3% CaO_2 (FMC Corp., Philadelphia, PA); C2 + 2.5% encapsulated lactic acid (CAP-SHURE® LCL-135-50, Balchem Corp., Slate Hill, NY). The non-meat ingredient solution was added and mixed with meat for 3 min with a dough hook in a Hobart mixer. Beef patties (~113 g; 12 cm dia; 1 cm thick) were manually formed in a 4S 3/8 mold (Hollymatic Corp., Park Forest, IL). The meat temperature was maintained at <5°C during grinding and forming.

Before freezing, a toothpick (7 cm) was inserted from the side to the geometric center of several patties in each group. Patties were placed individually on aluminum trays and frozen in a blast freezer (−27°C), then tightly packaged in plastic bags and stored at −27°C. Just before cooking, the toothpick was removed, and a thermocouple probe was inserted to monitor internal temperature during cooking.

Preliminary tests were conducted to determine use levels for browning agents. Because the cooked DC patties with <0.3% CaO_2 had red spots with undercooked appearance, 0.3% CaO_2 was chosen as the experimental use level. Encapsulated LA at 2.5% was adequate to lower pH of raw DC patties to a normal level of 5.6–5.8. The minimum level of caramel color adequate for color uniformity of raw and cooked patties was 0.2%. Glucose at 1% was adequate to enhance Maillard browning (Bedinghaus and Ockerman, 1995). Salt (1%) was used because some commercial pattie formulations include salt for flavor and texture effects.

Moisture, fat and pH measurements

Moisture and fat were measured by standard gravimetric procedures (AOAC, 1990a, b). Protein (%) was calculated by difference using the typical beef proximate composition for carbohydrates (1.2%) and inorganic salts (0.7%; Lawrie, 1968). Measurement of pH was done with an Orion pH meter model 420A (Orion Inc., Cambridge, MA) equipped with a combination pH electrode calibrated to pH 4.0 and 7.0 (Gariepy et al., 1992). The electrode was firmly placed in the center of a raw, lean ground beef chub (3–5°C). Readings were taken after pH had stabilized (1–2 min). Triplicate measurements were taken.

Meat pigment measurements

Myoglobin was extracted from raw or cooked samples in cold (3°C) 0.04M phosphate buffer, pH 6.8 (Warriss, 1979). Total myoglobin and metmyoglobin (% of total) were calculated based on absorbance of clarified extract at 525, 572, and 700 nm (Krzywicki, 1979) using a Model UV-2100 UV-VIS recording spectrophotometer (Shimadzu Co., Kyoto, Japan). Total myoglobin (Mb), metmyoglobin (MetMb, % of total), and percent Mb denatured during cooking (PMD) were calculated using the following formulas (Trout, 1989):

$$\text{Mb (mg/g)} = (A_{525} - A_{700}) \times 2.303 \times \text{dilution factor} \quad (1)$$

where Mb=deoxyMb + MbO_2 + MetMb.

$$\%\ \text{Metmyoglobin} = \{1.395 - [(A_{572} - A_{700})/(A_{525} - A_{700})]\} \times 100 \quad (2)$$

$$\text{PMD} = [1 - (\text{Mb conc after heating/Mb conc before heating})] \times 100 \quad (3)$$

Oxymyoglobin (MbO_2) and dexoymyoglobin (deoxyMb) levels were not calculated, since deoxyMb is rapidly converted to MbO_2 during extraction and blending. Thus values would not accurately reflect pigment levels in the pattie. Oxidation of deoxyMb (or MbO_2) to MetMb in air is much slower, occurring over hours or days. The half life for autoxidation of bovine metmyoglobin is 26.5h at pH 6.5 and 22°C (Brown and Mebine, 1969; Cornforth, 1994). Thus, extraction and blending would have minimal effects on sample MetMb levels. Total Mb levels were also not affected by pigment interconversion during extraction, since the spectrophotometric measurement of total Mb was done at the isobestic point (525 nm), where the absorbance was the same (millimolar extinction coefficient E_{525} = 7.6) for Mb, MetMb and MbO_2 (Broumand et al., 1958).

Hunter color measurements

Surface color of raw and cooked patties, and internal color of cooked patties was measured using the Hunter L, a, b system with the Hunter Lab Digital Color Difference Meter (D25D2A), standardized using a white (L = 94.9, a = −0.9, and b = 2.0) standard plate. Surface color of raw and cooked hamburgers was measured from both sides at room temperature immediately after production or cooking. Internal color readings of cooked hamburgers were taken immediately after cutting them longitudinally. Two patties were used per experimental unit. The hue-angle = $(b/a)^{\tan^{-1}}$ was calculated. It has been reported to be a more precise measure of color than Hunter A values in pork cooked to a wide range of temperatures (Howe et al., 1982). Larger hue-angle values are associated with less red color (Van Laack et al., 1996), where hue-angle corresponds to color in a 360° Munsell color wheel. Saturation index corresponds to color intensity.

Oxidation-reduction potential and total reducing ability

The method of Galesloot and Kooy (1960) for measuring oxidation-reduction potential (ORP) in cheese and milk was modified for ORP measurement in raw meat. A platinum redox electrode (Orion Model 96-78-00) was tightly inserted in the center of a raw extra lean ground beef chub (0.5 kg; 3–5°C). Chubs were placed in a foam chest with cooling packs (Blue Ice; Rubbermaid, Inc., Wooster, OH) to maintain temperature <5°C. The chub + electrode was wrapped with food grade polyvinyl chloride film to prevent drying. A temperature-reading sensor was also inserted. The redox electrode and temperature sensor were calibrated. ORP readings (mV) were taken for 48h, at 20 min intervals, using a pH meter model 420A (Orion Inc., Cambridge, MA). The pH meter was connected to an IBM-compatible computer and ORP, temperature and time data were collected using the communication program Terminal for Windows 3.1 (Microsoft Corp., Redmond, WA).

Total reducing ability was measured as described by Lee et al. (1981). A 2-g sample was blended with 10 mL of 25 mM PIPES {piperazine-n, n-bis (2-ethane-sulfonic acid)} buffer, pH 5.8. Homogenate (5mL) was transferred to a 10 mL volumetric flask, mixed with 2 mL of 5 mM potassium ferricyanide, then chilled at 2°C with stirring at 15 min intervals for 1h. Then 0.1 mL of 0.5% ammonium sulfamate and 0.2 mL of 0.5M lead acetate were added. The mixture was held at room temperature for 5 min, then filtered through Whatman No. 42 filter paper, and absorbance of filtrate was read at 420 nm. Sample reducing ability was expressed as absorbance of 1 mM ferricyanide - absorbance of the sample filtrate + ferricyanide.

Frying equipment

Hamburgers were fried on a Hotpoint electric grill (General Electric Model HG4, Chicago Heights, IL) under a ventilation hood at air velocity 5 m/sec. The grill consisted of a steel griddle plate, 600 × 500 × 25 mm with 2 temperature control devices, each connected to the heating elements mounted below the plate.

Frying procedures

Frozen patties were tempered at 5°C until meat temperature was about −2°C (1h). Tempered patties were placed on the preheated grill (165±5°C) until internal temperature reached 40°C in the geometric center (≈2.5 min). The pattie was flipped and cooked to 71°C in the geometric center (≈4.5 min total), then removed and allowed to cool to room temperature. Temperature of hamburgers during cooking was measured by inserting T-

Table 1—Composition, oxidation-reduction potential (ORP), and reducing ability of uncooked normal (pH<6.0) and extreme dark cutting (DC; pH>6.5) beef patties

Sample	pH	Moisture (%)	Fat (%)	Protein (%)	Mb[2] (mg/g)	MetMbe[e] (%)	ORP[f] at 25h (mV)	Reducing ability
Normal pH,lean	5.7±0.02[a]	73.7±0.4[b]	3.5±1.2[a]	20.9±0.9[a]	7.0±0.3[b]	16.7±4.5	–108±34[a]	0.47±0.04[a]
DC, lean	6.6±0.02[b]	72.8±0.1[b]	3.5±1.0[a]	21.8±1.0[a]	9.5±0.9[d]	26.4±1.3	–191±4.6[b]	0.36±0.01[b]
Normal pH,added fat	5.7±0.02[a]	61.4±0.8[a]	20.0±1.3[b]	16.7±1.9[b]	6.2±0.4[a]	20.6±5.2	—	—
DC, added fat	6.6±0.02[b]	60.2±0.3[a]	20.0±1.3[b]	17.9±1.5[b]	8.3±0.8[c]	29.9±10.0	—	—

[a-d]Means within columns with different superscript letters are different ($p<0.05$). Means (n = 6) ± standard deviation.
[e]Total myoglobin (deoxyMb + MbO_2 + MetMb). MetMb = metmyoglobin, % of total Mb.
[f]Oxidation-reduction potential (millivolts) after 24 h in lean ground beef chubs at 3°C.

type copper-nickel thermocouples (calibrated at 0° and 100°C) in the geometric center of frozen patties as described. Probes were also placed under the "skin" (1 mm) on the top and bottom side close to the geometric center axis. Temperature data were collected on an Easy Logger System (Omnidata International Inc., Logan, UT) and transferred to an IBM PC.

Physical measurements

Percentage change in hamburger thickness and diameter was calculated as follows:

$$\Delta\text{pattie thickness (\%)} = \{\text{Raw} - \text{Cooked pattie thickness/Raw thickness}\} \times 100 \quad (4)$$

$$\Delta\text{patty dia(\%)} = \{\text{Raw - Cooked pattie dia/Raw diameter}\} \times 100 \quad (5)$$

Ten patties were used for raw (5C) and cooked hamburger (20C) thickness and diameter measurements. Two measurements were taken per hamburger. Cooked yield was determined on 10 patties as follows:

$$\text{Cooked yield (\%)} = (\text{Cooked wt/Raw wt}) \times 100 \quad (6)$$

Penetration measurements

Penetration measurements were made using the penetrometer described by Dobson et al. (1993). The cooked and cooled patties (20C) were mounted on a plexiglass cylinder, and held in place by tapered needles, 0.4 cm apart and protruding 1.25 cm above the surface of the cylinder. The circle formed by the needles was 9 cm in diameter. The cylinder + cooked pattie was placed on a top-loading balance with digital readout and 1-g readability (Sartorius PT 6, 6000g capacity, Baxter Scientific Products, Salt Lake City, UT), centered under the penetrometer rod, and tared to zero. The rod was advanced at maximum speed (2 cm/min) and load (g) was recorded in 1 sec intervals until the polished steel ball (1.9 cm dia) on the end of the rod penetrated through the pattie. The balance was connected to an IBM-compatible computer. A QuickBasic program was used to collect data and specify the time intervals.

Trained panel sensory evaluation

For the trained panel, potential panel members (USU faculty, staff, or students; 18 individuals) attended two sessions. In the training session, they were presented with cooked beef pattie samples of variable pH and composition from preliminary trials. After initial sampling, standards for each sensory attribute were discussed, according to guidelines for cookery and sensory evaluations of fresh meat (AMSA, 1995). Panel input was also used to determine the pattie attributes evaluated in later sessions. In the screening session, panelists were presented with duplicate samples from preliminary trials. Individuals (15) with the most consistent responses among duplicate samples were retained on the final panel. Patties were cooked to "medium" (5 min cooking time, >71°C internal temperature). Each cooked patty was cut into 6 sections, while hot. Coded sections were randomly arranged on a partitioned dinner plate (8 sections per plate), covered with foil to prevent dehydration, and kept warm in a gas oven (<10 min) before serving. Texture, juiciness, beef flavor intensity and off-flavor intensity were evaluated using 7-point intensity scales, where 7 = very hard or rubbery, very juicy, very strong beef flavor, or very intense off-flavor, and 1 = mushy, dry, no beef flavor (bland), or no detectable off-flavor. Samples were evaluated in partitioned booths with red light to reduce color bias. Cold water was provided for drinking between samples. Panelists participated in 6 sessions with 8 samples tested per session. Sample position was altered between sessions to avoid positional bias.

RESULTS & DISCUSSION

Raw meat characteristics

Lean, DC samples had a mean pH of 6.6, compared to pH 5.7 for normal controls (Table 1), and a higher myoglobin level ($p<0.05$) than normal samples (9.5 vs 7.0 mg Mb/g meat, respectively). Lean samples of normal and DC beef contained ≈3.5% fat. Addition of fat trim to provide patties with 20% fat diluted other constituents (myoglobin, protein, and moisture). Oxidation-reduction potential (ORP) was initially about 0 - +50 millivolts for normal and dark-cutting samples (Fig. 1). However, ORP values declined steadily with time, possibly associated with tissue consumption of oxygen incorporated during grinding. After 24h at 3°C, DC beef samples had substantially lower ORP than normal samples (−191 vs −108 mV, respectively; Table 1). Perhaps unexpectedly, DC beef had lower reducing ability values than normal beef (O.36 vs 0.47, respectively). This was probably due to the lower levels of glycogen and glucose in DC meat (Apple et al., 1995). Glucose as a reducing sugar reduces ferricyanide in the reducing ability assay (Lee et al., 1981). Thus, in spite of lower ORP, DC beef had less ferricyanide reducing ability than normal beef, and a tendency for higher %MetMb levels (Table 1). The high deoxyMb characteristic of DC beef appeared to be the result of the high oxygen scavenging activity of DC muscle (Ashmore et al., 1972), rather than differences in reducing ability between DC and normal beef.

Pattie physical characteristics

Meat type (normal vs DC) affected raw pattie weight , since patties were made to a constant volume rather than a constant weight. Raw DC beef patties were heavier than normal patties (Table 2), but there were no differences in moisture, fat, or protein content of DC and normal meat (Table 1). Dark-cutting beef patties were more cohesive and sticky, particularly after addition of 10% water and 1% salt, and incorporated less air during pattie-forming, accounting for their higher density. As expected, fat level (3 vs 20%) also affected raw pattie weights. Mean raw weight of 3% fat patties, pooled among treatments and meat type, was 109g, compared to 105g for 20% fat patties (Table 2). Cooking time was about 4.5 min to reach 71°C internal temperature, and was unaffected by treatment or raw meat characteristics (Table 2). There were also no effects of treatment or meat type on pattie shape (diameter shrinkage or thickness expansion) after cooking. Cooked yield was substantially increased in most treatments with DC beef. Treatment with CaO_2 increased cooked yield of normal patties to 91%, similar to yields for DC patties (Table 2). Bind strength, as measured by penetration load of cooked patties, was always greater for DC patties, compared to normal pH beef. Predictably, penetration load was also increased for all patties made with 1% salt, compared to controls (C1) without additives. Sodium chloride increases raw meat protein extractability, enhancing bind strength and cohesiveness of cooked products (Wismer-Pedersen, 1987).

CaO_2 treatment greatly increased cooked meat pH (Table 5) and penetration load of normal and DC patties (Table 2), confirming previous results using phosphates (Siegel and Schmidt, 1979) or sodium hydroxide (Moiseev and Cornforth, 1997) to raise meat pH and cohesiveness.

Raw and cooked pattie color

Uncooked DC beef patties were darker ($p<0.05$), with lightness (L) overall mean 30.7, compared to 32.0 for normal patties (Table 3). Redness (A) and yellowness (B) values were not different between meat pH groups, in part because chilled, DC beef bloomed when spread thin and allowed to oxygenate prior to pattie-making. Fat level main effects were significant ($p<0.05$). Patties with 20% fat were lighter and more yellow than lean (3% fat) patties, with pooled mean Hunter color L and B values of 36.0 and 11.1, compared to 26.6 and 7.8, respectively, for lean patties (Table 3).

Uncooked control patties with no additives (C1) had a typical bright-red appearance, and higher redness than other treatments (Table 3). Patties with 1% salt (C2) were less red than C1 controls (Table 3), and also had higher percent MetMb (33.9 vs 23.4%, respectively; data not shown), confirming results showing a prooxidant effect of sodium chloride on Mb in ground beef (Trout, 1990). Raw patties with caramel color were very dark (Table 3). Raw patties with CaO_2, caramel color, or LA were much less red than patties made with glucose or controls, with A values <9.5, compared to >12 for C1, C2, or C2-glucose patties (Table 3).

After cooking, main effects of pH and pattie fat level had no effect on external pattie color. Lightness values were not higher for normal vs DC patties (36.7 vs 33.2, respectively). Hunt and Hedrick (1977) reported DC beef steaks to have noticably less surface browning than normal steaks after cooking, due to lower reducing sugars available for Maillard browning. Patties in this study made with CaO_2, caramel color, or glucose had darker cooked surface appearance than other treatments ($p<0.05$), with L values of 31.8, 32.1, and 33.7, respectively, compared to 35.6, 36.4, and 40.0 for C1, C2, and LA treatments, respectively (data not shown).

Treatment effects were compared on internal color of cooked patties (Table 4). Dark-cutting control (C1, C2) and DC patties + glucose all exhibited persistent pinking, with nonuniform areas of very red, undercooked appearance and high redness values. The persistent pink appearance was eliminated with LA, CaO_2, or caramel color treatments. Patties formulated with CaO_2 had a uniform gray appearance after cooking, but developed a slight greenish tinge after 30 min. exposure to air, indicative of excessive pigment oxidation. Dark-cutting patties with caramel color had very dark internal appearance, with a mean L value of 31.3, the lowest of any treatment (Table 4). The DC-LA patties were the only ones to exhibit a typical uniform yellowish-brown internal appearance, with lightness (L) and yellowness (B) values of 40.3 and 9.7, respectively, similar to normal patties, but higher than other DC patties. Dark cutting patties formulated with LA or CaO_2 also had higher hue angle values than other DC patties, indicative of less redness (Table 4).

Table 2—Treatment effects on physical characteristics of patties cooked to 71°C internal temperature

Treatment[h]	Initial wt (g)	Cook time (sec)	Cook yield (%)	Diameter shrinkage (%)	Thickness expansion (%)	Penetration load (g)
Main Effects						
Normal (pH 5.7)	102.9[b]	257	84.1	10.6	5.0	825[b]
DC (pH 6.6)	111.1[a]	267	92.3	8.8	13.7	1368[a]
LSD[i]	3.7	NS	NS	NS	NS	72
3% fat	109.0[a]	260	89.0	9.0	6.4[b]	1149
20% fat	105.0[b]	265	87.5	10.5	12.3[a]	1044
LSD[i]	1.4	NS	NS	NS	5.7	NS
Interactions[j]						
C1*Normal	104[b]	270	83.5[ab]	9.1	1.3	513[a]
C1*DC	111[cde]	257	92.2[bc]	9.5	14.0	902[d]
C2*N	105[b]	272	84.9[a]	10.7	3.8	820[c]
C2*DC	114[e]	258	95.4[c]	8.8	16.3	1353[f]
CaO_2*N	103[b]	257	91.3[bc]	9.9	6.3	1359[f]
CaO_2*DC	108[bcd]	277	88.8[bc]	7.0	10.0	2195[g]
Caramel*N	107[bcd]	262	85.4[b]	10.8	7.5	825[c]
Caramel*DC	112[de]	257	94.4[c]	8.5	13.8	1355[f]
Glucose*N	106[bc]	271	84.8[b]	11.7	11.3	724[b]
Glucose*DC	114[e]	233	94.9[c]	8.1	12.5	1343[f]
LA*N	93[a]	268	74.7[a]	11.5	2.5	708[b]
LA*DC	108[bcd]	261	87.8[bc]	11.1	16.3	1061*
LSD[i]	6	NS	9.9	NS	NS	75

[a-g]Means in columns by group with a common superscript letter are not different (p>0.05). N=48 for main effect means. N=8 for interaction means.
[h]Normal beef, pH 5.7; dark-cutting (DC) beef, pH 6.6.
[i]LSD=Fisher's least significant difference among means (p<0.05). NS=not significant.
[j]C1=control, no additives; C2=control + 1% salt + 10% water. Browning treatments: C2 + 0.3% CaO_2, 0.2% caramel color, 1% glucose, or 2.5% encapsulated lactic acid, respectively.

Table 3—Treatment effects on Hunter color parameters of raw beef patties

Treatment[h]	L (lightness)	A (redness)	B (yellowness)	Saturation index[i]	Hue angle[j]
Main Effects					
Normal (pH 5.7)	32.0[a]	11.0	9.4	14.7	42.1
DC (pH 6.6)	30.7[b]	12.7	9.5	16.0	37.0
LSD[j]	1.1	NS	NS	NS	NS
3% fat	26.6[b]	11.9	7.8[b]	14.3[b]	34.8[b]
20% fat	36.0[a]	11.9	11.1[a]	16.4[a]	44.3[a]
LSD[j]	4.2	NS	1.1	1.6	1.4
Interactions					
C1*Normal	33.2[a]	16.4[a]	10.5[ab]	19.6[a]	33.1[fg]
C1*DC	32.2[abc]	17.0[a]	10.6[a]	20.2[a]	31.9[g]
C2*N	33.0[ab]	12.9[c]	9.7[cd]	16.3[c]	37.2[de]
C2*DC	31.1[abcd]	13.1[bc]	9.3[de]	16.2[c]	35.0[efg]
CaO_2*N	32.8[abc]	5.8[g]	8.4[fg]	10.3[f]	55.3[a]
CaO_2*DC	30.3[cde]	12.3[cd]	9.9[bcd]	15.6[cd]	37.8[de]
Caramel*N	28.6[de]	8.8[ef]	7.8[g]	11.8[e]	41.7[c]
Caramel*DC	28.1[e]	9.3[e]	8.4[fg]	12.6[e]	41.8[c]
Glucose*N	33.4[a]	14.5[b]	10.3[abc]	17.9[b]	35.5[ef]
Glucose*DC	30.5[bcde]	13.3[bc]	9.7[cd]	16.6[bc]	35.5[ef]
LA*N	30.5[bcde]	7.7[f]	9.0[ef]	12.0[e]	49.8[b]
LA*DC	31.5[abc]	11.1[d]	9.3[de]	14.5[d]	39.8[cd]
LSD[j]	2.5	1.5	0.6	1.4	3.5

[a-g]Means in columns by group with a common superscript letter are not different (p>0.05).
[h]DC=dark cutting. Browning treatments: C1-no additives; C2-1% salt and 10% added water; C2 + 0.3% CaO_2; C2 + 1% glucose; C2 + 0.2% caramel color; C2 + 2.5% encapsulated lactic acid, respectively.
[i]Saturation index=$(a^2 + b^2)^{-1/2}$; Hue angle=$(b/a)^{\tan -1}$.
[j]LSD=Fisher's Least Significant Difference among means. NS=not significant. N=48 for main effect means. N=8 for interaction means.

Cooked pattie pH and myoglobin concentration

Meat pH increased by about 0.1–0.3 pH units after cooking of both normal and DC patties. Treatment with CaO_2 increased cooked meat pH to 7.26 for DC patties, while LA treatment decreased pH of DC patties to a normal level of 5.79 (Table 5).

Normal pH control patties had 1.8–2.4 mg Mb/g cooked meat (Table 5). Dark-cutting patties formulated with CaO_2 or LA had myoglobin levels within this range (2.3 and 1.7 mg Mb/g, respectively). Dark-cutting patties formulated with caramel color or glucose had 3.7 mg Mb/g pattie. The higher myoglobin level of patties containing glucose resulted in these patties appearing very red and under-

Table 4.—Treatment effects on internal color of patties cooked to 71°C internal temperature.

Treatment	L (Lightness)	A(Redness)	B(Yellowness)	Saturation Index	Hue Angle
Main Effects					
Normal (pH 5.7)	42.3	3.1	10.4[a]	11.0	73.9
DC (pH 6.6)	35.0	4.6	8.1[b]	9.5	60.7
LSD[f]	NS	NS	0.3	NS	NS
3% fat	37.3[a]	4.0	9.1	10.2	65.7
20% fat	40.0[b]	3.6	9.5	10.3	68.9
LSD[f]	1.5	NS	NS	NS	NS
Interactions[g]					
C1*Normal	44.2[d]	4.2[cde]	11.4[d]	12.2[d]	69.8[c]
C1*DC	33.8[a]	7.1[f]	8.0[a]	10.8[bcd]	48.5[a]
C2*N	42.6[cd]	3.8[bcde]	10.4[cd]	11.1[bcd]	69.8[c]
C2*DC	35.1[ab]	5.1[e]	7.7[a]	9.3[ab]	56.4[ab]
CaO_2*N	41.8[cd]	1.3[a]	10.3[cd]	10.4[abcd]	82.6[d]
CaO_2*DC	35.2[ab]	2.3[ab]	8.4[ab]	8.7[a]	74.4[cd]
Caramel*N	37.2[abc]	2.9[abc]	10.1[cd]	10.6[bcd]	73.6[cd]
Caramel*DC	31.3[a]	4.9[de]	7.0[a]	8.6[a]	54.7[ab]
Glucose*N	43.0[cd]	3.8[bcde]	10.5[cd]	11.3[cd]	70.5[c]
Glucose*DC	34.6[ab]	4.7[de]	8.1[a]	9.5[ab]	59.5[b]
LA*N	45.0[d]	2.2[ab]	9.9[c]	10.2[abc]	77.4[cd]
LA*DC	40.3[bcd]	3.3[bcd]	9.7[bc]	10.1[abc]	70.8[c]
LSD[f]	6.0	1.7	1.4	1.8	9.0[1]

[a-e]Means in columns by group with a common superscript letter are not different (p>0.05). N=48 for main effect means. N=8 for interaction means.
C1 = control, no additives;
[f]LSD=Fisher's least significant difference among means. NS=not significant.
[g]C2=control + 1% salt + 10% water. Browning treatments: C2 + 0.3% CaO_2, 0.2% caramel color, 1% glucose, or 2.5% encapsulated lactic acid, respectively.

Table 5—Treatment effects on myoglobin levels in patties after cooking to 71°C internal temperature

Treatment[f]	Cooked Meat pH	Undenatured Mb[h] (mg/g)	MetMb[h] (%)	Mb Denaturation (%)
Main Effects				
Normal (pH 5.7)[g]	6.06[b]	1.7[b]	77.3	71.4[a]
DC (pH 6.6)	6.65[a]	3.4[a]	74.1	56.8[b]
LSD[i]	0.10	0.5	NS	8.0
3% fat	6.39	2.6	72.7	66.1
20% fat	6.33	2.4	78.7	62.0
LSD[i]	NS	NS	NS	NS
Interactions				
C1*Normal	6.05[b]	2.4[bc]	67.1[a]	63.3[bcd]
C1*DC	6.70[c]	5.3[d]	72.2[a]	40.5[a]
C2*N	6.09[b]	1.8[ab]	72.5[a]	67.7[de]
C2*DC	6.70[c]	3.7[c]	72.0[a]	50.4[ab]
CaO_2*N	6.80[c]	1.3[ab]	85.7[a]	76.8[de]
CaO_2*DC	7.26[d]	2.3[bc]	89.3[b]	68.9[d]
Caramel*N	6.18[b]	2.0[b]	75.3[a]	62.8[bcd]
Caramel*DC	6.73[c]	3.7[c]	75.1[a]	52.0[abc]
Glucose*N	6.18[b]	1.8[ab]	74.3[a]	67.3[cd]
Glucose*DC	6.72[c]	3.7[c]	71.1[a]	51.5[ab]
LA*N	5.04[a]	0.5[a]	89.2[b]	90.4[e]
LA*DC	5.79[b]	1.7[ab]	64.9[a]	77.3[de]
LSD[i]	0.40	1.4	21.0	15.0[1]

[a-e]Means in columns by group with a common superscript letter are not different (p>0.05). N=48 for main effect means. N=8 for interaction means.
[f]C1=control, no additives; C2=control + 1% salt + 10% water. Browning treatments: C2 + 0.3% CaO_2, 0.2% caramel color, 1% glucose, or 2.5% encapsulated lactic acid, respectively.
[g]Normal beef, pH 5.7; DC beef, pH 6.6.
[h]Total soluble myoglobin (deoxyMb + MbO_2 + MetMb). MetMb = metmyoglobin, % of total Mb.
[i]LSD=Fisher's least significant difference among means (p<0.05). NS=not significant.

cooked, as noted. Caramel color effectively masked the red color, but resulted in a very dark internal pattie color, both before and after cooking.

DC patties with LA had acceptable cooked appearance and increased myoglobin (Mb) denaturation during cooking, compared to normal or DC controls (77% MetMb-LA; 63%-normal control; 40%-DC control; Table 5). Treatment with CaO_2 also increased browning and increased Mb denaturation of DC patties to 68.9%, similar to that of normal controls (63.3%; Table 5). In addition to pigment denaturation, cooking resulted in oxidation of the undenatured Mb fraction, from 16–29% MetMb in raw patties (Table 2), to 67–89% MetMb in cooked patties (Table 5). Myoglobin oxidation to MetMb was highest (89%) in normal patties formulated with CaO_2 or LA.

Cooked pattie sensory scores

Meat type (normal or DC) affected ($p<0.05$) panel scores for pattie texture and off-flavor intensity (Table 6). DC patties had firmer texture than normal patties (4.5 vs 4.0), and higher off-flavor intensity scores (3.2 vs 3.0, respectively). Fat level also affected ($p<0.05$) sensory scores. Lean (3% fat) patties were firmer than patties with 20% fat (4.8 vs 3.7, respectively). Panelists also rated lean patties higher than 20% fat patties for beef flavor, although mean differences were small (3.5 vs 3.3, respectively).

Dark-cutting patties containing CaO_2 were more firm than other samples, with the lowest mean score (2.0) for beef flavor, and the highest score (5.1) for off-flavor intensity (Table 6). Panelists described the off-flavor as rancid or oxidized. Compared to controls, inclusion of caramel color or glucose had no effect on sensory scores. Patties with LA were also rated similar to controls for texture, juiciness, and beef flavor intensity, but higher for off-flavor intensity (4.5 vs 2.1, respectively). Some panelists described the off-flavor as sour or tangy.

CONCLUSIONS

IN ADDITION TO HIGH PH (6.6), EXTREME DC beef rounds had higher than normal myoglobin concentration and lower than normal oxidation-reduction potential and reducing ability. Cooked yield and pattie cohesiveness, as measured by penetration load, were also substantially higher for patties from DC beef. Among browning agents, LA most effectively prevented the undesirable raw or persistent pink appearance in cooked patties made from DC beef, but a tangy off-flavor was noted. Addition of 0.3% CaO_2 also increased myoglobin denaturation and browning of cooked patties, but caused excessive oxidation, with slight greening of cooked patties and rancid off-flavor development. Caramel color eliminated undercooked appearance, but both raw and cooked patties were very dark. Glucose addition was not effective for prevention of undercooked appearance of DC patties.

REFERENCES

AMSA. 1995. *Research Guidelines for Cookery, Sensory Evaluation and Instrumental Tenderness Measurements of Fresh Meat*. National Live Stock and Meat Board, Chicago, IL.

AOAC, 1990a. Procedure 950.46, Moisture in meat. In *Official Methods of Analysis*, 15th ed. Assoc. Official Analytical Chemists, Arlington, VA.

AOAC, 1990b. Procedure 960.39, Fat (crude) or ether extract in meat. In *Official Methods of Analysis*, 15th ed. Assoc. Official Analytical Chemists, Arlington, VA.

Apple, J.K., Dikeman, M.E., Minton, J.E., McMurphy, R.M., Fedde, M.R., Leith, D.E. and Unruh, J.A. 1995. Effect of restraint and isolation stress and epidural blockage on endocrine and blood metabolite status, muscle glycogen metabolism, and incidence of dark-cutting longissimus muscle of sheep. J. Animal Sci. 73: 2295-2307.

Ashmore, C.R., Parker, W. and Doerr, L. 1972. Respiration of mitochondria from dark-cutting beef: Postmortem changes. J. Animal Sci. 34: 46-48.

Bedinghaus, A.J. and Ockerman, H.W. 1995. Antioxidative Maillard reaction production products from reducing sugars and free amino acids in cooked ground pork patties. J. Food Sci. 60(5): 992-995.

Broumand, H., Ball, C.O. and Stier, E.F. 1958. Factors affecting the quality of prepackaged meat II. E. Determining the proportions of heme derivatives in fresh meat. Food Technol. 12: 65-77.

Brown, W.D. and Mebine, L.B. 1969. Autoxidation of oxymyoglobins. J. Biol. Chem. 244: 6696-6701.

Cornforth, D.P. 1994. Color: Its Basis and Importance, Chapter 2 in *Quality Attributes and their Measurement in Meat, Poultry and Fish Products.* A.M. Pearson & T.R. Dutson (Ed.), Advances in Meat Research, Vol. 9, p. 34-78. Blackie Academic & Professional,

Table 6—Treatment effects on sensory scores[f] of patties cooked to 71°C internal temperature

Treatment[g]	Texture	Juiciness	Beef flavor intensity	Off-flavor intensity
Main Effects				
Normal[h]	4.0[b]	3.6	3.8	3.0[b]
DC	4.5[a]	3.7	3.0	3.2[a]
LSD[i]	0.02	0.7	1.5	0.04
3% fat	4.8[a]	3.3	3.5[a]	3.1
20% fat	3.7[b]	4.0	3.3[b]	3.1
LSD[i]	0.1	NS	0.1	0.5
Interactions				
C1*Normal	3.6[ab]	2.8	3.8[cde]	2.1[a]
C1*DC	3.4[a]	3.1	3.1[bc]	2.5[a]
C2*N	3.9[abc]	4.1	4.5[e]	2.0[a]
C2*DC	4.3[abc]	4.2	3.7[cde]	2.4[a]
CaO_2*N	4.6[bc]	3.7	2.6[ab]	4.7[b]
CaO_2*DC	6.0[d]	3.4	2.0[a]	5.1[b]
Caramel*N	4.0[abc]	4.3	4.5[e]	1.9[a]
Caramel*DC	4.4[abc]	3.8	3.2[bc]	2.5[a]
Glucose*N	3.6[ab]	4.1	4.3[de]	2.2[a]
Glucose*DC	4.9[c]	3.7	3.3[bcd]	2.3[a]
LA*N	4.2[abc]	2.8	3.0[bc]	5.0[b]
LA*DC	4.1[abc]	3.9	2.9[abc]	4.5[b]
LSD[i]	1.0	NS	0.9	0.6[1]

[a-e]Means in columns by group with a common superscript letter are not different (p>0.05). N=48 for main effect means. N=8 for interaction means.
[f]7=Very rubbery, very juicy, very intense beef flavor or off-flavor; 1=mushy, dry, no beef flavor, no off-flavor.
[g]C1=control, no additives; C2=control + 1% salt + 10% water. Browning treatments: C2 + 0.3% CaO_2, 0.2% caramel color, 1% glucose, or 2.5% encapsulated lactic acid, respectively.
[h]Normal beef, pH 5.7; DC beef, pH 6.6.
[i]LSD=Fisher's Least Significant Difference among means. NS=not significant.

London, England.
Cornforth, D., Calkins, C.R. and Faustman, C. 1991. Methods for identification and prevention of pink color in cooked meat. Reciprocal Meat Conf. Proc. 44: 53-58.
Dobson, B.N., Moiseev, I.V., Cornforth, D.P., Savello, P., Wood, R.J. and Andersen, R. 1993. Instrument for measuring bind strength of restructured and emulsion-type meat products. J. Texture Studies 24: 303-310.
Galesloot, T.E. and Kooy, J.S. 1960. The oxidation-reduction potential of starter and milk inoculated with starter. Netherlands Milk and Dairy J. 14: 1-22.
Gariepy, C., Amiot, J., Pommier, S.A., Filpot, P.M. and Girard, V. 1992. Electrical stimulation and 48 hours aging of bull and steer carcasses. J. Food Sci. 57: 541-544.
Hague, M.A., Warren, K.E., Hunt, M.C., Kropt, D.H., Stroda, S.L. and Johnson, D.E. 1994. Endpoint temperature, internal cooked color, and expressible juice color relationships in ground beef patties. J. Food Sci. 59: 465- 470.
Howe, J.L., Gullett, E.A. and Usborne, W.R. 1982. Development of pink color in cooked pork. Can. Inst Food Sci. Technol. J. 15: 19-23.
Hunt, M.C. and Hedrick, H.B. 1977. Chemical, physical and sensory characteristics of bovine muscle from four quality groups. J. Food Sci. 42: 716-720.
Kreikemeier, K.C., Unruh, J.A. and Eck, T.P. 1998. Factors affecting the occurrence of dark-cutting beef and selected carcass traits in finished beef cattle. J. Animal Sci. 76: 388-395.
Krzywicki, K. 1979. Assessment of relative content of myoglobin, oxymyoglobin and metmyoglobin at the surface of the beef. Meat Sci. 3: 1-5.
Lawrie, R.A. 1968. Chemical changes in meat due to processing-A review. J. Sci. Fd. Agric. 19: 233-240.
Lee, M., Cassens, R.G., and Fennema, O.R. 1981. Effect of metal ions on residual nitrite. J. Food Proc. Preserv. 5: 191-205.
Mendenhall, V.T. 1989. Effect of pH and total pigment concentration on the internal color of cooked ground beef patties. J. Food Sci. 54: 1-2.
Moiseev, I.V. and Cornforth, D.P. 1997. Sodium hydroxide and sodium tripolyphosphate effects on bind strength and sensory characteristics of restructured beef rolls. Meat Sci. 45: 53-60.
Newton, K.G. and Gill, C.O. 1981. The microbiology of DFD fresh meats: A review. Meat Sci. 5: 223-232.
SAS Institute, Inc. 1988. *SAS Users' Guide: Basic Statistical Analysis.* SAS Institute Inc., Cary, NC.
Siegel, D.G. and Schmidt, G.R. 1979. Ionic, pH, and temperature effects on the binding ability of myosin. J. Food Sci. 44: 1686-1689.
Trout, G.R. 1989. Variation in myoglobin denaturation and color of cooked beef, pork and turkey meat as influenced by pH, sodium chloride, sodium tripolyphosphate and cooking temperature. J. Food Sci. 54: 536.
Trout, G.R. 1990. The rate of metmyoglobin formation in beef, pork, and turkey meat as influenced by pH, sodium chloride, and sodium tripolyphosphate. Meat Sci. 28: 203-210.
USDA. 1997. Heat processing procedures, cooking instructions, and cooling, handling, and storage requirements for uncured meat patties. Code of Federal Regulations 9(2): 292-293.
Van Laack, R.L.J.M., Berry, B.W., and Solomon, M.B. 1996. Variations in internal color of cooked beef patties. J. Food Sci. 61(2): 410-414.
Warriss, P.D. 1979. The extraction of haem pigments from fresh meat. J. Food Technol. 14: 75-80.
Wismer-Pedersen, J. 1987. *Water*. Ch. 5 in *The Science of Meat and Meat Products*, 3rd ed. J.F. Price and B.S. Schweigert (Ed.), p. 148. Food & Nutrition Press, Inc., Westport, CT.
Wulf, D. 1998. Ohio State Univ. Extension Meat Specialist. Personal Communication.

MS 2278; received 5/26/98; revised 2/9/99; accepted 2/12/99.

This research was supported by the Utah Agricultural Experiment Station, Utah State University, Logan, UT 84322-4810, and the Utah Center for Excellence in Meat Processing. UAES journal paper no. 7051

Reprinted from J. Food Sci. 64(4): 738–743