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Relationships Among Glycolytic Potential, Dark Cutting (Dark, Firm, and Dry) Beef, and Cooked Beef Palatability

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ABSTRACT: One hundred beef carcasses were selected at three packing plants and were used to determine the relationship between glycolytic potential (GP) and dark, firm, and dry (DFD) beef and to determine the effects of DFD status and GP on cooked beef palatability. Eight individual muscles were excised from one hindquarter of each carcass at d 7 postmortem: longissimus lumborum, psoas major, gluteus medius, tensor fasciae latae, rectus femoris, semimembranosus, biceps femoris, and semitendinosus. Ultimate pH, colorimeter readings, and Warner-Bratzler shear force were determined for all eight muscles at d 7 postmortem. A nine-member trained sensory panel evaluated cooked longissimus lumborum, gluteus medius, and semimembranosus steaks. Traits determined solely for the longissimus lumborum were GP (2 × [glycogen + glucose + glucose-6-phosphate] + lactate) and ether-extractable fat. A curvilinear relationship existed between GP and ultimate pH within the longissimus muscle. There appeared to be a GP threshold at approximately 100 μmol/g, below which lower GP was associated with higher ultimate pH and above which GP had no effect on ultimate pH. The greatest pH and muscle color differences between normal and DFD carcasses were observed in the longissimus lumborum, gluteus medius, semimembranosus, and semitendinosus muscles. Cooked longissimus from DFD carcasses had higher shear force values (46% greater) and more shear force variation (2.3 times greater variation) than those from normal carcasses. Dark cutting carcasses also had higher shear force values for gluteus medius (33% greater) and semimembranosus (36% greater) than normal carcasses. Sensory panel tenderness of longissimus, gluteus medius, and semimembranosus was lower for DFD carcasses than for normal carcasses. Longissimus and gluteus medius flavor desirability scores were lower for DFD than for normal carcasses. Steaks from DFD carcasses had more off-flavor comments than steaks from normal carcasses, specifically more "peanutty," "sour," and "bitter" flavors. The DFD effect of higher shear force values was approximately five times greater (+3.11 kg vs +0.63 kg) for carcasses with "slight" marbling scores than for carcasses with "small" marbling scores. In general, higher GP was associated with increased tenderness, even among normal carcasses. In conclusion, low GP was associated with DFD beef and resulted in substantially less-palatable cooked steaks.

Key Words: Beef, Dark Cutting Meat, Glycogen, Palatability, Tenderness

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Introduction

The 1995 National Beef Quality Audit reported that the incidence of dark cutting (**DFD**) beef carcasses in the United States is 2.7% and costs the beef industry $172 million annually (Smith et al., 1995). Dark cutting beef results from cattle with lower-than-normal muscle glycogen stores at the time of slaughter, which causes lower-than-normal lactic acid production after slaughter and a higher-than-normal ultimate meat pH. Dark cutting beef is undesirable because it is aesthetically unpleasant and because it is more susceptible to microbial growth (Lawrie, 1998), but the eating quality of DFD beef is less defined. Numerous studies have reported a relationship between ultimate pH and beef tenderness and have reported that toughness is maximized at an ultimate pH of 5.8 to 6.0 (Purchas, 1990; Watanabe et al., 1995; Wulf et al., 1997). Recent studies with porcine muscle have found relationships among glycolytic potential (**GP**), ultimate pH, and pork tenderness (Hamilton et al., 2000; van Laack et al., 2001).

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Because of these relationships between ultimate pH and tenderness, one would speculate that there are palatability differences between normal and DFD beef and also that GP of beef muscle is an important factor in beef palatability. However, the effects of DFD on beef palatability are not well defined and there is some disagreement among studies on the subject (Dransfield, 1981; Wulf et al., 1996). In fact, the United States Standards for Grades of Carcass Beef state that "there is little or no evidence which indicates that the 'dark-cutting' condition has any adverse effect on palatability . . ." (USDA, 1997). Therefore, the objectives of this study were to determine the relationship between GP and DFD beef and to determine the effects of DFD status and GP on beef palatability.

Material and Methods

One hundred beef carcasses were selected at three packing plants in Illinois, Texas, and Ohio (n = 65, 20, and 15, respectively). These carcasses were selected at the time of grading to represent a wide range of muscle color and pH. For specific criteria used to select these 100 carcasses, see Wulf and Page (2000). All carcasses were selected within the "Small" and "Slight" USDA marbling scores because the vast majority (84%) of the U.S. beef carcass population is included in these two marbling levels (Smith et al., 1995). The breed-type distribution was monitored to match that identified by Smith et al. (1995) as the U.S. distribution (88% native, 7% Brahman, 5% dairy-type), resulting in 88 native carcasses, 7 Brahman carcasses, and 5 dairy carcasses selected in our study. "Native" carcasses were defined as those carcasses not classified as either Brahman or dairy.

All carcass data were collected by experienced personnel following a 24-h chill in the Illinois plant, a 48-h chill in the Texas plant, and a 24- to 96-h chill in the Ohio plant. Data collected at the packing plant for each carcass included breed type; sex class; hot carcass weight; fat thickness; ribeye area; kidney, pelvic, and heart fat; USDA yield grade; skeletal maturity; lean maturity; overall maturity; marbling score; dark cutting discount; and USDA quality grade, as well as muscle pH and colorimeter readings (L*, a*, b*) on the longissimus muscle. Muscle pH was measured at the exposed longissimus muscle using a Meatcheck 160 pH (Sigma Electronic GmbH Erfurt, Erfurt, Germany) equipped with a pH probe (LoT406-M6-DXK-S7/25, Mettler-Toledo GmbH, Urdorf, Switzerland). Colorimeter measurements were taken 90 min after ribbing on the exposed longissimus muscle between the 12th and the 13th ribs. Colorimeter readings (L*, a*, b* values) were measured with a Minolta Chroma Meter CR-310 (Minolta Corp., Ramsey, NJ) with a 50-mm-diameter measurement area using a D65 illuminant.

One hindquarter from each of the 100 selected carcasses was transported in refrigerated trucks to the Ohio State University Meat Laboratory for further data collection. Hindquarters were held at 0 to 2°C until they were fabricated into boneless subprimals on d 7 postmortem. Following boning, a cut was made perpendicular to the long axis of the muscle at the midpoint between the origin and insertion for each of the following eight muscles: longissimus lumborum (strip loin), psoas major (tenderloin), gluteus medius (top sirloin), tensor fasciae latae (tri-tip), rectus femoris (knuckle), semimembranosus (top round), biceps femoris (bottom round), and semitendinosus (eye of round). This freshly cut surface of each muscle was allowed to bloom for 90 min, and then pH and color were measured using the same instrumentation as previously described for the packing plant measurements. A sample was excised from the 13th rib location of the longissimus lumborum and ether-extractable fat was determined. A longissimus lumborum sample was also obtained for GP analysis. The subprimals were vacuum-packaged and frozen on d 7 postmortem at –26 to –30°C.

One gram of each longissimus lumborum was used to determine GP as described by McKeith et al. (1998). Perchloric acid was used to deproteinate the muscle samples. The resulting perchloric acid extracts were used to quantify glycogen, glucose, glucose-6-phosphate and lactate. Glycolytic intermediates were catalyzed to glucose-6-phosphate using hexokinase, and then into 6-phosphogluconate in the presence of NADP+, which was reduced to NADPH and the absorbance measured spectrophotometrically at 340 nm. Lactate was measured by adding excess NAD+ in a glycine and hydrazine buffer solution with lactate dehydrogenase, resulting in NADH being formed. Differences in absorbance were measured at 340 nm. Glycolytic potential was expressed in micromoles of lactate per gram and determined by $2 \times$ (glycogen + glucose + glucose-6-phosphate) + lactate.

Following freezing of the subprimals, 2.5-cm-thick steaks for Warner-Bratzler shear force and sensory panel were cut on a band saw, vacuum packaged, and placed back into frozen storage. Peak Warner-Bratzler shear force was measured on the previously mentioned eight muscles. A trained sensory panel evaluated longissimus lumborum, gluteus medius, and semimembranosus muscles. Steaks for shear force and sensory panel assessment were thawed for 24 h at 1 to 2°C and cooked on a belt-fed impingement oven (Model 1132-000-A, Lincoln Foodservice Products, Inc., Fort Wayne, IN). Preliminary test cooking was done to determine appropriate cooking times to reach 71°C internal temperature. Cooking times and actual internal temperatures reached for each muscle were reported by Wulf and Page (2000). Shear force was measured after the cooked steaks cooled to room temperature (≈21°C) by removing six cores from each steak parallel to the muscle fiber orientation and shearing each core once on a Warner-Bratzler shear machine. Sensory panel evaluation was conducted using a nine-member trained panel that evaluated tenderness, juiciness, flavor intensity, and flavor desirability using 8-point descriptive scales

(AMSA, 1995). Sensory panelists were encouraged to describe off-flavors in a "comments" section of the sensory panel form. Off-flavor descriptors were not determined beforehand; instead, each panelist was left to describe off-flavors in his or her own words. Sensory panel evaluation was conducted on warm, 1.3 cm × 2.5 cm × "cooked thickness of the steak" cubes within 15 min following cooking. Samples were kept warm until serving in Styrofoam bowls covered with aluminum foil. Sensory panel evaluation was conducted in individual booths under red incandescent light.

Three sets (subsets) of data were used for statistical analysis. Data set I included data from all 100 carcasses and was used to examine the relationship between ultimate pH and GP using polynomial regression. Data set II (n = 93) was a subset of Data set I and included all carcasses except the seven Brahman carcasses. The Brahman carcasses were excluded from all statistical analysis of palatability data because we were not able to obtain any DFD Brahman carcasses; therefore, Brahman status (which affected palatability) was confounded with DFD status, and, hence, GP level. Data set II was used to examine the effects of GP on palatability traits by assigning the carcasses to five equally spaced GP groups and using one-way ANOVA to test for differences among GP groups; means were separated using pairwise *T*-tests. Data set III (n = 47) was a subset of Data set II and was used to compare normal (non-DFD) and DFD carcasses. Data set III included all DFD carcasses (n = 11) and a selected subset of normal carcasses (n = 36). The normal carcasses used in our study were originally selected to represent a wide range of muscle color (Wulf and Page, 2000); therefore, a subset that represented the normal range of muscle color needed to be used as the "control" group. To obtain the subset of 36 normal carcasses in Data set III, carcasses toward the extreme ends of the color distribution were randomly excluded until the distribution of muscle color matched the distribution of muscle color defined by a recent U.S. beef color survey (Page et al., 2001). One-way ANOVA was used to test continuous dependent variables and chi squared was used to test discrete dependent variables for differences between normal and DFD carcasses using Data set III.

Results and Discussion

A curvilinear relationship existed between GP and ultimate pH within the longissimus muscle (Figure 1). There appeared to be a GP threshold at approximately 100 μmol/g, below which lower GP was associated with higher ultimate pH and above which GP had no effect on ultimate pH. Glycolysis occurs in postmortem muscle and produces lactic acid. This lactic acid accumulates within the postmortem muscle because the circulatory system is not functioning and causes a decline in muscle pH from approximately 7.0 at the time of death to 5.4 to 5.5 in normal beef. Presumably, postmortem glycolysis and muscle pH decline is stopped, under normal carcass chilling conditions, when one of two events occur: either 1) muscle glycogen stores are depleted or 2) muscle pH declines to approximately 5.45 and this low pH inhibits the activity of glycolytic enzymes. From our results, it appears that most of the carcasses with GP less than 100 μmol/g had a higher-than-normal ultimate pH because muscle glycogen stores were depleted before attaining a normal ultimate pH, and the amount of muscle glycogen present at death (as measured by GP) was directly related to the magnitude of pH decline for these carcasses. It appears that the ultimate muscle pH of carcasses with GP greater than 100 μmol/g was determined by pH inhibition of glycolytic enzymes because ultimate pH was very similar among these carcasses and was not related to the amount of muscle glycogen present at death (as measured by GP). There was substantial variation in GP among normal carcasses (Figure 1) and this has both practical and research implications. From a practical standpoint, some cattle will require greater amounts of stress to cause DFD than other cattle. For example, assuming a preslaughter stressor caused an antemortem reduction in GP of 40 μmol/g, an animal with an original GP of 110 μmol/g will produce a DFD carcass (110 – 40 = 70), whereas an animal with an original GP of 160 μmol/g will still produce a carcass with a normal ultimate pH (160 – 40 = 120) even though both animals were subjected to the identical stressor. This example assumes that variation exists among unstressed animals. In our study, the GP values of unstressed animals were unknown because all animals probably undergo some physiological stress during handling and transportation to slaughter. From a research standpoint, Figure 1 illustrates that GP would be a very useful dependent variable for studies examining factors affecting the incidence of DFD carcasses. Glycolytic potential provides a continuous dependent vari-

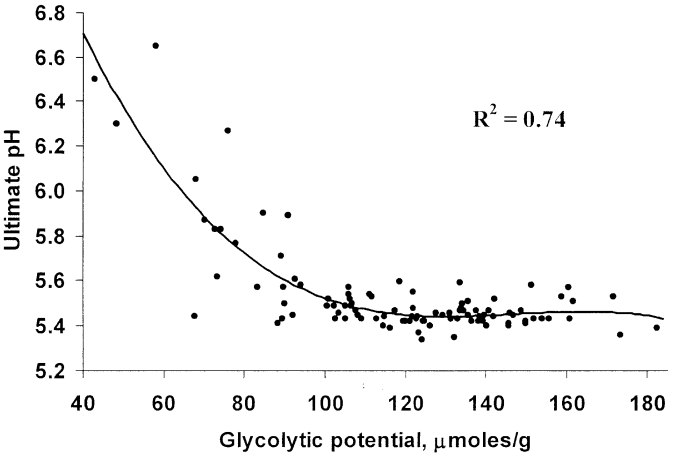

Figure 1. Relationship between glycolytic potential (GP) and ultimate pH in beef longissimus muscle (n = 100 beef carcasses). Regression line: predicted ultimate pH = 8.82 – (GP × 0.07) + (GP^2 × 0.000485) – (GP^3 × 0.000001097).

Table 1. Carcass characteristics for normal and dark cutting (DFD) carcasses

Variable	Normal (n = 36)	DFD (n = 11)	RSD	*P*-value
Plant				0.845
Illinois	72%	64%		
Texas	20%	27%		
Ohio	8%	9%		
Sex class				0.586
Steer	72%	64%		
Heifer	28%	36%		
Marbling score				0.953
Small	56%	55%		
Slight	44%	45%		
Hot carcass wt., kg	329	337	39	0.5620
Adj. Fat thickness, cm	0.93	0.71	0.38	0.0963
Rib eye area, cm^2	86.4	90.0	11.3	0.3579
KPH, %	2.2	2.0	0.5	0.2340
USDA yield grade	2.3	2.0	0.7	0.1463
Skeletal maturity[a]	168	162	17	0.3450
Lean maturity[a]	158	NA[g]	18	NA[g]
Overall maturity[a]	164	162	15	0.6053
Marbling score[b]	406	410	48	0.8292
USDA quality grade[c]	690	630	40	0.0001
Intramuscular fat, %	4.0	3.1	1.3	0.0609
L*[d]	41.1	34.8	2.9	0.0001
a*[e]	25.0	18.8	1.8	0.0001
b*[f]	11.1	6.7	1.3	0.0001
Ultimate muscle pH	5.46	6.06	0.16	0.0001
Glycolytic potential, μmol/g	122	71	23	0.0001

[a]Maturity: 100 = A^{00}, 200 = B^{00}, etc.
[b]Marbling: 300 = $Slight^{00}$, 400 = $Small^{00}$, etc.
[c]USDA quality grade: 600 = $Select^{00}$, 700 = $Choice^{00}$, etc.
[d]L*: 0 = black, 100 = white.
[e]a*: Lower numbers = more green, higher numbers = more red.
[f]b*: Lower numbers = more blue, higher numbers = more yellow.
[g]NA = not applicable (Lean maturity was not evaluated on dark cutting carcasses).

able that should correspond to "DFD risk." A continuous variable should provide a more powerful statistical test than an incidence variable when the incidence level is very low, as is the case with DFD carcasses. Shackelford et al. (1994) compared sire breeds for incidence of DFD and reported a DFD incidence of 2.6% averaged across breeds and a root mean square error (RMSE) of 14.8 percentage points. Using the data from Shackelford et al. (1994) along with our data, we calculated that it would require 1,150 cattle per treatment to detect a 2-percentage point difference in DFD incidence, whereas only 88 cattle per treatment would be required to detect a mean GP difference of 11.3 μmol/g, which approximates to a two percentage point difference in DFD incidence (calculated as number required to have a 90% chance of detecting a difference at the $\alpha = 0.05$ level).

Carcass characteristics of normal vs DFD carcasses are shown in Table 1. Carcass distributions among packing plants, sex classes, and marbling scores were not different ($P > 0.05$) between normal and DFD carcasses because the subsample of 36 normal carcasses was chosen to match the packing plant, sex class, and marbling score distributions of the 11 DFD carcasses. Furthermore, there were no differences ($P > 0.05$) between normal and DFD carcasses in any of the yield grade traits or maturity traits. Therefore, these 47 carcasses represented an excellent test for DFD effects alone because other carcass characteristics were very similar between normal and DFD carcasses. Dark cutting carcasses had lower USDA quality grades than normal carcasses, despite having similar marbling scores, because USDA grade standards require discounting quality grade according to severity of DFD (USDA, 1997). Dark cutting carcasses had 23% less ($P = 0.06$) intramuscular fat in the longissimus muscle than normal carcasses despite no difference in marbling score. It may be that marbling is more highly visible, because of greater contrast, in darker colored beef and therefore DFD carcasses receive higher visual marbling scores than normal carcasses at equal amounts of intramuscular fat. Dark cutting carcasses had longissimus muscles with lower colorimeter readings, higher ultimate pH, and lower GP than normal carcasses (Table 1).

The DFD condition was not uniformly expressed throughout all hindquarter muscles (Table 2). The greatest pH and muscle color differences between normal and DFD carcasses were observed in the longissimus muscle. These data are biased, however, because the determination of whether a carcass was classified as normal or DFD was based on the visual appraisal of the longissimus muscle, meaning that we would expect to see greater differences in the longissimus muscle as compared to other muscles. Dark cutting carcasses had gluteus medius, semimembranosus, and semitendinosus muscles with higher ultimate pH and lower colorimeter readings than those same muscles in normal carcasses. The pH of the biceps femoris differed slightly between normal and DFD carcasses; however, color of the biceps femoris was not affected ($P > 0.05$) by DFD status. The lower L* value for DFD tensor fasciae latae may be due to lower amounts of intramuscular fat because the tensor fasciae latae is a highly marbled muscle and DFD carcasses had lower amounts of intramuscular fat ($P = 0.06$ as measured in the longissimus muscle). Interestingly, the three muscles with the highest ultimate pH in normal carcasses (psoas major, tensor fasciae latae, and rectus femoris) were the same three muscles for which pH was not affected by DFD status ($P > 0.05$). The differences among muscles are probably due to differences in fiber type distributions (Hunt and Hedrick, 1977). Monin (1981) reported an inverse relationship between myofibrillar ATPase activity and ultimate pH among 18 beef muscles. Specifically, Monin (1981) found the highest ATPase activity in the semimembranosus and gluteus medius muscles, two of the muscles in which we observed a DFD effect.

Cooked beef palatability was substantially lower for DFD carcasses than for normal carcasses (Table 3). Cooked longissimus from DFD carcasses had shear force values 46% higher than those from normal carcasses. Additionally, tenderness variation was substantially greater in beef from DFD carcasses than in beef

Table 2. Muscle pH and color characteristics measured at 7 d postmortem for normal and dark cutting (DFD) carcasses

Variable	Normal (n = 36)	DFD (n = 11)	RSD	*P*-value
Longissimus				
Ultimate muscle pH	5.53	6.00	0.12	0.0001
L*[a]	40.6	34.0	2.7	0.0001
a*[b]	27.5	20.6	1.4	0.0001
b*[c]	12.4	7.4	1.2	0.0001
Psoas major				
Ultimate muscle pH	5.72	5.80	0.16	0.1474
L*	42.1	40.8	3.0	0.2119
a*	29.1	28.5	1.7	0.3612
b*	13.4	12.9	1.4	0.3737
Gluteus medius				
Ultimate muscle pH	5.54	5.72	0.09	0.0001
L*	45.0	39.3	3.7	0.0001
a*	31.9	28.8	1.9	0.0001
b*	16.0	13.2	1.6	0.0001
Tensor fasciae latae				
Ultimate muscle pH	5.61	5.66	0.14	0.3230
L*	46.3	43.8	3.3	0.0366
a*	29.0	28.6	2.5	0.6363
b*	14.0	13.6	2.1	0.5766
Rectus femoris				
Ultimate muscle pH	5.62	5.67	0.10	0.2105
L*	46.1	44.9	4.0	0.4169
a*	28.9	29.0	1.4	0.7818
b*	14.0	14.0	1.3	0.9786
Semimembranosus				
Ultimate muscle pH	5.54	5.67	0.07	0.0001
L*	41.4	36.5	3.2	0.0001
a*	29.0	26.1	2.1	0.0002
b*	13.6	11.0	1.6	0.0001
Biceps femoris				
Ultimate muscle pH	5.52	5.57	0.04	0.0032
L*	42.9	42.3	3.5	0.6039
a*	28.9	29.0	1.5	0.8674
b*	13.6	13.6	1.2	0.9769
Semitendinosus				
Ultimate muscle pH	5.55	5.83	0.13	0.0001
L*	46.0	39.8	3.4	0.0001
a*	28.6	24.9	2.1	0.0001
b*	15.3	11.3	1.8	0.0001

[a]L*: 0 = black, 100 = white.
[b]a*: Lower numbers = more green, higher numbers = more red.
[c]b*: Lower numbers = more blue, higher numbers = more yellow.

from normal carcasses (Figure 2). Shear force variation in DFD longissimus was 2.3 times greater than shear force variation in normal longissimus. Dark cutting carcasses also had higher shear force values for gluteus medius (33% greater) and semimembranosus (36% greater) as compared to normal carcasses (Table 3). Dark cutting status did not affect the mean shear force value for five of the eight muscles tested ($P > 0.05$); however, the standard deviations for shear force for DFD carcasses were numerically higher than those for normal carcasses for all eight muscles (data not shown), indicating greater tenderness variation among DFD carcasses. Sensory panel data also revealed less tender longissimus, gluteus medius, and semimembranosus for DFD carcasses than for normal carcasses. As rated by sensory panel, DFD carcasses produced a much higher percentage of "tough" longissimus steaks and a much lower percentage of "very tender" steaks than did normal carcasses. There has been very limited previous research comparing the tenderness of normal vs DFD beef; however, many researchers have examined the relationship between ultimate pH and meat tenderness. Dransfield (1981), using data from bull carcasses, reported that "DFD beef is markedly more tender than beef of normal pH." In agreement with Dransfield (1981), Jeremiah et al. (1991) reported that bull carcasses with darker colored lean and higher ultimate pH produced more tender meat than bull carcasses with lighter colored lean and lower ultimate pH. The seemingly conflicting results between these previous studies and our study could be explained by the following: 1) bull carcasses have higher ultimate pH values than

Table 3. Palatability characteristics for normal and dark cutting (DFD) carcasses

Variable	Normal (n = 36)	DFD (n =11)	RSD	*P*-value
Shear force, kg				
Longissimus	3.72	5.47	1.24	0.0002
Psoas major	3.22	3.17	0.38	0.6415
Gluteus medius	4.21	5.59	1.17	0.0014
Tensor fasciae latae	3.63	3.87	0.65	0.2797
Rectus femoris	3.45	3.92	0.89	0.1341
Semimembranosus	4.25	5.78	1.00	0.0001
Biceps femoris	4.98	5.49	0.86	0.0912
Semitendinosus	4.07	4.15	0.72	0.7518
Longissimus sensory panel[a]				
Tenderness	6.27	5.10	1.09	0.0032
Juiciness	6.18	5.92	0.52	0.1493
Flavor intensity	5.86	5.80	0.37	0.6316
Flavor desirability	5.82	5.18	0.52	0.0008
Moderately tough or worse	0%	27%	0.001	
Slightly tough or worse	0%	36%	0.001	
Very tender or better	44%	9%	0.033	
Gluteus medius sensory panel[a]				
Tenderness	6.16	4.54	0.83	0.0001
Juiciness	6.13	6.03	0.46	0.5090
Flavor intensity	5.84	5.64	0.40	0.1534
Flavor desirability	5.85	5.29	0.41	0.0002
Semimembranosus sensory panel[a]				
Tenderness	5.22	4.25	0.91	0.0035
Juiciness	5.61	5.75	0.60	0.5007
Flavor intensity	5.78	5.74	0.30	0.7031
Flavor desirability	5.41	5.14	0.55	0.1608

[a]Sensory panel ratings: 8 = extremely tender, extremely juicy, extremely intense, extremely desirable; 1 = extremely tough, extremely dry, extremely bland, extremely undesirable.

steer and heifer carcasses (Jeremiah et al., 1991, Page et al., 2001), and 2) the relationship between ultimate pH and meat tenderness is curvilinear with toughness maximized at an ultimate pH of 5.8 to 6.0 (Purchas, 1990; Watanabe et al., 1995). Based on our study and a review of scientific literature, approximate average ultimate pH values are 5.5 for normal steer and heifer carcasses, 6.0 for DFD steer and heifer carcasses, 5.8 for normal bull carcasses, and 6.7 for DFD bull carcasses (Jeremiah et al., 1991, Lahucky et al., 1998, Page et al., 2001). Therefore, the carcasses that fall into the ultimate pH range associated with maximum toughness (5.8 to 6.0) are DFD steer and heifer carcasses and normal bull carcasses. Therefore, within the U.S. "fed cattle" carcass population, which consists of 68.0% steer, 31.6% heifer, and only 0.4% bullock carcasses (Smith et al., 1995), DFD carcasses will likely produce less tender beef than normal carcasses.

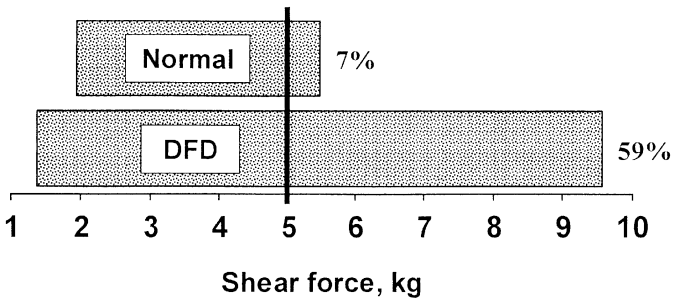

Figure 2. Effect of dark cutting (DFD) status on Warner-Bratzler shear force of cooked beef longissimus. Each bar represents the mean ± 2 standard deviations of shear force. The bold vertical line is drawn at a shear force of 5.0 kg. Values to the right of each bar represent the estimated percentage of carcasses within each DFD status with shear force greater than 5.0 kg (calculated as a value of $Z \times 100$ for the probability of an observation being greater than 5.0, Steel and Torrie, 1980).

Dark cutting status did not affect sensory panel juiciness or flavor intensity score ($P > 0.05$); however, longissimus and gluteus medius flavor desirability scores were lower for DFD than for normal carcasses (Table 3). Dransfield (1981) reported no difference in juiciness scores between normal and DFD beef, a finding confirmed by our study; however, Dransfield (1981) found that DFD beef had less beef flavor than normal beef, an effect that was not observed in our study.

The lower sensory panel flavor desirability scores for DFD carcasses (Table 3) are further described by examining off-flavor characteristics (Table 4). Longissimus steaks from DFD carcasses had more off-flavors than longissimus steaks from normal carcasses, but no significant differences ($P > 0.05$) were found in total number of off-flavors between normal and DFD gluteus medius steaks or between normal and DFD semimembranosus steaks. When totaled across all three muscles,

Table 4. Off-flavor characteristics (average number of flavor comments per carcass summed over nine panelists) for normal and dark cutting (DFD) carcasses

Variable	Normal (n = 36)	DFD (n = 11)	RSD	*P*-value
Total longissimus off-flavors	0.64	1.64	0.74	0.0003
Total gluteus medius off-flavors	0.53	0.45	0.66	0.7495
Total semimembranosus off-flavors	0.67	1.27	0.97	0.0759
Totaled across muscles				
Peanutty	0.03	0.36	0.28	0.0011
Sour	0.36	0.91	0.69	0.0251
Bitter	0.17	0.55	0.51	0.0367
Burnt	0.11	0.36	0.37	0.0526
Old	0.22	0.09	0.50	0.4475
Metallic	0.42	0.36	0.65	0.8152
Rancid	0.22	0.18	0.51	0.8203
Livery	0.11	0.09	0.32	0.8531
Other off-flavors	0.19	0.45	0.48	0.1227
Total off-flavors	1.83	3.36	1.70	0.0120
Bland[a]	0.39	0.45	0.62	0.7599

[a]"Bland" was not counted as an off-flavor for muscle totals or "total off-flavors."

DFD steaks received more "peanutty," "sour," and "bitter" comments. Only one panelist used the word "peanutty" to describe certain off flavors; therefore, that panelist rated 36% of DFD carcasses as having a "peanutty" flavor compared to only 3% of normal carcasses. Overall, steaks from DFD carcasses had 84% more off-flavors than steaks from normal carcasses.

The combined effects of marbling and DFD status on longissimus palatability traits are shown in Table 5. All carcasses in this study had either "small" or "slight" marbling scores. A significant marbling score × DFD status interaction existed for longissimus shear force ($P = 0.003$). The DFD effect of higher shear force values was approximately five times greater (+3.11 kg vs +0.63 kg) for carcasses with "slight" marbling scores as compared to the DFD effect for carcasses with "small" marbling scores. In fact, the differences in shear force and taste panel tenderness between normal and DFD carcasses with "small" marbling scores were not statistically significant ($P > 0.05$). Dark cutting carcasses had longissimus steaks with lower flavor desirability ratings than normal longissimus steaks regardless of marbling score. In general, there were no significant differences ($P > 0.05$) in palatability between "small" and "slight" marbling scores among normal carcasses; however, "slight" marbling scores resulted in less palatable steaks than "small" marbling scores among DFD carcasses. Currently, the United States Standards for Grades of Carcass Beef (USDA, 1997) require discounting the USDA quality grade of a beef carcass according to severity of the DFD condition; however, DFD carcasses are still eligible for all USDA quality grades, including Prime, Choice, and Select, which are the grades typically marketed to retail and restaurant consumers. Three recent studies (Wulf et al., 1996; Voisinet et al., 1997, and our study) that together total 798 carcasses of diverse biological types and include 53 "dark cutters" have shown substantially reduced tenderness from DFD beef. Based on the results of these three studies, we recommend that the USDA quality grade standards be revised to exclude all DFD carcasses from the Prime, Choice, and Select grades.

Our results show reduced palatability of DFD beef compared to normal beef. We also examined whether or not GP differences among normal carcasses were related to beef palatability (Table 6). Although the largest effects on palatability related to GP were those associated with the very lowest GP values (DFD car-

Table 5. Combined effects of marbling score and dark cutting status on palatability of cooked beef longissimus

	Small		Slight		
Marbling level:	Normal	DFD	Normal	DFD	
Variable Dark cutting status:	(n = 20)	(n = 6)	(n = 16)	(n = 5)	RSD
Shear force, kg	3.90[a,b]	4.53[b]	3.49[a]	6.60[c]	1.14
Sensory panel tenderness	6.07[a,b]	5.49[b,c]	6.51[a]	4.64[c]	1.07
Sensory panel juiciness	6.16	6.02	6.19	5.79	0.52
Sensory panel flavor intensity	5.92	5.84	5.78	5.74	0.37
Sensory panel flavor desirability	5.92[a]	5.51[b]	5.69[a,b]	4.78[c]	0.48

[a,b,c]Least-squares means within a row lacking a common superscript letter differ ($P < 0.10$).

Table 6. Effect of glycolytic potential on beef ultimate muscle pH, muscle color, and palatability

Variable	Glycolytic potential, μmol/g: Less than 80 (n = 11)	80 to 99.9 (n = 11)	100 to 119.9 (n = 21)	120 to 139.9 (n = 31)	140 and greater (n = 19)	RSD	*P*-value
Glycolytic potential, μmol/g	66[a]	90[b]	109[c]	130[d]	153[e]	7	0.0001
Longissimus ultimate pH	6.01[a]	5.60[b]	5.48[c]	5.44[c]	5.46[c]	0.15	0.0001
Longissimus L*[f]	35.2[a]	37.7[a,b]	39.3[b]	41.7[c]	39.2[b]	3.5	0.0001
Longissimus a*[g]	19.8[a]	22.5[b]	25.0[c]	25.4[c]	25.1[c]	2.7	0.0001
Longissimus b*[h]	7.3[a]	9.1[b]	11.0[c]	11.5[c]	11.0[c]	2.0	0.0001
Shear force, kg							
Longissimus	5.00[a]	4.64[a,b]	3.97[b,c]	3.86[b,c]	3.62[c]	1.29	0.0312
Psoas major	3.26	3.32	3.21	3.23	3.20	0.38	0.9172
Gluteus medius	5.66[a]	4.51[b]	4.37[b]	4.04[b]	4.28[b]	1.00	0.0006
Tensor fasciae latae	3.78	3.47	3.98	3.68	3.66	0.64	0.2441
Rectus femoris	3.88[a,b]	3.32[b,c]	3.93[a]	3.29[c]	3.40[b,c]	0.79	0.0239
Semimembranosus	5.66[a]	5.05[a,b]	4.44[b,c]	4.22[c]	4.15[c]	0.97	0.0002
Biceps femoris	5.41	4.96	5.29	5.06	4.85	0.92	0.4200
Semitendinosus	4.36	3.86	4.38	4.08	4.12	0.62	0.1605
Longissimus sensory panel[i]							
Tenderness	5.45	6.06	6.10	6.26	6.47	1.06	0.1447
Juiciness	5.94	6.04	6.25	6.07	6.09	0.55	0.5938
Flavor intensity	5.79	5.76	5.93	5.86	5.98	0.36	0.4446
Flavor desirability	5.23[a]	5.76[b]	5.90[b]	5.78[b]	5.82[b]	0.49	0.0083
Gluteus medius sensory panel[i]							
Tenderness	4.61[a]	5.62[b]	6.07[b]	6.08[b]	6.20[b]	0.81	0.0001
Juiciness	5.98	6.20	6.08	6.05	6.20	0.50	0.7076
Flavor intensity	5.62	5.78	5.86	5.78	5.87	0.35	0.3742
Flavor desirability	5.28[a]	5.60[b]	5.77[b,c]	5.82[b,c]	5.91[c]	0.38	0.0004
Semimembranosus sensory panel[i]							
Tenderness	4.37[a]	4.81[a,b]	4.93[a,b]	5.32[b,c]	5.52[c]	0.83	0.0022
Juiciness	5.35	5.94	5.75	5.58	5.65	0.55	0.1223
Flavor intensity	5.68	5.84	5.69	5.78	5.80	0.32	0.5948
Flavor desirability	5.06	5.29	5.50	5.32	5.51	0.50	0.1146

[a,b,c,d,e]Least-squares means within a row lacking a common superscript letter differ ($P < 0.05$).
[f]L*: 0 = black, 100 = white.
[g]a*: Lower numbers = more green, higher numbers = more red.
[h]b*: Lower numbers = more blue, higher numbers = more yellow.
[i]Sensory panel ratings: 8 = extremely tender, extremely juicy, extremely intense, extremely desirable; 1 = extremely tough, extremely dry, extremely bland, extremely undesirable.

casses), there were statistically significant differences in palatability among the "normal" GP groups. In general, higher GP was associated with increased tenderness. Therefore, genetic or environmental factors that increase GP in live cattle may improve the tenderness of their beef steaks. Researchers should develop preslaughter methods of increasing GP or lessening stress-induced reductions in GP and thereby reduce the incidence of DFD carcasses and probably improve tenderness.

Implications

It appears that some cattle are at greater risk of producing dark cutting beef than others because substantial variation existed in glycolytic potential among normal carcasses. For researchers examining factors causing dark cutters, glycolytic potential is a dependent variable that should provide a stronger statistical test than dark cutting incidence. Dark cutting beef was considerably less tender, exhibited more tenderness variation, and had more off-flavors than normal beef. Because of poor palatability, dark cutters should be excluded from USDA Prime, Choice, and Select grades and from premium beef marketing programs. Preslaughter methods of increasing glycolytic potential should be developed because beef palatability would probably be improved as a result.

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