



Effect of Postmortem Metabolic Rate on Meat Color

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ABSTRACT : The current study was conducted to evaluate carcass characteristics, objectives and sensory meat qualities of Hanwoo longissimus muscle as affected by ultimate pH. Twenty-four steers and bulls (556 ± 53 kg and 0.63 ± 0.32 cm for live weight and backfat thickness, respectively) were used. As there was a linear relationship ($r = 0.77$) between lean meat color and ultimate pH, cattles were thus segregated into normal ($\text{pH} \leq 5.8$, Normal, $n = 13$) and DFD ($\text{pH} > 5.8$, $n = 11$) groups. Normal pH group had significantly ($p < 0.05$) higher carcass weight, marbling score and backfat thickness than those for high pH group, while fat color and lean meat color were inverse. In principle component analysis for co-ordinates of DFD and normal meats, fat color, lean meat color, texture, time to pH 6.2 and pH at 24 h postmortem were associated with the positive range of the first factor (67.5%) while backfat thickness marbling score and temperature at 24 h were placed in negative values. The rate constant of decline in pH (pH k) did not differ between the two groups, implying that initial pH (i.e., pH at slaughtering) differed between two groups. Contour mapping of pH k between pH at 1 and 24 h postmortem indicated that high pH k was related to lower pHs at 1 and 24 h postmortem. This suggested that the high pH cattles (i.e., DFD cattle) resulted from their own potential. Although the time to reach pH 6.2 was significantly ($p < 0.05$) shorter for normal meat (i.e., 3.2 h) than that for DFD one (i.e., 19.8 h), there were no significantly differences in both WB-shear force and sensory attributes. Given that the experimental animals were sampled from a similar group, which implies a similar myoglobin pigment content, the current data suggested that pre- and post-slaughter animal handling likely had a significant effect on ultimate pH and consequently meat color of Hanwoo longissimus muscle, and also small animals with lower marbling score and backfat thickness had a higher risk for DFD meat. (Key Words : Beef, pH, DFD, Meat Color)

INTRODUCTION

Although meat colour is not a direct indicator of eating quality, the psychological attractiveness of the bright-red colour makes it a fundamental criterion at the point of purchase. Pre-slaughter stress affects the ultimate pH of the raw meat by depleting muscle glycogen reserves (Backer et al., 1998). If glycogen is depleted by chronic long-term stress before slaughter than less lactic acid is formed and the meat does not acidify normally which consequently results in high pH in meat (i.e., dark, firm and dry, DFD meat) (Schaefer, 1997). The colour of fresh meat is largely determined by the relative proportions and distribution of oxymyoglobin and metmyoglobin (Seideman et al., 1984). Oxygenation (blooming) is the development of a bright red colour when meat is exposed to air. On the other hand, DFD beef is not bloomed even exposed to air (Egbert and

Cornforth, 1986), while the dark beef turns red if mitochondrial respiration is inhibited with the mitochondrial respiratory inhibitor rotenone, or heat, allowing myoglobin at the muscle surface to be oxygenated (Gasperlin, 1998).

There has been a controversy in the literatures with regard to the relationship between ultimate pH and eating quality, while a large number of studies demonstrated a curve-linear relationship, with a minimum around pH 5.8-6.0 (eg., Purchas, 1999). The reasons is not fully elucidated, but sheep longissimus muscle with pH higher than approximately 6.0 showed an increased proteolysis (Watanabe et al., 1996) and DFD muscle is laterally swollen and consequently a small extracellular space, resulting in tender meat for cooked meat (Tornberg, 1996). Another possible explanation for tender meat of DFD meat was evident by Katsaras and Peetz (1990) who showed that morphological changes (i.e., fragmentation of myofibrils) in dark cutting beef was greater in DFD meat than in normal one, with cooking losses were much smaller. The difference might result in detectable difference in texture for consumers.

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On the other hand, it should be taken into consideration that in raw meat tenderness was not related to ultimate pH (Drandfield, 1981). In addition, when meat was cooked at high temperature (e.g., 90°C) the relationship was linear, while a medium cooking temperature (e.g., 65°C) resulted in a curvilinear relationship (Bouton et al., 1971). It also appeared that degree of shortening (Olsson et al., 1995; Purchas et al., 1999), methods employed for assessment (Wahlgren and Tomberg, 1996) and the degree of aging (Watanabe et al., 1996; Purchas et al., 1999) significantly affected the relationships. The fact might be a reflection of the variability of consumer's response to DFD meat in terms of the sensory attributes and preferences. Beef of normal pH was more acceptable than DFD beef due to the stronger beef flavour (Dransfield, 1981; Katsaras and Peetz, 1990). Katsaras and Peetz (1990) reported that DFD meat was unusually tender, while Viljoen et al. (2002) found no significant difference in sensory attributes of fried normal and DFD steaks, with female panels identified an "off-flavour" for DFD meat. The current study conducted to evaluate carcass characteristics, and objective and sensory meat qualities of Hanwoo longissimus muscle as affected by ultimate pH.

MATERIALS AND METHODS

Animal and determination of carcass characteristics

A total of 24 Hanwoo steers and bulls were sampled from a breeding herd at the National Livestock Research Institute (NLRI) and slaughtered at the experimental abattoir of NLRI. Average live weight and backfat thickness were 556±53 kg and 0.63±0.32 cm, respectively. The animals designated for slaughter were transported approximately 4 h from the research station to the research abattoir before being slaughtered the following day, and kept off feed, but given free access to water. Upon arrival of the animals at the abattoir, their live weight was determined and used as the live weight. The animals, after going through captive bolt stunning, were conventionally slaughtered, normally hung and placed in the cold storage facility at a temperature of 1°C. After an overnight chilling, cold carcass weight was determined, and sides were quartered between the 13th rib and the first lumbar vertebra to determine quality and yield grades including marbling score, lean meat color, fat color, texture, maturity, ribeye area and backfat thickness. This procedure was done by beef carcass graders from the Korean Animal Products Grading Service (APGS, 1995).

pH, temperature, objective and subjective meat qualities

Both muscle temperature and pH were determined at 1, 3, 6, 12 and 24 h postmortem using thermocouples (Tegam

866, USA) and a portable needle-tipped combination electrode (Oyster, Extech Co.) calibrated at room temperature (ca. 18°C), inserted into the geometrical center of the longissimus muscle at 12/13th ribs. Objective and subjective meat qualities of longissimus muscle (the first to last lumbar vertebra portion) were determined the following day after slaughter. Ultimate pH reading of ≤5.8 was taken as normal meat and ultimate pH reading of >5.8 was regarded as DFD meat according to a previous threshold suggested by Viljoen et al. (2002).

WB-shear force was measured on steaks (30-mm thick) cooked in a pre-heated water bath (70°C) for 10 min and then cooled in running water (ca. 18°C) for 30 min to reach a core temperature below 30°C. Eight cores of 1.27-cm diameter were made for each sample, and peak force was determined using a V-shaped shear blade with a cross-head speed of 400 mm/min (Wheeler et al., 2000). Cooking loss was determined by calculating the weight difference in steaks before and after cooking, expressed as percentage of initial weight. Sensory evaluation was performed by 10 trained sensory panels who were recruited from 15 initial panel pool. At each session, panels were served with a total of six samples and asked to score the samples for tenderness, juiciness and flavor. Scoring was done on a single sheet using a one to six non-continuous scale where tenderness = very tough (0) to very tender (6); juiciness = very dry (0) to very juicy (6); flavor = dislike extremely (0) to like extremely (6).

Objective meat color (Hunter L*, a* and b*) was determined by a Minolta Chromameter (CR301, Minolta, Japan) on freshly cut surface after a 30-min blooming at 1°C. The color meter was calibrated against a white tile ($Y = 92.40$, $x = 0.3136$, $y = 0.3196$) provided by the manufacturer.

Statistical analysis

Changes in both pH and temperature as functions of time were modeled in individual carcasses using the exponential function: $y_t = a_u + (a_i - a_u)e^{-a_k t}$, where y_t is pH, or temperature at time t , a_u is ultimate pH, or temperature, a_i is initial pH, or temperature, a_k is the exponential rate of pH or temperature fall and t is time post-mortem. This equation was fitted using PROC NLIN in SAS (SAS Institute, 1997). Parameters from the pH/time equation was used to predict the time to achieve pH 6.0, which was then used in the temperature/time equation to predict temperature at pH 6.0. Mean differences for carcass characteristics and objective and subjective meat quality traits between normal and DFD meats were evaluated by applying a general linear model against animal error terms (SAS, 1997). Principle component analysis was performed by applying SYSTAT version 10.2 (SYSTAT Software Inc., 2002).

Table 1. Mean and range of carcass weight, postmortem pH and temperature, and meat quality characteristics (n = 24)

	Mean	Min.	Max.
Live weight (kg)	556.3	447.0	681.0
Temperature k ¹	3.4	1.9	4.9
pH k ¹	16.1	0.0	88.7
Temperature at 24 h	3.8	0.3	7.5
pH at 24 h	5.8	5.3	6.7
Marbling score ²	6.5	3.0	14.0
Meat color ³	5.2	3.0	7.0
Hunter L*	25.8	23.3	29.1
Hunter a*	11.9	8.7	15.3
Shear force (kg)	4.8	1.9	10.7
Sensory juiciness ⁴	3.7	2.3	4.9
Sensory tenderness ⁴	3.9	1.9	5.3

¹ pH k and Temperature k: Rate constants of exponential function for changes in pH and temperature, respectively.

² Marbling score: 1 = low, 5 = very high.

³ Lean meat color: 1 = PSE lean, 2 = pseudo-PSE lean, 3, 4, 5 = normal lean color, 6 = pseudo-DFD lean, 7 = DFD lean color.

⁴ Sensory: 6 = extremely juicy, tender, or flavorful, 1 = extremely dry, tough, or bland.

RESULTS AND DISCUSSION

Even though characteristics of DFD meat have been

known for longer than 60 years, the problem with the frequency of DFD became highly acute with the centralized production and processing systems (Malmfors and Wiklund, 1996). Relationship between meat quality and ultimate pH has been well documented by numerous studies (for review Tornberg, 1996). In Korean beef market, although DFD frequency was approximately 9% (Park, 1997), consumers more than 53% ascribed meat color for the most important attribute to determine purchase (Cho et al., 1999). For the reason, the current study forced on identifying the cause of Hanwoo DFD meats in terms of carcass traits and postmortem pH and temperature interaction, and its quality characteristics compared with normal meat.

Table 1 shows means and ranges of carcass and meat quality traits. Decline in temperature postmortem was within a general range (0.3-7.5°C at 24 h) while there was a large range in ultimate pH (5.3-6.7 at 24 h). WB-shear and sensory attributes also showed large ranges. Although the animal group was recruited from a breeding herd of NLRI without no particular pre-slaughter treatment to induce a large range of ultimate pH, 11 out of 24 cattle showed pH higher than 5.8 (Table 2). The figure was unexpectedly high compared to other similar studies (Park et al., 2006), and

Table 2. Carcass and meat quality characteristics between DFD (pHu>5.8) and Normal (pHu≤5.8) meats

	DFD (n = 11)	Normal (n = 13)	Ave. SE	F value and sig. level
Carcass characteristics¹				
Live weight (kg)	531.3	577.4	14.055	5.38*
Backfat thickness (cm)	0.4	0.8	0.075	16.43***
Ribeye area (cm ²)	77.9	79	2.34	0.11
Marbling score	4.2	8.5	0.815	13.73**
Lean meat color	6.2	4.3	0.22	37.11***
Fat color	3.8	3.2	0.145	10.86**
Texture	9.1	6.7	0.385	19.01***
Postmortem metabolic rate²				
pH at 3 h postmortem	6.6	6.0	0.09	24.44***
pH at 24 h postmortem	6.1	5.5	0.065	48.88***
pH k	6.3	6.7	1.435	0.04
Temperature k	3.7	3.1	0.21	3.84 ^{P=0.062}
Temperature 3 h postmortem	28.1	29.9	0.615	4.11 ^{P=0.054}
Temperature 24 h postmortem	2.3	5.2	0.45	20.44***
Temperature at pH 6.2	7.3	30.2	3.67	18.82***
Time to reach pH 6.2	19.8	3.2	2.71	18.03***
Objective and subjective meat quality³				
Shear force (kg)	4.8	4.8	0.73	0
Cooking loss (%)	36.7	38.6	1.815	0.54
Hunter L*	25.9	25.6	1.185	0.02
Hunter a*	11.4	14.3	1.185	6.05*
Hunter b*	3.4	4.4	0.335	4.02
Sensory juiciness	3.6	3.8	0.25	0.39
Sensory tenderness	3.8	3.9	0.35	0.01
Sensory flavor	4.1	4.3	0.10	1.33

* <0.05, ** <0.01, *** <0.001.

¹ Marbling score: 1 = low, 5 = very high; Lean meat color: 1 = PSE lean, 2 = pseudo-PSE lean, 3, 4, 5 = normal lean color, 6 = pseudo-DFD lean, 7 = DFD lean color; Fat color: 1 = milk white, 2-6 = intermediate, 7 = yellow; Texture: 1 = good, 2 = average, 3 = bad.

² pH k and Temperature k: Rate constants of exponential function for changes in pH and temperature, respectively.

³ Sensory: 6 = extremely juicy, tender, or flavorful, 1 = extremely dry, tough, or bland.

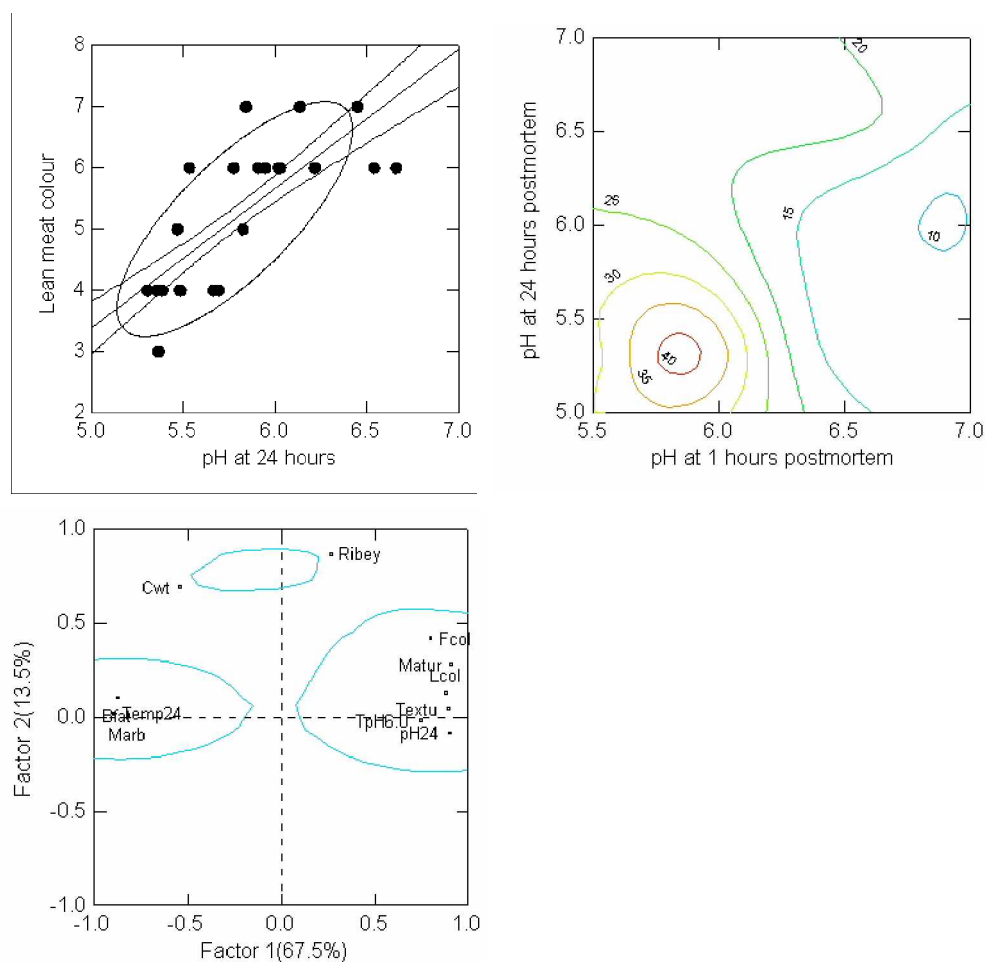


Figure 1. Relationship between lean meat color and pH at 24 h ($r = 0.77$, regression, two standard deviation confidential interval bars and ellipses) (upper left), contour map for rate constant of pH drop (pH k) between pH at 1 and 24 h postmortem (upper right), and principle component analysis for co-ordinates of DFD and normal meat groups with variables of carcass characteristics and postmortem pH and temperature (Ribey: ribeye area, Cwt: carcass weight, Temp 24: temperature at 24 h, Bfat: backfat thickness, Marb: marbling, Fcol: fat color, Matur: maturity, Lcol: Lean meat color, Textu: texture) (lower left).

the observations initially promoted us to characterize carcass and meat qualities between high (pH > 5.8, DFD) and low (pH ≤ 5.8, Normal) pH groups. The segregation was determined according to previous study conducted for beef muscle (Viljoen et al., 2002). Indeed, there was a linear relationship ($r = 0.77$) between lean meat color and ultimate pH where all cattle with pH higher than 5.8 showed lean meat color of 6 and 7, except unusual three cattle (Figure 1). The linear relationship for Hanwoo longissimus muscle was in consistency with the previous results obtained from other beef breeds (Schaefer, 1997).

At the first glance on Table 1, normal pH group had significantly ($p < 0.05$) higher carcass weight, marbling score and backfat thickness than those for high pH group, while fat color and lean meat color were in reverse. Because of insulating capacity of fat and temperature gradients in a muscle and between muscles, heavier carcass with high subcutaneous and intramuscular fat content showed a

slower decline in temperature under an identical chilling condition (Savell et al., 2005). In the current study, the significantly ($p < 0.05$) higher temperatures at 3 and 24 h with a lower rate constant of temperature decline (temperature k) was likely affected by the higher fat content and heavier carcass weight for the normal group compared with that for DFD one (Table 2). While it was not indefinite whether the difference in temperature decline greatly influenced pH drop during rigor development as shown by Devine et al. (2002), pH decline for the normal group was significantly ($p < 0.05$) faster as judged by pH at 3 h postmortem, resulting in significantly ($p < 0.05$) lower ultimate pH than these for DFD group. The difference was expectable as two groups were initially segregated based on ultimate pH. However, it was noticeable that the rate constant of decline in pH (pH k) did not differ between the two groups. Because the pH k indicates the speed of pH decline the result likely implied that initial pH (i.e., pH at slaughter time) differed between two groups. The notion

could be supported by the fact that the extent of pH decline is related to DFD meat, while the rate of pH decline is related to PSE meat (Tornberg, 1996). As the first measurement of pH was 1 hour postmortem, with a concern of prediction bias, we could not attempt to predict pH at the slaughtering time. Nevertheless, the presumption was in part verified by a graphic analysis for contour mapping of pH k between pH at 1 and 24 h postmortem (Figure 1). The diagram indicated that high pH k was related to lower pHs at 1 and 24 h postmortem. This suggested that cattle with lower pH at 1 hour postmortem had a faster decline in pH (i.e., higher pH k) and resulted in lower pH at 24 h postmortem. In other words, the results could be understood as the high pH cattle (i.e., DFD cattle) were resulted from their own initial potentiality prior to slaughter. Meat color is influenced by the myoglobin content and composition and physical state of muscle, and the latter is more directly related to the ultimate pH (Renner and Labas, 1987). Given the fact that myoglobin pigment content is largely affected by production factors such as species, animal age and feeding system, other extrinsic factors such as pre-slaughter animal handling and slaughtering process affected the potentiality of the extent of pH decline and consequently DFD meat.

The combination of pH-temperature-time during the onset of rigor mortis has a significant effect on meat quality as that affects proteolytic degradation and denaturation of myofibril component (Offer et al., 1992; Devine et al., 2004). Furthermore, time to reach pH is approximately 6.2 and the temperature at this pH are significant indicators of the metabolic processes in the muscle and meat tenderization (Dransfield, 1999). When the time to reach pH 6.2 was estimated using the exponential functions, normal meat showed significantly ($p < 0.05$) shorter time (i.e., 3.2 h) than DFD (19.8 h), and consequently temperature at pH 6.0 was significantly higher for normal meats (Table 2). Based on the threshold of Bendall (1976) who showed lamb longissimus muscle entered rigor either below 10°C with pH higher than 6.2, or higher than 30°C with pH lower than 6.2 had cold and heat shortening, respectively, and in particular the DFD meat had a risk of cold shortening to some extent. However, there was no significant difference in both WB-shear force and sensory tenderness (Table 2).

Wulf et al. (1996) studied the effect of lean colour on palatability and found that lean colour was significantly related to taste panel tenderness scores: darker colored meat was considered to be less tender compared to normal and pale lean. In addition, Dransfield (1996) reported that initially meat of high ultimate pH is more tender than normal pH meat as a result of a higher tenderization rate, but with prolonged ageing the ultimate tenderness becomes similar. The reason for the tender meat for high pH muscle has been explained by an increased proteolysis (Claeys et

al., 1994; Watanabe et al., 1996) and laterally swollen micro-structure (Tornberg, 1996). However, the current tenderness result which was determined at 24 h postmortem (eg., a very short ageing period) was not consistent with the findings of the previous literatures. On the other hand, a recent study (eg., Purchas et al., 1999) reported a curve-linear relationship between ultimate pH and tenderness, with a minimum around pH 5.8-6.0 and meat with pH higher than approximately 6.3 showed a similar tenderness with normal pH one. The data (i.e., Purchase et al.) was obtained from 70°C cooking for 90 min for beef longissimus muscle and WB-shear force for the current data was determined for the same muscle cooked at 70°C for 10 min. If the current data was resulted from the similar case, the inconsistency of tenderness results with majority previous studies was likely related in part (if any) to way of cooking. Similar, but different data set was also reported by Bouton et al. (1971) who showed that when sheep muscle was cooked at high temperature (e.g., 90°C) the relationship was linear, while a medium cooking temperatures (e.g., 65°C) resulted in a curvilinear relationship. There are also other possibility for the difference as other studies showed the relationship was affected by degree of shortening (Olsson et al., 1995), assessment methods (Walhgren and Tornberg, 1996) and the degree of aging (Watanabe et al., 1996; Silva et al., 1999).

Similarly, other sensory attributes such as juiciness and flavor did not differ between two groups. For the cooked meat juiciness is to some extent affected by water-holding capacity as that affect cooking loss. If the ultimate pH is high, the physical state of the proteins will be above their iso-electic point, resulting in excessive water entrapment in muscle fiber lattices (i.e., high water-holding capacity) (Seideman et al., 1984). However, in the current study cooking loss did not significantly differ between two groups of meats although there was a tendency to have higher cooking loss for normal meat than DFD. The current result for the sensory juiciness and flavor intensity were not in consistent with previous studies that showed beef of normal pH was more acceptable than DFD beef due to the stronger beef flavour (Dransfield, 1981; Katsaras and Peetz, 1990). On the other hand, Viljoen et al. (2002) found no significant difference in sensory attributes of fried normal and DFD steaks, with female panels identified an "off-flavour" for DFD meat.

Principle component analysis was performed with co-ordinates of DFD and normal meat groups with variables of carcass characteristics and postmortem pH and temperature (Figure 1) where 67.5% of the variance was attributable to the first factor, which clearly separated two meat color groups. Fat color, lean meat color, texture, time to pH 6.2 and pH at 24 h postmortem were associated with the positive range of this factor while both backfat thickness

marbling score and temperature at 24 h were placed in negative values. The analysis suggested that marbling score, backfat and carcass temperature were associated to the same casts for the segregation of normal and DFD meats, while the other factors placed in positive axis did similarly, but in opposite way.

CONCLUSIONS

Objective and subjective eating quality did not differ between normal and DFD meat groups, while the color was significantly affected by ultimate pH. The rate and extent of decline in pH were likely affected by muscle's initial potentiality. The current data suggested that pre- and post-slaughter animal handling likely had a significant effect on meat color, and small animals with lower marbling score and backfat thickness had a higher risk for DFD meat. On the other hand, the effect of rigor temperature on meat color was dependent on the day of ageing and its condition as a consequence of difference in the oxygen-consuming machinery of the mitochondria (Young et al., 1999), hence, the current results could not necessarily be extended for meats in the market.

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