Postmortem pH, Muscle, and Refrigerated Storage Effects on Ability of Vacuum-Packaged Pork to Bloom

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ABSTRACT: Effects of pH, muscle, and storage time on the ability of vacuum-packaged pork chops to bloom were investigated. Low pH samples exhibited more change in color measures during the 30 min blooming period than did the medium and high pH samples. The low pH sample bloomed more rapidly and to a greater extent than medium and high pH samples. Among the 3 muscles, *Longissimus* had the highest, while *Semimembranosus* had the lowest a* value and hue angle changes. Overall, refrigerated storage of vacuum packaged pork for 7 d or more resulted in more efficient blooming when pH was low. The ability of vacuum-packaged pork to rebloom is necessary for the meat to regain the consumer-expected pink-red color after opening the vacuum bag.

Keywords: pork, bloom, refrigerated storage, color, muscle

Introduction

COLOR IS A PRIMARY CONCERN OF THE PORK INDUSTRY AND consumers. Consumers often associate bright-pink color with pork freshness. However, fresh meat color is short-lived and meat discoloration is inevitable during storage (Zhu and Brewer 1998b). Meat color is principally determined by the relative contents of the 3 forms of myoglobin: deoxymyoglobin, oxymyoglobin, and metmyoglobin (Giddings 1977). Purplish-red deoxymyoglobin is the predominant form of myoglobin at the freshly cut meat surface and in the interior of meat, where oxygen partial pressure is very low (Faustman and Cassens 1990). However, deoxymyoglobin is unstable due to its high affinity for oxygen (Giddings 1977). The process in which deoxymyoglobin is oxygenated to oxymyoglobin when exposed to air is called "blooming" (Lawrie 1991; Ledward 1992). Muscle blooming results in a bright-red meat surface. Over time, oxymyoglobin is oxidized resulting in metmyoglobin accumulation and meat surface browning. Muscle tissue has the ability to reduce metmyoglobin back to deoxymyoglobin enzymatically and/or nonenzymatically (Giddings 1974; Faustman and Cassens 1990; Lawrie 1991; Zhu and Brewer 1998a), which will allow it to reversibly bind oxygen again.

The interconversion of the myoglobin forms is influenced by environmental factors such as temperature, oxygen partial pressure, light, and microbial load, as well as factors inherent to muscle such as pH, muscle fiber type, oxygen consumption rate, and metmyoglobin reducing capacity (O'Keefe and Hood 1982; Faustman and Cassens 1990; Zhu and Brewer 1998a). As meat blooms, the thin surface layer of oxymyoglobin penetrates into the meat. The depth to which the oxygen diffuses is affected by the external oxygen pressure and by the activities of oxygen-utilizing enzymes, which compete with deoxymyoglobin for oxygen when meat is blooming. High tissue consumption of oxygen is linked to poor oxygen penetration (Feldhusen and others 1995). Thus, blooming would be expected to be more efficient under conditions that increase oxygen solubility and discourage enzymatic activity such as low temperature and low pH (Ledward 1992). However, it is well-known that the color of low pH meat, especially pork, is markedly less stable than that of high pH meat (Zhu and Brewer 1998a, 1998b).

Morley (1971) found variability in oxygen penetration into freshly cut meat from different muscles. Because a wide variability of activities of certain oxidative enzymes has been found in different beef muscles (Lawrie 1991), one may anticipate that the abilities of different muscles to bloom would be markedly different.

Nominally anoxic packaging has been used effectively to preserve both meat color and microbiological condition during periods of storage and transport. Vacuum packaging results in rapid conversion of most myoglobin to deoxymyoglobin (Faustman and Cassens 1990). Most red meat is marketed fresh in oxygen-permeable or modified atmosphere packaging. Therefore, there is the need for vacuum-packaged meat to rebloom after being exposed in air to give it the consumer-expected pink-red color before display. Any condition, which influences the ability of the muscle to bloom, would affect its ability to regain the pink-red color after opening the vacuum bag. In the present study, vacuum-packaged pork chops were stored for up to 28 d under refrigeration. The effects of pH, muscle, and storage time on the ability of vacuum-packaged pork to bloom were evaluated.

Materials and Methods

Experimental Design

Pigs were slaughtered in the Univ. of Illinois Meat Science abattoir. A total of 18 carcasses were selected 24 h postmortem. pH was determined before choosing a carcass for use in the experiment. Very high ultimate pH was "created" by pre-slaughter epinephrine injection (McCaw and others 1997). After carcass selection, Longissimus lumborum et thoracis (LT), gluteus medius (GM), and semimembranosus (SM) muscles were excised and individual muscle pH was determined. Muscles were sliced (1 cm thick) and vacuum-packaged individually, then stored at 4 °C for up to 28 d. With the exception of the 0 d samples (original bloom), all samples to be stored were allowed to bloom prior to vacuum packaging. Samples were removed from storage at d 0, 7, 14, 21, and

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28 to evaluate bloom.

Muscle pH ranged from 5.2 to 6.8. Based on muscle pH, samples were separated into 3 groups for statistical analysis purposes. Those samples with pH from 5.2 to 5.5 were classified as the low pH group (LT = 5.4 ± 0.1, GM = 5.4 ± 0.1; SM = 5.4 ± 0.1); those with pH from 5.6 to 6.0 as the medium pH group (LT = 5.8 ± 0.2, GM = 5.8 ± 0.0; SM = 5.8 ± 0.2); and those with pH over 6.0 as the high pH group (LT = 6.5 ± 0.2, GM = 6.3 ± 0.2; SM = 6.3 ± 0.2). These pH ranges correspond to the commonly used pH ranges for the PSE, normal, and DFD classifications (Van der Wal and others 1988). Each muscle x pH group had 3 to 8 replicates; low: LT = 7, GM = 6, SM = 8; medium: LT = 7, GM = 6, SM = 3; high: LT = 4, GM = 6, SM = 7.

pH Determination

The pH of carcasses was determined 24-h postmortem using a SSK pH-Star probe (SSK Technology Co., Cedar Rapids, Iowa, U.S.A.). A 1.3 cm slice was removed from the center of each muscle perpendicular to the muscle fibers and a 5 g sample from the slice was homogenized (Brinkman Polytron) in deionized water (25 ml). pH was determined using an Orion pH meter (Model 720A, Boston, Mass. U.S.A.) standardized at pH 4, 7, and 10.

Color Measurement

Immediately upon cutting the fresh slice for d 0 samples or immediately upon opening the vacuum bag for d 7, 14, 21, and 28 samples, instrumental measures were determined at 0, 5, 10, 20, and 30 min. All color measures at 0 min bloom time are referred to as unbloomed color; stored samples had been allowed to bloom before packaging. The 30 min bloom time was selected based on instrumental color parameter stabilization in a previous study in our lab (Brewer and others 2001). Muscles were allowed to bloom at 4 °C with no surface covering. Spectral reflectance was determined every 10 nm over the 400 to 700 nm range using a HunterLab MiniScan Spectrocolorimeter (model 300; Hunter Assoc., Reston, Va., U.S.A.) using a 2.5 cm port with glass cover calibrated against black and white tiles. CIE L*, a*, and b* values, hue angle (arc tan b*/a*) and chroma ($[a^{*2} + b^{*2}]^{1/2}$) were calculated based on illuminant D_{65} and the 10^0 standard observer (CIE 1978). The percent color change after the 30 min blooming period was calculated using the following equations:

$$\text{Color increment (\%)} = \frac{\text{Color attribute at 30 min} - \text{Color attribute at 0 min}}{\text{Color attribute at 0 min}} \times 100 \quad (1)$$

$$\text{Color decrement (\%)} = \frac{\text{Color attribute at 0 min} - \text{Color attribute at 30 min}}{\text{Color attribute at 0 min}} \times 100 \quad (2)$$

Statistical Analysis

A 3 (pH level) × 3 (muscle) × 5 (storage time) × 5 (bloom time) factorial design was used to evaluate main effects and interactions on pork color using the General Linear Model (SAS 1993). The main effects and interactions for color change (increment or decrement) and color characteristics at 0 min bloom time were analyzed statistically as a 3 (pH level) by 3 (muscle) by 5 (storage time) factorial design. In both analyses, Least Square Means were separated using probabilities of difference. Differences were considered significant at $p < 0.05$.

Table 1—Bloom time effects on pork color characteristics[1]

Bloom time (min)	Color characteristics				
	L*	a*	b*	Hue angle	Chroma
0	48.4[a]	8.4[a]	14.3[a]	59.5[a]	16.7[a]
5	48.5[a]	10.2[b]	15.6[b]	57.0[b]	18.7[b]
10	48.4[a]	10.9[c]	16.2[c]	56.2[c]	19.6[c]
20	48.6[a]	11.5[d]	16.7[d]	55.6[c]	20.4[d]
30	48.5[a]	11.8[e]	17.2[e]	55.6[c]	21.0[e]
SEM[2]	0.5	0.1	0.1	0.3	0.1

[1]Pooled over muscle, pH group, and storage time
[2]SEM: Standard Error of the LSMean
[a-e]Means in a column with a common superscript letter do not differ ($p > 0.05$).

Results and Discussion

No significant 4-way (muscle × pH × storage time × bloom time) interactions occurred for any of the color characteristics evaluated. Therefore only 3-way and 2-way interactions, and main effects are presented.

Brewer and others (2001) reported that individual color measures (a*, b*, hue angle, and chroma) changed at different rates during blooming, and that each required a different period of time to stabilize. They reported that a minimum of 5 min bloom time was required for hue angle, 10 min was required for a* and b* values, and 20 min was required for chroma to stabilize. For these reasons, in the present study, muscles were allowed to bloom for 30 min.

In the present study, with the exception of L* value and hue angle, instrumental color measures (a*, b*, and chroma) continued to change during the entire 30 min (Table 1). This indicated that the bloom may not have been complete within the 30 min. However, the majority of the color changes during the entire 30 min occurred within the first 20 min. Brewer and others (2001) also reported insignificant changes in L* value of pork muscle during blooming. Based on the current results and those of Brewer and others (2001), L* value is not a good indicator for investigating muscle blooming ability. In the present study, a* and b* values increased continuously for 30 min. However, hue angle decreased only during the first 10 min. Because hue angle is based on polar coordinates, even though the individual a* and b* values may continue to change, hue angle may stabilize if a* and b* values are changing in a proportional way. This indicates that the color (hue) is remaining constant relative to the true red axis (a* = 0) even though the chroma (saturation) may be different.

Since the sensitivity of instrumental methods to color differences is not the same as that of visual perception, small color differences detected instrumentally may not be detected visually. Zhu and Brewer (1999) reported that in order for consumers to perceive a significant difference in meat redness under halogen light, a minimum a* value change of 0.6 (over the 15 to 28 range) and a minimum hue angle change of 0.9 degrees (over the 34 to 55 range) were required when instrumentally measured using Illuminant A. This suggested that while some instrumental color measures in the present study did not stabilize during the 30 min bloom time, only changes which occurred within 20 min would likely be visually perceptible.

Effects of Muscle, pH, Storage Time, and Bloom Time on Unbloomed Pork Color

Effects of pH, muscle, and storage time on color characteristics of unbloomed samples (0 min) were evaluated.

Table 2—Probabilities of main effects and interactions for color characteristics of vacuum packaged pork prior to blooming (0 min bloom time)

	L*	a*	b*	Hue angle	Chroma
pH[1]	0.00	0.00	0.00	0.01	0.15
Day[2]	0.17	0.00	0.00	0.99	0.00
Muscle[3]	0.00	0.00	0.17	0.00	0.00
pH*Day	0.44	0.41	0.09	0.92	0.02
pH*Muscle	0.23	0.06	0.93	0.28	0.09
Day*Muscle	0.96	0.96	0.72	0.93	0.95
pH*Day*Muscle	1.00	0.98	0.63	0.22	0.57

[1]pH: Low = 5.2 – 5.5; Medium = 5.6 – 6.0; and High = 6.1-6.8
[2]Day: 0, 7, 14, 21, and 28 d
[3]Muscle: LT = Longissimus lumborum et thoracis; GM = gluteus medius; SM = semimembranosus

Table 3—pH effects on L*, a*, and b* values, and hue angle prior to blooming (0 min bloom time)[1]

	Color characteristics			
pH	L*	a*	b*	Hue angle
5.2-5.5	56.1^a	7.4^a	14.9^a	63.6^a
5.6-6.0	46.8^b	8.4^b	14.0^b	59.2^b
6.1-6.8	42.5^c	9.5^c	13.9^b	55.8^c
SEM[2]	0.6	0.2	0.1	0.6

[1]Pooled over storage time and muscle.
[2]SEM: Standard Error LSMean
[a-c]Means in a column with a common superscript letter do not differ ($p > 0.05$).

Table 4—Muscle effects on L*, a*, and b* values, hue angle and chroma prior to blooming (0 min bloom time)[1]

	Color characteristics				
Muscle[2]	L*	a*	b*	Hue angle	Chroma
LT	51.5^a	7.1^a	14.2^a	63.4^a	15.9^a
GM	48.4^b	8.8^b	14.4^a	58.6^b	16.9^b
SM	47.3^b	9.2^b	14.5^a	57.6^b	17.2^b
SEM[3]	0.5	0.2	0.1	0.5	0.1

[1]Pooled over pH and storage.
[2]Muscle: LT = Longissimus lumborum et thoracis; GM = gluteus medius; SM = semimembranosus
[3]SEM: Standard Error of the LSMean.
[a-c]Means in a column with a common superscript letter do not differ ($p > 0.05$).

Table 5—Storage time effects on L*, a*, and b* values and hue angle prior to blooming (0 min bloom time)[1]

Storage time	Color characteristics			
(d)	L*	a*	b*	Hue angle
0	47.7^a	7.8^a	13.4^a	60.0^a
7	48.6^a	8.4^b	14.4^b	59.8^a
14	49.4^a	8.5^b	14.5^{bc}	59.9^a
21	49.6^a	8.5^b	14.6^{bc}	59.8^a
28	49.8^a	8.7^b	14.8^c	59.7^a
SEM[2]	0.7	0.2	0.2	0.7

[1]Pooled over muscle and storage.
[2]SEM: Standard Error of the LSMean
[a-c]Means in a column with a common superscript letter do not differ ($p > 0.05$).

These color attributes are the original values prior to blooming, both before and after storage, and reflect differences in inherent muscle characteristics such as pH, pigment concentration, and muscle fiber type. The probabilities of main effects and their interactions are shown in Table 2. pH had significant effects on all color characteristics except chroma. Storage time affected a* and b* values (but not L* value or hue angle) of unbloomed meat. A significant storage time by pH interaction occurred for chroma. All color characteristics, except b* values, were influenced by muscle.

Prior to blooming, higher pH samples had lower L* and b* values, and hue angles, and higher a* values, than did lower pH samples (Table 3), indicating that higher pH muscle was darker and more true red, and that muscles with different pH start the blooming process from a different color baseline. Among the 3 muscles, LT had a higher L* value and hue angle, and a lower a* value and chroma than did GM and SM indicating that it was lighter and less true red and had less saturated color than GM and SM (Table 4).

The effects of storage time on color characteristics of unbloomed samples are shown in Table 5. L* value and hue angle did not change during storage, a* value increased after 7 d; further changes in a* value were not significant. The b* value also increased during storage. These changes in color characteristics indicated that all muscles became redder and more yellow during storage. The lack of change in hue angle and L* value during storage indicated that departure from the true red axis, in degrees, and the lightness were essentially constant at the start of the bloom time (0 min) regardless of when (0, 7, 14, 21, or 28 d) the blooming was initiated.

The pH and storage time interaction was significant for chroma of unbloomed samples (Table 2). Chroma generally increased during storage (Table 6) indicating that the color had a higher saturation index. However, the changes differed among different pH groups. The chroma of unbloomed samples with low pH values did not change (from 0 d) until 21 d of storage, however, those of the medium and high pH samples increased by d 7. Further increases were not significant. Chroma is the combined effects of a* and b* values which gives an indication of color saturation (Little 1976) and in different muscles, it is related primarily to myoglobin concentration. However, several studies have shown that chroma correlates poorly with visual pinkness or redness of pork (Joo and others 1995; Zhu and Brewer 1999).

Effects of Muscle, pH, and Storage Time on Color Changes During Blooming

Color changes during the blooming period were evaluated as the difference between the unbloomed sample and the bloomed sample (0 min and 30 min). The percent change, expressed as either increment or decrement, uses the sample's unbloomed color (at that storage time) as the starting point. The probabilities of main effects and interactions for color characteristics changes during the 30 min blooming period are shown in Table 7. L* value did not change during blooming (Table 1). Increments in a* and b* values and chroma after 30 min were affected by all factors. A significant pH by storage time interaction occurred for a* value and hue angle changes. Hue angle decrement was also influenced by muscle.

Significant a* value increments and hue angle decrements occurred during blooming of all muscles. The a* value increments between 0 and 30 min were 47%, 41%, and 40% for LT, GM, and SM, respectively (data not shown in tabular form). In addition, most of the a* value increments occurred within the first 5 min of the blooming period. Among the 3 muscles, LT had the greatest hue angle decrement (8%) and SM muscle had the least (5%) indicating that by moving closer to the

Table6—pH and storage time effects on chroma prior to blooming (0 min bloom time)[1]

Storage time (d)	pH Level		
	5.2 t– 5.5	5.6 – 6.0	6.1 – 6.8
0	16.2[b]	15.0[a]	15.3[a]
7	16.7[bcd]	16.5[bcd]	17.1[cde]
14	16.5[bc]	17.0[cde]	17.5[e]
21	16.7[bcd]	16.7[bcde]	17.3[de]
28	17.3[de]	17.1[cde]	17.3[de]
SEM[2]	0.33	0.33	0.33

[1]Pooled over muscle.
[2]SEM: Standard Error of the LSMean.
[a-e]Means in a column with a common superscript letter do not differ ($p > 0.05$).

Table 7—Probabilities of main effects and interactions for color characteristic changes during 30 min blooming (0 to 30 min changes)

	a*	b*	Hue angle	Chroma
pH[1]	0.00	0.00	0.05	0.00
Day[2]	0.00	0.00	0.32	0.00
pH*Day	0.01	0.38	0.02	0.13
Muscle[3]	0.03	0.00	0.00	0.01
pH*Muscle	0.53	0.86	0.95	0.85
Day*Muscle	0.88	0.76	0.68	0.84
pH*Day*Muscle	0.85	0.47	0.45	0.62

[1]pH: Low = 5.2 to 5.5; Medium = 5.6 to 6.0; and High = 6.1 to 6.8
[2]Day: 0, 7, 14, 21, and 28 d
[3]Muscle: LT = Longissimus lumborum et thoracis; GM = gluteus medius; SM = semimembranosus

true red axis of the color space, LT muscle blooms to the greatest degree while SM muscle blooms to the least degree. However, the range of difference from baseline values was < 3%. The difference in blooming ability among the 3 muscles probably results from their different oxidative potentials. Bendall and Taylor (1972) found differences in OCR among different beef muscles and attributed these differences to mitochondrial density, enzyme activity, and NAD content of the muscles. Both Lanari and Cassens (1991) and Renerre and Labas (1987) found higher mitochondrial content in GM muscle than in LT muscle. Muscles with an elevated mitochondrial content will be highly oxidative, therefore, a high OCR is anticipated (Renerre and Labas 1987), which has been confirmed by the finding that GM muscle has a higher OCR than LT muscle (Lanari and Cassens 1991). Difference in oxygen penetration has also been shown among different muscles (MacDougall and Taylor 1975).

A significant pH by storage time interaction occurred for a* value increments and hue angle decrements (Table 7). a* value increment during the 30 min blooming period increased during storage for all samples (Figure 1). However, the increments occurred at different rates and to different extents for samples in different pH groups. In general, a* value increments of freshly cut samples were smaller than those of stored samples. At low pH, the a* value increment during blooming increased after 7 d (from 37% at d 0 to 60%); at medium pH, after 14 d (from 34% at d 0 to 45%); and at high pH level, after 21 d (from 31% at d 0 to 39%). The a* value increment of low pH samples decreased from 60% at d 21 to 47% at d 28. However, this drop did not occur for either medium or high pH samples. The lower the pH of a sample, the greater the a* value increment during blooming and the earlier in the storage period that change occurred.

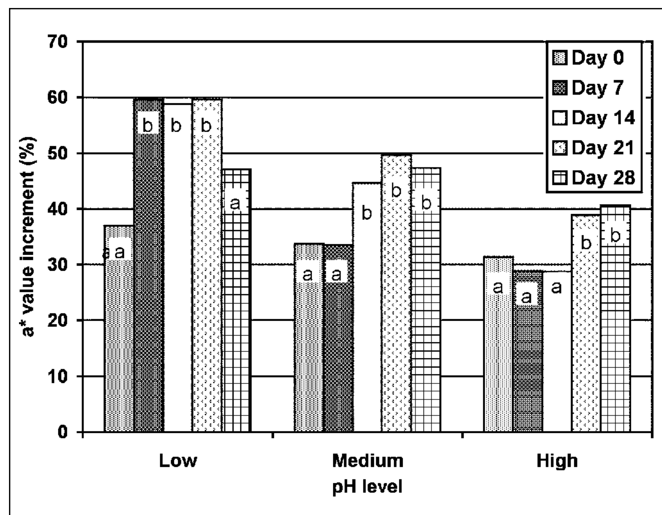

Figure 1—Effects of pH and storage time on a* value increment during 30 min blooming period. Means in each pH category with a common superscript letter do not differ (p > 0.05).

The effects of pH and storage time on hue angle decrements during the 30 min blooming period are shown in Figure 2. It is apparent that the overall hue angle decrements for low pH samples were greater than for either medium or high pH samples. Lower pH resulted in large hue angle decrements during blooming. In addition, the hue angle decrements changed during storage in different ways among different pH groups. At low pH, the hue angle decrement doubled after 7 d (from 4% to 9%), remained constant until 21 d, then dropped to the same level as that of freshly cut samples; at medium pH, the change in hue angle decrement occurred after 21 d; at high pH, the hue angle decrement was constant for all storage times. Overall, the hue angle decrement during storage was greater and occurred earlier for low pH samples than for high pH samples. Together these findings indicate that during a 30 min blooming period, the increase in redness of pork occurred at a faster rate and to a greater extent for low pH samples than for high pH samples. Low pH samples had a greater ability to bloom than high pH samples, and refrigerated storage enhanced the blooming ability.

During blooming, the increments in b* value and chroma were influenced by pH, muscle, and storage time (Table 7). Low pH samples had the greatest ($p < 0.05$) b* value increment (approximately 23%), whereas high pH samples had the smallest (almost 18%, Table 8). The chroma increment differences among the 3 pH groups followed the same trend. Muscle also affected b* value and chroma increments during 30 min blooming. LT had the smallest b* value increment (almost 18%), and SM had the largest (almost 24%). Both b* value and chroma increments increased during storage (Table 9). The increments in the first 7 d were not significant. However, both b* value and chroma increments increased from d 7 to d 21 with no additional changes thereafter.

Since the blooming of muscle tissue is primarily due to the oxygenation of deoxymyoglobin, which depends on the depth and the speed of oxygen penetration, competition between oxygen diffusion into and oxygen consumption by the muscle tissue becomes critical (O'Keefe and Hood 1982). In

Table 8—Effects of pH and muscle on percent b* value and chroma increments during blooming (0 to 30 min) [1]

Color	pH				Muscle[2]			
	5.2-5.5	5.6-6.0	6.1-6.8	SEM[3]	LT	GM	SM	SEM[3]
b*	23.3[a]	20.5[b]	18.1[c]	1.0	17.7[a]	20.7[b]	23.5[c]	0.9
chroma	28.8[a]	25.7[b]	22.8[c]	1.1	23.5[a]	25.9[ab]	27.8[b]	1.0

[1]Expressed as a percentage of b* value and chroma prior to blooming (0 min bloom time)
[2]Muscle: LT = Longissimus lumborum et thoracis; GM = gluteus medius; SM = semimembranosus
[3]SEM: Standard Error of the LS Mean
[a-c]Means in a row (within pH or muscle group) with a common superscript letter do not differ ($p > 0.05$).

Table 9—Effects of storage time on percent b* value and chroma increments during blooming (0 to 30 min)[1]

Color	Storage time (d)					
	0	7	14	21	28	SEM[2]
b*	16.3[a]	17.8[ab]	20.7[b]	23.9[c]	24.5[c]	1.2
Chroma	20.5[a]	22.9[ab]	25.8[b]	29.9[c]	29.5[c]	1.3

[1]Expressed as a percentage of b* value and chroma prior to blooming (0 min bloom time).
[2]SEM: Standard Error of the LSMean.
[a-c]Means in a row with a common superscript letter do not differ ($p > 0.05$).

the present study, the activities of oxygen-utilizing enzymes likely contributed to differences in blooming ability since all samples were stored at the same temperature and oxygen partial pressure.

Low oxygen consumption rate (OCR) by oxygen-utilizing enzymes such as cytochrome oxidase and succinic oxidase usually results in more oxygen penetration into muscle allowing formation of a thicker layer of oxymyoglobin than does high OCR (O'Keefe and Hood 1982; Renerre and Labas 1987; Millar and others 1994). Effects of pH on OCR have been reported. Zhu and Brewer (1998a) found that lower pH pork muscle tissue had much lower OCRs than did higher pH tissue. The OCR of beef muscle has been shown to increase with increasing muscle pH (Ledward 1985) and decrease with decreasing pH (O'Keefe and Hood 1982). The depressed OCR in low pH samples has been recognized as the consequence of discouraged activities of oxidative enzymes and mitochondria under low pH conditions (Ledward 1992). Therefore, more efficient blooming is anticipated when muscle pH is low (Ledward 1992). DFD beef muscle, which is characterized by a high pH, will not bloom when exposed to air due to its high mitochondrial respiration rate (Egbert and Cornforth 1986). Low pH appears to enhance muscle bloom, which was evidenced in our study. The a* and b* values, and chroma increments, and the hue angle decrement after 30 min of bloom time increased as the sample pH decreased indicating that larger color changes and more rapid blooming occurred in low pH samples than in high pH samples (Table 8, Figures 2 and 3. However, low pH has been shown to be the primary reason of poor meat color stability. These finding are in agreement with those reported by Gasperlin and others (2000) for beef muscle.

The effects of storage time on color changes indicated a trend: stored muscles experienced greater blooming ability than did freshly cut samples. The increase in color change with increasing storage time was more obvious and occurred earlier in the storage period when pH was low. Similar findings have been reported by O'Keefe and Hood (1982). Ledward (1992) attributed the difference in blooming ability between freshly cut and stored meat to some loss of activity of the oxygen-utilizing enzymes, which has been confirmed by the finding that OCR of pork *Longissimus* declined exponentially during storage at 4 °C (Zhu and Brewer 1998a). Low pH has been shown to be the main factor in the postmortem loss of mitochondrial structural integrity and functionality (Ashmore and others 1972; Cheah and Cheah 1974; Giddings 1974).

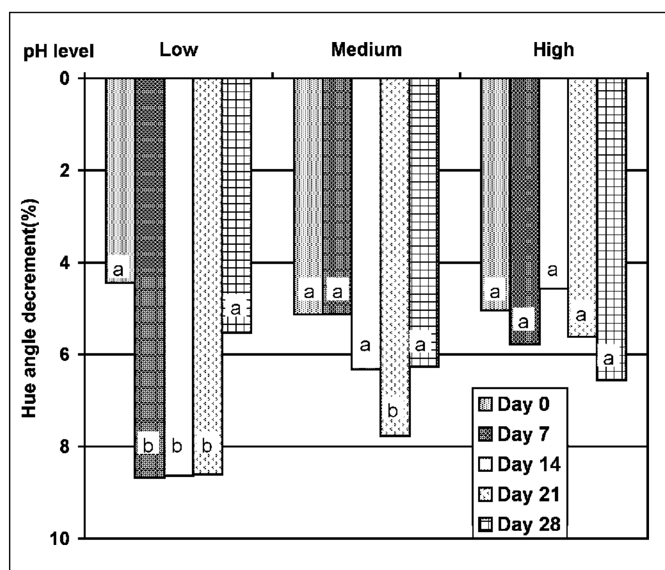

Figure 2—Effects of pH and storage time on hue angle decrement during 30 min blooming period. Means in each pH category with a common superscript letter do not differ (*p* > 0.05).

Conclusions

PORK COLOR CHANGED SIGNIFICANTLY AS VACUUM PACKAGED, refrigerated meat was allowed to bloom after varying storage periods. L* value was not a good indicator to evaluate color change during blooming. The a* and b* values, and chroma increments, and the hue angle decrement indicated that pork became more red and yellow during blooming. pH, muscle, and storage time affected the rate and extent of pork color changes during the blooming. Longer times in refrigerated storage and lower pH resulted in more rapid blooming in terms of instrumental color characteristic changes. Some instrumental color measures may not stabilize in 30 min. However, the majority of the changes during the 30 min bloom period occurred within 20 min. Gains in blooming ability of low pH compared to high pH pork must be weighed against color instability during retail display.

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