Title: Infrared Thermography of Market Hogs as a Predictor of Pork Quality - **NPB #02-025**

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Abstract: Infrared thermography (IRT) was used as a non-invasive, rapid method of detecting pigs with surface temperatures warmer and/or cooler than normal, to predict pork quality. We used four replications consisting of a total of 556 pigs (154, 98, 145, 158, respectively) were conducted in ambient temperatures ranging from -2 to 26˚C (9 to 14, 21 to 26, -2 to 1, 6 to 9, respectively). Hot pigs (higher than 1.3 sd from the mean) in replications 1 and 4 had a higher percentage of "high expressible moisture pigs" (EM>170 mg/g) than normal pigs (44 vs. 31% and 36 vs. 12%, respectively). Cold pigs (lower than 1.3 SD from the mean) in replication 2 (pigs were misted with water) had a higher percentage of "high expressible moisture" pigs (EM>170mg/g) than normal pigs (44 vs. 22%). However in replication three where environmental temperatures were the coldest, no differences in the percentage of high expressible moisture pigs were detected. Infrared thermography detected pigs more susceptible of producing poor meat quality, but the effectiveness of infrared thermography was dependent on environmental conditions, which may trigger physiological changes in the flow of blood to the skin's surface.

Introduction: Unrealized revenue due to the PSE condition exceeds $275 million annually for the U.S. pork industry. Currently, rapid methods for identifying individual or groups of pigs likely to produce in PSE meat are not in commercial use. If a method was utilized prior to slaughter that was practical and accurate, intervention strategies could be put in place to reduce the risk or prevalence of PSE carcasses. Antemortem use of infrared thermography may offer the potential to identify pigs that have warmer and cooler temperatures than normal and which have an increased risk of poor meat quality. Once identified, these pigs could be segregated and management decisions made to help optimize their pork quality.

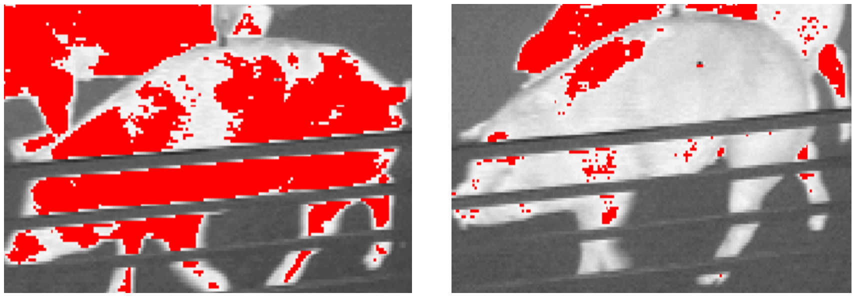
Thermography is a technology that uses a thermal imaging radiometer or a camera to collect infrared radiation emitted from the animal's surface to develop a quantitative representation of temperature patterns of the animal. Invisible energy patterns are turned into a visible picture. Infrared energy emitted from any object above absolute zero (-273.16 ˚C), such as an animal's body, passes as photons through the atmosphere, which can be quantified when they strike the surface of the camera. On the detectors surface, electrons are displaced and the resultant current flow is measured to determine the amount of radiant energy emitted from the target object. The emitted infrared energy is an exponential function of its temperature. The camera then converts the captured energy data into temperature data without the aid of external computers and over distances of a few centimeters to several hundred meters which causes no or minimal disturbances of the animal. The camera can display acquired temperature profiles on a monitor in varying intensities of black to white or in color. These images can be used to classify animals into high, normal, or low energy emitters.

Objectives of Research Proposal: The long-range goal of this research was to develop predictive IRT imaging systems that will enable processors to predict pork quality ante-mortem. The objective of this project was to determine the relationship of pre-slaughter IRT measurements of the surface temperatures of hogs taken across a range of environmental temperatures to ultimate muscle quality. The central hypothesis of the project was that IRT measurements of surface temperature would be related to measures of muscle quality; high surface temperatures might be related to the prevalence of PSE carcasses. Upon completion of this research, IRT surface temperature ranges may be developed to predict the incidence of PSE meat of individual or group of pigs.

Materials and Methods: Skin temperatures for all replications were collected using a short-wave infrared radiometer (PM280 Thermacam, Inframetrics, N. Baillerica, MA) prior to slaughter at a commercial plant. Mean surface temperature for each pig was calculated in the loin and side region from the shoulder to the hip.

Replication I and III: Baseline values for infrared thermography were taken the day prior to classification on 163 and 150 pigs for replications 1 and 3, respectively. Means and standard deviations of each group of pigs were determined at their respective ambient temperatures (9 to14˚C and -1 to 2˚C, respectively). Baseline data were used the following day to categorize 154 and 145 pigs in replication 1 and 3, respectively. Pigs were classified (from baseline data) as "hot" (pigs with thermal images indicating skin temperatures higher than 1.3 standard deviations from the mean) or "normal" (pigs whose skin temperature was within 1.3 standard deviations from the mean). To aid in classification, a saturation palette within the infrared camera was set where pixels greater than the minimum preset temperature (the lowest allowable maximum temperature) would appear red, and those pixels within the temperature range set would be in a gray scale in the camera. Pigs were classified subjectively by their color in the camera. Pigs that appeared primarily red (Figure 1, left) were classified as "hot" and pigs that appeared primarily gray (Figure 1, right) were classified as "normal". Those animals that were equally red and gray were not selected for the trial. However, using the saturation palette limited the software used in data analysis to the range of set temperatures. Therefore, it was not possible to obtain the actual skin temperatures of individual pigs in replications 1 and 3.

Figure 1. Infrared images of a hot (left) and normal (right) pig.



Replications II and IV: In replications 2 and 4, randomly selected pigs (99 and 158, respectively) were scanned using IRT and individual skin temperatures (ST) recorded, which contrasts with replications 1 and 3 where individual temperatures of pigs were not determined. Pigs were later classified as "hot" (ST > 1.3 SD above the mean), "normal" (ST within 1.3 SD of the mean) and "cold" (ST> 1.3 SD below the mean).

All Replications: Ambient temperatures were obtained from the local weather station. Barn temperatures and relative humidity were recorded using a HOBO temperature relative humidity reader. Pigs were lairaged for 2 to 4 h (after scanning), then slaughtered at a commercial plant. At 45 min postmortem, 10^{th}-rib longissimus muscle pH and temperature were taken on random carcasses using the Star pH probe (Model 6.05, SFK Technology Inc., Peosta, IA) and a hand-held thermocouple thermometer (450 ATT Type T, Omega Engineering Inc., Stamford, CT) attached to a rapid response probe thermocouple (Type T, Omega Engineering Inc., Stamford, CT). At 24 h postmortem and after a 30 min bloom at 3˚C, boneless loins from all carcasses were cut in half and the longissimus muscle of sirloin, center, and blade faces were evaluated for instrumental color (L*, a*, b*, 10^{o} observer, Illuminant D65; HunterLab Miniscan^{TM} XE Plus, Hunter and Associates, Reston, VA). Ultimate pH was measured at the center-loin face using the Star Probe pH meter. A 2-in thick chop was taken posterior to the center-loin face and vacuum packaged for determination of expressible moisture using a modified method of Herring et al. (1971) at 3 d postmortem. Transmission values (solubility of water-soluble proteins) were determined on d 3 and 4 postmortem using the method of Hart (1962) as described in Sammel (2000).

For replications 1 and 3, baseline data were analyzed as a one-way treatment structure in an unbalanced, completely-randomized design. Individual pigs were the experimental unit. Correlations for replications 2 and 4 were calculated using PROC CORR to determine relationships of meat quality traits with skin temperature.

Results:

Environmental Effects

The environmental temperatures for all replications ranged from -2 to 26°C (Table 1). The ambient temperature ranged from 11 to 26°C within the receiving barn housing the pigs before harvest. Skin temperatures tended to increase as ambient temperatures increased, with the exception of replication 2, where misting of pigs with water occurred. Pigs in Rep 3 and 4 at lower ambient temperatures had significantly higher 45 min and 24 h pH values and less denatured sarcoplasmic proteins (lower transmission values) compared to pigs in reps 1 and 2 at higher ambient temperatures.

Replication I

Pigs had surface skin temperatures (Table 1) that ranged from 18.3 to 33.4°C with a mean of 26.3°C at ambient temperatures ranging from 11 to16°C. The minimum and maximum temperatures of 23.2°C and 29.5°C, respectively, for the saturation palette, were set at 1.3 standard deviations from the mean of the 163 pigs viewed using the IRT camera the previous day. Significant differences were detected between hot and normal pigs from trial 1 (Table 2). Hot pigs had higher ($P \leq 0.05$) expressible moisture values and displayed more variability in their 24 h pH and expressible moisture measurements than normal pigs that had more variability in transmission values (Table 2). Very little PSE was observed in any pigs in this replication, which agrees with the lack of significant differences in L*, a*, b*, hue angle and chroma for the longissimus muscle. However, hot pigs had a 3.8 times (19 to 5 pigs) greater incidence of a high level of expressible moisture and twice (16 to 8 pigs) the incidence of a low level of expressible moisture when compared to their contemporary normal pigs (Table 4).

Replication III

Ambient temperatures ranged from -2 to 1°C for the coldest environmental temperature. The mean skin temperature was 18.0°C with a standard deviation of 1.0. Saturation palette minimum and maximum values were set at 15.1°C and 20.1°C, respectively, from the 150 pigs scanned the previous day. Chops from hot pigs had higher transmission values (more denatured protein) and contained more variability in their pH24 and a*, b* and hue values in the center loin eye (Table 3) than pigs in the normal group. In contrast with replication 1, where hot pigs had more variation in quality traits, hot and normal pigs in replication 3 had equal numbers of pigs with a low and high level of expressible moisture values (Table 4).

Replications II and IV

In these replications, individual skin temperatures were determined and correlated with muscle quality indicators. The highest correlated factor with skin temperature was expressible moisture (0.25) for replication 2 (Table 5). Cold pigs (ST> 1.3 SD below the mean) had a higher percentage of pigs with high expressible moisture (Table 6) and higher mean expressible moisture value compared to hot and normal pigs (table 7). In general, skin temperatures of pigs in replication 2 had low correlations with quality. In replication 4, 45 min pH was most correlated with skin temperature (0.23). In contrast to replication 2, hot pigs had a higher percentage of pigs with a high level of expressible (Table 6) moisture and a higher mean expressible moisture ($p<.05$)(Table 7).

Discussion:

Influence of Environmental Factors on Skin Temperature

Infrared thermography is a non-invasive way to quickly determine pig skin temperatures, which may be used to predict pork muscle quality. Environment factors such as ambient temperature, wind speed, relative humidity, physical activity and the amount of moisture on the skin temperature effect skin temperatures in pigs and likely influence the effectiveness of IRT to predict muscle quality but these relationship have not been documented. When exposed to ambient temperatures above and below their thermal neutral zone, pigs adjust peripheral blood flow to maintain a constant core body temperature. The magnitude of vasodilatation increases as ambient temperature increases (Ingram and Legge, 1971). The physiological response of pigs to their environment may also impact infrared thermograph's ability to predict pork quality.

Loughmiller et al. (2001) found a linear relationship [y(mean skin temperature)= 0.40x + 24.82] between ambient temperature and skin temperature within ambient temperatures ranging from 10 to 32˚C. Conversely, at a temperature below the thermal neutral zone, pigs will experience vasoconstriction, which should help conserve body heat. This change could impact IRT images by making stressed and “normal” pigs have similar skin temperatures even though their internal biochemistry may be different. Stress also plays a role in the control of peripheral blood flow. Cathecholamines, primarily norepinephrine, are released during times of stress increasing blood flow to muscles and the brain while reducing peripheral blood flow (Topel, 1972). However, as an animal utilizes glycogen, excess heat that is produced is dissipated through increased blood flow to the skin (Ingram, 1965).

Limited research has been conducted relating IRT to PSE, but it suggests that stressed pigs may have surface-skin temperatures warmer or cooler than normal pigs. Schaefer et al. (1989), using IRT, found halothane positive pigs had a high negative correlation between expressible juice (-0.87) and percent drip loss (-0.75) with mean live skin temperature. Contradictory data from Gairiepy et al. (1989) and Lawrence et al. (2001) found the percentage of normal carcasses decreased and the percent of PSE carcasses increased as surface skin temperatures increased.

In replications 1 and 4 of our study, where ambient and barn temperatures were within the thermal neutral zone of pigs (10 to 32°C), pigs had a mean skin temperature of 26.3°C and 29.0˚C respectively. In replication 2, where ambient temperatures were the highest (21 to 26°C), skin temperatures would be expected to be the highest. However, the mean skin temperature was 22.3°C (range of 19.3 to 25.9°C) due to the presence of moisture on the skin and evaporative cooling resulting from the spraying of pigs with water on the truck to reduce heat stress. The mean skin temperature of 18.0°C in replication 4 was the lowest of the four replications due to the low ambient temperature (-1 to 2˚C). Thus, environmental conditions such as temperatures below thermal neutrality and moisture on the skin may reduce the ability of IRT to detect temperature changes due to stress.

Using IRT to predict pork quality

Replication 1

The environmental conditions of replication 1 elevated the skin temperature of some of the pigs and the effectiveness of IRT to predict muscle quality. Hot pigs (ST> 29.5˚C) had a higher incidence (44 vs. 31%) of high and low expressible moisture compared to normal pigs (ST≤ 29.5˚C), which agrees with the findings of Gairepy et al. (1989) who found pigs with skin temperatures above 32.2°C had 71% meat quality defects compared to 50% quality defects in pigs with skin temperatures of 21 to 32.2°C. No significant differences occurred in instrumental color (and little PSE meat), which contrasts with findings of Lawrence et al. (2001), who reported hot pigs had lower a* and chroma values and higher hue angles, all indicative of paler muscle color.

Replication 2

Skin temperatures from pigs sprayed with water (replication 2) had low correlations with meat quality measurements. Misting animals with water at temperatures below ambient temperatures decreased skin temperatures due to evaporative cooling (Panagakis et al., 1996). Cold pigs in our experiment were more susceptible of producing poor meat quality, which agrees with the findings of Schaefer et al. (1987). Therefore, misting made it more difficult to separate animals based on skin temperatures. It appeared that some of the colder pigs had lower quality, which contrasts with replication 1. If we know about relationships in “stressed” pigs, skin temperatures and their internal biochemistry and physiology, these opposite effects may be detected.

R*eplication 3*

In our coldest experiment, hot and cold pigs had no significant differences in meat quality. This result may not be unexpected since the ambient temperatures during this replication were mildly below the thermal neutral zone of pigs, which reduced peripheral blood flow to the skin surface of both groups. The ability of IRT likely will be less accurate in pork quality prediction when pigs are transported and handled using good procedures, whereas more extreme antemortem stresses may have been detectable.

Replication 4

Skin temperatures had low correlations with meat quality measurements. However, hot pigs were found to be more susceptible to producing poor meat quality than normal pigs (36 vs. 12%), which agrees with the results of replication 1.

All Replications

The results of these replications and previous studies indicate that pigs warmer and/or colder than normal, identified by IRT, are more likely to produce poor meat quality. Infrared thermography was able to detect 44 of the 96 pigs, which had high expressible moisture values. However, up to 36% of normal pigs produced high or low expressible moisture and were undetected by IRT. Using infrared thermography to monitor skin temperatures over a period of time may reduce the amount pigs not detected as hot or cold by infrared thermography, compared to measurements taken at a single time, which may not account for stress that occurs before and after skin temperatures were measured. Additionally, environmental conditions that affect peripheral blood flow may reduce the ability of IRT to detect meat quality defects.

Lay Interpretation

Infrared thermography is a non-invasive, rapid technique capable of detecting pigs with warmer and/or cooler skin surface temperatures than normal, which could be related to variation in pork quality. Effectiveness of infrared thermography varied between replications, which also varied in environmental conditions (temperature, etc). Additional work could refine these predictive relationships. Environmental temperatures below the thermal neutral zone of swine and moisture on the skin surface reduced the ability of infrared thermography to detect such animals more likely to have abnormal quality. Until these factors are overcome, they will limit the utility of infrared thermography.

References:

Gariespy C., J. Armoit and S. Nadia. 1989. Ante-mortem detection of PSE and DFD by infrared thermography of pigs before stunning. Meat Sci. 25:37-41.

Ingram, D. L. and Legge K. F.. 1971. The influence of deep body temperatures and skin Temperatures on peripheral blood flow in the pig. J. Physiol. 215:693-707.

Lawrence, T. E., M. F. Spire, M. E. Dikeman, M. C. Hunt, S. B. Hogge, and B. W. James. 2001. Utilizing infrared thermography to predict pork quality.

Loughmiller, J.A., M. F. Spire, S. S. Dritz, B. W. Fenwick, M. H. Hosni and S. B. Hogge. 2001 Relationship between mean body surface temperature measured by infrared thermography and ambient temperature in clinically normal pigs and pigs inoculated with Actinobaillus pleuropneumoniae. Am. J. Vet. Res. 62(5):676-681.

Schaefer, A. L., D. M. Jones, A. C. Murray, A. P. Sather, and A. K. Tong. 1989. Infrared thermography of pigs with known genotypes for stress susceptibility in relation to pork quality. Can. J. Anim. Sci. 69:451-459.

Topel, D. G. 1972. A review of animal physiology and the porcine stress syndrome in relation to meat quality. In: The proceeding of the pork quality symposium 26-91.

Table 1. Variation in Pork Loin Longissimus Muscle Quality from Pigs Imaged by Infrared Thermography and Slaughtered after 2 to 4 h of Lairage.

	Replication			
	1	2	3	4
Ambient temperature, °C	9 to 14	21 to 26	-2 to 1	6 to 9
Barn temperature, °C	11 to 16	22 to 24	25 to 26	14 to 15
Skin temperature range, °C	18.3 to 33.4 **	19.3 to 25.9	15.1 to 20.1 **	20.1 to 34
Skin temperature mean, °C	26.3 **	22.3	18.0 **	29.0
45 min pH	6.0a	6.2b	6.3c	6.3c
45 min Temperature	36.6a	42.6d	38.2b	39.1c
24 h pH	5.6a	5.5a	5.8c	5.6b
Expressible moisture (mg/g)	132.8a	137.1ab	142.6b	132.5a
Transmission value	12.5d	10.3c	8.1a	9.3b
Center Loin				
L*	53.4b	54.0b	53.4b	52.6a
a*	8.1a	8.5b	8.1a	10.5c
b*	13.1b	13.5c	12.8a	26.4d
Hue	58.2a	58.0a	57.7a	68.3b
Chroma	15.4a	16.0b	15.2a	28.4c

** Data are baseline values taken the day prior to selection.
abcd Within a row, means without a common superscript letter differ ($p<.05$).

Table 2. Variation in Pork Loin Longissimus Muscle Quality from Pigs Imaged by Infrared Thermography and Slaughtered after 2 to 4 h of Lairage for Replication 1.

	Mean			Variance		
	Normal	Hot	P-value	Normal	Hot	P-value
Number	74	80		74	80	
24 h pH	5.57	5.59	0.36	0.012b	0.024a	0.004
Expressible moisture (mg/g)	127.2b	137.9a	0.05	641.1b	1,712.9a	<.001
Transmission values	12.9	12.2	0.14	12.2a	7.7b	0.04
Center Loin						
L*	53.6	53.3	0.46	6.1	8.0	0.24
a*	8.1	8.2	0.55	1.2	1.7	0.12
b*	13.1	13.1	0.87	1.0b	1.6a	0.07
Hue	58.4	58.0	0.42	7.5b	11.6a	0.06
Chroma	15.4	15.5	0.85	1.7b	2.5a	0.09

ab Within a row, means without a common superscript letter differ ($p<.05$).

Table 3. Variation in Pork Loin Longissimus Muscle Quality from Pigs Imaged by Infrared Thermography and Slaughtered after 2 to 4 h of Lairage for Replication 3.

	Mean			Variance		
	Normal	Hot	P-value	Normal	Hot	P-value
Number	72	73		72	73	
24 h pH	5.75	5.77	0.36	0.02b	0.03a	0.05
Expressible moisture (mg/g)	141.5	143.7	0.71	111.9	138.9	0.36
Transmission value	7.9b	8.4a	0.03	1.8	1.5	0.54
Center Loin						
L*	53.4	53.4	0.99	5.6b	8.4a	0.08
a*	8.2	8.1	0.98	1.2b	2.0a	0.05
b*	12.9	12.7	0.36	0.9b	1.4a	0.05
Hue	57.8	57.5	0.65	8.9b	15.7a	0.01
Chroma	15.3	15.2	0.58	1.5b	2.3a	0.06

[ab] Within a row, means without a common superscript letter differ (p<.05).

Table 4. Replications 1 and 3:Classification of Pigs into Groups of Low, Medium and High Expressible Moisture within Hot* and Normal Groups.**

	Replication 1		Replication 3	
Expressible moisture	Hot	Normal	Hot	Normal
<102mg/g	16	8	10	10
102-170mg/g	45	61	48	46
>170mg/g	19	5	15	16

* Pigs with a skin temperature higher than 1.3 stand deviations of the mean.

** Pigs with a skin temperature within 1.3 standard deviations of the mean.

Table 5. Replications 2 and 4: Correlations of skin temperature (ST) with muscle quality measurements.

	Replication 2				
	ST	ST^2	Log (ST)	SQRT (ST)	Exp (ST)
pH 45 min	-0.14	**-0.14**	-0.14	-0.14	-0.06
Temperature 45 min	0.13	0.13	0.12	0.12	**0.19**
pH 24h	0.11	0.11	0.11	0.11	**0.12**
Expressible moisture	-0.25	-0.25	**-0.25**	-0.25	-0.20
Transmission Value	-0.098	-0.10	-0.09	-0.10	**-0.13**
Center Loin					
L*	-0.03	-0.03	-0.02	-0.03	**-0.17**
a*	-0.09	-0.09	**-0.10**	-0.09	-0.016
b*	0.02	0.02	**0.02**	0.02	-0.07
Hue	0.11	0.11	**0.18**	0.12	-0.03
Chroma	0.04	-0.04	-0.04	-0.04	**-0.05**
	Replication 4				
	ST	ST^2	Log (ST)	SQRT (ST)	Exp (ST)
pH 45min	0.06	0.07	0.05	0.06	**0.23**
Temperature 45 min	0.17	0.16	**0.17**	0.17	-0.11
pH 24hr	-0.03	-0.04	-0.02	-0.03	**-0.14**
Expressible moisture	0.13	**0.14**	0.13	0.13	0.12
Transmission Value	0.14	0.14	0.13	0.14	**0.19**
Center Loin					
L*	-0.11	-0.10	-0.12	-0.11	**0.12**
a*	-0.02	-0.03	-0.02	0.02	**-0.06**
B*	-0.08	-0.08	**-0.09**	-0.09	0.08
Hue	-0.02	-0.02	-0.03	-0.03	**-0.11**
Chroma	**0.08**	-0.08	-0.08	-0.08	0.06

Within a row, **Bold** indicates highest correlation.

Table 6. Replications 2 and 4:Classification of Pigs into Groups of Low, Medium and High Expressible Moisture within Hot*, Normal, Cold*** Groups.**

	Replication 2			Replication 4		
Expressible Moisture	Hot	Normal	Cold	Hot	Normal	Cold
<102mg/g	1	12			22	2
102-170mg/g	9	50	5	7	97	10
>170mg/g		17	4	4	14	2

* Pigs with a skin temperature higher than 1.3 standard deviations of the mean.
** Pigs with a skin temperature within 1.3 standard deviations of the mean.
***Pigs with a skin temperature lower than 1.3 standard deviations of the mean.

Table 7. Variation in Pork Loin Longissimus Muscle Quality from Pigs Imaged by Infrared Thermography, Classified by Skin Temperature and Slaughtered after 2 to 4 h of Lairage for Replication 2.

	Replication 2		
	Hot	Normal	Cold
Number	10	79	9
24 h pH	5.60a	5.54a	5.48b
Expressible moisture (mg/g)	120.6b	136.0b	168.1a
Transmission values	10.2a	10.4a	10.0a
Center Loin			
L*	52.4b	54.2a	54.3ab
a*	8.4a	8.4a	8.8a
b*	13.1a	13.5a	13.5a
Hue	57.6a	58.3a	57.0a
Chroma	15.6a	15.9a	16.1a

[ab] Within a row, means without a common superscript letter differ (p<.05).
* Pigs with a skin temperature greater than 1.3 standard deviations of the mean.
** Pigs with a skin temperature within 1.3 standard deviations of the mean.
***Pigs with a skin temperature less than 1.3 standard deviations of the mean.

Table 8. Variation in Pork Loin Longissimus Muscle Quality from Pigs Imaged by Infrared Thermography, Classified by Skin Temperature and Slaughtered after 2 to 4 h of Lairage for Replication 4.

	Replication 4		
	Hot	Normal	Cold
Number	11	133	14
24 h pH	5.55a	5.66a	5.62[a]
Expressible moisture (mg/g)	155.3a	130.7b	129.5[b]
Transmission values	9.7a	9.2a	9.5a
Center Loin			
L*	53.4a	52.4a	53.7a
a*	10.3a	10.5a	10.3a
b*	26.7a	26.3a	26.7a
Hue	68.8a	68.2a	68.9a
Chroma	28.6a	28.3a	28.6a

[ab] Within a row, means without a common superscript letter differ (p<.05).
* Pigs with a skin temperature greater than 1.3 standard deviations of the mean.
** Pigs with a skin temperature within 1.3 standard deviations of the mean.
***Pigs with a skin temperature less than 1.3 standard deviations of the mean.