RESEARCH REPORT
ANIMAL SCIENCE

pork checkoff

Title: Stepwise discriminate and latent variable analysis of pre-harvest process factors influence on fresh pork quality – NPB #05-101

Investigator: Eric P. Berg, Ph. D.

Institution: North Dakota State University

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Abstract

Objectives of this study were to determine effects of seasonal environment, top and bottom deck transport, transport duration, and time in lairage on overall pork quality and blood serum concentrations of the stress hormone cortisol of market hogs. Mixed commercial crossbred market hogs (PIC, Franklin, KY) were harvested at dates representing traditional seasonal environments in the Midwestern United States: February 14 and 16, 2006 (n = 599), May 16 and 18, 2006 (n = 660), August 1 and 3, 2006 (n = 649), and October 17 and 19, 2006 (n = 661). Within season, pigs were randomly assigned to one of 8 treatments in a 2 x 2 x 2 factorial arrangement, with two transport durations; short (3 hours) or long (6 hours), two trailer deck locations; top or bottom, and two lairage durations; short (3 hours) or long (6 hours). Environmental conditions (temperature and relative humidity) in the trailer were monitored at one minute intervals using portable data loggers located in the three compartments (front, middle, rear) of both decks. All pigs originated from the same commercial source and identical transport procedure, data collection, and harvest procedure was repeated on Tuesday and Thursdays within the same week within season. Blood was collected from each carcass at exsanguination on the bleed table for analysis of serum cortisol concentration. Fresh pork loin quality parameters were evaluated on boneless pork loins for color (L*, a*, and b*), pH, and drip loss. Loins were classified as pale, soft, and exudative (PSE) if 24h drip loss exceeded 5% and L* was greater than 55. Least-squares means were generated and tested for least significant difference across all main effects and appropriate interactions for fresh pork quality parameters and serum cortisol concentration. Cortisol levels were the greatest during the summer and fall seasons and interacted significantly ($P < 0.05$) between lairage, deck, and haul. Pigs transported in the bottom deck (regardless of duration traveled or time spent in lairage) had a higher rate of PSE loins (6.94%) in the winter compared to loins from pigs transported in the winter on the top deck (3.58%). Furthermore, pigs removed from the bottom deck entering short lairage generated 5.28% PSE loins while the pigs that came off the bottom deck into a long lairage generated 2.86% PSE loins.

Introduction

After the 1992 Checkoff-funded Pork Quality Audit was released, the National Pork Board (NPB) used the information to propose dramatic changes to the pork production chain. In fact, the Pork Board made the bold prediction that pork would be the "Meat of Choice" by the year 2000. Positive changes were made in the 10 years following the 1992 Audit. Comparisons of the 1992 data with the more recent 2002 Pork Quality Audit reveal that pork carcass backfat was dramatically decreased from 1.07 (1992) to 0.69 inches (2002). The focus on reducing carcass fat and the implementation of carcass merit price incentives drove the changes and the industry saw an equally remarkable change in percent carcass lean; increasing from 49.5 to 55.5% carcass lean.

Not all changes were positive. In 1992 the estimated occurrence of PSE (pale, soft, and exudative) pork at the packing plant was 10.2% and in 2002 it was reported to have increased to 15.5%. An increase in the occurrence of poor quality meat greater than five percent is a big problem for an industry striving to be the consumers' *Meat of Choice*. The increase in PSE pork cannot be hung solely on genetic advances pushing for the reduction in fat and an increase in muscle. The selection for lean gain has led to physiological changes that influence muscle metabolism and muscle development.

Muscle growth is enhanced by a certain level of stress. We see this illustrated very well in training athletes, whereby training (an environmental stimulus) combined with genetics generate maximum muscular size and (or) performance. Pigs do not train, however genetic selection for maximum efficiency of muscular rate of gain and enhanced metabolism for efficient use of dietary calories for lean gain (not fat gain), has resulted in 5.2% more muscle in the average market hog. Data collected by the USDA (presented by McKeith and Ellis at the 2004 Pork Quality and Safety Summit) showed a steady increase in the number of DOA (dead on arrival) hogs corresponding with the period from 1992 to 2002 when genetic changes in swine body composition were being made. An extrapolation could be made that muscular, metabolically efficient market hogs are more sensitive to the stress of loading and transport.

The National Pork Board has funded a number of successful projects evaluating genetic differences in carcass composition and meat quality. Also, several studies have evaluated environmental factors that influence pork quality at the packing plant from lairage to chilling. The missing factors in the pork quality puzzle center around events that the producer and packer have limited control over. It is proposed that aspects of market hog transport and handling from lairage to slaughter have a significant environmental influence on fresh pork quality and could account for a significant proportion of pork quality variation identified post-harvest.

From 1992 to 2002 pork carcass backfat levels dropped, percent muscle increased, and PSE increased. Physiological triggers activating metabolic pathways within pigs that have been genetically improved to maximize efficient muscle growth can lead to pork quality problems. Genetics, nutrition, feed withdrawal, rate of carcass chilling have all been well documented. Animal handling has become a focal point, therefore aspects of transport and handling from lairage to slaughter have a significant environmental influence on fresh pork quality and could account for much of the variation currently seen in post-harvest muscle metabolism associated with the conversion of muscle to meat and ultimate fresh pork quality.

Objectives

Objectives of this study were to determine effects of seasonal environment, top and bottom deck transport, transport duration, and time in lairage on overall pork quality and blood serum cortisol concentrations of market hogs.

Materials and Methods

Animals and Experimental Design

Mixed commercial crossbred market hogs (PIC, Franklin, KY) were harvested at dates representing traditional seasonal environments in the Midwestern United States: February 14 and 16, 2006 (**winter**; n = 599), May 16 and 18, 2006 (**spring**; n = 660), August 1 and 3, 2006 (**summer**; n = 649), and October 17 and 19, 2006 (**fall**; n = 661). Within season, pigs were randomly assigned to one of 8 treatments in a 2 x 2 x 2 factorial arrangement, with two transport durations; short (3 hours) or long (6 hours), two trailer deck locations; top or bottom (of a conventional six compartment pot design; Figure 1) and two lairage durations; short (3 hours) or long (6 hours). Environmental conditions in the trailer were monitored at one minute intervals using portable data loggers (HOBO Pro Series RH/Temp. Onset Computer Corp., Pocasset, MA, USA) located in the three compartments (front, middle, rear) of both the top and bottom decks. The two different lairage durations required slaughter at two different times (Table 1). All pigs originated from the same commercial source and identical transport procedure, data collection, and harvest procedure was repeated on Tuesday and Thursdays within the same week within each season.

Preslaughter and slaughter

All pigs were fed the same commercial diet and withheld from feed 12 h prior to slaughter. Upon arrival at the commercial slaughterhouse (QPP, Austin, MN), pigs from the long haul were unloaded first, with the bottom deck getting priority. All pigs were unloaded at in small groups of 20 and alternately assigned to long or short lairage pens. Each pig in the small subgroups was tattooed with a unique tattoo number to specify transport duration, top or bottom deck, and lairage length. Pigs were given free access to water during lairage.

All pigs were subjected to humane head-to-heart electrical stunning procedures in compliance with the standard industry practices and the Humane Slaughter Act.

At exsanguination, blood was collected from each pig in pre-numbered disposable 15 ml tubes (Cat. No. 362695; Nalge NUNC International). Self-piercing "round post" metal eartags sequentially numbered to correspond with the blood collection tubes were then tagged in the ear of each pig while still on the gambrel table. Carcasses then proceeded through the scalding tanks and dehairing equipment.

After all blood samples had been collected, blood tubes were allowed to clot under refrigeration in the laboratory. Centrifugation of blood samples began eight to 10 hours after collection. Samples were centrifuged for 10 minutes at 2,500 X *g*. After centrifugation, serum (5 ml) was transferred from tubes into 48 well plates and stored at –20°C until analysis for cortisol concentration. For the analysis of cortisol levels, 25μl of serum was assayed in duplicate using the procedures described by the technical manual from Diagnostic Systems Laboratories, Inc (Webster, TX). Values were reported in ng/ml.

At the point just after the final carcass polisher, ear tag number was transferred to the carcass by writing the number onto the left shoulder of each carcass using an edible blue carcass crayon to maintain identity throughout the harvest floor. When carcasses were through the harvest floor and the initial water chill, a cooler room sequence was obtained along with eartag number (blood tube number) and tattoo number which were documented to allow matching of transport, deck, and lairage treatments with blood data. The carcass eartag ID was then transposed onto the left side thoracic vertebrae with an edible carcass crayon for further identification of the fresh pork loins which were removed for pork quality analysis from the loin fabrication line after a 20h chill.

Pork quality measurements

Left-side loins were collected from the loin fabrication line and moved to the loin boning line. The boneless loins were cut at the $10^{th}/11^{th}$ rib interface, tagged with the original eartag ID, and moved to a remote table for ultimate meat quality assessment. Ultimate *longissimus* muscle (LM) pH (MPI pH-Meter, Meat Probes, Inc. Topeka, KS) and objective lean color [L* (lightness), a*(redness), b*(yellowness)] was evaluated on the cut surface (10^{th} rib surface) of the loin after allowing for a 10 minute blooming period. All objective color measurements were obtained using a Konica-Minolta portable Chroma Meter (Model CR 410, Minolta, Osaka, Japan) with an illuminant setting of D65/10 and calibrated to a white tile. Hue angle (arctangent ((b*/a*) * 360° / (2 * 3.14)) and chroma (square root $(a^*)^2+(b^*)^2$) were calculated. Hue angle is a measure of true red, where 0 is "true red" and chroma (color saturation) is a measurement of how vivid or concentrated a color appears, where by the higher the calculation the more vivid the color (Minolta, 1994). A one-inch thick LM chop was fabricated originating from the $10^{th}/11^{th}$ rib interface and a one-inch circumference core sample was subsequently removed from the center of this chop for determination of drip loss as described by

Rasmussen and Stouffer (1996). Briefly, one-inch circumference core samples were removed from the chop, weighed to the nearest 0.01 g, and then placed into a specialized drip loss tube (meat juice containers; C. Christensen Laboratory, Denmark; Figure 2). The filled tubes were then placed in drip loss rack and the entire rack moved to a 39°F cooler for 24 h. After 24 h, samples were reweighed. The percentage of moisture loss (24 h drip loss) was calculated by dividing the difference between weights by the initial sample weight, multiplied by 100. Classification of PSE pork was determined through identification of those pork loins possessing a 24 hour drip loss > 5% and an L* value > 55.

Statistical Analysis

Data were analyzed as a general linear model (PROC GLM) of SAS (version 8.02; SAS Inst., Inc., Cary, NC). Least-squares means were generated by the LSMEANS statement and tested for least significant difference across all main effects and appropriate interactions for fresh pork quality parameters and serum cortisol concentration. Tests of multiple comparisons of LSMEANS were considered significant at a level of $P < 0.05$. The model applied included the fixed effects of season, transport length, transport deck location, lairage duration, as well as their interactions. The random effect was slaughter day nested within season.

Results and Discussion

Transport climatic conditions & pig welfare

The range of temperature and humidity recorded in the trailer during a long haul (Figure 3) was greatest during the winter season, with the bottom front compartment showing the most volatility. Climatic conditions within the trailer during short haul (Figure 4) had a wider range of temperature during the fall season transport. The Weather Safety Index is a tool that truckers can use to determine if temperature and humidity conditions reach a point during transport where animals could be in a "danger" or an "emergency" condition with regard to their welfare (if not mortality). Figure 5 is a scatter plot of two compartments within the trailer during the summer, long haul transport. Climatic conditions in the bottom deck, front compartment were often the most climatically unfavorable due to reduced ventilation while the top deck rear compartment was the most temperate during summer transport. The red dots in Figure 5 indicate the number of times that the temperature and humidity reached a level of Danger or Emergency during the 6 hours of transport. Tracking of pigs from each trailer compartment was beyond the capabilities of this project. More research is necessary to quantify the influence of location within trailer, pig welfare, and pork quality is warranted.

The number of market pigs classified as "slows" during unloading was highest in the winter and summer seasons (7 each; Table 2), yet the fall season had the most dead-on-arrival (DOA) pigs (a total of three). It is important to note that all three DOA pigs were removed from the bottom deck. Long hauls resulted in a greater number of DOA hogs (n = 6) versus the short hauls (n = 2), while five deads were removed from the bottom deck versus 3 from the top deck over the course of the trial (Table 2). The number of slows reported in this study are well below the United States average of approximately 1% (Ellis et al., 2004). This could be attributed to the fact that all truckers used in the experiment were certified under the NPB Trucker Quality Assurance Program (NPB, 2004) or the fact that all pigs used in the study were of similar genetics and from the same productions site.

According to Scanga et al. (2003) and the results of the 2002 NPB U.S. Pork Quality Audit, 51.8% of all pigs delivered to market traveled less than 100 miles to the point of destination while 32.6% of pigs were transported 101 – 200 miles (approximately three hours duration) and 15.6% of pigs transported over 200 miles. The present study evaluated the median and longest range of transport duration as reported by Scanga and associates (2003). According to the Scientific Committee on Animal Health and Animal Welfare (European Commission, 2002), market hog welfare during transport is highly dependent on vehicle design, driving method, and road quality. This European committee found that adequate ventilation of trailers was the most important criteria in maintaining proper market hog welfare during transport. Automated ventilation systems that opened or closed to maintain appropriate climatic conditions to maximize pig welfare reduced transport mortality by nearly 50% (Nielsen (1981). Research by Christensen and Barton Gade (1999) found that all DOA pigs in their experiment were removed from the front compartment on the lower deck where the temperature and humidity were highest and ventilation was the poorest. The observation of Christensen and Barton Gade (1999) is consistent with the findings in our study with regard to climatic conditions within the trailer. However, more research is necessary in the United States to evaluate climatic conditions of the various trailer compartment with regard to market hog welfare and ultimate pork quality.

Serum cortisol concentration

The stress hormone cortisol plays a major role in regulating energy (glucose) metabolism in livestock species (Knowles and Warriss, 2000). Cortisol remains active in the body longer than the more potent “fight or flight” hormones epinephrine and norepinephrine (Gregory, 1998) and is generally regarded as an indication of an animal’s psychological state, as well as an index of its physiological reaction to environmental conditions and (or) welfare situation (Knowles and Warriss, 2000). Therefore, assessment of circulating cortisol is common in research which evaluates preharvest stress. If we accept the generally recognized theory that higher concentrations of cortisol in the blood are an indication of elevated stress, in the present study, pigs transported in the summer and fall seasons were experiencing the most stress as indicated by higher serum cortisol concentration collected at slaughter (Table 3). Cortisol concentrations were highest in the fall season (119.69 ng/ml). Furthermore, pigs that were subject to longer transport had higher cortisol concentrations than those transported for a shorter duration (103.01 vs. 95.16 ng/ml, respectively; Table 3). While the main effect of lairage duration was not significant alone, differences were seen for lairage time within season of the year

(Figure 6). Short or long lairage was inconsequential during the spring, yet in the winter and fall seasons, short lairage (3 hours) appeared to be more stressful (higher cortisol levels observed). In contrast, a longer lairage in the summer season resulted in higher cortisol levels. Martoccia *et al.* (1995) concluded that transport distance itself did not seem to determine severe levels of stress in pigs and found that transport stress may be offset by the amount of time pigs spend in lairage before stunning. It is generally accepted that time spent in lairage allows a stressed animal time to recover from loading, transport, and unloading stressors. Noted animal welfare specialist Temple Grandin (Grandin, 1994) recommends that pigs should be rested (transport recovery period) 2 to 4 hours before entering the stunning chute. The findings of the present study are consistent with Carr et al. (in press) who found that during the heat of the summer months, pigs that had a shorter lairage (45 minutes) had lower circulating cortisol concentration than pigs held in the longer lairage (three hours). It is also interesting to note that short lairage after a long haul in our study appeared to induce a much greater stress response in pigs (cortisol concentration = 105.42 ng/ml) than those held in short lairage after a short haul (cortisol concentration = 92.3 ng/ml) as shown in Figure 7, suggesting that market hogs require a longer duration lairage (transport recovery time) after a longer transport duration.

Transport duration and season of the year had the most significant influence on serum cortisol levels (Table 3). Statistical comparison of top or bottom trailer deck revealed no difference as a main affect (comparison of all pigs transported on the top or bottom of the trailer throughout the entire year did not differ), yet when we do a more thorough analysis, deck location within season and length of transport did differ, revealing a significant three-way interaction; deck × haul × season (Figure 8). Long hauls within season were numerically higher moving through the calendar year from winter to fall. Pigs transported the long distance on the top deck in the fall season had the highest cortisol levels of any group of pigs (Figure 8). During the summer month, pigs on the bottom deck during the long haul had a significantly higher cortisol concentration than those on the top. In winter, pigs on top had higher cortisol levels.

It is interesting and perhaps surprising to note that historical (unpublished) data provided by industry contacts reveals that the highest incidence of slows and DOA pigs are removed from trailers during the fall of the year. The cortisol data from the present study indicates that the pigs are indeed experiencing a higher physiological stress response in the fall season that is exacerbated by transport duration and deck location. Traditionally we think of heat and humidity as the primary drivers of stress during transport, yet our findings show moderate climatic conditions during the fall of the year. More research is necessary to determine the factors that deteriorate market hog welfare during the fall season.

Longissimus muscle pH

Traditional meat science studies have long attributed intramuscular pH as the principal, quantitative measurement driving fresh and further processing pork quality conditions. It is commonly known that pork with a low pH has a poorer water-holding capacity and a paler color. In the present study, season of the year and time in lairage were the two main effects (Table 3) significantly influencing intramuscular pH. Consistent with the cortisol data, pigs transported to harvest in the summer had higher pH after a long lairage and those transported the short duration in the fall had a higher pH (Figure 9). This would suggest that the higher cortisol was influencing muscle glycogen stores. As previously stated, cortisol plays a major role in regulating energy (glucose) metabolism. Therefore, intramuscular concentrations of glycogen (glucose) may be metabolized in response to the elevated cortisol concentrations. This would mean that there is less glucose in the muscle at the point of slaughter to drive down intramuscular pH during the conversion of muscle to meat; less glucose to convert to lactic acid. A significant deck × haul interaction was also noted (Figure 10) with pigs transported for six hours (long haul) on the bottom deck having a higher loin pH than those on the top deck.

Statistically, differences in pH were seen, yet care must be taken with regard to biological significance of these results. Evaluation of least squares means shows a maximum difference of 0.10 pH units between short and long haul duration in the summer. The reader and the pork industry must decide for themselves if 0.10 pH units is a large enough difference to adopt new industry practices based on this small biological difference.

Longissimus muscle percentage drip loss

Season of the year (summer) had the most significant influence on loin muscle water-holding capacity. Drip losses collected in the summer were much lower than any other season of the year (Table 3). Furthermore, deck location played a role in influencing drip loss during season of the year with higher drip losses seen in loins from pigs transported on the bottom deck in the winter and the top deck in the fall (Figure 11). No differences were seen between long or short hauls within the winter or summer season (Figure 12). Loins from pigs transported a shorter duration in the spring had significantly lower drip loss than the long transport, while the opposite affect was observed in the fall (Figure 12).

This season phenomenon is very difficult to explain. Traditional meat science research suggests that pH measurements are higher and drip losses lower in the winter months as pigs utilize intramuscular glycogen to maintain body temperature through shivering. Therefore, muscle glucose is "burned up" prior to harvest leaving less substrate to convert to lactic acid during postmortem metabolism. The opposite was seen in the present study with winter and spring seasons possessing the highest moisture losses (Table 3). Cortisol levels were the lowest in the winter and spring season (Table 3) which would indicate that the physiological status of the pigs was such that the endocrine system was not calling for a greater need for glucose. In contrast, cortisol concentrations were the second highest in the summer season when drip loss percentages were the lowest. Furthermore, cortisol concentrations were not significantly correlated to drip loss (Table 4) so it would appear that in this present study, stress was not related to drip loss. In fact, there was no significant correlation between cortisol concentration and percentage drip loss when data were run separately for each season (data not presented). We must therefore conclude that the data collected in the present study cannot explain the seasonal variation in loin muscle drip loss and must be attributed to some undocumented preharvest or packing plant variable.

Longissimus muscle color; L, saturation, and hue angle*

Objective measurement of fresh pork color variability has been limited to observations recorded by colorimeter or spectrophotometer equipment that generates L* (lightness), a* (redness), b* (yellowness) data points. Measurement of paleness (L*) and (or) redness (a*) of a pork chop are relatively easily understood, however, many meat science research papers find differences in b* values (yellowness) that are not easily explained. The naked eye cannot readily discern the level of “yellow” in a fresh pork sample so when treatment influences this color observation it cannot be readily explained. In the present study, we opted to report two lesser used color variables; color saturation and hue angle. These two color measurements are calculated using the a* and b* color variables as described in the Materials and Methods section of this paper. Hue angle is a measure of true red, where 0 is “true red” and chroma (color saturation) is a measurement of how vivid or concentrated a color appears, whereby the higher the calculation the more vivid the color (Minolta, 1994).

The main effects of season and lairage had a significant influence on L* value (Table 3) as was the interaction term of haul within season. Though significant differences were noted between treatments, the true physical differences capable of being discerned by the naked eye (as in the case of a consumer rejecting a pork chop based on pale color) are minimal. Brewer et al. (2001) reported that consumers evaluating the lightness of fresh pork chops were able to discern differences if the L* value difference was greater than three L* units. The greatest comparable statistical difference was observed between winter and spring season L* values (Table 3) which was under three L* units difference. Therefore, care must be taken in interpretation of the data with regard to the practical industry value of L* observations reported in Table 3 and Figure 13.

Pigs held in long lairage in the summer produced loins that were more vivid (higher color saturation) than loins from pigs held in short lairage (Figure 14). The higher saturation value of loins from long lairage pigs complies with the higher cortisol concentration (Figure 6) and intramuscular pH (Figure 9) of the same pigs. Higher cortisol concentrations during long lairage may have led to intramuscular glycogen reduction, the lower pH, and the subsequent improvement in the saturation of the muscle pigment.

As was seen with the L* values, the practical applicability of hue angle observations (Table 3, Figures 15 and 16) must also be evaluated with care as the significant differences may not discern a practical difference.

Longissimus muscle PSE characterization

Scanga et al. (2003) reported that the yearly industry average for the occurrence of pale, soft, and exudative (PSE) pork was 15.5%. Berg (2006) conducted a follow-up survey to further clarify the occurrence of PSE pork and found that 3.34% of the loins fabricated in U.S. packing plants exhibited all three conditions of classic PSE pork (they were pale *and* soft *and* exudative) The range reported by the respondents to the survey was from 0.1 to 10% occurrence. In the present study, PSE classification was objectively determined by using the percentage drip loss and L* thresholds as classification criteria whereby PSE= 24h drip loss > 5% and L* value > 55. These values were chosen for PSE classification based on their relationship with visible characteristics of fresh pork. The amount of moisture loss and the paleness (L*) of a fresh pork chop are characteristics that a consumer can observe when choosing pork at the retail case. The levels were selected based on data accumulated by the NPB in various pork quality studies. The threshold for drip loss set in the Pork Quality Targets is "not to exceed 2.5%" (NPB, 1998), therefore this value was doubled as an indication of extreme purge or drip loss. The L* level was chose as it corresponds to the NPB color standard of 2 (NPB, 1999). Acceptable pork quality targets for color are a color score of 3.0 to 5.0 utilizing a 6-point scale (NPB, 1998).

No statistical differences ($P > 0.05$) were observed for the main effects of season, deck location, transport duration, or lairage duration on occurrence of the PSE condition. Winter saw the highest numeric occurrence of PSE (5.26%) of any season with spring (4.26%), fall (3.78%), and summer (3.21%) following (Table 3). Trailer deck within season (Figure 17) did have a significant influence on percent occurrence of PSE ($P = 0.05$). In the winter, there was a significantly greater occurrence of PSE loins originating from pigs transported on the bottom trailer deck (6.94%) versus the top deck (3.58%). The classification of PSE in this case may be driven by similar differences seen for percentage drip loss reported for bottom vs. top deck in the winter season (Figure 11). Stress condition for winter transport of pigs (comparing the top and bottom compartments of the trailer) is inconclusive as cortisol concentration did not differ between top or bottom transported pigs in the winter season. Further evaluation of the influence of deck location shows a higher percentage of PSE loins manifest from pigs transported on the bottom deck then slaughtered after a short lairage (Figure 18). Of the loins from bottom deck pigs provided a short lairage, 5.28% were PSE loins compared to 2.86% of loins from bottom deck/ long lairage. This indicates that at least part of the potential for developing PSE loins may be alleviated by providing pigs with a longer lairage.

<u>Lay Interpretation</u>

Pork producers have often been told that stressing pigs can not only have negative consequences on the pig's welfare but also on the quality of pork that they generate. Removing pigs from their familiar environment, loading them on a trailer, trucking them to a packing plant, unloading them, and leaving them in an unfamiliar pen most definitely introduces stress on the animal. The objective of this study was to evaluate these pre-slaughter stressors, looking at location in the trailer, specifically the top or bottom deck of a traditional pot-bellied trailer, a short (3 hours) or long (6 hours) haul, and a short (3 hours) or long (6 hours) lairage at the packing plant. Since weather conditions will also introduce a level of stress under these three circumstances, we evaluated deck location, haul duration, and time in lairage during four distinct seasons of the year; winter, spring, summer, and fall. The concentration of the stress hormone cortisol was evaluated for each pig in the study. Higher levels of cortisol at the time of bleeding were considered an indication that the animal was stressed. Mixed commercial crossbred market hogs (PIC, Franklin, KY) were used in this study. The dates and number of pigs harvested in this study are as follows: February 14 and 16, 2006 (n = 599), May 16 and 18, 2006 (n = 660), August 1 and 3, 2006 (n = 649), and October 17 and 19, 2006 (n = 661). Climatic conditions (temperature and relative humidity) in the trailer were monitored at one minute intervals using portable data recording devices located in the three compartments (front, middle, rear) of the top and bottom decks of the trailer. All pigs came from the same commercial source and identical transport protocol, data collection techniques, and slaughter procedure was repeated on Tuesday and Thursdays within the same week of each seasonal slaughter. Blood was collected from each carcass when they were stuck on the bleed table for determining serum cortisol concentration. Fresh pork loins were collected from the loin line during carcass processing and fresh pork quality parameters were evaluated for objective color recording L* (color lightness), a* (redness), and b* (yellowness) values, loin muscle pH, and the percentage drip loss over a 24 hour period. We evaluated statistical differences between the averages of each quality parameter and blood cortisol concentrations for differences between deck location, transport duration, length of lairage, and the seasonal effects. We also separated the data further looking at each transport variable within the season of the year.

The range of temperature and humidity recorded in the trailer during the long haul was greatest during the winter season, with the bottom front compartment showing the most fluctuation. Climatic conditions within the trailer during the short haul had a wider range of temperature during the fall season transport. Climatic conditions in the bottom deck, front compartment were often the most unfavorable for pig welfare during the summer haul as the temperature and humidity often reached a point putting the pigs in an "emergency" category of the Weather Safety Index. More research is necessary in the U.S. to evaluate climatic conditions of the various trailer compartments with regard to market hog welfare and ultimate pork quality.

Stress, as indicated by the level of cortisol in the blood, was the greatest during the summer and fall seasons and pigs transported a longer duration had higher cortisol concentrations in their blood (indicating greater stress). Short or long lairage didn't matter during the spring, yet in the winter and fall seasons, short lairage was more stressful as indicated by higher cortisol levels. In contrast, a longer lairage in the summer season resulted in higher cortisol levels. This indicates that to improve pig welfare (reduce stress) in the summer months, a shorter lairage is beneficial.

We classified loins as pale, soft, and exudative (PSE) if they had a 24 hour drip loss greater than 5% and a lightness score (L*) greater than 55. Keep in mind that a higher L* value is more pale and an L* of 100 is white. We found that pigs transported in the bottom deck (regardless of duration traveled or time spent in lairage) had a higher rate of PSE loins (6.94%) in the winter compared to loins from pigs that were transported in the winter on the top deck (3.58%). Furthermore, pigs removed from the bottom deck of the trailer that went into a short lairage (3 hours) prior to slaughter generated 5.28% PSE loins while the pigs that came off the bottom deck into a long (6 hour) lairage generated only 2.86% PSE loins. This indicates that at least part of the potential for developing PSE loins may be alleviated by providing pigs with a longer lairage prior to slaughter.

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Figure 1. Diagram of experimental trailer design and compartment location within trailer.

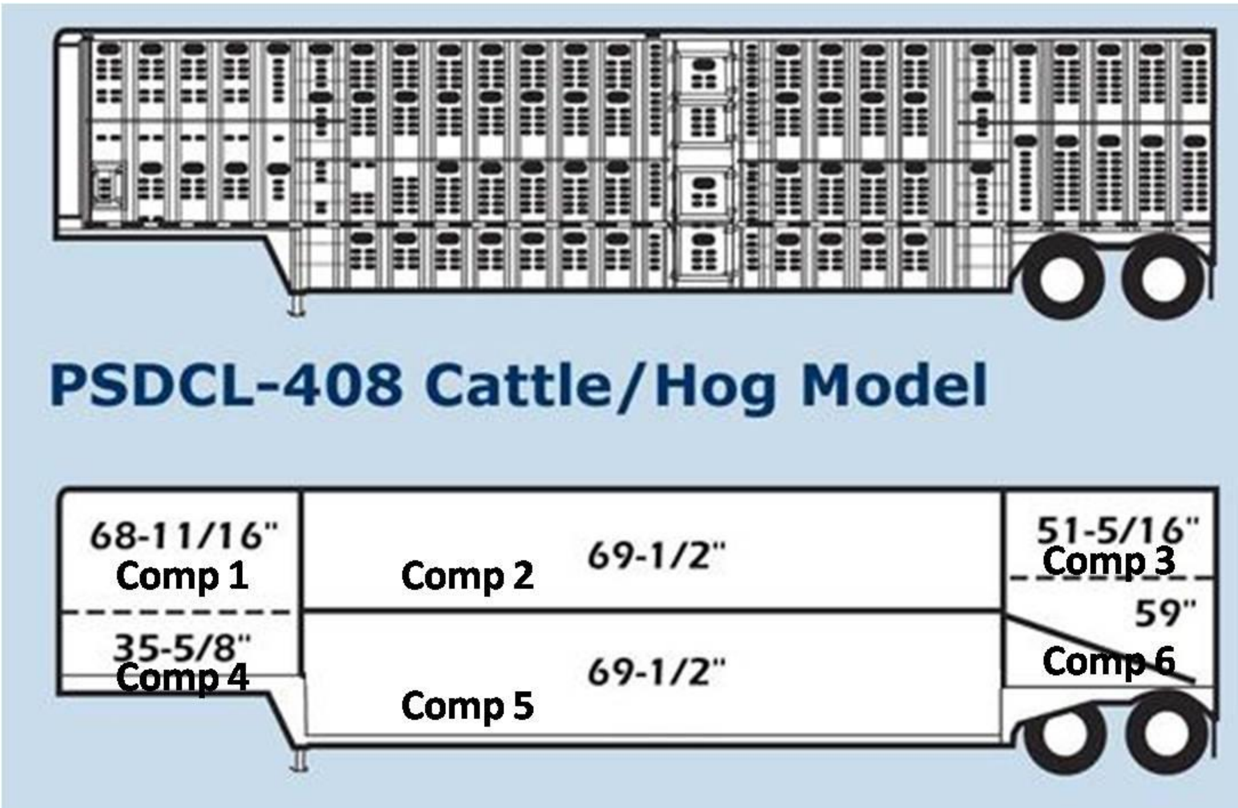
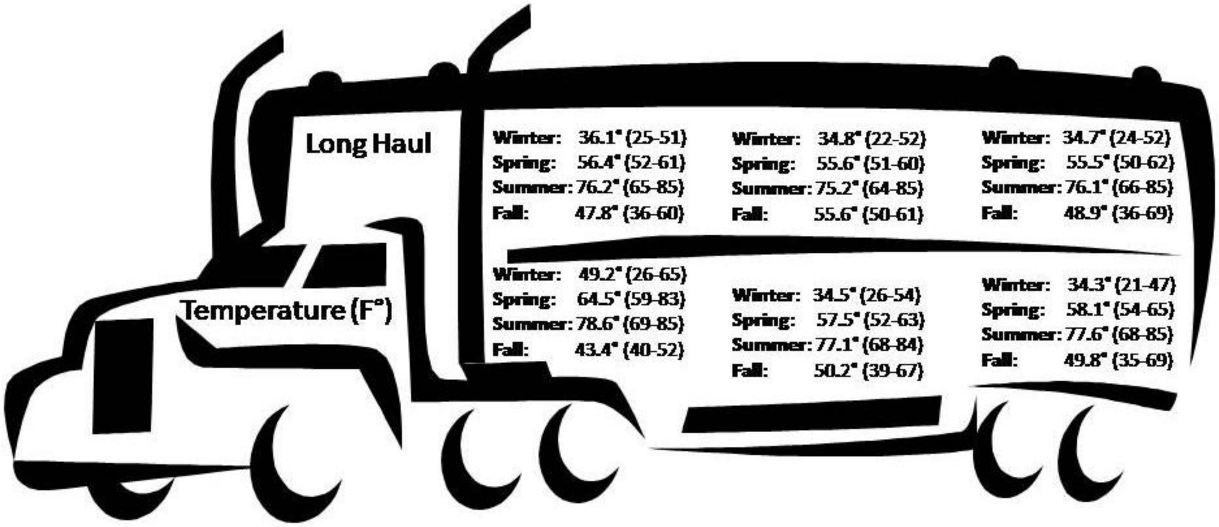
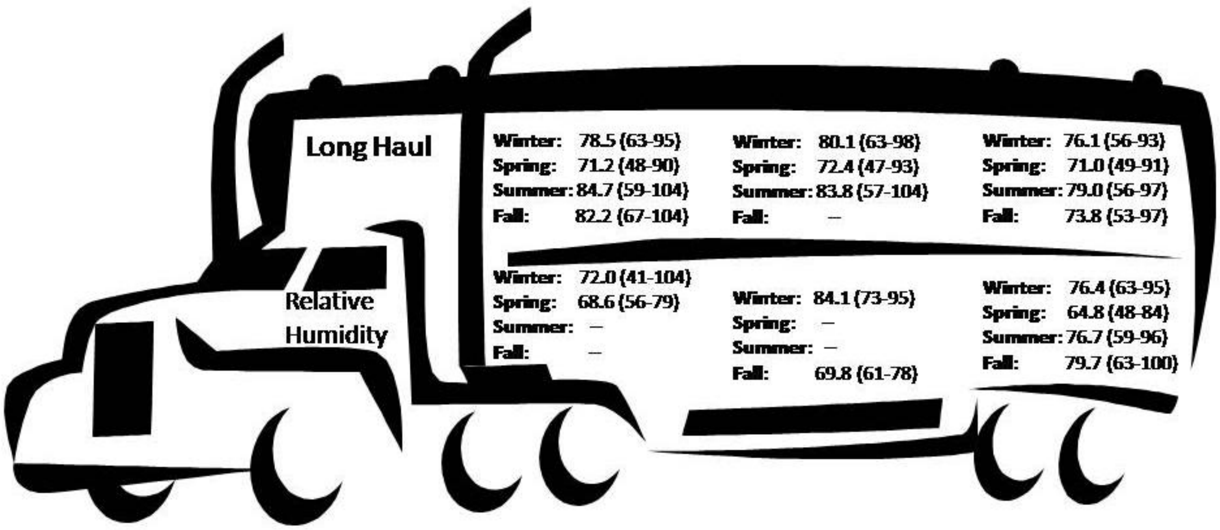


Figure 2. Example of specialized drip loss tube (manufactured and distributed by C. Christensen Laboratory, Denmark) and storage rack.

Figure 3. Average and ranges of temperatures (a) and relative humidity (b) for each trailer compartment of the top and bottom trailer deck for each season of the long (6 hour) transport duration.

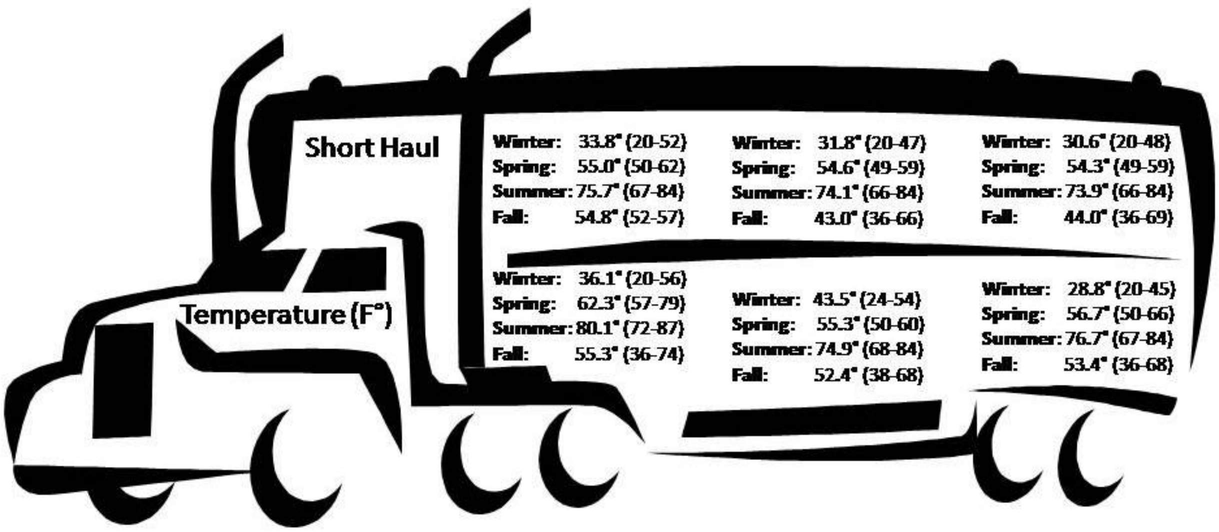


a)

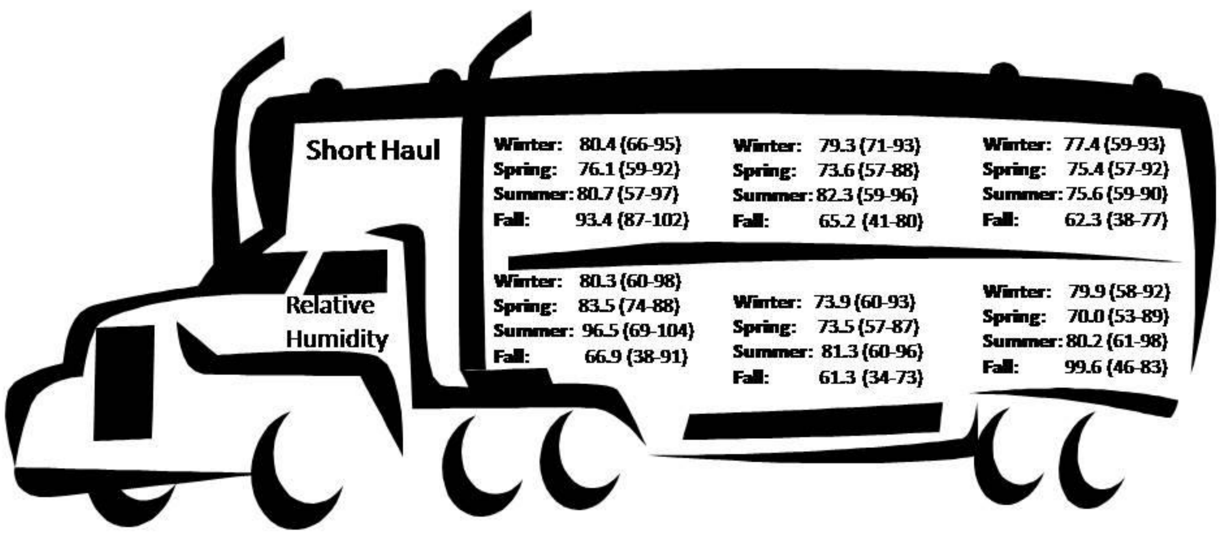


b)

Figure 4. Average and ranges of temperatures (a) and relative humidity (b) for each trailer compartment of the top and bottom trailer deck for each season of the short (3 hour) transport duration.



a)



b)

Figure 5. Scatter plot of the occurrence of temperature and relative humidity reaching the "danger" and "emergency" zones in the bottom front (warmest) and top rear (coolest) compartments within the trailer during the long haul (6 hours) summer transport.

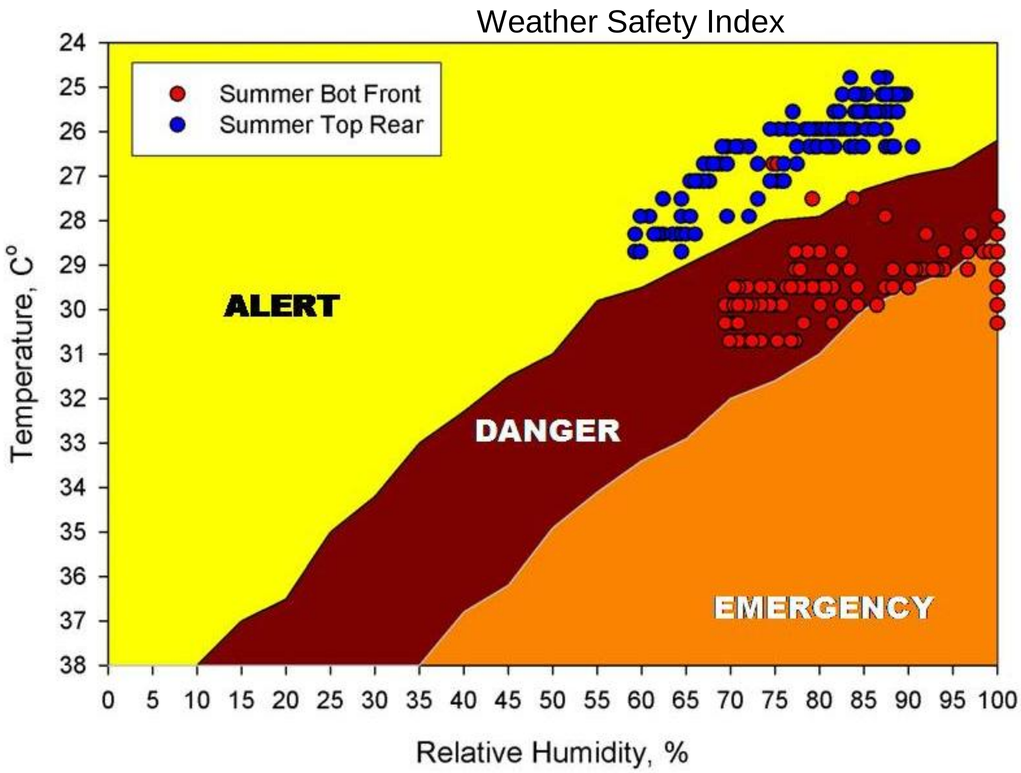


Figure 6. Least squares means and standard error bars for cortisol concentration for short (3 hours) or long (6 hours) time in lairage within season; lairage × season.

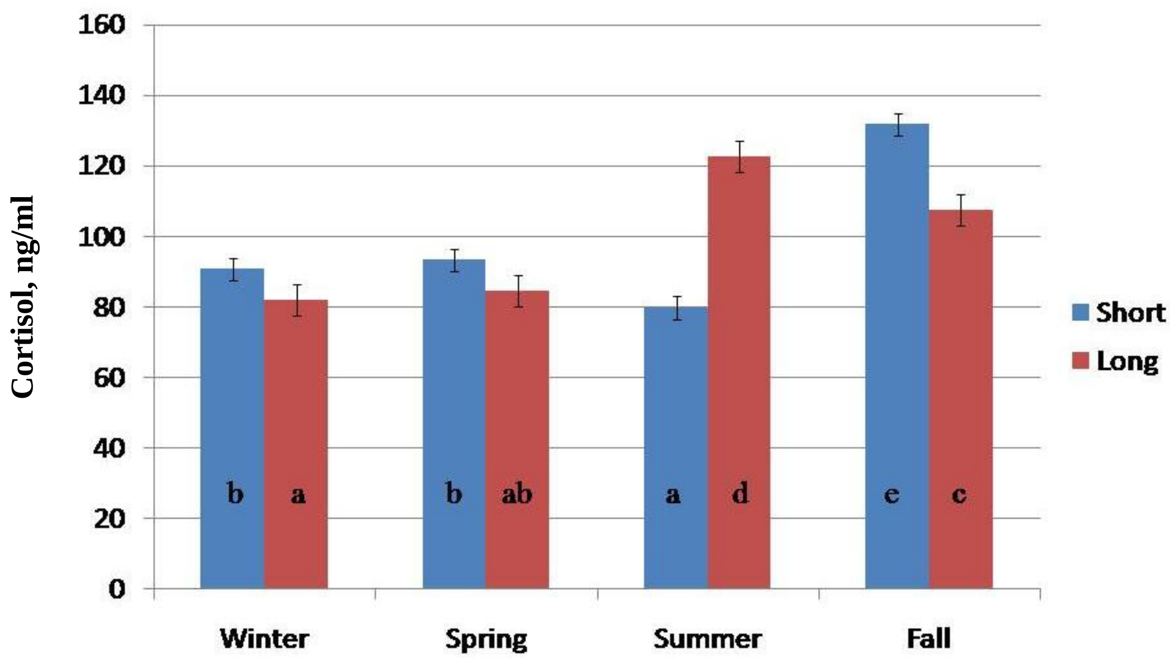


Figure 7. Least squares means and standard error bars for cortisol concentration for long (6 hours) or short (3 hours) lairage within long (6 hours) or short (3 hours) haul; lairage × haul.

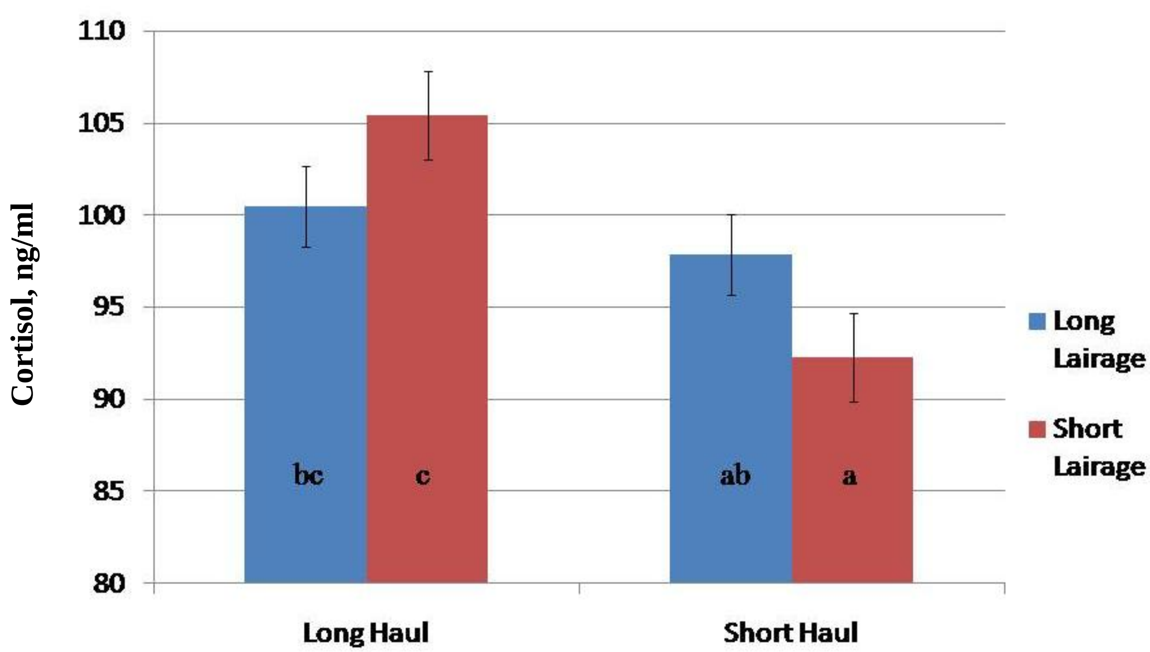


Figure 8. Least squares means and standard error bars for cortisol concentration for top or bottom (**Bot**) trailer deck and short (**SH**; 3 hours) or long (**LH**; 6 hours) haul within season; haul × deck × season.

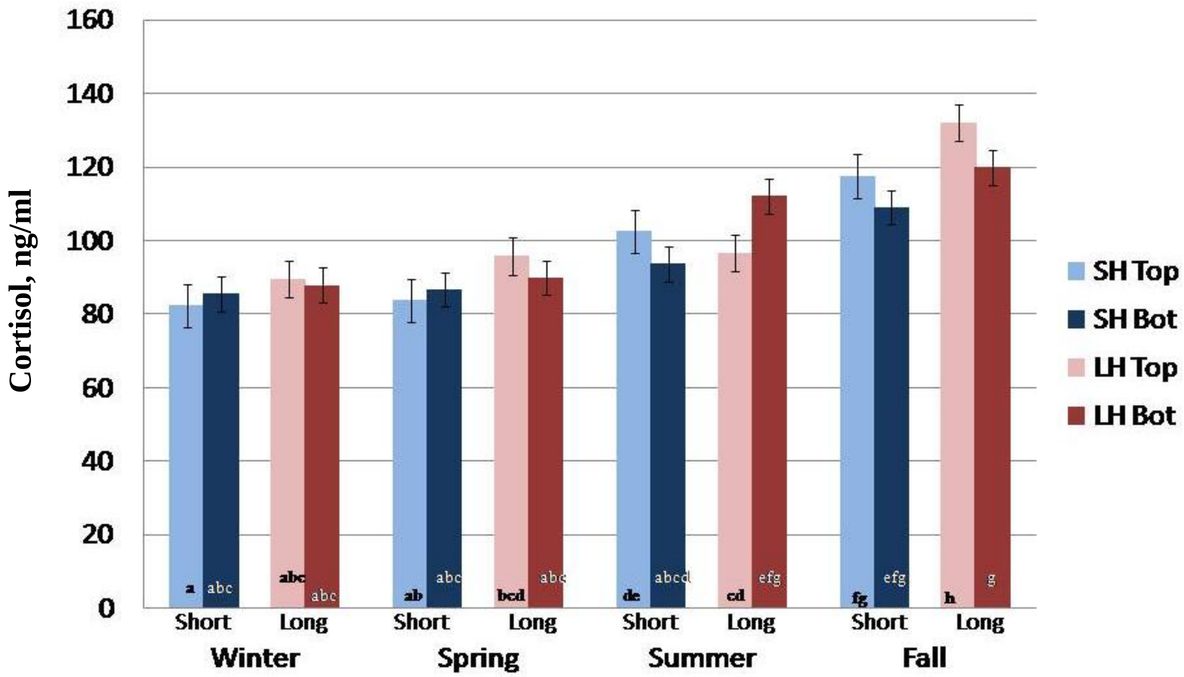


Figure 9. Least squares means and standard error bars for loin muscle ultimate pH for long (6 hours) or short (3 hours) lairage within season; lairage × season.

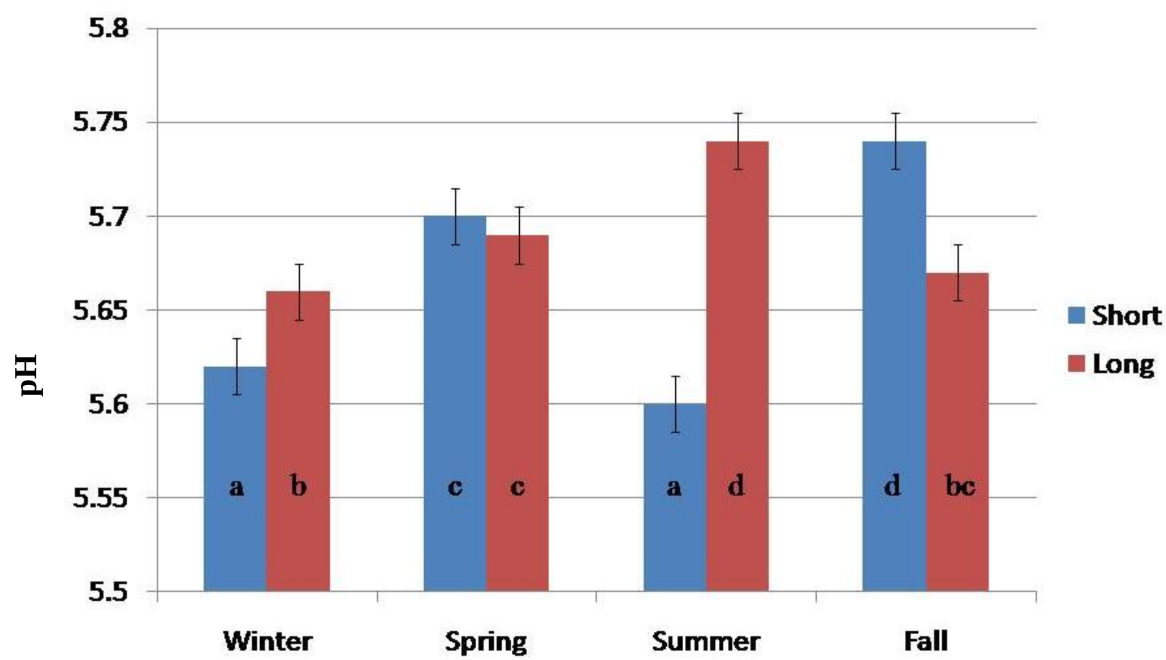


Figure 10. Least squares means and standard error bars for loin muscle ultimate pH for top or bottom trailer deck within short (3 hours) or long (6 hours) haul; deck × haul.

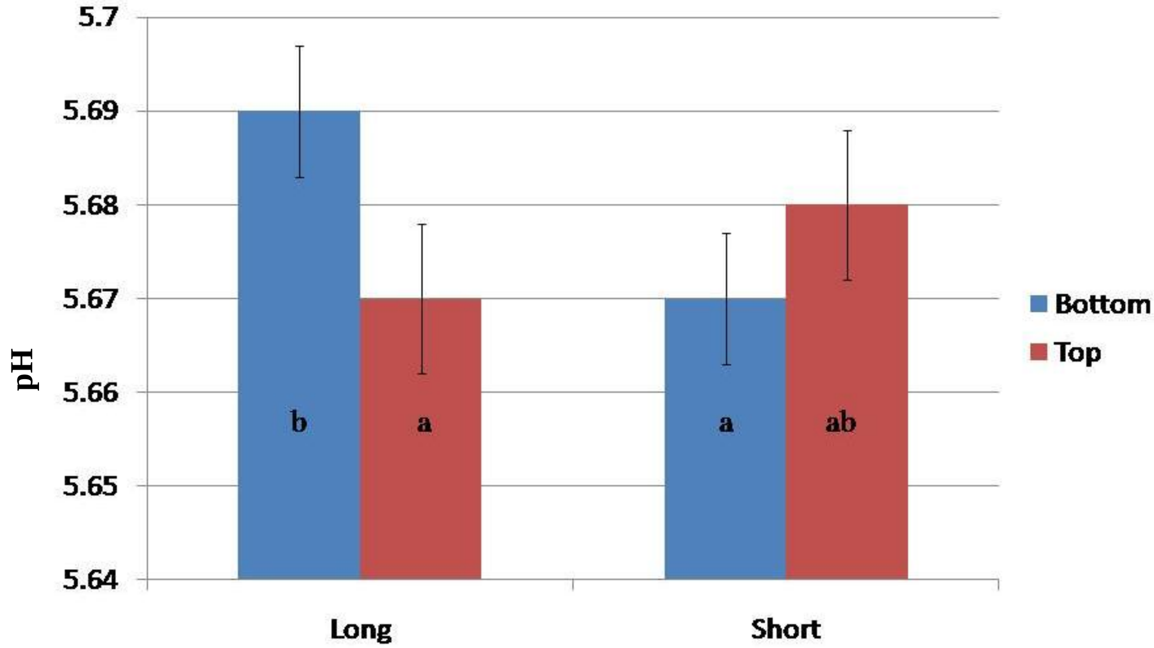


Figure 11. Least squares means and standard error bars for loin muscle percentage drip loss for top or bottom trailer deck within season; deck × season.

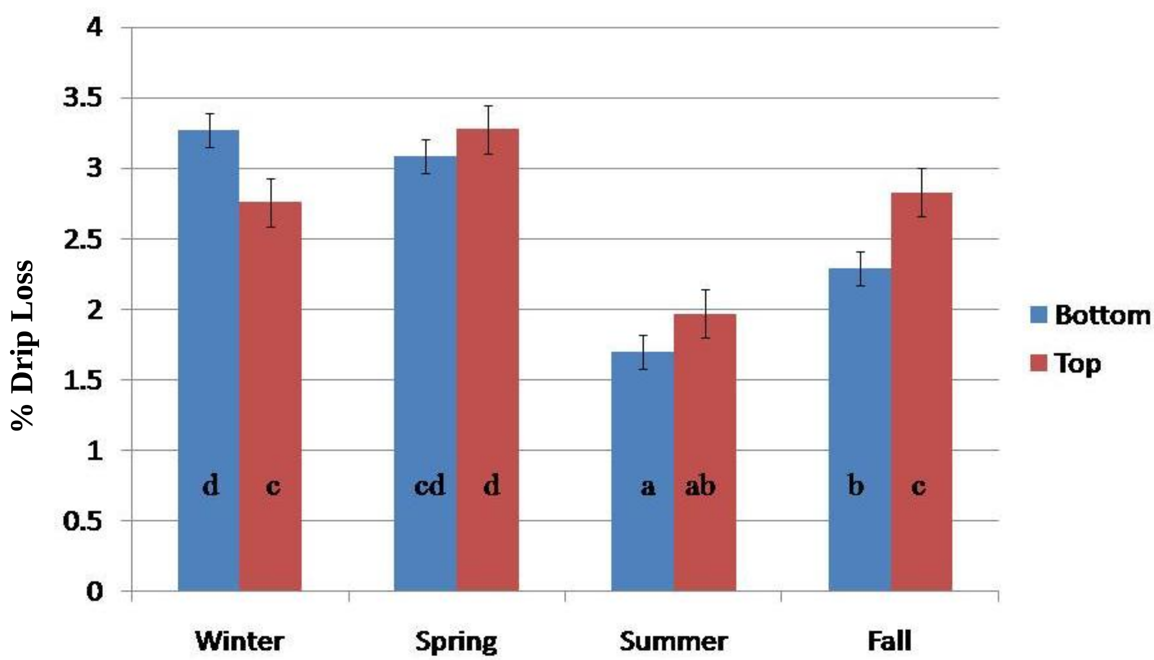


Figure 12. Least squares means and standard error bars for loin muscle percentage drip loss for short (3 hours) or long (6 hours) haul within season; haul × season.

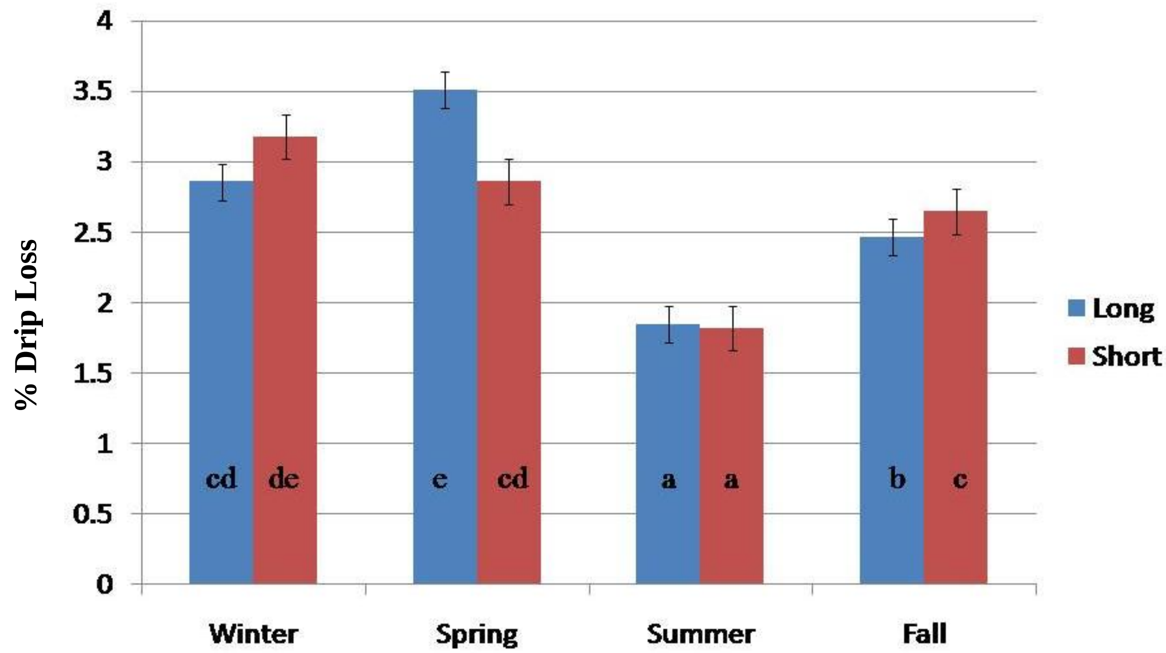


Figure 13. Least squares means and standard error bars for loin muscle L* value (lightness) for short (3 hours) or long (6 hours) haul within season; haul × season.

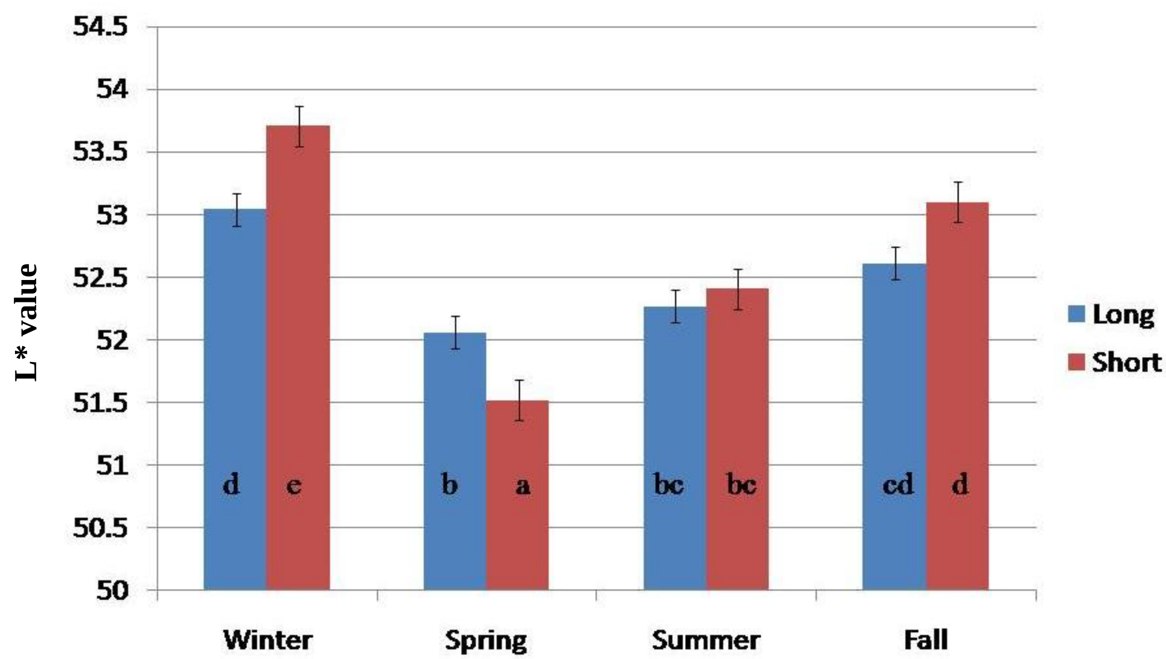


Figure 14. Least squares means and standard error bars for loin muscle color saturation (total pigment; higher is a more intense/ vivid color) for short (3 hours) or long (6 hours) lairage within season; lairage × season.

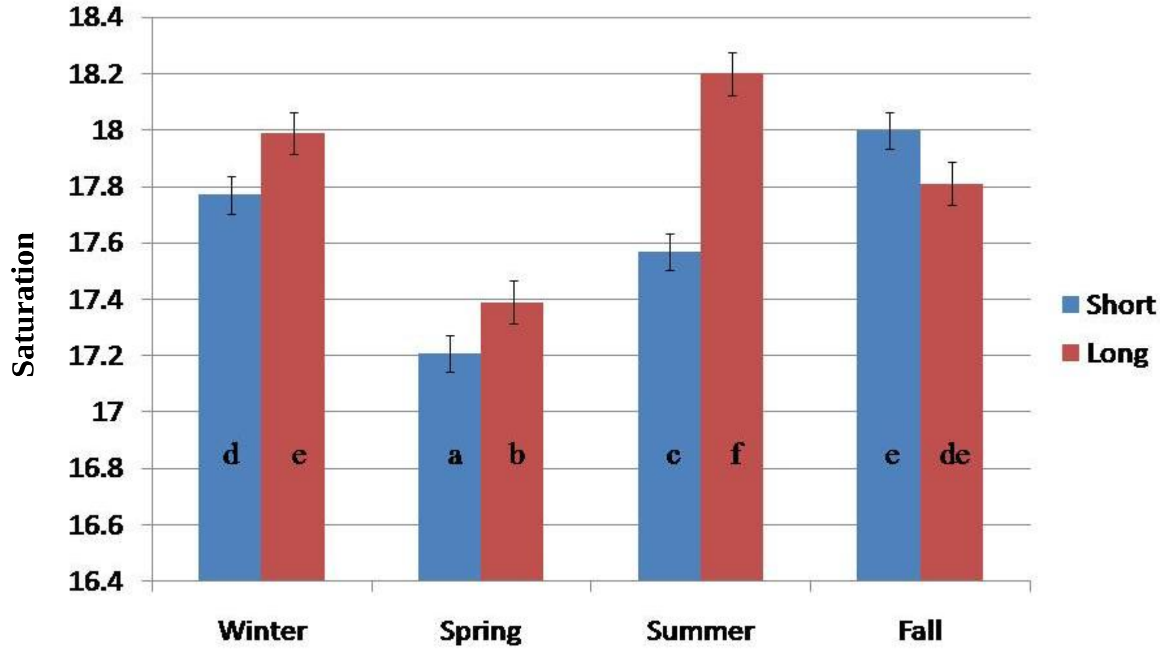


Figure 15. Least squares means and standard error bars for loin muscle hue angle (a value of zero equals "true" red) for short (3 hours) or long (6 hours) haul within season; haul × season.

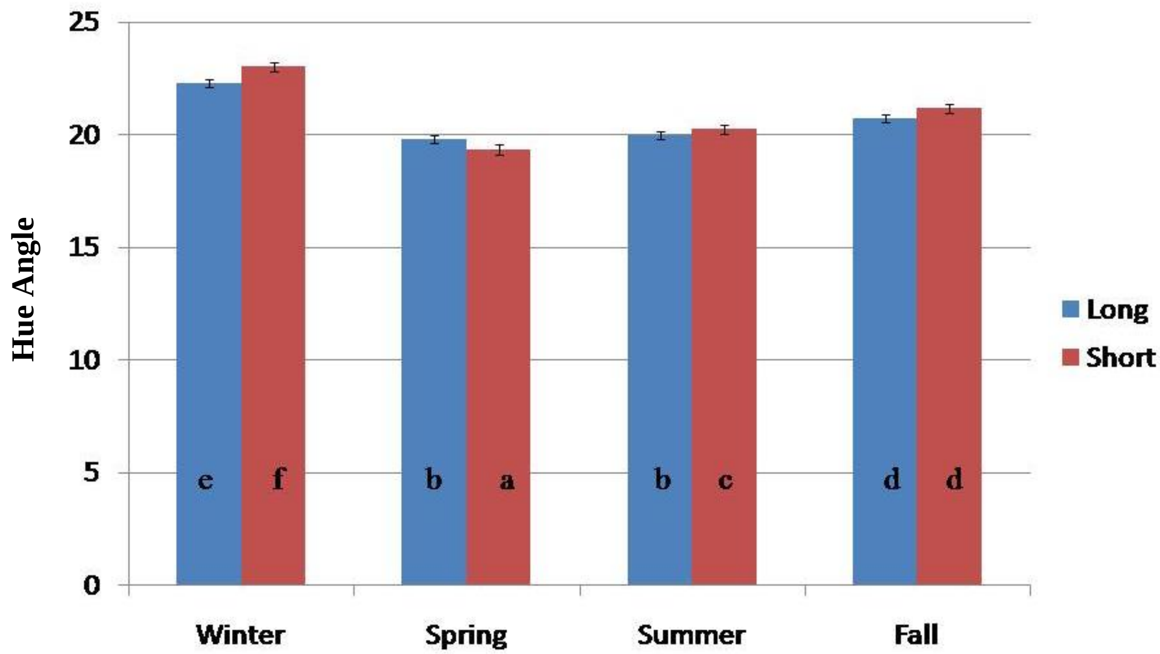


Figure 16. Least squares means and standard error bars for loin muscle hue angle (a value of zero equals “true” red) for short (3 hours) or long (6 hours) lairage within season; lairage × season.

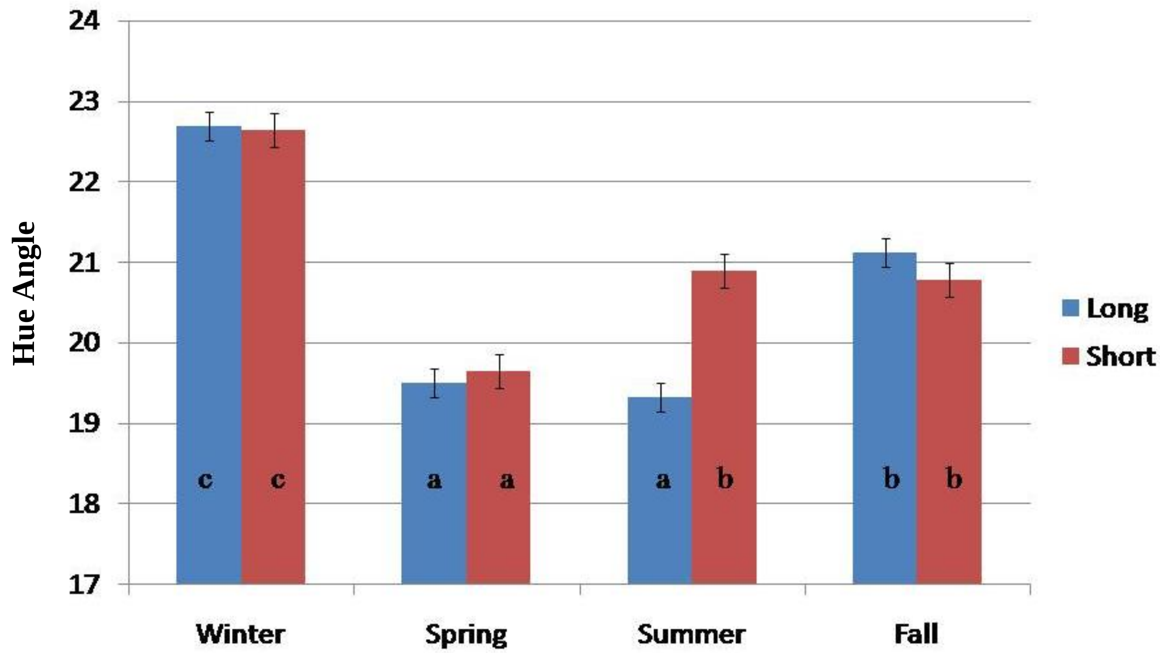
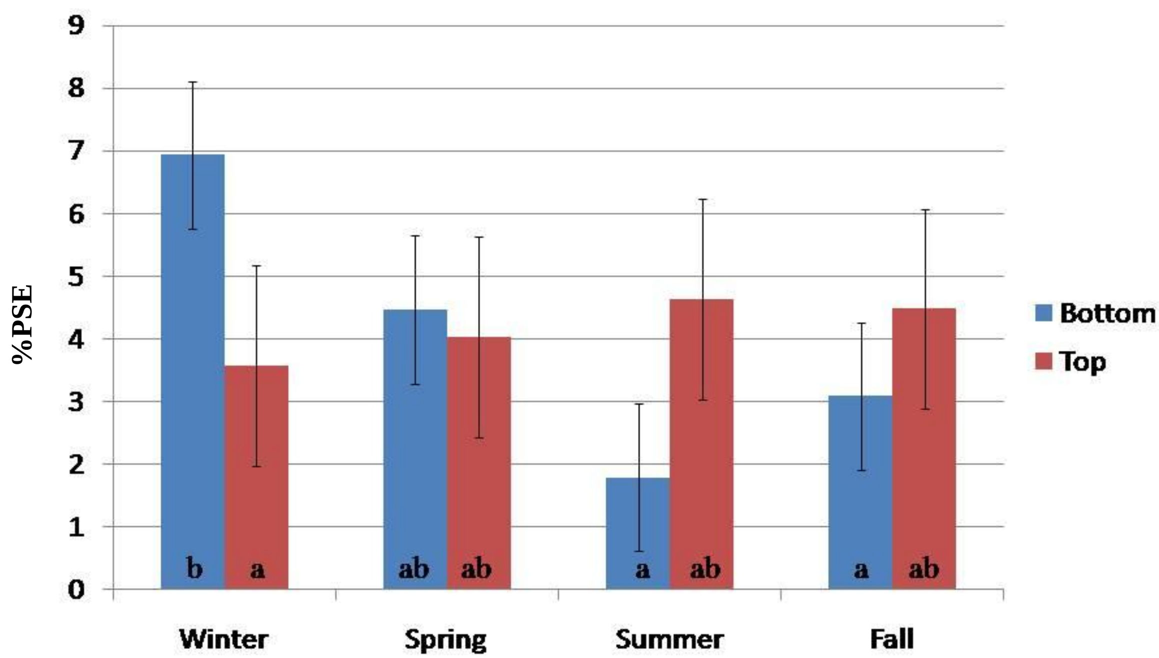
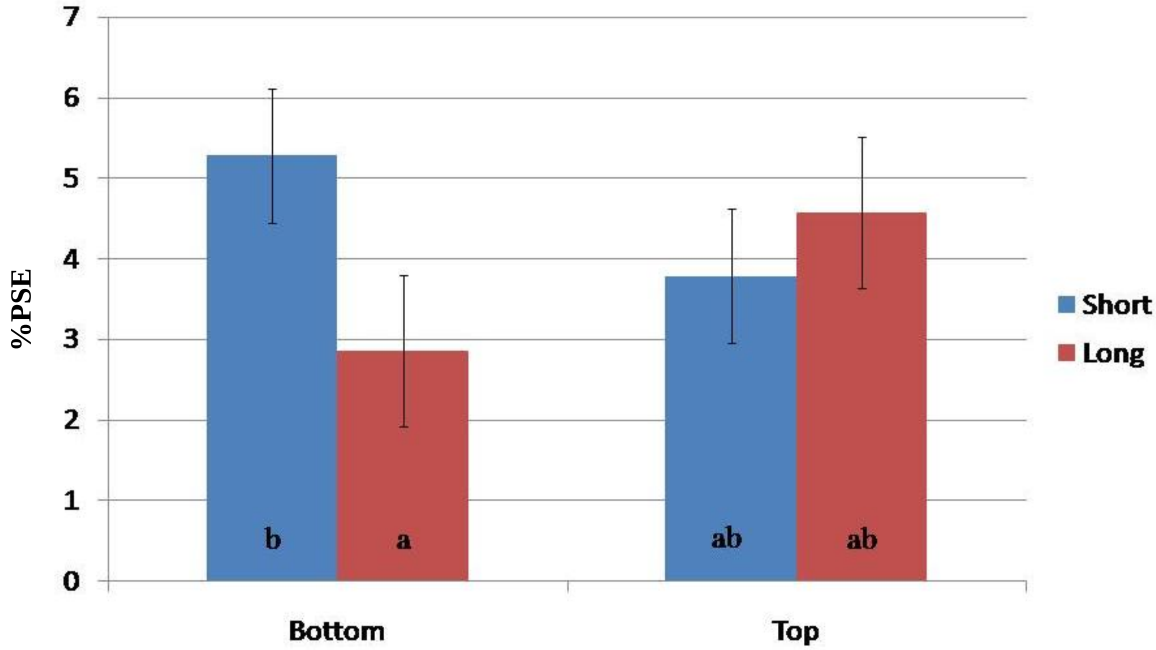


Figure 17. Least squares means and standard error bars for the frequency of occurrence of pale, soft, and exudative (PSE) classified loin muscles for top or bottom trailer deck within season; deck × season.



[1]PSE = 24h drip loss > 5% and L* value > 55

Figure 18. Least squares means and standard error bars for the frequency of occurrence of pale, soft, and exudative (PSE[1]) classified loin muscles for short (3 hours) or long (6 hours) lairage associated with trailer deck location; deck × lairage.



[1]PSE = 24h drip loss > 5% and L* value > 55

Table 1. Time schedule for pigs going to slaughterhouse.

Action	Time schedule	
	Short lairage	Long lairage
Loading pigs for long transport:	2300 – 2330h	2300 – 2330h
Loading pigs for short transport:	0130 – 0200h	0130 – 0200h
Arrival at slaughterhouse:	0500h	0500h
Begin driving to stunner:	0755h	1055h
Slaughter:	0800h	1100h

Table 2. Account of pig welfare conditions during trailer unloading for the main effects of season, transport duration, trailer deck, and deck × season.

Main effect	**Slows**	**Deads**
Season		
Winter	7	2
Spring	3	2
Summer	7	1
Fall	3	3
Transport Duration		
Long haul (6 hours)	9	6
Short haul (3 hours)	11	2
Trailer deck		
Bottom	12	5
Top	8	3
Deck × Season		
Winter – Bottom deck	4	1
Winter – Top deck	3	1
Spring – Bottom deck	1	1
Spring – Top deck	2	1
Summer – Bottom deck	6	0
Summer – Top deck	1	1
Fall – Bottom deck	1	3
Fall – Top deck	2	0

Table 3. Least squares means (standard error) for main effects of season, top or bottom deck, long (6h) or short (3h) haul duration, short (3h) or long (6h) lairage.

	Season (S)				Deck (D)		Haul (H)		Lairage (L)			
	Winter	Spring	Summer	Fall	Bottom	Top	Long	Short	Long	Short	Signif	Intrxn[1]
Cortisol, ng/ml	86.35^{a} (2.24)	89.05^{a} (2.62)	101.24^{b} (1.84)	119.69^{c} (2.59)	98.13 (1.48)	100.03 (1.70)	103.01 (1.54)	95.16 (1.65)	98.92 (1.45)	99.24 (1.78)	<0.001 0.380 <0.001 0.888	S×L H×L S×D×H
pH	5.64^{a} (0.007)	5.69^{bc} (0.009)	5.67^{b} (0.009)	5.71^{c} (0.009)	5.68 (0.005)	5.67 (0.006)	5.68 (0.005)	5.67 (0.006)	5.66 (0.006)	5.69 (0.006)	<0.001 0.491 0.315 0.002	D×H S×L
Drip, %	3.02^{c} (0.09)	3.18^{c} (0.08)	1.84^{a} (0.08)	2.56^{b} (0.11)	2.59 (0.06)	2.71 (0.07)	2.67 (0.06)	2.63 (0.07)	2.66 (0.06)	2.64 (0.06)	<0.001 0.163 0.596 0.859	S×D S×H
L*	53.38^{d} (0.12)	51.79^{a} (0.11)	52.34^{b} (0.11)	52.85^{c} (0.15)	52.56 (0.08)	52.63 (0.09)	52.50 (0.08)	52.68 (0.09)	52.71 (0.08)	52.46 (0.09)	<0.001 0.579 0.104 0.037	S×H
Saturation	17.88^{b} (0.04)	17.30^{a} (0.04)	17.88^{b} (0.04)	17.91^{b} (0.05)	17.76 (0.03)	17.73 (0.03)	17.74 (0.03)	17.75 (0.03)	17.64 (0.03)	17.85 (0.03)	<0.001 0.511 0.781 <0.001	S×L
Hue Angle	22.66^{a} (0.12)	19.57^{b} (0.11)	20.12^{c} (0.11)	20.95^{d} (0.15)	20.81 (0.08)	20.84 (0.09)	20.70 (0.08)	20.95 (0.09)	20.66 (0.08)	20.99 (0.09)	<0.001 0.796 0.036 0.004	S×H S×L
PSE, %	5.26 (0.87)	4.26 (0.78)	3.21 (0.78)	3.78 (1.04)	4.07 (0.57)	4.18 (0.65)	3.81 (0.58)	4.45 (0.64)	4.53 (0.89)	3.72 (0.62)	0.364 0.896 0.456 0.3288	S×D D×L

[1]Significant (P < 0.05) interaction terms

Table 4. Simple correlation coefficients, level of significance, and number of observations (n) for serum concentration of cortisol and all fresh pork quality variables.

	pH	**%Drip**	**L***	**a***	**b***	**Saturation**	**Hue angle**
Cortisol	0.1641	-0.0293	-0.0310	0.1294	0.0684	0.1306	0.0197
	< 0.001	0.186	0.159	< 0.001	0.002	< 0.001	0.370
	1994	2031	2063	2065	2067	2064	2064
pH		-0.2867	-0.4872	-0.0389	-0.3365	-0.1417	-0.3497
		< 0.001	< 0.001	0.073	< 0.001	< 0.001	< 0.001
		2080	2115	2117	2119	2116	2116
%Drip			0.3982	0.0713	0.2833	0.1532	0.2838
			< 0.001	0.001	< 0.001	< 0.001	< 0.001
			2333	2335	2337	2334	2334
L*				-0.1484	0.6167	0.0822	0.7213
				< 0.001	< 0.001	< 0.001	< 0.001
				2429	2430	2428	2428
a*					0.3560	0.9482	0.0021
					< 0.001	< 0.001	0.917
					2432	2432	2432
b*						0.6329	0.9328
						< 0.001	< 0.001
						2432	2432
Saturation							0.3163
							< 0.001
							2432