THE EFFECTS OF GENOTYPE, CHROMIUM PICOLINATE SUPPLEMENTATION, SEX, AND THEIR INTERACTIONS ON GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, AND MUSCLE QUALITY IN PIGS

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Abstract

Halothane Gene, Chromium Picolinate Supplementation, and Sex Effects on Growth Performance, Carcass Traits, and Muscle Quality Characteristics in Pigs

Two trials (n = 160) were conducted to evaluate the effects of the halothane gene, chromium picolinate supplementation, and sex on growth performance, carcass characteristics, and meat quality in pigs. Halothane negative (NN) and halothane carrier (Nn) pigs (barrows, gilts) were supplemented with either 0 or 200 ppb chromium picolinate from 28.7 to 107.3 kg. There were no differences between genotypes for ADG or G/F. Chromium had no significant effect on any growth, carcass, or muscle quality characteristics, although chromium-fed pigs were slightly fatter.

Barrows gained faster ($P < .001$) and consumed more feed ($P < .001$) than gilts, yielding heavier ($P < .001$) carcasses, and heavier ($P < .05$) wholesale cuts. Gilts had less backfat ($P < .001$) and larger ($P < .01$) LMA, and tended to gain more efficiently than barrows.

Carrier pigs had lower pH values, higher CIE L* values, higher drip loss, and lower protein solubility ($P < .05$), all indicators of decreased quality. Chromium supplementation resulted in pork with higher ($P<.05$) CIE a*, CIE b*, and Chroma C values. Halothane carrier barrows and all gilts that were not fed chromium had lower lipid muscle content than NN barrows ($P < .05$).

Gilts had higher CIE L* and a* values ($P < .001$), less lipid, and higher moisture percentage ($P < .02$) than barrows. Chromium picolinate did not negatively affect pork muscle quality.

Key words: Pigs, Pork Quality, Halothane, Chromium Picolinate, Sex

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Chapter 1

Introduction

One of the biggest challenges for the U.S. swine industry is to provide a consistent, quality product to the consumer. In recent years, the industry has been striving to meet consumer demand for leanness by developing genotypes that produce a higher percentage of lean pork. Unfortunately, many heavily muscled, lean pigs produce lower quality retail cuts (Kauffman et al., 1994). Problems associated with these pigs include pork that is lighter in color, less firm, lower in water holding capacity, and less marbled than normal. Pale, soft, and exudative (PSE), and red, soft, and exudative (RSE) pork are quality classifications that describe some of these quality problems. Kauffman et al. (1992) reported that in 1991, the U.S. pork supply contained approximately 16% PSE pork and nearly 60 % RSE pork. Dark, firm and dry (DFD) pork is also a problem in the industry, but has a lower overall incidence than PSE or RSE pork. The high occurrence of these undesirable qualities has the potential to create a negative perception of pork for the consumer. Thus, there is a growing need to determine which factors affect pork muscle quality.

As research reveals more about genetics, environment, and nutrition, more consistent management of these factors should produce a more desirable, quality product for the consumer. A major genetic contributor to lower quality pork is the so-called halothane gene. A considerable amount of research has been conducted to ascertain the

effects of the halothane gene on growth, carcass characteristics, and pork quality. When the gene occurs in the homozygous recessive form (nn), pigs are often susceptible to Porcine Stress Syndrome (PSS), which affects the live pig in the form of malignant hyperthermia and the carcass by reducing the quality of pork. When the live PSS pig is exposed to stress, malignant hyperthermia causes the pig's temperature and muscle metabolism to increase, resulting in an increase in glycolysis (Christian and Mabry, 1990). Increased glycolysis produces large amounts of lactic acid in the muscle. Normal pigs can control increases in lactic acid via aerobic and anaerobic metabolism, but stress-susceptible pigs lose this ability when the increased metabolism depletes the oxygen and converts ATP to adenosine diphosphate (Backstrom and Kauffman, 1995). Many stress-susceptible pigs die when exposed to stress and pigs that survive to slaughter often produce a high percentage of PSE pork.

The halothane gene has shown some potential benefits including increased meatiness, improved feed efficiency, and decreased backfat when it occurs in the heterozygous (Nn) form (Zhang et al., 1992). Researchers have obtained differing results on the effect of the halothane gene on muscle quality, however. Some research has shown that heterozygous pigs produced pork of acceptable quality, similar to that of halothane normal (NN) animals (van Laack et al., 1993), but other research has shown Nn pigs to produce carcasses with a considerably higher percentage of PSE pork than halothane negative animals (Goodwin, 1994; Leach et al., 1996).

Studies have also been conducted to determine the effects of nutritional supplements on carcass composition and pork muscle quality characteristics. Porcine somatotropin (pST), vitamin E, and ractopamine have shown potential for improving

leanness in pork carcasses. Another dietary supplement to show potential for affecting carcass characteristics is chromium tripicolinate (CrP). Page et al. (1993) and Boleman et al. (1995) reported that dietary supplementation of CrP increased muscle in pork carcasses by 3 to 4%, and increased loin muscle area by 10 to 20%, while decreasing total carcass fat. Wang et al. (1994) reported that chromium supplementation of swine diets had no effect on muscle quality, but there is minimal research in determining the effects of CrP on muscle quality. CrP is approved for use in swine diets, but the other additives mentioned have not been approved. Additionally, the interactive effects of the halothane gene and CrP supplementation have yet to be ascertained.

The objectives of this research were to determine the interactive effects of the halothane gene, dietary chromium picolinate supplementation, and sex on swine growth performance, carcass composition characteristics, and quality characteristics of pork.

Literature Cited

Backstrom, L. and R. G. Kauffman. 1995. The porcine stress syndrome: a review of genetics, environmental factors, and animal well-being implications. Agri-Practice 16:24-30.

Boleman, S. L., S. J. Boleman, T. D. Bidner, L. L. Southern, T. L. Ward, J. E. Pontif, and M. M. Pike. 1995. Effect of chromium picolinate on growth, body composition, and tissue accretion in pigs. J. Anim. Sci. 73:2033-2042.

Christian, L. L. and J. W. Mabry. 1990. Stress susceptibility of swine. In: Genetics of Swine. pp. 49 - 69. National Pork Producers Council, Des Moines, IA.

Goodwin, R. N. 1994. Genetic parameters of pork quality traits. Ph.D Dissertation, Iowa State Univ., Ames.

Kauffman, R. G, R. D. Warner, and S. T. Joo. 1994. One Step Closer to Providing Ideal Pork Quality for Consumers in 1994. Part V: Genetics. In: Pork Chain Quality Audit. p 115. National Pork Producers Council, Des Moines, IA.

Kauffman, R. G., R. G. Cassens, A. Scherer, and D. L. Meeker. 1992. Variations in pork quality. National Pork Producers Council, Des Moines, IA.

Leach, L. M., M. Ellis, D. S. Sutton, F. K. McKeith, and E. R. Wilson. 1996. The growth performance, carcass characteristics, and meat quality of halothane carrier and negative pigs. J. Anim. Sci. 74:934-943.

Page, T. G., L. L. Southern, T. L. Ward, and D. L. Thompson, Jr. 1993. Effect of chromium picolinate on growth and serum and carcass traits of growing-finishing pigs. J. Anim. Sci. 71:656-662.

van Laack, L. J. M., C. Faustman, and J. G. Sebranek. 1993. Pork quality and the expression of stress protein hsp 70 in swine. J. Anim. Sci. 71:2958-2964.

Wang, H., J. R. Claus, and M. D. Lindemann. 1994. Effect of supplemental dietary chromium on the characteristics of pork. (Abstr.) Institute of Food Technologists Annual Meeting, Atlanta, GA, p. 90.

Zhang, W., D. L. Kuhlers, and W. E. Rempel. 1992. Halothane gene and swine performance. J. Anim. Sci. 70:1307-1313.

Chapter 2

Literature Review

Quality Characteristics of U.S. Pork

The National Pork Producers Council's Pork Chain Quality Audit (1994) reported that fresh pork consumption accounted for only 18% of all fresh meat consumed in the U.S. in 1994. Only 23% of consumers surveyed, however, reported that they were "very satisfied" with fresh pork products. Customers participating in the audit cited the following as major concerns in the pork retail case: 46% said that there was too much color variation in the same package, 31% said that there was too much blood in the package, 31% said that there was too much liquid in the package, and 11% said that some cuts were too light in color. These consumer perceptions are a direct result of an industry wide problem: producing too much lower quality pork. In addition, lower quality fresh pork can have negative effects on further processed pork products, such as Canadian-style bacon, ham, and pork sausage. Functional properties of meat are decreased considerably for further processing when PSE pork is used (Pearson and Gillett, 1996).

Quality is also becoming an important factor in pork shipped overseas. For future increases in pork shipments overseas to occur, the consistency of our product must be addressed more directly by the pork industry. Paleness in color, two toned cuts, and poor water holding capacity have been recent complaints about U.S. pork from Japanese buyers (NPPC, 1994). Though most major U.S. packers pay on lean yield and not quality, it is likely that a pricing system based on consistency and quality attributes will be implemented

in the near future (NPPC, 1994). This is driven by the fact that yields (and ultimately profits) for the processor are decreased for both fresh and processed when dealing with lower quality pork.

To stay competitive with the other major muscle foods and meet consumer demands, the U.S. pork industry will need to improve the overall quality of both fresh and further processed products.

Optimum Quality Characteristics

Kauffman et al. (1994) indicated that ideally pork must have a bright reddish pink color, be free of surface exudate and firm in appearance and have adequate marbling (visible intramuscular fat). Marbling contributes to flavor, juiciness, and tenderness of the final cooked product, but the desired amount of marbling is quite subjective. DeVol et al. (1988) recommended a minimum of 2.5 to 3.0 % marbling for acceptable tenderness and juiciness. Water retention of pork must also be high to provide for juiciness and tenderness of the product after cooking. High water retention also contributes to higher yields in processed products. Obviously, pork must also be free of contaminants that could pose health risks for the consumer.

Combining all of these aspects, a basis for 'ideal' pork quality can be obtained by using a classification of red, firm, and non-exudative (RFN) to most closely describe an ideal wholesale or retail cut (Kauffman et al., 1992). Most importantly, pork quality should be defined as consumer satisfaction (NPPC, 1994).

Color and Water Holding Capacity of Fresh Pork

Color

Muscle color depends upon the amounts and distribution of the various muscle pigments. The main pigments found in muscle are hemoglobin (Hb) and myoglobin (Mb) (Stryer, 1995). Hemoglobin, the pigment of blood, is a tetrameric, globular heme protein that carries oxygen to the cells in the body (Fox, 1987). Fox (1987) determined that 20 to 30 % of the total pigment in a live animal is Hb. Because hemoglobin is located within the red blood cells, the majority of it is lost during exsanguination at slaughter. Improper exsanguination can leave a residual level of hemoglobin in the carcass that could affect the muscle color, however.

Myoglobin, the major pigment of the muscles, is a monomeric globular heme protein which is a single polypeptide chain of 153 amino acids with a mass of 18 kd (Horton et al., 1993). The myoglobin molecule is composed of an atom of iron surrounded by an array of pyrrole rings. The iron enables myoglobin to gain (reduction) or lose (oxidation) electrons. Myoglobin, found in highest concentration in red muscle cells, has a primary function to transfer oxygen from hemoglobin to the muscle cell. Myoglobin is responsible for the majority of the meat color and comprises 50 to 80% of the total muscle pigments (Fox, 1987). Differences in fresh meat muscle color depends primarily on the concentrations and distribution of the three types of myoglobin. The three forms are purplish-red deoxymyoglobin, bright red oxymyoglobin and brown metmyoglobin (Broumand et al., 1958). The purplish-red deoxymyoglobin is the color of meat in the absence of oxygen (DMb), bright red oxymyoglobin is the color in the

presence of oxygen (OMb), and brown metmyoglobin (MMb) is the color as a result of oxygenation of the iron atom at low partial pressures of oxygen.

Color differences between species are due primarily to Mb concentration. Pork muscle has the lightest color of the red meat species due to lower concentrations of Mb (Fox, 1987). Muscles that are used frequently (such as the ham and leg muscles) tend to have a darker red color due to higher concentrations of myoglobin. In pork, different levels of myoglobin in different muscles affect the overall muscle color. Topel et al. (1966) reported 2.87 mg/g of myoglobin in pork *Longissimus dorsi* and 6.37 mg/g in pork *Psoas major*.

Color also depends on the types of fibers within the muscles. Red fibers with higher concentrations of myoglobin are darker in appearance while white fibers with lower concentrations of myoglobin are lighter in appearance. The percentage of red (oxidative) fibers has decreased and the mean fiber diameter has increased with the high degree of selection in domestic pigs (Rust and Olson, 1973).

Water Holding Capacity

Water holding capacity (WHC) is the ability of meat to hold all or part of its own and/or added water (Honikel and Hamm, 1994). Offer et al. (1989) indicated that WHC of meat is determined by several factors, including pH, sarcomere length, protein denaturation, and intra and interfascicular spacing. Fresh pork contains 75% water. Approximately 85% of this water is intracellular (Hamm, 1975). The intracellular water is located primarily between the thick and thin filaments (Offer and Trinnick, 1983) and the remaining water (15%) is located in extracellular spaces. Water holding capacity

determination methods differ in technique and the values can vary significantly among methods (Trout, 1988; Warner, 1994). Several intrinsic factors also affect WHC, including muscle (Warner, 1993), breed (Goodwin, 1994), and marbling (Trout, 1988). Joo et al. (1995) reported that drip loss (a form of measuring WHC) was higher for PSE and RSE pork when compared to DFD and RFN pork.

Pale, Soft, and Exudative Pork

Typical PSE pork is pale gray to white in color, has a soft texture, and exhibits excessive fluid loss from the muscle. The incidence of PSE meat is high in animals with Porcine Stress Syndrome (PSS), but also occurs in some normal pigs (Grandin, 1994). Immediately after slaughter, PSE-producing animals tend to have a high rate of anaerobic glycolysis, due to muscles becoming anaerobic when the animal's blood (and oxygen) supply is terminated. The biochemical reactions in the muscle tissue take place rapidly and heat is generated in the muscle tissue. Under normal circumstances the carcass temperature declines after stunning and prior to chilling. In some pig carcasses, however, the muscle after slaughter exhibits an increase in temperature above that of the physiological temperature of the live animal (Backstrom and Kauffman, 1995). These biochemical and histological processes are especially characteristic of the *biceps femoris* and *longissimus dorsi*. These two muscles exhibit a higher initial glycogen concentration, lower myoglobin concentration, and generally a lower intramuscular fat percentage (Briskey and Wismer-Pedersen, 1961). The higher glycogen concentration in these muscles can convert to high percentages of lactic acid during glycolysis, thus decreasing muscle pH and degrading the proteins to cause PSE pork.

Pigs that experience short-term stress prior to slaughter are often most susceptible to PSE pork (Pearson, 1987). These short-term stresses include travel, handling of the animals, and fasting. Resting pigs prior to slaughter has been shown to decrease the incidence of PSE pork compared to those pigs that are slaughtered immediately upon arrival at the plant (Grandin, 1994).

Temperature. Temperature can play an important role in the development of the PSE condition in pork carcasses (Bendall and Wismer-Pedersen, 1962; Bendall and Swatland, 1988). Faustman and Cassens (1990) reported that biochemical reaction rates can double with each 10^{o} C increase in temperature. In PSE muscles, biochemical reactions post-mortem can cause carcass temperatures to be higher than the temperature of the live animal because of the glycolysis (conversion of glycogen to lactic acid) taking place. Bendall (1973) discovered that the hydrolysis of creatine phosphate and ATP in the pork carcass also generates heat. All of these reactions together can cause the carcass temperature to increase by as much as 3^{o} C. Elevated muscle temperature can contribute to rapid denaturation of myosin before ultimate pH is attained (Bendall and Wismer-Pedersen, 1962), resulting in PSE pork. Fernandez and Tornberg (1994), however, determined that a minimum pH value must be attained at a given temperature to induce enough protein denaturation to result in PSE characteristics.

Rate of pH Decline. There has been some question about how the rate of pH decline affects quality characteristics of pork. The normal rate of pH decline for pork carcasses is about 0.01 units per minute between initial pH and ultimate pH, corresponding to a rigor time of approximately 150 minutes (Offer, 1991). Offer (1991) also indicated that a carcass with mild PSE has a rate of pH decline of about 0.02 units per

minute while an extreme PSE carcass would show a pH decline of 0.1 units per minute. In this extreme case, rigor is achieved in only 15 minutes compared to the normal time of approximately 150 minutes.

However, Offer (1991) reported that PSE meat occurred if the extent of, rather than the rate of, glycolysis is large. This results in a lower ultimate pH regardless of the rate that pH fell.

Ultimate pH. In PSE pork, ultimate pH value is obtained while the carcass is still warm. This is due to the increased glycolysis resulting in excessive lactic acid production. This contributes to the denaturation of sarcoplasmic and myofibrillar proteins (Wismer-Pedersen, 1959). *Longissimus dorsi* muscles in swine with an ultimate pH of 5.5 or below often result in PSE meat (Joo et al., 1995).

Protein Denaturation. Fernandez and Tornberg (1994) discovered that denaturation of both sarcoplasmic and myofibrillar proteins depends on the balance between temperature and pH. When temperature is high and pH is low, then muscle proteins can rapidly degrade.

Solubility of proteins in PSE pork is generally lower than normal pork. Warner (1994) stated that PSE pork showed a sarcoplasmic protein solubility of 28% less than RFN pork. Warner (1994) also determined that PSE pork has lower myofibrillar protein solubility than RSE, RFN, or DFD pork. In that study, 58% fewer proteins were solubilized in PSE pork when compared to RFN pork. Decrease in solubility of the myofibrillar proteins is caused by the reduced extraction of myosin (Kauffman, 1996). Myosin denatures quickly in PSE meat that can often have a pH of 5.5 or lower and temperatures of 40 ^{o} during anaerobic glycolysis (Penny, 1967). In addition, sarcoplasmic

proteins (creatine kinase and phosphorylase) are present with myosin extractions in PSE pork, suggesting they could be instrumental in the formation of PSE pork. Phosphorylase, for example, binds to the myofibril due to a combination of low pH and high muscle temperature in pre-rigor muscle.

Red, Soft, and Exudative Pork

RSE pork is a relatively new quality category class and there is still much to be learned about what contributes to the formation of it. Generally, water loss and meat color are highly correlated, but some research (van Laack and Solomon, 1994) indicates that the two could be somewhat independent of each other. RSE pork illustrates this concept well. Even though color is similar to RFN (ideal) pork (Table 1), RSE pork generally has a higher drip loss percentage. Warner (1994) proposed that the increased drip loss in RSE pork was related to the reduction in myofilament lattice spacing at a lower pH.

Warner (1994) stated that both myofibrillar and sarcoplasmic protein solubility differences were not statistically different between RSE and RFN classes of pork. Numerically, RSE showed a lower solubility. This study showed that the sarcoplasmic proteins creatine kinase and phosphorylase are degraded to a similar extent in RSE pork. More research needs to be conducted to determine the causes of RSE pork as well as the major biochemical differences between RSE and PSE pork.

The Effects of PSE Pork on Further Processed Meats

PSE pork produces products with lower yields and reduced functionality. It is well known that proteins that have been damaged in PSE pork have poor emulsifying and binding properties (Pearson and Gillett, 1996). This can substantially decrease the value and appearance of further processed meats.

Kauffman et al. (1978) showed that commercially pumped hams made with PSE pork displayed a higher percentage shrink during transportation and processing than normal hams. Knipe (1995) showed that Canadian-style bacon processed with 100% PSE pork had lower processing yields, were paler in color and less firm, had poorer sliceability, and were less acceptable to a consumer sensory panel than Canadian-style bacon made with 100% normal quality pork muscle.

Methods of Assessing Pork Quality

Most quality characteristics of pork in the U.S. are measured post-mortem. Major variables important to assessing pork quality post-mortem include water holding capacity, color, protein denaturation, and pH. The incidence and extent of each of these measured characteristics is related to the amount of PSE pork.

Water Holding Capacity

Various methods have been used for assessing WHC in pork muscle. In the past, visual assessment of WHC has been commonly used (NPPC, 1991). Usually, surface area of an exposed muscle is observed and then assessed according to amount of surface water

or drip. Although this method can be fairly accurate with highly trained personnel, it is considered to be too subjective to personal opinion and preference to be accurate.

One widely used objective measurement is the drip loss method (Honikel, 1987). This procedure involves placing a muscle sample in a plastic bag (or sealed container) 24 h postmortem, suspending it at 2 C for 48 h, then removing it from the bag, blotting the fluids off the sample with a paper towel, and measuring the gravimetric weight loss.

Color Assessment

Color is a major criterion that consumers use to judge whether a cut of meat is acceptable for quality (Cornforth, 1994). Consumers expect to see pinkish-gray pork and any deviation of this can result in lost sales. Cornforth (1994) estimated that 4 to 10% of retail muscle cuts are discounted or discarded due to unattractive color.

The color of pork generally depends upon pigment concentration (primarily myoglobin), the chemical state of the myoglobin, and the extent of light scattering. Assessing the color of meat is a result of measuring reflectance and absorbance of light. Common methods of measuring color include CIE L* a* b* and reflectance spectrophotometry. The CIE measurements describe hue value and chroma C while reflectance spectrophotometry is used to predict the various chemical states of myoglobin (AMSA, 1991).

Protein Denaturation

Proteins are denatured more in PSE pork than in normal pork and as proteins are denatured more, they become less soluble (Penny, 1967). Warner (1994) developed a

procedure for measuring the solubility of sarcoplasmic and myofibrillar proteins. In this method, a potassium phosphate buffer is added to small, minced or ground samples of the *longissimus dorsi*. Solubility is determined by the biuret method after the samples are pulverized, shaken for 3 h, and centrifuged.

pH

Measuring rate of pH decline can help to determine the rate and extent that proteins denature in the meat. Measuring ultimate pH (pH at 24 h post-mortem) can help to determine and classify quality classes of pork as well (Table 1). The extent of the pH decline (ultimate pH) can help to determine incidence of PSE pork because lower ultimate pH values are associated with PSE pork (Bendall and Swatland, 1988). Ultimate pH is a useful quality indicator because it can be measured easily with a solid-state electrode in a processing plant immediately prior to fabrication. Low processing plant temperature, however, must be taken into account because it can affect the accuracy of pH measurements (Kauffman and Warner, 1993).

Timing of Quality Measurements

Timing of pork quality assessment is quite important. In commercial slaughter plants, it is much easier to assess quality differences prior to chilling because the carcass can still be easily identified at that point (Kauffman et al., 1992) and plant personnel could sort carcasses according to quality, composition, and weight. This would assist in preparing the product for possible further processing, and distribution of appropriate quality categories to specific customers. If quality measurements are assessed early post-

mortem prior to chilling, however, some of the quality properties are not yet fully expressed physiologically and are not accurate indicators of ultimate quality (Kauffman et al., 1992). For example, the quality attributes of color, exudate, firmness, and marbling are best assessed on the surface of a cut muscle, preferably the loin (*longissimus thoracis et lumborum*) and ham muscles (*semimembranosus, gluteus medius, biceps femoris, and semitendinosus*) at 24h post mortem (Warner, 1993). Therefore, although it would be convenient to measure quality prior to chilling, most pork quality measurements are done on the surface of these cut muscles after chilling and and cutting has taken place.

Quality Categories of Pork

Pale, soft, and exudative pork has been recognized as a quality classification for many years. In recent years, however, new quality categories of pork have been suggested (Kauffman et al., 1992; Warner, 1994; Joo et al., 1995). The newest category that is of major concern in the U.S. pork supply is RSE (red, soft, and exudative) pork. This type of pork is similar to RFN (red, firm, and non-exudative pork) in color, but loses additional water. PFN (pale, firm, and non-exudative) is another new quality category of pork, but occurs rarely (Kauffman et al., 1993). The characteristics of the most common quality classes of pork are listed in Table1.

Table 1. Quality categories of pork and their characteristics[a]

Category	Ultimate pH	Drip loss, %	Color - CIE L*
PSE[b]	<5.5	>8.0	>50
RSE[c]	<5.6	>5.0	43 - 50
RFN[d]	5.6 - 5.9	<5.0	43 - 50
DFD[e]	>6.0	<2.0	<43

[a](Joo et al., 1995).
[b]PSE = Pale, soft, and exudative.
[c]RSE = Red, soft, and exudative.
[d]RFN = Red, firm, and non-exudative; 'Ideal'.
[e]DFD = Dark, firm, and dry.

There are various factors, both ante and postmortem, that can affect the ultimate quality characteristics of pork. Genetics, nutrition, pre-slaughter handling, fasting, carcass temperature during slaughter, and carcass chilling rate can all affect pork muscle quality. The focus of this next section will be on the effect of the halothane gene and chromium picolinate on carcass composition and muscle quality.

The Halothane Gene

A major genetic contributor to lower quality pork is the halothane gene (HAL). The halothane gene is a single autosomal gene that affects a wide range of production traits in swine. The gene is expressed equally in both sexes and is inherited as a recessive trait. The halothane gene received its name from the halothane gas stress test. When exposed to halothane gas, a heavy metal anesthesia, approximately 95% of pigs homozygous for HAL (nn) demonstrate limb rigidity (Reik et al., 1983). Fujii et al. (1991) developed a DNA assay test to identify the halothane gene in pigs. This method can be used to identify both halothane positive (nn) and carrier (Nn) animals.

The halothane gene can affect live animal performance as well as carcass and meat quality traits in pigs. Halothane positive pigs are known to be leaner and have larger loin muscles (Christian and Mabry, 1990), but often have poorer growth characteristics (Goodwin, 1994). Carrier pigs have similar growth characteristics but have a larger amount of lean meat content in the ham, loin, and the carcass as a whole (Leach et al., 1996). Goodwin (1994) indicated that the halothane gene increases leanness in pig carcasses by 1 to 2% per copy of the gene.

The halothane gene also has some negative effects. Porcine stress syndrome (PSS) is controlled by the halothane gene (Reik et al., 1983). PSS pigs are easily excitable and usually develop malignant hyperthermia (MH) when exposed to stress. Malignant hyperthermia is an inherited myopathy signified by hypermetabolism, increased body temperature, and muscle contractions. Pigs with PSS have a greater likelihood of sudden death in response to stresses such as transport and fighting (Christian and Mabry, 1990).

Porcine Stress Syndrome

When a live animal is exposed to stress, stress hormones (catecholamines) are released and muscle metabolism and glycolysis increases. This causes an increase in the conversion of glycogen to lactic acid (Backstrom and Kauffman, 1995). For normal pigs, the muscle pH declines from 7.3 to 6.9 as a result of the increase in lactic acid production. Adenosine triphosphate (ATP) provides enough energy to convert this extra lactic acid into carbon dioxide and water, and the normal muscle pH would soon return.

In stress susceptible animals, however, lactic acid cannot be so easily controlled. These animals have an abnormal calcium ion homeostasis, and when exposed to stress, the

sarcoplasmic reticulum releases excess calcium ions due to depolarization of striated muscle (Vogeli et al., 1992). This causes muscle contraction and an increase in glycolysis that is difficult for the animal to regulate. Oxygen consumption can increase as much as three-fold at this point and lactate and potassium in the blood can increase as much as 15-fold, inducing hyperthermia in which body temperature can reach 41^{o}C or greater (Backstrom and Kauffman, 1995). The increase in the release of calcium ions also induces energy loss by stimulating ATP to transform to adenosine diphosphate (ADP) and adenosine monophosphate (AMP) (Mickelson and Louis, 1992). Many animals die at this point due to increased acidosis, vasoconstriction, hypertension, and decreased cardiac output (Backstrom and Kauffman, 1995). The pigs that don't die in response to MH often produce PSE meat.

Heterozygous (Nn) animals do not express PSS as readily as homozygous recessive pigs (nn) (Vogeli et al., 1992) but still produce a high percentage of PSE meat (McPhee and Trout, 1995). Not all nn pigs exhibit PSS when stressed, however, demonstrating that the HAL gene does not have complete penetrance (van Laack and Solomon, 1994). Also, Pommier and Houde (1992) reported that PSE pork does not result only from PSS, but PSS can increase the severity of the PSE condition.

HAL Effects on Growth and Carcass Composition

Heterozygotes have been identified as intermediate between homozygous positive and negative pigs for traits such as leanness, amount of muscle, and growth rate (Zhang et al., 1992). Leach et al. (1996) reported no difference in gain between NN and Nn pigs, but gain:feed was higher for heterozygotes, resulting in a savings of approximately 21 kg

of feed per pig between 40 and 125 kg. Heterozygotes also displayed heavier chilled carcass weights and an increased dressing percentage compared to halothane-free pigs. McPhee and Trout (1995) reported intermediate results of Nn pigs for carcass length, loin muscle area, and dressing percentage. Goodwin (1994) reported that halothane carrier pigs had larger loin muscle areas, and 0.5% greater yield for dressing percentage than halothane free pigs. Decreased backfat has been reported for both Nn and nn animals (Zhang et al., 1992; Goodwin, 1994). Fisher et al. (1994), however, reported no significant differences among the three halothane genotypes in backfat depth. McPhee and Trout (1995) reported positive HAL effects on carcass traits including backfat and overall reduction of fatness on the carcass, but a less significant difference was obtained than what was expected. Simpson and Webb (1989) reported that under different feeding regimes, heterozygotes provided a net economic advantage. McPhee and Trout (1995) reported that the effect of the halothane gene for increasing lean content would not be enough to offset its negative effect on muscle quality characteristics, however.

HAL Effects on Meat Quality

Research has revealed varied results in meat quality characteristics for pigs that are heterozygous at the halothane locus (Nn). van Laack et al. (1993) reported acceptable quality characteristics (similar to that of NN pigs) for halothane carrier pigs. Goodwin and Christian (1994) reported that meat from NN pigs showed superior quality over both Nn and nn pigs. Sather et al. (1991) reported extreme cases of PSE in Nn animals. Other research indicates intermediate quality characteristics for Nn animals (Lundstrom et al., 1989; De Smet et al., 1992; Cheah et al., 1994).

Some recent studies have determined that meat quality characteristics can be negatively affected for normal (NN) pigs when preslaughter handling methods are inappropriate (Heinze and Mitchell, 1991; Karlsson and Lundstrom, 1992; Martoccia et al., 1995). Pommier and Houde (1993) concluded that preslaughter handling conditions must be improved to reduce the incidence of lower quality pork from animals with either one or two copies of the halothane gene.

pH. Leach et al. (1996) reported lower pH values at 45 minutes (initial pH) and 24 h (ultimate pH) after slaughter for the *Longissimus thoracis* muscle of Nn pigs when compared to NN animals. Fisher et al. (1994) reported initial pH differences between the three genotypes (NN=6.3, Nn=5.9, and nn=5.4). In contrast, Lundstrom et al. (1989) reported no difference in pH_u among NN, Nn, and nn pigs, but later reported lower pH_u values for pork from Nn pigs when compared to NN pigs. Henckel et al. (1992) reported that final pH in NN animals was significantly higher than in the other two genotypes.

Henckel et al. (1992) reported that the pH drop may be induced *in vivo* before the animal is slaughtered due to stresses such as transport and handling procedures. However, pigs that experience long term stress (such as extensive handling, fasting, and long transportation) can produce darker pork with a higher pH (Kauffman, 1996). McPhee and Trout (1995) reported an initial pH of 5.96 in nn pigs while Nn pigs were 6.23 and NN pigs were 6.40. The pH decline for these nn pigs was small to an ultimate pH of 5.90, and they produced no PSE pork. These results could likely have been related to long-term handling stresses on the animal prior to slaughter.

Water Holding Capacity. Studies have shown that both carrier and homozygous positive pigs exhibit increased drip loss percentage in fresh porcine longissimus muscle

(Leach et al., 1996; DeSmet et al., 1996). van Laack et al. (1993) reported that WHC was less in both nn and Nn animals in the longissimus muscle but there was no difference among the genotypes for the semimembranosus muscle. Sather et al. (1991) reported that Nn pigs had the highest percentage of drip loss when compared to NN and nn pigs. Klont and Lambooy (1995b) found that drip loss was increased in both Nn and nn pigs when they were exposed to higher preslaughter temperatures. In addition, Klont and Lambooy (1995a) reported that when muscles of anesthetized animals were exercised by electrical stimulation for 15 minutes, NN animals had 7.7, Nn animals had 7.5, and nn animals had 9.5 percentage drip losses. This study highlights the importance of pre-slaughter handling on muscle quality in pork, regardless of genotype.

Color. It is well known that the halothane gene usually contributes to a more pale color (as measured by higher CIE L* or HunterLab L* values or subjective visual scoring) in pork *longissimus* muscle. Various studies have reported Nn or nn pigs to have inferior color when compared to NN animals (Lundstrom et al., 1989; Sather et al., 1991; Goodwin, 1994; McPhee and Trout, 1995). van Laack et al. (1993) reported color to be intermediate for Nn pigs when compared to NN and nn pigs. In contrast, De Smet et al. (1996) and Mayo Rizo (1995) reported no differences in color when comparing pork from NN and Nn pigs.

Protein Denaturation. Boles et al. (1992) reported a lower sarcoplasmic protein solubility from the muscle of nn animals when compared to NN or Nn animals. Myofibrillar protein is generally less soluble in stress positive animals as well (Bendall and Wismer-Pedersen, 1962; Boles et al., 1992). van Laack et al. (1993) reported nn animals

to have less soluble total protein (sarcoplasmic and myofibrillar) than carrier or normal pigs.

Other Effects. Lundstrom et al. (1989) determined that differences between the HAL genotypes were greater for gilts than castrates. Oliver et al. (1993) determined that heavy muscled breeds such as Belgian Landrace and Pietrain, that often contain the halothane gene, produce fresh hams with a higher incidence of PSE. In contrast, Goodwin (1994) reported that the halothane gene had the same effects on all breeds. In addition, the Rendement Napole (RN) gene is known to negatively affect pork quality traits. Enfalt et al. (1997) reported that pork from pigs carrying the RN gene had lighter color, lower pH, less soluble protein, and less water holding capacity.

Halothane potential?

It is still controversial whether or not the halothane gene can successfully be used in swine industry today. Cheah et al. (1994) suggested that Nn genotypes that exhibit superior WHC can be selected to avoid producing high percentages of PSE meat. Pigs with superior WHC could only be identified through testing after slaughter, however, so a live animal tests, such as the DNA assay for the HAL gene (Fujii et al., 1991) could not be used to accurately identify these animals. The possibility of producing higher quality carcasses with the Nn pigs could also be enhanced with appropriate pre- and post-slaughter management techniques (Grandin, 1994; Pommier and Houde, 1993). Some of these practices include gentle handling, carefully designed load out and slaughter facilities, appropriate rest time prior to slaughter, and showering pigs prior to slaughter (Grandin, 1994). If these methods were used, the economic benefits of increased muscle and

leanness of the Nn pigs could possibly be obtained without the adverse effects on meat quality (Simpson and Webb, 1989; Cheah et al., 1994).

Chromium

Chromium (Cr) is an essential nutrient that is involved with lipid and carbohydrate metabolism (Anderson, 1987; Evock-Clover et al., 1993). The effect of Cr on insulin activity could directly affect protein synthesis as well. Anderson (1987) found that Cr deficient humans often have impaired glucose tolerance and sometimes these individuals develop maturity-onset diabetes (Mertz, 1992). When adequate amounts of biologically available Cr are provided, lower amounts of insulin are required in humans to regulate blood sugar levels (Anderson, 1987). Lower insulin levels helps to prevent secondary signs of diabetes.

Mertz (1992) reported that Cr can enhance the action of insulin both in vitro and in vivo. For maximum activity in vitro, the chemical form known as Glucose Tolerance Factor (GTF) is necessary (Chang and Mowat, 1992). Currently, it is believed that the GTF consists of trivalent Cr, nicotinic acid, and some various amino acids. Generally, individuals with blood sugar regulation difficulties such as maturity onset diabetes, hypoglycemia, and hyperglycemia respond to Cr supplementation (Anderson et al., 1989). However, individuals with no glucose tolerance difficulties do not respond to supplemental Cr (Anderson, 1987). Anderson (1992) indicated that these individuals probably don't respond because they receive adequate amounts of dietary Cr.

The type of Cr supplemented can affect its overall influence. Chromium picolinate (CrP^4), first created by the United States Department of Agriculture, seems to be the most

effective supplement in both human and animal diets. Evans and Bowman (1992) noted that when CrP^4 was supplemented, insulin internalization increased in rat muscle. Chromium picolinate also increased insulin absorption in pigs (Amoikon et al., 1995). Steele and Rosebrough (1979) reported that chromium supplementation could increase breast muscle growth in turkeys. In addition, Kitchalong et al. (1995) reported that chromium supplementation reduced yield grade and tenth rib backfat in wethers.

Chromium Picolinate in Swine Diets

Recently, chromium from chromium picolinate (CrP^4) has been discovered as a possible nutritional supplement for growing swine diets (Page et al., 1993; Mooney and Cromwell, 1995; Lindemann et al., 1995). Benefits include a decrease in backfat depth, increase in muscle tissue deposition, increase in total percent carcass lean, and improved utilization of diets that are marginally deficient in protein. Page et al. (1993) reported a linear reduction in daily feed intake and an increase in daily gain for pigs supplemented with 50, 100 and 200 parts per billion (ppb) chromium picolinate. Lindemann et al. (1995) reported that chromium picolinate increased longissimus muscle area and decreased 10^{th} rib backfat in market pigs.

In contrast, Harris et al. (1995) reported no differences in daily gain, daily feed intake, gain:feed ratio, loin muscle area, or backfat depth for pigs when supplemented with chromium picolinate. Wenk et al. (1995) reported no differences in wholesale cut weights, backfat thickness, or loin muscle area in pigs supplemented with chromium. In addition, Page et al. (1993) reported no differences in growth or carcass characteristics for

their first of three experiments conducted with pigs supplemented with chromium picolinate.

Chromium and Muscle Quality

There is currently little information on how chromium affects muscle quality in swine. Wang et al. (1994) designed a study to determine possible effects of chromium on quality aspects of pork *longissimus* muscle. Chromium had no effects on cooking loss, oxidative rancidity, marbling, or moisture content. There was a slight decrease in tenderness, but it was not statistically significant. Boleman et al. (1995) determined that CrP^4 supplementation did not affect sensory or shear force values in pork. There was, however, a greater shear force needed for those pigs fed CrP^4 during growing and finishing stages compared to those fed CrP^4 during only the finishing stage of production. Wenk et al. (1995) reported that chromium-fed pigs showed no differences in intramuscular fat content.

There is potential for chromium to impact the muscle food industry in positive ways. However, information on chromium in both human and meat animals is inconsistent and more thorough research needs to be conducted to determine the full impacts of chromium supplementation in animal diets.

Literature Cited

Amoikon, E. K., J. M. Fernandez, L. L. Southern, D. L. Thompson, Jr., T. L. Ward, and B. M. Olcott. 1995. Effect of chromium tripicolinate on growth, glucose tolerance, insulin sensitivity, plasma metabolites, and growth hormone in pigs. J. Anim. Sci. 73:1123-1130.

AMSA. 1991. Guidelines for meat color evaluation. Am. Meat Sci. Assoc. and National Live Stock and Meat Board, Chicago, IL.

Anderson, R. A. 1987. Chromium. In: W. Mertz (Ed.). Trace Elements in Human and Animal Nutrition (5th Ed.). p 225. Academic Press, San Diego, CA.

Anderson, R. A. 1992. Chromium, glucose tolerance, and diabetes. Biol. Trace Elem. Res. 32:19-24.

Anderson, R.A., N.A. Bryden, M.M. Polansky, and M.P. Richards. 1989. Chromium supplementation of turkeys: Effects on tissue chromium. J. Agric. Food Chem. 37:131-134.

Backstrom, L. and R.G. Kauffman. 1995. The porcine stress syndrome: a review of genetics, environmental factors, and animal well-being implications. Agri-Practice 16:24-30.

Bendall, J. R. 1973. Postmortem changes in muscle. In: G. H. Bourne (Ed.). The Structure and Function of Muscle. Academic Press, New York.

Bendall, J. R. and H. J. Swatland. 1988. A review of the relationships of pH with physical aspects of pork quality. Meat Sci. 24:85-126.

Bendall, J.R. and J. Wismer-Pedersen. 1962. Some properties of the fibrillar proteins of normal and watery pork muscle. J. Food Sci. 27:144-159.

Boleman, S.L., S.J. Boleman, T.D. Bidner, L.L. Southern, T.L. Ward, J.E. Pontif, and M.M. Pike. 1995. Effect of chromium picolinate on growth, body composition, and tissue accretion in pigs. J. Anim. Sci. 73:2033-2042.

Boles, J. A., F. C. Parrish, T. W. Huiatt, and R. M. Robson. 1992. Effect of porcine stress syndrome on the solubility and degradation of myofibrillar/cytoskeletal proteins. J. Anim. Sci. 70:454-464.

Briskey, E. J., and J. Wismer-Pedersen. 1961. Biochemistry of pork muscle structure. I. Rate of anaerobic glycolysis and temperature change versus the apparent structure of muscle tissue. J. Food Sci. 26:297-305.

Broumand, H., C. O. Ball, and E. F. Stier. 1958. Factors affecting the quality of prepackaged meat. Food Technol. 12:65-77.

Chang, X. , and D. N. Mowat. 1992. Supplemental chromium for stressed and growing feeder calves. J. Anim. Sci. 70:559-565.

Cheah, A. M., K. S. Cheah, R. Lahucky, L. Kovac, H. L. Kramer, and C. P. McPhee. 1994. Identification of halothane genotypes by calcium accumulation and their meat quality using live pigs. Meat Sci. 38:375-384.

Christian, L.L. and J.W. Mabry. 1990. Stress susceptibility of swine. In: Genetics of Swine. pp. 49 - 69. National Pork Producers Council, Des Moines, IA.

Cornforth, D. 1994. Color - its basis and importance. In: Quality Attributes and their Measurement in Meat, Poultry, and Fish Products. p 34. Blackie Academic & Professional, Glasgow, Scotland.

De Smet, S. M., H. Pauwels, S. De Bie, D.I. Demeyer, J. Callewier, and W. Eeckhout. 1996. Effect of halothane genotype, breed, feed withdrawl, and lairage on pork quality of Belgian slaughter pigs. J. Anim. Sci. 74:1854-1863.

De Smet, S. M., H. Pauwels, W. Eeckhout, D. Demeyr, I. Vervaeke, S. De Vie, G. Van De Voorde and M. Casteels. 1992. Relationships between halothane sensitivity, carcass quality and meat quality in Belgian slaughter pigs. In: E. Puolanne, D. I. Demeyer, M. Ruusunen, and S. Ellis (Ed.). Pork Quality: Genetic and Metabolic Factors. p 160-184. CAB International, Wallingford, UK.

DeVol, D.L. F.K. McKeith, P.J. Bechtel, J. Novakofski, R.D. Shanks, and T.R. Carr. 1988. Variation and palatability traits and relationships between muscle characteristics and palatability in a random sample of pork carcasses. J. Anim. Sci. 66:385-395.

Enfalt, A. C., K. Lundstrom, A. Karlsson, and I. Hansson. 1997. Estimated frequency of the RN allele in Swedish Hampshire pigs and comparison of glycolytic potential, carcass composition, and technological meat quality among Swedish Hampshire, Landrace, and Yorkshire pigs. J. Anim Sci. 75:2924-2935.

Evans, G.W., and T.D. Bowman. 1992. Chromium picolinate increases membrane fluidity and rate of insulin internalization. J. Inorg. Biochem. 46:243-250.

Evock-Clover, C.M., M.M. Polansky, R.A. Anderson, and N.C. Steele. 1993. Dietary chromium supplementation with or without somatotropin treatment alters serum hormones and metabolites in growing pigs without affecting growth performance. J. Nutr. 123:1504-1512.

Faustman, C. and R.G. Cassens. 1990. The biochemical basis for discoloration in fresh meat: a review. J. Muscle Foods 1:217-243.

Fernandez, X. and E. Tornberg. 1994. The influence of high post-mortem temperature and differing ultimate pH on the course of rigor and ageing in pig *longissimus dorsi* muscle. Meat Sci. 36:345-363.

Fisher, P., L. Purves, R. Rubenstein, and F.D. Mellett. 1994. The effect of the malignant hyperthermia gene on carcass characteristics of commercial crossbred pigs in the western cape. S. Afr. J. Anim. Sci. 24(3):111-112.

Fox, J.B. 1987. The pigments of meat. In: J.F. Price and B.S. Schweigert (Ed.). The Science of Meat and Meat Products. p 193. Food and Nutrition Press, Inc., Westport, CT.

Fujii, J., K. Otsu, F. Zorzato, S. De Leon, V. K. Khanna, J. E. Weiler, P. J. O'Brien, and D. H. Maclennan. 1991. Identification of a mutation in porcine ryanodine receptor associated with malignant hyperthermia. Science 253:448-451.

Goodwin, R.G. 1994. Genetic parameters of pork quality traits. Ph.D Dissertation, Iowa State Univ., Ames.

Goodwin, R.G. and L.L. Christian. 1994. Genetic Variation of Pork Quality. Part IV, F: Genetics. In: Pork Chain Quality Audit. p 115. National Pork Producers Council, Des Moines, IA.

Grandin, T. 1994. Methods to Reduce PSE and Bloodsplash. Part IV, D: Marketing Hogs. In: Pork Chain Quality Audit. p 115. National Pork Producers Council, Des Moines, IA.

Hamm, R. 1975. Water holding capacity. In: D. J. Cole, R. A. Lawrie (Ed.). Meat. p. 321. Butterworths, London.

Harris, J.E., S.D. Crow, and M.D. Newcomb. 1995. Effect of chromium picolinate on growth performance and carcass characteristics on pigs fed adequate and low protein diets. J. Anim. Sci. 73(Suppl. 1):194(Abstr.).

Heinze, P. H. and G. Mitchell. 1991. A comparison of some muscle metabolites in stress susceptible and resistant Landrace gilts after halothane exposure or exercise stress. Meat Sci. 30:337-349.

Henckel, P., P. F. Jorgensen, and P. Jensen. 1992. Glycogen content, buffering capacity, and resting pH in live muscles of pigs of different halothane genotypes. Meat Sci. 32:131-138.

Honikel, K. O. 1987. How to measure the water-holding capacity of meat? Recommendation of standardized methods. In: P.V. Tarrant, G. Eikelenboom and G. Monin (Ed.). Evaluation and Control of Meat Quality in Pigs, p. 129. Martinus Nijhoff Publishers, Dordrecht, The Netherlands.

Honikel, K.O., and R. Hamm. 1994. Measurement of water-holding capacity and juiciness. In: Quality Attributes and their Measurement in Meat, Poultry, and Fish Products. p 34. Blackie Academic & Professional, Glasgow, Scotland.

Horton, R. H., L. A. Moran, R. S. Ochs, J. D. Rawn, and K. G. Scrimgeour. 1993. Proteins: three dimensional structure and function. In: Principles of Biochemistry. p 4-34. Neil Patterson Publishers/Prentice-Hall, Inc., Englewood Cliffs, NJ.

Joo, S. T., R.G. Kauffman, B. C. Kim, and C. J. Kim. 1995. The relationship between color and water-holding capacity in postrigor porcine longissimus muscle. J. Muscle Foods 6:211-226.

Karlsson, A. and K. Lundstrom. 1992. Meat quality pigs reared in groups kept as a unit during the fattening period and slaughter. Anim. Prod. 54:421-426.

Kauffman, R.G. 1996. Revelations about pork muscle quality. Seminar on Recent Advances in Animal Breeding and Meat Production Against the Background of Quality and Quantity of Meat as a Raw Material, Poznan, Poland.

Kauffman, R.G., R.G. Cassens, A. Scherer, and D.L. Meeker. 1992. Variations in Pork Quality. National Pork Producers Council, Des Moines, IA.

Kauffman, R.G., W. Sybesma, F.J.M. Smulders, G. Eikelenboom, B. Engel, R.L.J.M. van Laack, A.H. Hoving-Bolink, P. Sterrenburg, E.V. Nordheim, P. Walstra, and P.G. van der Wal. 1993. The effectiveness of examining early post-mortem musculature to predict ultimate pork quality. Meat Sci. 34:283-301.

Kauffman, R. G., D. Wachholz, D. Henderson, and J. V. Lochner. 1978. Shrinkage of PSE, normal, and DFD hams during transit and storage. J. Anim. Sci. 46:1236-1240.

Kauffman, R.G. and R.D. Warner. 1993. Evaluating pork carcasses for composition and quality. In: G. R. Ellis (Ed.). Growth of the Pig. p 141. CAB International, Wallingford, England.

Kauffman, R.G, R.D. Warner, and S.T. Joo. 1994. One Step Closer to Providing Ideal Pork Quality for Consumers in 1994. Part V: Genetics. In: Pork Chain Quality Audit. p 115. National Pork Producers Council, Des Moines, IA.

Kitchalong, L., J.M. Fernandez, L.D. Bunting, L.L. Southern, and T.D. Bidner. 1995. Influence of chromium tripicolinate on glucose metabolism and nutrient partitioning in growing lambs. J. Anim. Sci. 73:2694-2705.

Klont, R. E., and E. Lambooy. 1995a. Effects of preslaughter muscle exercise on muscle metabolism and meat quality studied in anesthetized pigs of different halothane genotypes. J. Anim. Sci. 73:108-117.

Klont, R. E., and E. Lambooy. 1995b. Influence of preslaughter muscle temperature on muscle metabolism and meat quality in anesthetized pigs of different halothane genotypes. J. Anim. Sci. 73:96-107.

Knipe, C. L. 1995. Increasing the functionality and use of pale, soft, and exudative pork in canadian-style bacon. In: 1995 Research Investment Report. p 443-450. National Pork Producers Council, Des Moines, IA.

Leach, L.M., M. Ellis, D.S. Sutton, F.K. McKeith, and E.R. Wilson. 1996. The growth performance, carcass characteristics, and meat quality of halothane carrier and negative pigs. J. Anim. Sci. 74:934-943.

Lindemann, M.D., C.M. Wood, A.F. Harper, E.T. Kornegay, and R.A. Anderson. 1995. Dietary chromium picolinate additions improve gain:feed and carcass characteristics in growing-finishing pigs and increase litter size in reproducing sows. J. Anim. Sci. 73:457-465.

Lundstrom, K., B. Essen-Gustavsson, M. Rundgren, I. Edfors-Lilja, and G. Malmfors. 1989. Effect of halothane genotype on muscle metabolism at slaughter and its relationship with meat quality: a within litter comparison. Meat Sci. 25:251-263.

Martoccia, L., G. Brambilla, A. Macri, G. Moccia, and E. Cosentino. 1995. The effect of transport on some metabolic parameters and meat quality in pigs. Meat Sci. 40:271-277.

Mayo Rizo, J.M. 1995. Effects of Stress Genotype, Pre-slaughter Mixing, Pre-slaughter Resting Time, and Chilling Rate on Muscle Quality of Swine. M.S. thesis, Iowa State Univ., Ames.

McPhee, C. P., L. J. Daniels, H. L. Kramer, G. M. Macbeth, and J. W. Noble. 1994. The effects of selection for lean growth and halothane allele on growth performance and mortality of pigs in a tropical environment. Livest. Prod. Sci. 34:117-123.

McPhee, C. P., and G. R. Trout. 1995. The effects of selection for lean growth and the halothane allele on carcass and meat quality of pigs transported long and short distances to slaughter. Livest. Prod. Sci. 42:55-62.

Mertz, W. 1992. Chromium:history and nutritional importance. Biol. Trace Element Res. 32:3-8.

Mickelson, J. R., and C. F. Louis. 1992. Calcium regulation in porcine skeletal muscle - review. In: E. Puolanne, D. I. Demeyer, M. Ruusunen, and S. Ellis (Ed.). Pork Quality: Genetic and Metabolic Factors. p 160-184. CAB International, Wallingford, UK.

Mooney, K.W. and G.L. Cromwell. 1995. Effects of dietary chromium picolinate supplementation on growth, carcass characteristics, and accretion rates of carcass tissues in growing-finishing swine. J. Anim. Sci. 73:3351-3357.

NPPC. 1991. Procedures to Evaluate Market Hogs (Third Ed.). National Pork Producers Council, Des Moines, IA

NPPC. 1994. Part A: Consumer Quality Audit Summary. In: Pork Chain Quality Audit. p 16. National Pork Producers Council, Des Moines, IA.

Offer, G. 1991. Modelling of the formation of pale, soft, and exudative meat: Effect of chilling regime on rate and extent of glycolysis. Meat Sci. 30:157-184.

Offer, G., P. Knight, R. Jeacocke, R. Almond, T. Cousins, J. Elsey, N. Parsons, A. Sharp, R. Starr, and P. Purslow. 1989. The structural basis of the water-holding capacity, appearance, and toughness of meat and meat products. Food Microstruct. 8:151-170.

Offer, G. and J. Trinick. 1983. On the mechanism of water holding in meat: the swelling and shrinking of myofibrils. Meat Sci. 8:245-281.

Oliver, M. A., M. Gispert, and A. Diestre. 1993. The effects of breed and halothane sensitivity on pig meat quality. Meat Sci. 35:105-118.

Page, T. G., L. L. Southern, T. L. Ward, and D. L. Thompson, Jr. 1993. Effect of chromium picolinate on growth and serum and carcass traits of growing-finishing pigs. J. Anim. Sci. 71:656-662.

Pearson, A. M. 1987. Muscle function and postmortem changes. In: J. F. Price and B. S. Schweigert (Ed.). The Science of Meat and Meat Products (Third Ed.). p 180-184. Food and Nutrition Press, Inc., Westport, CT.

Pearson, A. M. and T. A. Gillett. 1996. Purposes of meat processing. In: Processed Meats. p 1-22. Chapman and Hall, New York.

Penny, I. F. 1967. The influence of pH and temperature on the properties of myosin. Biochem. J. 104: 609-615.

Pommier, S. A. and A. Houde. 1993. Effect of the genotype for malignant hyperthermia as determined by a restriction endonuclease assay on the quality characteristics of commercial pork loins. J. Anim. Sci. 71:420-425.

Reik, T. R., W. E. Rempel, C. J. McGrath, and P. B. Addis. 1983. Further evidence on the inheritance of halothane reaction in pigs. J. Anim. Sci. 57:826-831.

Rust, R. E., and D. G. Olson. 1973. Meat Curing Principles and Modern Practice. Iowa State Univ. Press, Ames.

Sather, A. P., S. D. M. Jones, A. K. W. Tong, and A. C. Murray. 1991. Halothane genotype by weight interactions on pig meat quality. Can. J. Anim. Sci. 71:645-658.

Simpson, S. P., and A. J. Webb. 1989. Growth and carcass performance of British Landrace pigs heterozygous at the halothane locus. Anim. Prod. 49:503-509.

Steele, N.C. and R.W. Rosebrough. 1979. Trivalent chromium and nicotinic acid supplementation for the turkey poult. Poult. Sci. 58:983-984.

Stryer, L. 1995. Protein structure and function. In: Biochemistry (Fourth Ed.). p 31-32. W.H. Freeman and Co., New York.

Topel, D. G., R. A. Merkel, D. L. Mackintosh, and J. L. Hall. 1966. Variation of some physical and biochemical properties within and among selected porcine muscles. J. Anim. Sci. 25:277-282.

Trout, G. R. 1988. Techniques for measuring water-binding capacity in muscle foods - a review of methodology. Meat Sci. 23:235-252.

van Laack, L. J. M., C. Faustman, and J. G. Sebranek. 1993. Pork quality and the expression of stress protein hsp 70 in swine. J. Anim. Sci. 71:2958-2964.

van Laack, L. J. M., and M. B. Solomon. 1994. Strategies to improve lean meat yield and their effects on pork quality. Tenth Annual Carolina Swine Nutrition Conference, Raleigh, NC, p. 2-7.

Vogeli, P., R. Fries, R. Bolt, C. Gerwig, P. Affentranger, N. Kunzi, H. U. Bertschinger, and G. Stranzinger. 1992. Genetics of porcine stress syndrome and association with oedema disease. In: E. Puolanne, D. I. Demeyer, M. Ruusunen, and S. Ellis (Ed.). Pork Quality: Genetic and Metabolic Factors. p 22-36. CAB International, Wallingford, UK.

Wang, H., J. R. Claus, and M. D. Lindemann. 1994. J. Effect of supplemental dietary chromium on the characteristics of pork. (Abstr.) Institute of Food Technologists Annual Meeting, Atlanta, GA, p. 90.

Warner, R. D. 1993. Quality attributes of major porcine muscles: a comparison with the *longissimus lumborum*. Meat Sci. 33:359-372.

Warner, R. D. 1994. Physical properties of porcine musculature in relation to postmortem biochemical changes in muscle proteins. Ph.D Dissertation, Univ. of Wisconsin, Madison.

Wenk, C., S. Gebert, and H.P. Pfirter. 1995. Chromium supplements in the feed for growing pigs: influence on growth and meat quality. Arch. Anim. Nutr. 48:71-81.

Wismer-Pedersen, J. 1959. Quality of pork in relation to rate of pH change postmortem. Food Res. 24:711-727.

Zhang, W., D. L. Kuhlers, and W. E. Rempel. 1992. Halothane gene and swine performance. J. Anim. Sci. 70:1307-1313.

Chapter 3

Halothane Gene, Chromium Picolinate Supplementation, and Sex Effects on Live Animal Performance, Carcass Traits, and Subjective Quality Characteristics in Pigs

ABSTRACT

Two trials were conducted to evaluate the effects of the halothane gene (HAL), chromium picolinate (Cr) and gender on live animal performance and carcass characteristics. Pigs (n=160) were assigned to pens based on sex (barrow, gilt), genotype (NN, Nn), and initial weight. Pens (n=64) were randomly allotted to two dietary treatments, 0 or 200 ppb Cr added to standard grower and finisher corn-soybean meal diets. The 2x2x2 factorial arrangement was replicated four times in each trial. Average initial weight was 28.7 kg; pigs averaged 107.3 kg off test. Gain/feed (G/F) and average daily gain (ADG) were calculated. Pigs were transported to Virginia Tech, rested overnight, and slaughtered according to standard Meats Lab procedures. Carcass data included dressing percentage (DP), hot carcass weight (HCW), chilled carcass weight (CCW), carcass length (CL), loin muscle area (LMA), first (BF1), last (BFLR), tenth (BF10) and last lumbar (BFLUM) backfat, and weights of trimmed wholesale cuts. Lean gain (LG) and percent lean (PL) were calculated. Subjective scores for color, marbling, and firmness of the loin were assigned. There were no differences between genotypes for ADG, but there was a trend of improved G/F for Nn animals. Nn carcasses had less ($P < .05$) BF10, BF1, and BFLUMB, and heavier ($P < .05$) hams and Boston butts. Loins from

Nn animals were paler, softer and wetter, and had less marbling ($P < .001$) than NN animals, but there were no differences between genotypes for other carcass characteristics. Chromium had no significant effect on any growth, carcass, or muscle quality characteristics although chromium fed pigs had slightly more backfat. Barrows gained faster and consumed more feed ($P < .001$) than gilts, yielding heavier ($P < .05$) HCW, CCW and wholesale cuts. Gilts tended to gain more efficiently, and had less backfat ($P < .001$) and larger ($P < .01$) LMA than barrows. Loins from barrows were lighter ($P < .01$) and tended to be more soft and watery than those from gilts. The halothane gene improved some carcass composition traits, but chromium picolinate supplementation did not affect any growth, carcass, or quality traits.

Key Words: Pigs, Halothane, Chromium Picolinate, Sex

Introduction

To remain profitable in the swine industry today, farmers must produce fast growing pigs that yield high quality, lean pork. The halothane (HAL) gene is known to contribute positively to lean carcass composition characteristics (Aalhus et al., 1991; Zhang et al., 1992; Leach et al., 1996). When the gene occurs in pigs in the homozygous recessive form (nn), however, animals are stress-susceptible and can often die or produce high percentages of pale, soft, and exudative (PSE) pork if they survive (Christian and Mabry, 1990; Backstrom and Kauffman, 1995). In contrast, Webb (1981) reported that when the gene occurs in heterozygous form, there are few or no effects on muscle quality. In addition, studies with chromium picolinate (CrP) have indicated that it improved improved muscle percentage, decreased backfat, and increased loin muscle area (Page et al., 1993; Lindemann et al., 1995). Wang et al. (1994) reported that CrP had no effects on muscle quality. There has been no work completed to determine possible interactions between the halothane gene and CrP, which could potentially give producers another means of providing high quality lean carcasses. The objectives of this study were to determine the interactive effects of the halothane gene, chromium picolinate supplementation, and sex on growth, carcass characteristics, and subjective quality characteristics in commercial pigs.

Materials and Methods

Animals and feeding. Two trials were conducted to evaluate the interactive effects of the halothane gene (HAL), chromium picolinate (CrP) and sex on live animal and carcass characteristics in pigs. Background genotypes were kept as similar as possible by breeding HAL-free (NN) sows (Yorkshire x Chester White cross) to two littermate heterozygous (Nn) Hampshire boars via artificial insemination at the Virginia Tech Tidewater Agricultural Research Center (TAREC). For Trial 1, 31 multi-parous sows were each mated to one of the two littermate boars. For Trial 2, 17 of the same sows were mated to the same boars. For both trials, each sow was inseminated twice daily (a.m. and p.m.) to the same boar until estrus ended. The offspring had their tails docked between two and seven days of age and triplicate samples of the tail (3 mm each) were immediately frozen in liquid nitrogen. The samples were shipped to the Animal and Poultry Sciences Department at Virginia Tech and genotyped using the HAL-1843® DNA test (Fujii et al., 1991).

Of the 317 pigs genotyped, 96 were assigned to pens for Trial 1 and 64 for Trial 2 according to outcome groups based on genotype (NN, Nn), sex (barrows, gilts) and weight. Average initial weight for the pigs going on test was 33.7 kg (Trial 1) and 22.7 kg (Trial 2) and average off-test weight was 103.9 kg (Trial 1) and 110.7 kg (Trial 2). Pens were randomly allotted in a 2 x 2 x 2 factorial arrangement to two dietary treatments of 0 or 200 ppb CrP added to standard corn-soybean meal diets (Table 1). Four replications were included in Trial 1 (two replications with four pigs per pen and two replications with two pigs per pen) and four replications (four replications of two pigs per

pen) in Trial 2. The diets were formulated to meet NRC (1988) requirements. Chromium containing diets were prepared using 0.45 kg of CHROMAX® in place of 0.45 kg of limestone per ton. While on test, pigs were housed in a totally slatted, confinement grower-finishing barn at the TAREC. Feed and water were provided ad libitum. Pigs were weighed and feed intake was determined biweekly. Gain/feed ratio (G/F) and average daily gains (ADG) were calculated for both trials and are presented on a pen basis.

Slaughter and processing procedures. When pigs within a replicate reached a minimum average final weight of 102 kg, they were weighed off test and tattooed. Replicates with two pigs per pen remained intact throughout the slaughter and processing procedures. Replicates with four pigs per pen were equally divided between two consecutive slaughter days. Pigs remained in their original pens until loaded for the 5 h drive to the Virginia Tech Meats Lab in Blacksburg. Upon arrival, the pigs were rested overnight in one large pen, allowed free access to water but were not allowed to consume feed. Immediately prior to slaughter, each animal was exercised continuously at a moderate pace for 10 full minutes in a rectangular (~2 x 5 m) holding pen to increase the probability of triggering the expression of pale, soft, and exudative (PSE) pork in both NN and Nn animals. Each pig was then weighed and slaughtered according to standard Meats Lab protocols. Hot carcass weight (HCW) was obtained, then carcasses were air-chilled overnight (18 to 24 h) at 4^{o}C prior to measuring and processing.

Chilled carcass weight (CCW), carcass length (CL), loin muscle area (LMA), first rib (BF1), tenth rib (BF10), last rib (BFLAST), and last lumbar (BFLUMB) backfat depth as well as kilograms of lean (KLN), percentage lean (PCTLN), and lean gain (LNGAIN)

were all determined according to procedures recommended by the National Pork Producers Council (NPPC, 1991). The left side of each carcass was ribbed between the 10^{th} and 11^{th} rib for backfat and loin muscle area measurement and assessment by a subjective quality sensory panel. Both sides of each carcass were then fabricated into trimmed wholesale cuts (Romans et al., 1994) and weighed. In addition, belly thickness was determined by measuring depth at six evenly spaced points across the belly and then averaging the six measurements.

After ribbing, the carcass was allowed to bloom (oxygenate) 40 minutes prior to subjective quality analysis. A 5-point scale (NPPC, 1991) was used to determine color and moisture/firmness (1 = pale pinkish gray, very soft and watery; 2 = grayish pink, soft and watery; 3 = reddish pink, slightly firm and moist; 4 = purplish red, firm and moderately dry; 5 = dark purplish red, very firm and very dry) of chops taken from the *longissimus thoracis et lumborum* between the 10^{th} and 11^{th} thoracic vertebra. The scale was modified by allowing additional ½ point increments for each trait analyzed.

The samples were displayed under Natural White fluorescent lighting (Philips 40W 5C, F40SPEC30, State Electric Supply Co., Inc. Christiansburg, VA) in a processing room (10^{o}C). Distance from the lighting to the chops was set at 1076 lux with a hand held digital light meter (model L096080, Extech Instrument Corp. Waltham, MA). A trained, 9-member sensory panel assigned the subjective scores. The panel was trained according to AMSA (1995) guidelines and met for five training sessions prior to evaluating samples for Trial 1. For each training session, panelists were trained to subjectively rank the desired characteristics on 10 to 15 fresh pork chops. After sufficient training was conducted, the panelists evaluated 16 chops per day in the fabrication cooler (10^{o}C) for

each of the six processing days during Trial 1. Marbling was also evaluated on a five-point scale (1 = practically devoid; 2 = traces to slight; 3 = small to modest; 4 = moderate to slightly abundant; 5 = moderately abundant or more) with ½ point increments by an expert 2-member panel for Trial 1.

Statistics. The experiment was designed as a Generalized Randomized Block Design (GRBD) with subsampling. Trial was the blocking factor and the eight treatment combinations were replicated four times within each block. Pens were the experimental unit and pigs were the observational unit. Data were analyzed using SAS (1991) GLM procedures. The model included the main effects of the halothane gene, chromium picolinate, and sex as well as all two-way interactions. The main effects and interactions were tested for significance using Rep(Hal x Cr x Sex x Trial) as the experimental error term. Initial weight (WI) was included in the model as a covariate for the carcass data. Means were separated using pairwise differences while controlling for the comparisonwise error rate.

Results and Discussion

Growth Performance and Feed Efficiency

Least squares means, standard errors, and P-values of the main effects and interactions of the halothane gene, sex, and chromium picolinate on live animal performance characteristics are shown in Tables 2, 3, 4 and 5. There were no significant interactions, so only the main effects are discussed.

Halothane effects. Pen average daily gain, daily feed intake (DFI), and final weight on the farm (FW) did not differ between normal and heterozygous genotypes. These results agree with some studies which have shown no differences between carrier and homozygous negative halothane genotypes for growth rate (Sather et al., 1991b; Goodwin and Christian, 1994; Leach et al., 1996). Sather et al. (1991b) used commercial Yorkshire and Landrace cross sows bred to heterozygous Yorkshire or Landrace boars and Leach et al. (1996) used PIC Camborough 15 sows bred to carrier boars (PIC Line 405). Both studies had similar results, showing no effects on growth rate between normal and carrier offspring.

Goodwin (1994) and McPhee et al. (1994), however, reported slower growth rates for heterozygous animals compared to NN pigs. In addition, Simpson and Webb (1989) and van Laack and Solomon (1994) reported that the halothane gene had negative effects on growth rate. In contrast, Aalhus et al. (1991) reported that carrier animals grew faster than homozygous normal animals, but determined that this increased growth could be influenced by breed and feeding regime. They used Norwegian Landrace pigs, which responded similarly to pigs of the same breed and genotype in other studies.

The varied responses in these studies illustrate that differences between halothane genotypes can vary by breed background. In addition, Sather et al. (1991b) reported that halothane carrier pigs fed a lower energy diet (14% protein, 3050 MJ kg^{-1}) did not grow as fast as similar animals fed a higher energy diet (17% protein, 3250 MJ kg^{-1}). Leach et al. (1996), however, fed higher energy diets in three phases and found no differences between halothane carrier and normal pigs for growth rate. Christian and Mabry (1990) also reported that differences between NN and Nn animals were minimal or nonsignificant regardless of nutritional regime.

In this study, carrier animals tended ($P < .09$) to have a higher gain:feed (G/F) ratio compared to NN pigs. These findings are in agreement with McPhee et al. (1994) and Leach et al. (1996), who reported more efficient gain for carrier pigs compared to homozygous negative pigs. Leach et al. (1996) reported that any advantage in feed efficiency for carriers could be due to a preferential deposition of lean rather than fat in carriers. In contrast, Carlson et al. (1980) and Christian and Mabry (1990) reported no significant differences between halothane carrier and normal animals for feed efficiency.

Chromium effects. Chromium picolinate supplementation did not affect FW, ADG, DFI, or G/F. The literature has shown a wide variety of responses due to dietary supplementation of CrP. Our results are in agreement with Evock-Clover et al. (1993), Page et al. (1993), Amoikon et al. (1995) and Harris et al. (1995). Boleman et al. (1995), however, reported that Yorkshire x Chester White or Yorkshire x Duroc pigs fed 200 ppb CrP in a diet adjusted to 120% of the NRC requirements for lysine during the finishing phase had decreased ADG. In contrast, Mooney and Cromwell (1995) reported that Hampshire x Yorkshire barrows supplemented with 200 ppb CrP in a diet adjusted to an

NRC lysine requirement of 125% tended to grow faster than pigs that were not supplemented with chromium. Wenk et al. (1995) reported that CrP supplementation did not affect growth in the growing period, but increased ADG during the finishing period.

Lindemann et al. (1995) reported that supplementing 250 or 500 ppb CrP tended to reduce DFI, which in turn increased G/F in crossbred pigs. They also reported that response to CrP may be dependent upon lysine or crude protein content of the diet. Wenk et al. (1995) also reported improvements in G/F for pigs supplemented with CrP. In addition, Ward et al. (1997) reported that chromium supplementation of diets that were deficient in lysine (80% of NRC requirement) improved G/F and ADG in Yorkshire x Landrace x Hampshire pigs, but only in the finishing phase. In the same trial, however, they reported that pigs fed CrP and 120% of the lysine requirement had decreased ADG and G/F.

Sex effects. Barrows consumed more feed, gained faster, and and therefore weighed more ($P < .001$) than gilts, which is consistent with prior studies (Aalhus et al., 1991; Hammell et al., 1993). Gilts tended ($P < .09$) to gain more efficiently than barrows, which agrees with Friesen et al. (1994) and Leach et al. (1996). In contrast, Christian et al. (1980) and Hammell et al. (1993) reported no differences in feed efficiency between sexes.

Carcass Traits

Halothane effects. HCW, CCW, and CL did not differ due to genotype (Table 6). Nn animals tended to have a higher dressing percentage calculated using FW (DPF), but for dressing percentage calculated using the Meats Lab weight (DPL), Nn animals dressed

significantly higher ($P < .01$) (Table 7). Leach et al. (1996) reported that halothane carriers had heavier CCW and higher dressing percentage than homozygous negative animals, and Aalhus et al. (1991) reported higher HCW for Nn animals. Fisher et al. (1994), however, reported no differences in HCW or CCW when comparing halothane carrier and normal animals. In agreement with previous studies (Sather et al., 1991b; Garcia-Macias et al., 1996; Leach et al., 1996), there also were no differences in carcass length.

As shown in Table 6, carrier pigs had less BF10 ($P < .01$), BFLUMB ($P < .05$), and average backfat ($P < .05$) than NN pigs. Carrier pigs also tended ($P < .06$) to have less BF1 but there was no difference between the genotypes for LRBF. Simpson and Webb (1989) also reported less BF1 for carrier pigs and Goodwin (1994) reported less BF10, but no difference in BFLAST or BFLUMB when comparing carrier to normal pigs. Other studies have reported no differences in backfat between carrier and normal pigs (Fisher, 1994; Goodwin and Christian, 1994; Garcia-Macias et al., 1996; Leach et al., 1996).

Some of these differences in fat and carcass weight could be explained by the relative growth rate of lean tissue for animals carrying the halothane gene compared to NN pigs. Aalhus et al. (1991) reported that as nn pigs aged, they eventually lost the lean growth advantage over normal pigs. This in turn caused a lower coefficient for lean and a higher growth coefficient for fat. They concluded that at market weight nn pigs were at a later stage of maturity than NN animals. If this is true for carrier pigs as well, it is possible that the heterozygous pigs in this study could be at a later stage of maturity than the halothane negative pigs, therefore showing more lean carcass advantages than NN pigs.

Carrier animals had larger LMA ($P < .01$) than halothane negative animals (Table 6). This is in agreement with Simpson and Webb (1989) and Garcia-Macias et al. (1996). These results differ, however, with research conducted by Goodwin and Christian (1994) and Leach et al. (1996), who reported no significant differences between the genotypes for LMA.

As would be expected from the above discussion, carrier animals yielded more kilograms of lean (KLN) ($P < .03$), a higher PCTLN ($P < .001$), and greater LNGAIN ($P < .01$) than NN pigs (Table 7). van Laack and Solomon (1994) reported carrier animals to be intermediate between NN and nn animals for lean meat content. The results of this study are in agreement with work by Leach et al. (1996), who determined that the weight of fat free lean and kg of lean was higher for Nn than in NN pigs. In contrast, De Smet et al. (1996) and Garcia-Macias et al. (1996) found no differences in lean contents between Nn and NN carcasses. Goodwin and Christian (1994) reported that lean differences between halothane carrier and normal animals was only 1.1%. In this study, the halothane carriers displayed 1.6 more percentage lean than the normal pigs.

Carrier pigs had heavier hams ($P < .02$) and Boston butts ($P < .05$) than normal animals (Table 8) . There were no differences due to genotype in the weights of the loins, sides, picnic shoulders, or belly thickness. Aalhus et al. (1991) found loins to be heavier for carrier pigs and reported heavier Boston butt weights for homozygous normal animals. Leach et al. (1996) reported heavier loins and shoulders for carrier animals, but no other differences for wholesale cut weights. They attributed this to a greater preferential deposition of lean for carrier animals.

Chromium effects. Chromium picolinate supplementation had no significant effect on any of the carcass measurements (Tables 6, 7, and 8), although there was a trend toward increased LRBF ($P < .07$) with CrP supplementation. Ward et al. (1997) reported that 400 ppb CrP resulted in increased backfat for pigs that did not have adequate pen space, but decreased backfat for those pigs that had adequate pen space. Harris et al. (1995) and Mooney and Cromwell (1995) reported that supplementation of CrP at 200 ppb did not affect average backfat or BF10.

For LMA (Table 6), the results of this study are in agreement with other studies that showed there was no effect of CrP on LMA (Harper et al., 1995; Harris et al., 1995; Mooney and Cromwell, 1995; Wenk et al., 1995). In contrast, several studies have shown an increase in LMA for pigs supplemented with CrP (Page et al., 1993; Lindemann et al., 1995; Kornegay et al., 1997). Kornegay et al. (1997) reported that pigs placed on 200 ppb CrP at a lighter weight showed more response to CrP, especially for LMA. They speculated that the pigs put on CrP at a lighter weight responded more due to either the effect of time on muscle accretion or perhaps a relationship of natural depletion of CrP in the pigs and amount of response. In this study, pigs were placed on trial later and at a heavier weight than in most studies, which would be consistent with their hypothesis. Wenk et al. (1995) also reported no differences in wholesale cut weights for CrP supplemented pigs, which is consistent with results in this study.

Sex effects. Barrows produced heavier HCW and CCW ($P < .001$) than gilts (Table 6), but there was no difference between the sexes in DPF or DPL (Table 7), which is in agreement with Friesen et al. (1994). Gilts were leaner ($P < .001$) and yielded larger LMA ($P < .02$) than barrows (Table 6). Consequently, gilts also had a higher PCTLN (*P*

< .001) than barrows (Table 7). These results are consistent with other studies (Hammell et al., 1993; Friesen et al., 1994; Leach et al., 1996). Gilts did not differ from barrows in KLN and LNGAIN (Table 7) because the increases in HCW for barrows offset the decrease in backfat and increased LMA for gilts

Gilts yielded heavier wholesale cuts than barrows (Table 8). This is appropriate because gilts gained faster and were leaner than barrows. Barrows had thicker belly measurements ($P < .001$) than gilts, however, which is in agreement with Lundstrom et al. (1995). This is normal because barrows deposit more fat during growth than gilts.

Interactions. Two-way interactions are presented in Tables 9 through 17. There was a sex x halothane gene interaction for PCTLN (Table 14). Carrier barrows had a higher percent lean than normal barrows. Gilts were leaner than barrows regardless of genotype, but carrier gilts were not statistically leaner than homozygous normal gilts. It appears that barrows showed greater response to the halothane gene for carcass characteristics, though there are no other studies that have reported this. There also tended to be an interaction between sex and the halothane gene ($P < .10$) for LMA (Table 11), showing that NN barrows consistently had smaller LMA than NN gilts and Nn animals of either sex. Leach et al. (1996) also reported greater LMA for gilts. There also tended ($P < .10$) to be an interaction between CrP and Hal for BFLAST (Table 9). NN pigs fed no CrP were leaner than NN pigs fed CrP, but heterozygous pigs did not differ. Wenk et al. (1995) also reported pigs supplemented with CrP to have slightly more backfat. In contrast, Page et al. (1993) reported pigs supplemented 100 and 200 ppb CrP had less backfat than those fed no dietary CrP.

Subjective Muscle Quality Characteristics

Halothane effects. Halothane carrier pigs produced pork that was lighter in color, softer, more exudative, and with less marbling than HAL-free pigs (Table 18). This is consistent with several prior studies (Zhang et al., 1992 ; Goodwin and Christian, 1994; Leach et al., 1996). As expected, these results suggest a higher incidence of PSE pork in carrier pigs. In contrast, Sather et al. (1991b) reported that Nn and NN pigs had similar subjective color and structure scores, but they reported that Nn pigs had lighter colored loins when measured objectively by CIE L* values.

Chromium effects. Chromium had no effect on color moisture/firmness, or marbling, although CrP fed pigs had lower numerical marbling scores (Table 18). Wang et al. (1994) reported that supplementation of CrP at 200 or 1000 ppb had no effects on color or fat percentage in pork *longissimus* muscle and Wenk et al. (1995) reported that pigs supplemented with CrP tended to have higher percentages of intramuscular fat.

Sex effects. Gilts produced pork that was consistently darker ($P < .002$) in color than that of barrows (Table 18). In addition, gilts tended ($P < .09$) to yield meat that was firmer and less exudative than that from barrows. These results suggest that barrows produced a higher incidence of PSE pork than gilts. In contrast, Leach et al. (1996) found no differences in color, moisture/firmness, or marbling between barrows and gilts. Sather et al. (1991a) also reported no differences in color between barrows and gilts. Both of these studies did report the incidence of PSE pork in their work, but not related directly to sex.

Interactions. There was an interaction ($P < .03$) between sex and the halothane gene for color (Table 21). Carrier barrows yielded lighter colored pork than any other

combination of genotype and sex. Again, barrows seem to have expressed the effects of the halothane gene more readily than gilts. There also tended to be an interaction between chromium picolinate and sex for color (Table 20). Gilts that were not fed CrP tended to yield higher color scores than barrows on either CrP treatment, but did not differ from gilts fed CrP.

There was an interaction between chromium picolinate and the halothane gene for marbling (Table 19). For those pigs not fed chromium, Nn animals had lower marbling scores than NN pigs. All pigs (NN and Nn) fed chromium had higher amounts of marbling than Nn animals not fed chromium, but lower marbling than NN pigs that did not receive CrP. This is in contrast to Mooney and Cromwell (1995) who reported a lower lipid percentage in muscle of pigs that had been supplemented with CrP. Currently, it is unclear why CrP yields such inconsistent results in carcass traits between different studies.

Implications

The halothane gene negatively affected muscle quality as measured by color, moisture/firmness, and marbling. Supplementation of chromium picolinate had no effects on growth performance, minimal effects on carcass measurements, and did not affect any muscle quality scores. These results suggest that supplementation of chromium picolinate in conjunction with the halothane gene will not produce much benefit for the swine industry for carcass quantity or quality characteristics.

Literature Cited

Aalhus, J. L., S. D. M. Jones, W. M. Robertson, A. K. W. Tong, and A. P. Sather. 1991. Growth characteristics and carcass composition of pigs with known genotypes for stress susceptibility over a weight range of 70 to 120 kg. Anim. Prod. 52:347-353.

Amoikon, E. K., J. M. Fernandez, L. L. Southern, D. L. Thompson, Jr., T. L. Ward, and B. M. Olcott. 1995. Effect of chromium tripicolinate on growth, glucose tolerance, insulin sensitivity, plasma metabolites, and growth hormone in pigs. J. Anim. Sci. 73:1123-1129.

AMSA. 1995. Research Guidelines for Cookery, Sensory Evaluation, and Instrumental Tenderness Measurements of Fresh Meat. Am. Meat Sci. Assoc. and National Live Stock and Meat Board, Chicago, IL.

Backstrom, L., and R. G. Kauffman. 1995. The porcine stress syndrome: a review of genetics, environmental factors, and animal well-being implications. Agri-Practice 16:24-30.

Boleman, S. L., S. J. Boleman, T. D. Bidner, L. L. Southern, T. L. Ward, J. E. Pontif, and M. M. Pike. 1995. Effect of chromium picolinate on growth, body composition, and tissue accretion in pigs. J. Anim. Sci. 73:2033-2042.

Carlson, J. P., L. L. Christian, D. L. Kuhlers, and B. S. Rasmusen. 1980. Influence of the porcine stress syndrome on production and carcass traits. J. Anim. Sci. 50:21-28.

Christian, L. L., and J. W. Mabry. 1990. Stress susceptibility of swine. In: Genetics of Swine. pp. 49 - 69. National Pork Producers Council, Des Moines, IA.

Christian, L. L., K. L. Strock, and J. P. Carlson. 1980. Effects of protein, breed cross, sex, and slaughter weight on swine performance and carcass traits. J. Anim. Sci. 51:51-58.

De Smet, S. M., H. Pauwels, S. De Bie, D. I. Demeyer, J. Callewier, and W. Eeckhout. 1996. Effect of halothane genotype, breed, feed withdrawal, and lairage on pork quality of Belgian slaughter pigs. J. Anim. Sci. 74:1854-1863.

Evock-Clover, C. M., M. M. Polansky, R. A. Anderson, and N. C. Steele. 1993. Dietary chromium supplementation with or without somatotropin treatment alters serum hormones and metabolites in growing pigs without affecting growth performance. J. Nutr. 123:1504-1512.

Fisher, P., L. Purves, R. Rubenstein, and F. D. Mellett. 1994. The effect of the malignant hyperthermia gene on carcass characteristics of commercial crossbred pigs in the western cape. S. Afr. J. Anim. Sci. 24(3):111-112.

Friesen, K. G., J. L. Nelssen, J. A. Unruh, R. D. Goodband, and M. D. Tokach. 1994. Effects of the interrelationship between genotype, sex, and dietary lysine on growth performance and carcass composition in finishing pigs fed either to 104 or 127 kilograms. J. Anim. Sci. 72:946-954.

Fujii, J., K. Otsu, F. Zorzato, S. De Leon, V. K. Khanna, J. E. Weiler, P. J. O'Brien, and D. H. Maclennan. 1991. Identification of a mutation in porcine ryanodine receptor associated with malignant hyperthermia. Science 253:448-451.

Garcia-Macias, J. A., M. Gispert, M. A. Oliver, A. Diestre, P. Alonso, A. Munoz-Luna, K. Siggens, and D. Cuthbert-Heavens. 1996. The effects of cross, slaughter weight, and halothane genotype on leanness and meat and fat quality in pig carcasses. Anim. Sci. 63:487-496.

Goodwin, R. N. 1994. Genetic parameters of pork quality traits. Ph.D Dissertation, Iowa State Univ., Ames.

Goodwin, R. G. and L. L. Christian. 1994. Genetic variation of pork quality. In: Pork Chain Quality Audit. p 115-123. National Pork Producers Council, Des Moines, IA.

Hammell, K. L., J. P. Laforest, and J. J. Dufour. 1993. Evaluation of the growth performance and carcass characteristics of commercial pigs produced in Quebec. Can. J. Anim. Sci. 73:495-508.

Harper, A. F., M. D. Lindemann, and E. T. Kornegay. 1995. Effect of supplemental dietary chromium on growth performance of weanling swine. J. Anim. Sci. 73(Suppl. 1): 194.

Harris, J. E., S. D. Crow, and M. D. Newcomb. 1995. Effect of chromium picolinate on growth performance and carcass characteristics on pigs fed adequate and low protein diets. In: 1995 Research Investment Report. p 615-621. National Pork Producers Council, Des Moines, IA.

Kornegay, E. T., Z. Wang, C. M. Wood, and M. D. Lindemann. 1997. Supplemental chromium picolinate influences nitrogen balance, dry matter digestibility, and carcass traits in growing-finishing swine. J. Anim. Sci. 75:1319-1323.

Leach, L. M., M. Ellis, D. S. Sutton, F. K. McKeith, and E. R. Wilson. 1996. The growth performance, carcass characteristics, and meat quality of halothane carrier and negative pigs. J. Anim. Sci. 74:934-943.

Lindemann, M. D., C. M. Wood, A. F. Harper, E. T. Kornegay, and R. A. Anderson. 1995. Dietary chromium picolinate additions improve gain:feed and carcass characteristics in growing-finishing pigs and increase litter size in reproducing sows. J. Anim. Sci. 73:457-465.

Lundstrom, K., A. Karlsson, J. Hakansson, I. Hansson, M. Johansson, L. Anderson, and K. Andersson. 1995. Production, carcass and meat quality traits of F_2 crosses between European wild pigs and domestic pigs including halothane gene carriers. Anim. Sci. 61:325-331.

McPhee, C. P., L. J. Daniels, H. L. Kramer, G. M. Macbeth, and J. W. Noble. 1994. The effects of selection for lean growth and halothane allele on growth performance and mortality of pigs in a tropical environment. Livest. Prod. Sci. 34:117-123.

Mooney, K. W., and G. L. Cromwell. 1995. Effects of dietary chromium picolinate supplementation on growth, carcass characteristics, and accretion rates of carcass tissues in growing-finishing swine. J. Anim. Sci. 73:3351-3357.

NPPC. 1991. Procedures to Evaluate Market Hogs (Third Ed.). National Pork Producers Council, Des Moines, IA.

NRC. 1988. Nutrient Requirements of Swine (9^{th} Ed.). National Academy Press, Washington, DC.

Page, T. G., L. L. Southern, T. L. Ward, and D. L. Thompson, Jr. 1993. Effect of chromium picolinate on growth and serum and carcass traits of growing-finishing pigs. J. Anim. Sci. 71:656-662.

Romans, J. R., W. J. Costello, C. W. Carlson, M. L. Greaser, and K. W. Jones. 1994. Pork identification and fabrication. In: The Meat We Eat (Thirteenth Ed). p 509-542. Interstate Printers and Publishers, Inc., Danville, IL.

SAS. 1991. SAS User's Guide: Statistics (Fifth Ed.). SAS Inst. Inc., Cary, NC.

Sather, A. P., S. D. M. Jones, A. K. W. Tong, and A. C. Murray. 1991a. Halothane genotype by weight interactions on pig meat quality. Can. J. Anim. Sci. 71:645-658.

Sather, A. P., A. C. Murray, S. M. Zawadski, and P. Johnson. 1991b. The effect of the halothane gene on pork production and meat quality of pigs reared under commercial conditions. Can J. Anim. Sci. 71:959-967.

Simpson, S. P., and A. J. Webb. 1989. Growth and carcass performance of British Landrace pigs heterozygous at the halothane locus. Anim. Prod. 49:503-509.

van Laack, L. J. M., and M. B. Solomon. 1994. Strategies to improve lean meat yield and their effects on pork quality. Tenth Annual Carolina Swine Nutrition Conference, Raleigh, NC, p. 2-7.

Wang, H., J. R. Claus, and M. D. Lindemann. 1994. Effect of supplemental dietary chromium on the characteristics of pork. Institute of Food Technologists Annual Meeting, Atlanta, GA, p. 90. (Abstr.).

Ward, T. L., L. L. Southern, and T. D. Bidner. 1997. Interactive effects of dietary chromium picolinate and crude protein level in growing-finishing pigs provided inadequate and adequate pen space. J. Anim. Sci. 75:1001-1008.

Webb, A. J. 1981. The halothane sensitivity test. In: T. Troystein, E. Slinde, and N. Standal (Ed.) Porcine Stress and Meat Quality. p 105. Agricultural Food Research Society, As, Norway.

Wenk, C., S. Gebert, and H. P. Pfirter. 1995. Chromium supplements in the feed for growing pigs: influence on growth and meat quality. Arch. Anim. Nutr. 48:71-81.

Zhang, W., D. L. Kuhlers, and W. E. Rempel. 1992. Halothane gene and swine performance. J. Anim. Sci. 70:1307-1313.

Table 1. Diet composition, %

	Grower 1		Grower 2		Finisher	
	Chromium, ppb		Chromium, ppb		Chromium, ppb	
	0	200	0	200	0	200
Corn	73.15	73.15	75.29	75.29	81.65	81.65
Soybean Meal (44%)	23.00	23.00	21.10	21.10	15.37	15.37
Monocalcium phosphate	1.17	1.17	.96	.96	.82	.82
CHROMAX[b]	---	.05	---	.05	---	.05
Ground limestone	1.08	1.03	1.05	1.00	1.03	.98
Salt	.35	.35	.35	.35	.35	.35
Vitamin premix[c]	.25	.25	.25	.25	.25	.25
Trace mineral premix[d]	.08	.08	.08	.08	.08	.08
Selenium premix[e]	.05	.05	.05	.05	.05	.05
Soy oil	.87	.87	.87	.87	.87	.87
Calculated analysis:						
Me, kcal/lb.	1502	1502	1507	1507	1506	1506
Crude protein, %	16.3	16.3	15.7	15.7	13.7	13.7
Lysine, %	.85	.85	.80	.80	.65	.65
Ca, %	.70	.70	.65	.65	.60	.60
P, %	.60	.60	.55	.55	.50	.50
Chromium, ppb	0	200	0	200	0	200

[a]As fed basis.
[b]Provided 200 ppb of chromium picolinate per kilogram of diet.
[c]Provided the following per kilogram of diet: 7,197 IU vitamin A, 460 IU vitamin D_3, 28.8 IU vitamin E, 2.3 mg vitamin K (as menadione), 4.6 mg riboflavin, 23 mg pantothenic acid, 23 mg niacin, 23 μg vitamin B_{12}, 576 mg choline, 288 μg biotin, and 2.3 mg folic acid.
[d]Provided the following per kilogram of diet: 75 mg Zn, 87.5 mg Fe, 30 mg Mn, 8.75 mg Cu, and 1 mg I.
[e]Provided .3 mg of Se per kilogram of diet.

Table 2. Least squares means and standard errors (SEM) of the main effects of the halothane gene, chromium picolinate, and sex on growth performance in pigs[a]

	Halothane Gene		Chromium Picolinate, ppb		Sex			P - Values[b]		
Variable	NN	Nn	0	200	Barrow	Gilt	SEM	Hal	CrP	Sex
Final wt, kg[c]	107.3	107.3	107.9	106.7	111.2	103.4	.7	.96	.29	.001
Daily gain, g/day	846.8	849.2	853.0	843.0	889.8	806.2	8.0	.84	.39	.001
Feed intake, g/day	2618.7	2571.4	2605.2	2584.9	2748.9	2441.2	23.7	.17	.55	.001
Gain/Feed	.32	.33	.33	.33	.32	.33	.003	.09	.80	.09

[a]Pen means (n = 64).
[b]Hal = Halothane gene; CrP = Chromium Picolinate.
[c]Represents the final average pen weight measured at the farm.

Table 3. Least squares means and standard errors (SEM) of chromium picolinate x halothane gene effects on growth performance in pigs[a]

	Chromium picolinate, ppb					
	0		200			
	Halothane		Halothane			
Variable	NN	Nn	NN	Nn	SEM	P-Value
Final wt, kg[b]	107.5	108.2	107.1	106.4	1.0	.51
Daily gain, g/day	849.4	856.6	844.1	841.9	11.4	.69
Feed intake, g/day	2624.3	2586.0	2613.1	2556.8	33.5	.79
Gain/Feed	.33	.33	.32	.33	.004	.92

[a]Pen means (n = 64).
[b]Represents the final average pen weight measured at the farm.

Table 4. Least squares means of chromium picolinate x sex effects on growth performance in pigs[a]

	Chromium picolinate, ppb					
	0		200			
	Sex		Sex			
Variable	Barrows	Gilts	Barrows	Gilts	SEM	P-Value
Final wt, kg[b]	111.8	103.9	110.6	102.9	1.0	.90
Daily gain, g/day	895.5	810.4	884.0	802.0	11.4	.90
Feed intake, g/day	2749.7	2460.6	2748.1	2421.8	33.5	.59
Gain/Feed	.33	.33	.32	.33	.004	.48

[a]Pen means (n = 64).
[b]Represents the final average pen weight measured at the farm.

Table 5. Least squares means and standard errors (SEM) of sex x halothane gene effects on growth performance in pigs[a]

	Sex					
	Barrows		Gilts			
	Halothane		Halothane			
Variable	NN	Nn	NN	Nn	SEM	P-Value
Final wt, kg[b]	111.6	110.8	103.0	103.8	1.0	.43
Daily gain, g/day	892.3	887.2	801.2	811.2	11.4	.52
Feed intake, g/day	2797.5	2700.3	2439.9	2442.5	33.5	.15
Gain/Feed	.32	.33	.33	.33	.004	.46

[a]Pen means (n = 64).
[b]Represents the final average pen weight measured at the farm.

Table 6. Least squares means and standard errors (SEM) of the main effects of the halothane gene, chromium picolinate, and sex on carcass characteristics of pigs[a]

	Halothane Gene		Chromium Picolinate, ppb		Sex			P - Values[b]		
Variable	NN	Nn	0	200	Barrow	Gilt	SEM	Hal	CrP	Sex
Final wt, kg[c]	105.7	105.9	106.3	105.3	109.4	102.2	.8	.84	.42	.001
Hot carcass wt, kg	82.2	82.9	83.0	82.1	85.4	79.7	.7	.46	.36	.001
Chilled carcass wt, kg	80.3	81.0	81.2	80.2	83.5	77.8	.7	.47	.32	.001
Carcass length, cm	78.9	78.7	78.9	78.6	78.9	78.7	.23	.64	.38	.47
Loin muscle area, cm^{2}[d]	41.2	43.9	42.2	42.9	41.4	43.7	.50	.001	.33	.002
10^{th} rib backfat, cm	2.61	2.42	2.51	2.52	2.91	2.11	.05	.02	.92	.001
1^{st} rib backfat, cm	4.25	4.10	4.17	4.19	4.40	3.96	.05	.06	.79	.001
Last rib backfat, cm[e]	2.65	2.59	2.56	2.68	2.83	2.41	.05	.39	.08	.001
Last lumbar backfat, cm	2.53	2.36	2.43	2.47	2.63	2.27	.05	.03	.61	.001
Average backfat, cm	3.15	3.02	3.05	3.11	3.29	2.89	.04	.03	.27	.001

[a]Individual pigs (n = 160).
[b]Hal = Halothane gene; CrP = Chromium Picolinate.
[c]Represents the final weight measured at the Virginia Tech Meats Lab immediately prior to slaughter.
[d]There tended to be an interaction between sex and the halothane gene ($P < .11$). See Table 9.
[e]There tended to be an interaction between CrP and Hal ($P < .10$). See Table 7.

Table 7. Least squares means and standard errors (SEM) of the main effects of the halothane gene, chromium picolinate, and sex on dressing percentage and measures of lean meat content in pork carcasses[a]

	Halothane Gene		Chromium Picolinate, ppb		Sex			P - Values[b]		
Variable	NN	Nn	0	200	Barrow	Gilt	SEM	Hal	CrP	Sex
DPF,%[c]	76.3	76.9	76.7	76.5	76.5	76.7	.22	.07	.62	.40
DPL, %[d]	77.8	78.3	78.1	77.9	78.0	78.0	.13	.006	.30	.92
Lean, kg[e]	41.7	43.4	42.7	42.4	42.1	43.0	.40	.003	.67	.14
Lean percentage[e, f]	50.9	52.5	51.5	51.8	49.4	54.0	.31	.001	.55	.001
Lean gain, g/day[e]	335.3	354.6	346.5	343.4	340.5	349.4	4.3	.003	.62	.15

[a]n = 160.
[b]Hal = Halothane gene; CrP = Chromium Picolinate.
[c]DPF = dressing percentage calculated using on-farm final weight and hot carcass weight.
[d]DPL = dressing percentage calculated using Virginia Tech Meats Lab final weight and hot carcass weight.
[e]Calculated using formulas found in *Procedures to Evaluate Market Hogs* (NPPC, 1991).
[f]There was an interaction between sex and the halothane gene ($P < .05$). See Table 13.

Table 8. Least squares means and standard errors (SEM) of the main effects of the halothane gene, chromium picolinate, and sex on wholesale cut weight and belly thickness of pork carcasses[a]

	Halothane Gene		Chromium Picolinate, ppb		Sex			P - Values[b]		
Variable	NN	Nn	0	200	Barrows	Gilts	SEM	Hal	CrP	Sex
Hams, kg	9.4	9.7	9.6	9.4	9.7	9.4	.09	.02	.09	.03
Loins, kg	7.6	7.8	7.7	7.7	7.8	7.6	.08	.11	.68	.06
Picnic shoulders, kg	5.0	5.0	5.0	5.0	5.2	4.8	.05	.38	.21	.001
Boston butts, kg	3.4	3.5	3.5	3.4	3.6	3.4	.03	.05	.15	.001
Belly, kg	4.1	4.1	4.1	4.0	4.3	3.8	.07	.91	.35	.001
Belly thickness, mm[c]	30.3	29.6	30.3	29.6	32.3	27.5	.59	.38	.46	.001

[a]n = 160.
[b]Hal = Halothane gene; CrP = Chromium Picolinate.
[c]Average of six measurements across the belly.

Table 9. Least squares means and standard errors (SEM) of chromium picolinate x halothane gene effects on carcass characteristics of pigs[a]

	Chromium picolinate, ppb					
	0		200			
	Halothane		Halothane			
Variable	NN	Nn	NN	Nn	SEM	P-Value
Final wt, kg[b]	105.9	106.6	105.4	105.2	1.2	.74
Hot carcass wt, kg	82.4	83.6	82.0	82.2	1.0	.61
Chilled carcass wt, kg	80.6	81.7	80.1	80.3	1.0	.65
Carcass length, cm	79.1	78.8	78.7	78.6	.33	.82
Loin muscle area, cm^2	40.3	44.1	42.0	43.8	.71	.15
10^{th} rib backfat, cm	2.57	2.45	2.65	2.39	.08	.38
1^{st} rib backfat, cm	4.24	4.10	4.27	4.11	.08	.87
Last rib backfat, cm	2.54[c]	2.59[cd]	2.76[d]	2.60[cd]	.07	.10
Last lumbar backfat, cm	2.50	2.35	2.56	2.37	.08	.83
Average backfat, cm	3.09	3.01	3.20	3.03	.05	.39

[a]n = 160.
[b]Represents the final weight measured at the Virginia Tech Meats Lab immediately prior to slaughter.
[c, d]Means with different superscripts tend to differ ($P < .10$).

Table 10. Least squares means and standard errors (SEM) of chromium picolinate x sex effects on carcass characteristics of pigs[a]

	Chromium picolinate, ppb					
	0		200			
	Sex		Sex			
Variable	Barrows	Gilts	Barrows	Gilts	SEM	P-Value
Final wt, kg[b]	109.8	102.7	108.9	101.7	1.1	.97
Hot carcass wt, kg	85.8	80.2	85.0	79.2	1.0	.92
Chilled carcass wt, kg	84.0	78.4	83.1	77.3	1.0	.94
Carcass length, cm	79.1	78.7	78.7	78.6	.32	.59
Loin muscle area, cm^2	41.0	43.4	41.8	44.0	.71	.97
10^{th} rib backfat, cm	2.90	2.12	2.93	2.11	.08	.83
1^{st} rib backfat, cm	4.43	3.91	4.37	4.01	.08	.33
Last rib backfat, cm	2.79	2.34	2.88	2.48	.06	.72
Last lumbar backfat, cm	2.57	2.29	2.69	2.24	.08	.30
Average backfat, cm	3.26	2.85	3.31	2.91	.05	.92

[a]n = 160.
[b]Represents the final weight measured at the Virginia Tech Meats Lab immediately prior to slaughter.

Table 11. Least squares means and standard errors (SEM) of sex x halothane gene effects on carcass characteristics of pigs[a]

	Sex					
	Barrows		Gilts			
	Halothane		Halothane			
Variable	NN	Nn	NN	Nn	SEM	P-Value
Final wt, kg[b]	109.6	109.2	101.7	102.7	1.1	.56
Hot carcass wt, kg	85.3	85.5	79.1	80.3	1.0	.61
Chilled carcass wt, kg	83.4	83.6	77.2	78.5	1.0	.58
Carcass length, cm	79.1	78.8	78.7	78.7	.32	.68
Loin muscle area, cm^2	39.4[c]	43.4[d]	42.9[d]	44.5[d]	.71	.11
10^{th} rib backfat, cm	3.07	2.76	2.15	2.08	.08	.12
1^{st} rib backfat, cm	4.47	4.33	4.03	3.88	.08	.97
Last rib backfat, cm	2.90	2.77	2.40	2.42	.06	.23
Last lumbar backfat, cm	2.77	2.49	2.30	2.23	.08	.17
Average backfat, cm	3.38	3.20	2.91	2.85	.05	.26

[a]n = 160.
[b]Represents the final weight measured at the Virginia Tech Meats Lab immediately prior to slaughter.
[c, d]Means with different superscripts tend to differ ($P < .10$).

Table 12. Least squares means and standard errors (SEM) of chromium picolinate x halothane gene effects on dressing percentage and measures of lean meat content in pork carcasses[a]

	Chromium picolinate, ppb					
	0		200			
	Halothane		Halothane			
Variable	NN	Nn	NN	Nn	SEM	P-Value
DPF, %[b]	76.3	77.0	76.3	76.8	.31	.68
DPL, %[c]	77.8	78.5	77.8	78.1	.18	.24
Lean, kg[d]	41.7	43.7	41.7	43.2	.56	.61
Lean percentage[d]	50.7	52.4	51.0	52.6	.44	.97
Lean gain, g[d]	335.4	357.5	335.2	351.6	6.0	.64

[a]n = 160.
[b]DPF = dressing percentage calculated using on-farm final weight and hot carcass weight.
[c]DPL = dressing percentage calculated using Virginia Tech Meats Lab final weight and hot carcass weight.
[d]Calculated using formulas found in *Procedures to Evaluate Market Hogs* (NPPC, 1991).

Table 13. Least squares means and standard errors (SEM) of chromium picolinate x sex effects on dressing percentage and lean meat content in pork carcasses[a]

	Chromium picolinate, ppb					
	0		200			
	Sex		Sex			
Variable	Barrows	Gilts	Barrows	Gilts	SEM	P-Value
DPF, %[b]	76.5	76.9	76.5	76.6	.31	.67
DPL, %[c]	78.1	78.1	78.0	77.9	.18	.75
Lean, kg[d]	42.3	43.1	42.0	42.9	.55	.99
Lean percentage[d]	49.3	53.8	49.5	54.1	.44	.97
Lean gain, g[d]	342.0	350.9	338.9	348.0	6.0	.99

[a]n = 160.
[b]DPF = dressing percentage calculated using on-farm final weight and hot carcass weight.
[c]DPL = dressing percentage calculated using Virginia Tech Meats Lab final weight and hot carcass weight.
[d]Calculated using formulas found in *Procedures to Evaluate Market Hogs* (NPPC, 1991).

Table 14. Least squares means and standard errors (SEM) of sex x halothane gene effects on dressing percentage and measurements of lean meat content in pork carcasses[a]

	Sex					
	Barrows		Gilts			
	Halothane		Halothane			
Variable	NN	Nn	NN	Nn	SEM	P-Value
DPF, %[b]	76.2	76.8	76.5	77.0	.31	.83
DPL, %[c]	77.8	78.3	77.8	78.3	.18	.94
Lean, kg[d]	41.0	43.2	42.4	43.6	.55	.38
Lean percentage[d]	48.1[e]	50.6[f]	53.6[g]	54.3[g]	.44	.05
Lean gain, g[d]	328.0	352.9	342.6	356.2	6.0	.35

[a]n = 160.
[b]DPF = dressing percentage calculated using on-farm final weight and hot carcass weight.
[c]DPL = dressing percentage calculated using Virginia Tech Meats Lab final weight and hot carcass weight.
[d]Calculated using formulas found in *Procedures to Evaluate Market Hogs* (NPPC, 1991).
[e, f, g]Means with different superscripts are different ($P < .05$).

Table 15. Least squares means and standard errors (SEM) of chromium picolinate x halothane gene effects on wholesale cut weights and belly thickness of pork carcasses[a]

	Chromium picolinate, ppb					
	0		200			
	Halothane		Halothane			
Variable	NN	Nn	NN	Nn	SEM	P-Value
Hams, kg	9.5	9.8	9.3	9.5	.13	.86
Loins, kg	7.6	7.8	7.7	7.8	.11	.61
Picnic shoulders, kg	5.0	5.1	4.9	5.0	.07	.83
Boston butts, kg	3.5	3.6	3.4	3.5	.04	.76
Belly, kg	4.1	4.1	4.0	4.0	.09	.67
Belly thickness, mm[b]	30.4	30.1	30.3	29.0	.84	.55

[a]n = 160.
[b]Average of six measurements across the belly.

Table 16. Least squares means and standard errors (SEM) of chromium picolinate x sex effects on wholesale cut weights and belly thickness of pork carcasses[a]

	Chromium picolinate, ppb					
	0		200			
	Sex		Sex			
Variable	Barrows	Gilts	Barrows	Gilts	SEM	P-Value
Hams, kg	9.8	9.4	9.5	9.3	.13	.36
Loins, kg	7.8	7.6	7.8	7.6	.12	.89
Picnic shoulders, kg	5.2	4.9	5.1	4.8	.07	.98
Boston butts, kg	3.6	3.4	3.5	3.3	.04	.93
Belly, kg	4.4	3.9	4.3	3.7	.09	.66
Belly thickness, mm[b]	32.4	28.1	32.3	27.0	.85	.57

[a]n = 160.
[b]Average of six measurements across the belly.

Table 17. Least squares means and standard errors (SEM) of sex x halothane gene effects on wholesale cut weights and belly thickness of pork carcasses[a]

	Sex					
	Barrows		Gilts			
	Halothane		Halothane			
Variable	NN	Nn	NN	Nn	SEM	P-Value
Hams, kg	9.5	9.8	9.2	9.5	.13	.80
Loins, kg	7.7	7.9	7.5	7.7	.12	.98
Picnic shoulders, kg	5.1	5.2	4.8	4.9	.07	.75
Boston butts, kg	3.5	3.6	3.3	3.4	.04	.44
Belly, kg	4.4	4.3	3.8	3.8	.09	.34
Belly thickness, mm[b]	33.1	31.6	27.6	27.5	.85	.38

[a]n = 160.
[b]Average of six measurements across the belly.

Table 18. Least squares means and standard errors (SEM) of the main effects of the halothane gene, chromium picolinate, and sex on subjective quality characteristics in fresh pork[a]

	Halothane Gene		Chromium Picolinate, ppb		Sex			P - Values[b]		
Variable	NN	Nn	0	200	Barrow	Gilt	SEM	Hal	CrP	Sex
Color[c, e, f]	2.8	2.5	2.6	2.6	2.5	2.7	.04	.001	.52	.002
Moisture/Firmness[c]	2.9	2.6	2.7	2.7	2.7	2.8	.05	.001	.68	.09
Marbling[d, g]	2.1	1.5	1.9	1.7	1.8	1.8	.07	.001	.17	.89

[a]Values based on standards published in *Procedures to Evaluate Market Hogs* (NPPC, 1991).
[b]Hal = Halothane gene; CrP = Chromium Picolinate.
[c]Data from Trial 1 (n = 96).
[d]Data from Trial 1 and Trial 2 (n = 160).
[e]There was an interaction between sex and the halothane gene ($P < .05$). See Table 21.
[f]There tended to be an interaction between chromium picolinate and sex ($P < .11$). See Table 20.
[g]There was an interaction between chromium picolinate and the halothane gene ($P < .004$). See Table 19.

Table 19. Least squares means and standard errors (SEM) of chromium picolinate x halothane gene effects on subjective quality characteristics in fresh pork[a]

	Chromium picolinate, ppb					
	0		200			
	Halothane		Halothane			
Variable	NN	Nn	NN	Nn	SEM	P-Value
Color[b]	2.8	2.5	2.7	2.5	.06	.85
Moisture/Firmness[b]	2.9	2.6	2.9	2.6	.07	.69
Marbling[c]	2.4[d]	1.4[e]	1.9[f]	1.6[f]	.10	.004

[a]Values based on *Procedures to Evaluate Market Hogs* (NPPC, 1991).
[b]Data from Trial 1 (n = 96).
[c]Data from Trial 1 and Trial 2 (n = 160).
[d, e, f]Means with different superscripts are different ($P < .05$).

Table 20. Least squares means and standard errors (SEM) of chromium picolinate x sex effects on subjective quality characteristics in fresh pork[a]

	Chromium picolinate, ppb					
	0		200			
	Sex		Sex			
Variable	Barrows	Gilts	Barrows	Gilts	SEM	P-Value
Color[b]	2.5[d]	2.8[e]	2.5[d]	2.7[de]	.06	.11
Moisture/Firmness[b]	2.6	2.8	2.7	2.8	.07	.28
Marbling[c]	1.9	1.8	1.7	1.8	.10	.51

[a]Values based on *Procedures to Evaluate Market Hogs* (NPPC, 1991).
[b]Data from Trial 1 (n = 96).
[c]Data from Trial 1 and Trial 2 (n = 160).
[d, e]Means with different superscripts tended to be different ($P < .11$).

Table 21. Least squares means and standard errors (SEM) of sex x halothane gene effects on subjective quality characteristics in fresh pork[a]

	Sex					
	Barrows		Gilts			
	Halothane		Halothane			
Variable	NN	Nn	NN	Nn	SEM	P-Value
Color[b]	2.7[d]	2.3[e]	2.8[d]	2.6[d]	.06	.03
Moisture/Firmness[b]	2.8	2.5	2.9	2.7	.07	.83
Marbling[c]	2.2	1.5	2.1	1.5	.10	.41

[a]Values based on *Procedures to Evaluate Market Hogs* (NPPC, 1991).
[b]Data from Trial 1 (n = 96).
[c]Data from Trial 1 and Trial 2 (n = 160).
[d, e]Means with different superscripts are different ($P < .05$).

Chapter 4

Halothane Gene, Chromium Picolinate Supplementation, and Sex Effects on Pork Quality Characteristics

ABSTRACT

Two trials (n = 160 pigs) were conducted to evaluate halothane gene, chromium picolinate supplementation, and sex effects on pork muscle quality. Halothane carrier pigs produced pork that was lighter in color, had greater drip loss, and lower protein solubility ($P < .05$) than halothane-free pigs. Chromium supplementation resulted in higher values for CIE a*, CIE b*, and Chroma C ($P < .05$). Halothane carrier barrows and all gilts not fed chromium had lower lipid muscle content than homozygous normal barrows ($P < .05$). Gilts produced pork that was lighter, more red, with less lipid, and higher moisture than barrows ($P < .02$). Chromium supplementation may be used for potential live animal performance and carcass composition benefits without undesirable changes in pork quality.

Key Words: pork quality, halothane, chromium picolinate, sex

INTRODUCTION

Consumers recognize inconsistencies in the quality of pork which could potentially influence their purchasing decisions (NPPC, 1994). Genetics, nutrition, pre-slaughter handling, and carcass chilling procedures can affect pork muscle quality. Most studies have demonstrated that pigs carrying two copies of the halothane gene (nn) usually produce pale, soft, and exudative (PSE) pork (Simpson and Webb, 1989; Casteels et al., 1995; DeSmet et al., 1996), but the effects on pork muscle quality in heterozygous (Nn) pigs is less clear. Webb (1981) reported that carrier (Nn) pigs produced normal muscle quality but several studies since have reported carrier pigs produced lower quality pork (Simpson and Webb, 1989; Goodwin, 1994; DeSmet et al., 1996). In addition, Grandin (1994) reported that PSE pork could result from stress-resistant (NN) pigs. Some studies have shown improved lean characteristics in pork from carrier pigs (Zhang et al., 1992; Lundstrom et al., 1995) but other studies did not demonstrate differences between carrier and normal pigs for lean characteristics (Aalhus et al., 1991; Garcia-Macias et al., 1996).

Chromium picolinate supplementation has shown potential in improving carcass characteristics in pigs. In some studies, pigs supplemented with chromium picolinate (CrP) produced carcasses with improved muscle percentages, decreased backfat, and increased loin muscle area (Page et al., 1993; Lindemann et al., 1995). Wang et al. (1994) reported that supplementing pigs with CrP had no effects on pork muscle quality. Boleman et al. (1995) reported that CrP supplementation did not affect sensory values or shear force in pork. However, there has been no research published that analyzed

possible interactions of the chromium picolinate and the halothane gene on pork composition and quality characteristics.

The differences in growth rate and carcass composition between barrows and gilts has been known for many years (Christian et al., 1980; Leach et al., 1996). In addition, Goodwin (1994) reported several differences in pork quality between barrow and gilt carcasses. Therefore, the objectives of this study were to determine the main effects and interactions of chromium picolinate, the halothane gene, and sex on various chemical properties and quality characteristics of pork.

MATERIALS AND METHODS

Animals and Feeding

Halothane-free (NN) sows (Yorkshire x Chester White cross) were bred to two littermate heterozygous (Nn) Hampshire boars via artificial insemination at the Virginia Tech Tidewater Agricultural Research Center (TAREC). Ninety-six pigs were used for Trial 1 and 64 for Trial 2. Average initial weight for the pigs going on test was 33.7 kg (Trial 1) and 22.7 kg (Trial 2) and average off-test weight was 103.9 kg (Trial 1) and 110.7 kg (Trial 2). Pigs were assigned to pens based on sex (barrow, gilt), genotype (NN, Nn), and initial weight. Pens were randomly allotted to two dietary treatments of 0 or 200 ppb CrP added to standard corn-soybean meal diets. Four replications were included in Trial 1 (two replications with four pigs per pen and two replications with two pigs per pen) and four replications (four replications of two pigs per pen) in Trial 2. Chromium containing diets were prepared by replacing .05% limestone with .05%

CHROMAX® (Prince Agri-Products, Decatur, IL). While on test, pigs were housed in a totally slatted, confinement grower-finishing barn at TAREC. Feed and water were provided ad libitum.

Slaughter and Fabrication Procedures

When pigs reached the desired final weight within a replicate, they were weighed off test, and tattooed. Pigs were then mixed with those from the same replicate and transported approximately 5 h to the Virginia Tech abattoir. Pigs were rested overnight and allowed free access to water but were not allowed to consume feed. Pigs were removed from feed for a total of 15 to 20 h prior to slaughter. Each animal was exercised continuously at a moderate pace for 10 minutes in a rectangular (~2 x 5 m) holding pen immediately prior to slaughter to establish potential conditions that could promote the expression of pale, soft, and exudative (PSE) pork. Each pig was then weighed and immediately slaughtered in Virginia Tech's state inspected Meats Laboratory. After obtaining hot carcass weight, carcasses were air-chilled overnight (18 to 24 h) at 4^{o}C before collecting further measurements and processing into wholesale cuts.

After chilling, the left side of each carcass was ribbed between the 10^{th} and 11^{th} costal bones and allowed to bloom 40 minutes (for oxygenation of myoglobin) prior to removal of one chop (2.54 cm, 12^{th} thoracic vertebrae) used for sensory evaluation and CIE L* a* b* color measurements. Both sides of each carcass were fabricated and wholesale cuts were removed from the carcass and weighed. Additional chops (2.54 cm) were then removed from the *longissimus thoracis et lumborum* of both the right and left side of the carcass as shown in Figure 1. The chops (2.54 cm) for sarcomere length,

Warner-Bratzler Shear (d1, d10), lipid determination, and protein solubility were cut, vacuum packaged in moisture impermeable bags (Type B540, Cryovac Division W.R. Grace, Duncan, SC) frozen and stored (–20^{o}C) for later analysis. One 5.0 cm chop was stored (4^{o}C) for 4 to 6 h in an unsealed plastic bag prior to initiating drip loss determination.

Fresh Muscle Quality Measurements

pH and Temperature Decline

pH and temperature decline were determined by measurements taken at 0.75 h, 3 h, and 24 h. An iodoacetate procedure (Bendall, 1973) was used on samples taken at 45 min and 3 h. A 2-g sample of muscle was removed from the posterior end (3rd lumbar vertebrae) of the *longissimus lumborum* and immediately homogenized (Virtishear homogenizer, no. 225318, The Virtis Company, Inc., Gardener, NY) in 20 ml of .005 *M* iodoacetate. For 24 h pH (pH_u), a 1-g sample of muscle was removed from the same anatomical location and homogenized (Virtishear homogenizer, no. 225318, The Virtis Company, Inc., Gardener, NY) in 10 ml of distilled deionized water. pH was measured on the individual samples with a pH meter (model 240, Corning Inc., Corning, NY) with a pH electrode (model 576570, Corning Inc., Corning, NY).

Temperature decline was measured (Electrotherm digital thermometer, no. TM99A, Cooper Instrument Corp., Middlefield, CT) on the loin by inserting the probe directly into the loin at the 3rd lumbar vertebrae and on the ham by inserting the probe directly into the ham slightly above the aitchbone.

Color Measurements

CIE L* a* b* values were measured in triplicate on the cut surface of the *longissimus lumborum* with a chroma meter (model CR-200, Minolta Camera Co., Ltd., Osaka, Japan). The chroma meter was calibrated to white (CIE L* = 97.91, a* = -0.68, b* = +2.45, part # 2093326), red (CIE L* = 52.06, a* = 42.13, b* = 19.38, part # 11533041, CR-A47 R), and beige (CIE L* = 57.26, a* = 9.45, b = 10.77, part # 13433234, CR-A47 B) calibration plates and was operated using the 'auto select' feature. Reflectance values (400 to 700 nm) were determined in duplicate measurements with a scanning reflectance spectrophotometer (model 2101PC, UV-Visible Scanning Spectrophotometer, Shimadzu Corp., Kyoto, Japan) calibrated to the same white Minolta plate. The spectrophotometer was configured for a sampling interval of 1.0 nm, slit width of 2.0 nm, and fast scan speed. Myoglobin forms were calculated as follows: %R 474nm/525nm for deoxymyoglobin, %R 572nm/525nm for metmyoglobin, and %R 610/525 for oxymyoglobin (AMSA, 1991).

Color Storage Study

All chops were wrapped in polyvinylchloride (PVC) film and stored at 3^{o}C continuously under Natural White flourescent lighting (model F40SPEC30, Philips 40W 5C, State Electric Supply Co., Inc. Christiansburg, VA). Distance between the light fixture and the chops was set to provide 1076 lux with a hand-held digital light meter (model L096080, Extech Instrument Corp. Waltham, MA).

Drip Loss

The drip loss procedure was conducted according to Honikel (1987) on approximately 50-g cores (~40 mm diameter). The cores were removed from the center of the *longissimus lumborum* chop (5 cm thick) parallel with the muscle fibers. Each core (one per treatement) was weighed immediately and hung on a fishhook in a round (7.5 cm diameter) plastic container (16.5 cm height). After 48 h (4^{o}C) drip loss was determined by the following equation:

(initial weight - post 48 h weight) ÷initial weight x 100.

% Fat and Moisture

Chops (2.54 cm) were frozen and stored at -20^{o}C for 5 months prior to analysis. Each chop was thawed, trimmed of external fat, and ground (Kitchen Aide Classic Grinder/Mixer, Kitchen Aide, Inc., St. Joseph, MI). Thaw fluid was reincorporated into ground samples. Both moisture and fat determinations were conducted according to AOAC (1990) procedures.

Shear Force

Prior to shear force measurement, chops (2.54 cm) were frozen and stored for 6 weeks. The chops from the *longissimus thoracic* were thawed at 4^{o}C for 15 to 18 h and roasted to an internal temperature of 71^{o}C in a convection oven (Model Mark V-III, Blodgett Corp., Burlington, VT) according to AMSA guidelines (1995). Two thermocouples were inserted into the geometric center of each chop (spaced 1 to 2 cm apart) and temperature was monitored with an electronic temperature recorder (model 2160 A-T, Omega, Engineering, Inc., Stanford, CT). Chops were allowed to cool for

approximately 20 minutes prior removing 6 cores (12.7 mm diameter) per chop parallel to the muscle fibers. Warner-Bratzler shear peak force (kg) values for these samples were determined with a computer interfaced Instron (Model 1011, Instron Corp., Canton, Mass.). A 50 kg load transducer was used with a crosshead speed of 200 mm/min and a 10% load range. Shear force averages were calculated for each chop.

Sarcomere Length

Chops (2.54 cm) frozen for 6 months were thawed at 10^{o}C for 15 to 18 h prior to removing 3 cores (approximately 12.5 mm diameter each). These samples were chemically fixed and sarcomere length was measured (Cross et al., 1981) using He-Ne laser (Model OEMIP, Aerotech Inc., Pittsburg, PA). Eight fibers per core were used to determine sarcomere length. Averages were calculated for each chop.

Cooking Loss

The chops used for d 10 shear force determination were used for cooking loss. Chops were thawed at 4^{o}C, removed from the vacuum package, blotted with a paper towel prior to weighing, and then cooked to an internal temperature of 71^{o}C. Chops were then allowed to cool for 20 minutes before being blotted with a paper towel and weighed again. Cooking loss was calculated based on the weights of the meat prior to and after cooking.

Protein Solubility

Protein solubility was determined by a slightly modified version from Warner (1994). The differences in procedure were the thawing method and the time and force at which the centrifuge was used. Chops (2.54 cm) from the *longissimus thoracis* were frozen (-20^{o}C) for 9 months prior to analysis. The samples were thawed two hours (4^{o}C) so the samples could be cut with a knife, without losing significant fluid during grinding. Chops were trimmed of external fat, sliced into approximately 7.5 x 7.5 x 10 mm cubes, and ground quickly through a 9.5 mm grinding plate (Kitchen Aide Classic Grinder/Mixer, Kitchen Aide, Inc., St. Joseph, MI). To determine sarcoplasmic protein solubility (mg/g), quadruplicate 1.0-g samples from each chop were immediately weighed and homogenized (model no. 225318 Virtishear homogenizer, The Virtis Company, Inc., Gardener, NY) in 10 ml of .0025M potassium phosphate buffer (pH 7.2) for three, 4-sec bursts using a macro-fine attached to a 20 mm shaft generator (Item number 225466, Virtis Co. Gardener, NY). To determine myofibrillar protein solubility, quadruplicate 1.0-g samples from each chop were weighed and homogenized as done for sarcoplasmic solubility in 10 ml of 1.1 KI/0.1M potassium phosphate buffer. The Virtishear was set on a speed of 40 and 50 ml centrifuge tubes (no. 05-539-9, Fisher Scientific, Raleigh, NC) were used for both sarcoplasmic and myofibrillar homogenation. The samples were placed on a shaker (4^{o}C) for 3h at 150 rpm, then centrifuged at 2600 x g for 30 minutes. The respective supernatants were used for protein denaturation. Biuret protein determination was performed on the samples the same day according to Gornall et al. (1949). Total solubility was determined by adding sarcoplasmic and myofibrillar solubility values.

Statistics

The experiment was designed as a Generalized Randomized Block Design with subsampling in a 2 x 2 x 2 factorial arrangement. When data were used from only the first trial, a complete randomized design (CRD) was used. For data analyzed over time, a split-plot design was used. Trial was the blocking factor and the eight treatment combinations (2 chromium x 2 halothane x 2 sex) were repeated four times (Rep) within each block. Pens were the experimental unit and pigs were the observational unit. Data were analyzed with GLM procedures (SAS, 1991). The main effects (chromium picolinate, halothane gene, and sex) and two-way interactions (chromium x halothane gene, chromium picolinate x sex, and sex x halothane gene) were analyzed. The main effects and interaction were tested against the experimental error term of Replication(Halothane x Chromium x Sex x Trial). Means were separated using the pairwise comparisons procedure while controlling for the comparisonwise error rate.

RESULTS AND DISCUSSION

pH and Temperature Decline

Carcasses from carrier pigs had a lower ($P<0.05$) pH at .75 h, 3 h, and 24 h (pH_u) than homozygous normal carcasses (Table 1). These results agree with Leach et al. (1996), who found lower pH values for carrier pigs at both .75 h and 24 h. Neither genotype produced carcasses that were PSE suspect, but both genotypes produced carcasses with a an ultimate pH of less than 5.5 (NN = 5.21; Nn = 5.13) that would fit into the quality category of PSE pork (Joo et al., 1995; Warner et al., 1997). Although

carrier pigs are known to produce a lower pH_u, these values are quite low. The ten minutes of exercise that the pigs received prior to slaughter could have contributed to this lower pH_u. Because each pig's metabolism was potentially at a higher state than normal, more glycogen could have been converted to lactic acid, which in turn could have decreased muscle pH.

Another possible explanation for this low pH_u could be related to the Hampshire ancestry of the pigs. Monin et al. (1987) reported a higher glycolytic potential, that in turn caused a lower pH_u, in pigs from Hampshire lines. This condition is caused by the Renement Napole (RN) gene (LeRoy et al., 1990). Lundstrom et al. (1996) reported that pigs expressing the RN gene had lower pH_u in both the *longissimus thoracis et lumborum* and *rectus femoris* muscles. Lundstrom et al. (1996) also reported that pigs with the RN gene can often have a glycolytic potential of up to 70% more than normal pigs, which in turn could contribute to a lower pH_u. Although it was not possible to identify the RN gene in the carcasses after slaughter in the present study, other research suggests that the gene could be present in these pigs. Chromium and sex had no effects on pH decline. The halothane gene, chromium, and sex did not have any effect on temperature decline.

Color Evaluation

When compared to normal animals (Table 2), carrier pigs displayed higher CIE L* values ($P<0.05$). Several studies have found L* values to be higher for Nn pigs (Casteels et al., 1995; Leach et al., 1996; Garcia-Macias et al., 1996). In contrast, DeSmet et al. (1996) found no differences in CIE L* values between carrier and normal pigs rested for varying periods of time prior to slaughter. DeSmet et al. (1996) reported that L* values

decreased if pigs were rested a few hours instead of being slaughtered immediately upon arrival to the plant. Klont and Lambooy (1995a) reported higher L* values for *longissimus* muscle in both NN and Nn pigs that had been anesthetized and exercised (through electrical stimulation). It is likely that the 10 minutes of pre-slaughter exercise in our study negatively influenced L* values as well. In the same study, however, Klont and Lambooy (1995a) reported that L* values for the control group (non-exercised) were still higher for carrier pigs compared to NN pigs. MacDougall (1982) also stated that variability in lightness (L* value) is attributable to protein structural changes which can be affected by the differences in chilling rates throughout the muscle. Because our chilling system was air-chill, the rates of chilling among larger and smaller carcasses could have differed, affecting the protein structural changes and in turn the lightness of the muscle. In addition, the differences in sizes of *longissimus* muscles could affect the chilling rate and lightness characteristics of the muscle.

Carrier pigs produced pork with higher CIE a* and b* values (Table 2) which is in agreement with Garcia-Macias et al. (1996). In contrast, Klont and Lambooy (1995a,b) reported no differences between NN and Nn genotypes for CIE a* and b* values even when the muscles were exercised by electrical stimulation immediately after slaughter. Leach et al. (1996) reported no differences in CIE a* values, but higher b* values for carrier animals.

Carrier pigs also produced pork with higher hue and chroma C values (Table 2). The higher hue values indicate pork that has a less red and more yellow hue. The chroma higher chroma C values show that the hue is more highly saturated in the pork from carrier pigs. This is in agreement with Garcia-Macias et al. (1996). The chromium

supplementation did not affect CIE L* or hue values, but pigs fed CrP had higher ($P<0.05$) values for CIE a*, b*, and chroma C, suggesting a slightly more intense and highly saturated color.

Barrows had greater ($P<0.05$) CIE L* and b* values as well as higher ($P<0.05$) hue and chroma C values, but were not different from gilts in CIE a* (Table 2). Sather et al. (1991) also reported higher CIE L* values for barrows, but no differences between sexes for CIE b* values. Leach et al. (1996) reported no differences between sexes for CIE L*, a*, or b* values. In the current study, differences in color could have been induced by the increased metabolism in the muscle post-mortem due to each animal's pre-slaughter exercise.

Color Storage Study

As indicated in Table 3, Nn pigs produced pork that was lighter (higher CIE L*) all storage days compared to NN pigs ($P<0.09$). This suggests a higher incidence of PSE pork for carrier animals. It is well known that the combination of high temperature at a low pH in PSE meat causes a decrease in protein solubility (Sayre and Briskey, 1963). This, in turn, allows for more liberation of water and the wet meat surface reflects more light (MacDougall, 1982), potentially causing it to appear lighter (higher CIE L* values) in color.

CIE a* values started out higher ($P<0.05$, day 1) for carrier pigs and then were lower (day 7 and 10) compared to the NN pigs. This suggests that the redness of the meat during storage deteriorates faster in carrier pigs. In addition, there was an interaction between the halothane gene, sex, and storage day for CIE a* values (Table 5),

because there were no differences in a* values for gilts of either genotype and NN barrows for d 1, 3, 7, and 10; Nn barrows, however, had higher a* values for d1 but a* values were lower for d 7 and d 10. CIE b* values were higher for Nn pigs for all storage days (Table 3). Chroma C values were also higher for carrier pigs for d 1 and d 3, but there were no differences between the two genotypes for d 7 and d 10. Hue angle was consistently greater ($P<0.05$) for carrier pigs, indicating that the pork color was more yellow.

There was no difference between genotypes for oxymyoglobin (OMb) on d 1, but carrier pigs had lower OMb values for d 3, 7, and 10. Deoxymyoglobin (DMb) was lower for Nn animals for d 1, 3, and 10. A slight numerical difference was noted for DMb on d 7 as well, but it was not statistically significant. Carriers had higher metmyoglobin (MMb) values for all storage days. It is important to note that the lower pH of pork from carrier animals likely contributed to the higher MMb values. This is in agreement with Faustman and Cassens (1990) who reported that lower pH values (<5.4) in meat resulted in greater oxidation of myoglobin. There was an interaction between sex, the halothane gene, and storage day for MMb values (Table 6). Nn barrows consistently displayed higher MMb values on each storage day compared to NN barrows and all gilts, illustrating a greate incidence of PSE pork from the barrows.

Chromium had no effect on color over storage time (data not shown). Barrows, compared to gilts, had higher ($P<0.05$) L* and b* values at d 1, 3, and 7 (Table 4). However, gilts had higher ($P<0.05$) a* values at d 3, 7, and 10. Chroma C values were higher ($P<0.05$) for barrows at d1, but were not different at d 3, 7, and 10. Gilts had higher ($P<0.05$) values for OMb on d 3, 7, and 10 and a higher ($P<0.05$) DMb percentage

on d1. Barrows displayed higher ($P<0.05$) MMb values on all storage days, demonstrating a higher amount of oxidation (or browning) of the pork.

Drip Loss

Carrier pigs showed a considerably higher drip loss (Table 7) than normal pigs ($P<0.001$). Several other studies have shown the same results (Lundstrom et al., 1989; Mayo Rizo, 1995; De Smet et al., 1996; Leach et al., 1996). It is important to note that both carrier and normal animals across all treatments displayed high drip losses. Most of the main effect treatments were drawing near to the PSE pork category of >5.0% drip loss (Joo et al., 1995; Warner et al., 1997). This could have been influenced by increased anaerobic glycolysis both before and after slaughter due to the pre-slaughter exercise. But, the higher drip loss for both halothane carrier and normal animals could be partially attributed to the RN gene. Lundstrom et al. (1995) reported higher drip loss values for pigs expressing the RN gene. In the present study, there were no differences in drip loss due to chromium or sex.

Lipid and Moisture %

Homozygous normal pigs had a higher percentage of lipid (Table 7) in the *longissimus thoracis* ($P<0.03$). There were no differences in moisture between the two genotypes (Table 7). Leach et al. (1996) reported no differences between the genotypes for fat content or moisture. Mayo Rizo (1995) and Garcia-Macias et al. (1996) also reported no difference in lipid percentage between halothane carrier and normal animals.

There were also no differences in lipid or moisture due to chromium supplementation (Table 7). Barrows had a higher percentage of lipid in the muscle ($P<0.008$), but gilts had a higher moisture percentage ($P<0.003$). Sather et al. (1991) and Leach et al. (1996) also reported that barrows had higher lipid percentages in *longissimus lumborum* muscle. There was an interaction between chromium picolinate and the halothane gene for lipid percentage (Table 8). Carrier pigs that were not fed chromium had lower lipid percentages than homozygous normal pigs on the same diet. For pigs fed chromium, however, there was not a difference in the lipid content between genotypes. Because the NN pigs showed slightly higher lipid percentage values, consistent with previous studies (Leach et al., 1996; DeSmet et al, 1996) and CrP lowered lipid percentage in the muscle, in agreement with Mooney and Cromwell (1995), an interaction was created.

Sarcomere Length

Sarcomere length was not affected by the halothane gene, chromium supplementation, or sex. Our results agree with Honikel et al. (1986). It is known that shortening of sarcomeres increases drip loss. However, because there were no differences in sarcomere length due to the halothane gene, the elevated drip loss in the pork from carrier animals must have been associated with the rapid decline in pH.

Shear Force

Shear force values were not different between the two genotypes (Table 7). This is in agreement with Leach et al. (1996) and De Smet et al. (1996) who reported no differences in shear force due to halothane genotype. In contrast, Goodwin (1994)

reported higher shear force values for pork aged for 1 d from pigs of the Nn genotype. In our study, carrier pigs produced pork that had higher ($P<0.05$) shear force values for samples that were aged 10 days. This is in agreement with Lundstrom et al. (1995) who reported that pork from Nn pigs that was aged 3 days had higher shear force values than pork from normal animals. Koohmaraie et al. (1991) reported that most of the changes that occur in the postmortem storage period for meat are similar to the changes caused by calpains in vitro, and therefore are thought to result from calpain activity. However, Dransfield (1994) reported that the rate of proteolysis postmortem by calpains is limited in PSE muscle because calpain inactivation increases at a low pH regardless of temperature. In addition, Sensky et al. (1997) reported that m-calpain activity was reduced by 25% in Nn genotypes. Warner et al. (1997) reported reduced degradation of titin in PSE pork, which is normally degraded by calpains. Because muscle that develops into PSE pork usually has a high rate of pH decline (Backstrom and Kauffman, 1995), there would be less opportunity for the calpains to act at the optimum higher pH that they need. The reduction in tenderness ($P<0.05$) at d 10 in pork from Nn pigs could be related to the lack of initial tenderization by calpains, limiting subsequent tenderization effects.

Wang et al. (1994) reported a trend towards higher shear force values for chromium fed pigs. However, there was no difference in shear force due to chromium supplementation or sex in this study (Table 7).

Cooking Loss

Presence of the halothane gene resulted in higher ($P<0.05$) cooking loss (day 10) than for halothane-free pigs. This is in contrast to Goodwin (1994) and Leach et al.

(1996) who reported no difference in cooking loss due to halothane genotype. Leach et al. (1996) speculated that most of the water had been lost in the fresh muscle prior to cooking and there wasn't much free moisture left in the muscle to lose during the cooking process. A pH closer to the isoelectric point of the proteins is known to reduce the water holding capacity. Lundstrom et al. (1996) reported higher cooking losses for pigs carrying the RN gene. Chromium supplementation and sex did not affect cooking loss.

Protein Solubility

Sarcoplasmic and total protein solubility (Table 7) were reduced ($P<0.05$) for Nn pigs and there was a trend in reduction of myofibrillar protein solubility ($P<0.08$). The reduction of protein solubility indicates a higher incidence of PSE pork in this study. Warner (1994) stated that PSE pork showed a sarcoplasmic protein solubility of 28% less than red, firm, and non-exudative (RFN) pork. Warner (1994) also determined that 58% less total proteins were solubilized in PSE pork when compared to RFN pork. Although there were no differences in temperature decline in the current study, carrier pigs had pH values at .75 h, 3 h, and 24 h that were lower, indicating a likelihood of increased protein degradation. However, Boles et al. (1992) and van Laack et al. (1993) found no difference in protein solubility between NN and Nn pigs. Several studies have reported lower protein solubilities for halothane positive (nn) animals (Boles et al., 1992; van Laack et al., 1993; Oliver et al., 1993). The differences in protein solubility in the genotypes in the current study could be partially attributed to excessive muscle metabolism both before slaughter and immediately afterwards because of the planned exercise that the pigs went through. Lundstrom et al. (1996) reported lower protein

sarcoplasmic and total protein solubility for pigs carrying the RN gene. Chromium supplementation did not affect protein solubility.

CONCLUSIONS

The halothane gene negatively influenced muscle quality as expected. Chromium had minimal effects on muscle quality. Chromium did result in chops that were more intense red (higher CIE a* and Chroma C). Interactions between the halothane gene, chromium picolinate, and sex were minimal. Feeding carrier pigs chromium offers no guarantees to producers who might want to use this combination of genetics and nutrition to try to improve carcass composition. However, if chromium is used, quality should be comparable to pork from pigs not fed chromium.

REFERENCES

Aalhus, J.L., Jones, S.D.M., Robertson, W.M., Tong, A.K.W., and Sather, A.P. 1991. Growth characteristics and carcass composition of pigs with known genotypes for stress susceptibility over a weight range of 70 to 120 kg. Anim. Prod. 52: 347-353.

AMSA. 1991. Guidelines for meat color evaluation. Am. Meat Sci. Assoc. and National Live Stock and Meat Board, Chicago, IL.

AMSA. 1995. *Research Guidelines for Cookery, Sensory Evaluation, and Instrumental Tenderness Measurements of Fresh Meat*. Am. Meat Sci. Assoc. and National Live Stock and Meat Board, Chicago, IL.

AOAC. 1990. *Official Methods of Analysis*, 15th ed. Association of Official Analytical Chemists, Washington, D.C.

Backstrom, L. and Kauffman, R.G. 1995. The porcine stress syndrome: a review of genetics, environmental factors, and animal well-being implications. Agri-Practice 16: 24-30.

Bendall, J.R. 1973. Postmortem changes in muscle. In: *The Structure and Function of Muscle*. Bourne, G.H. ed. Academic Press, New York, NY.

Boleman, S.L., Boleman, S.J., Bidner, T.D., Southern, L.L., Ward, T.L., Pontif, J.E., and Pike, M.M. 1995. Effect of chromium picolinate on growth, body composition, and tissue accretion in pigs. J. Anim. Sci. 73: 2033-2042.

Boles, J.A., Parrish, F.C., Huiatt, T.W., and Robson, R.M. 1992. Effect of porcine stress syndrome on the solubility and degradation of myofibrillar/cytoskeletal proteins. J. Anim. Sci. 70: 454-464.

Casteels, M., Van Oeckel, M.J., Boschaerts, L., Spincemaille, G., and Boucque, C. V. 1995. The relationship between carcass, meat and eating quality of three pig genotypes. Meat Sci. 40: 253-269.

Christian, L. L., Strock, K.L., and Carlson, J.P. 1980. Effects of protein, breed cross, sex, and slaughter weight on swine performance and carcass traits. J. Anim. Sci. 51: 51-58.

Cross, H.R., West, R.L., and Dutson, T.R. 1981. Comparison of methods for measuring sarcomere length in beef semitendinosus muscle. Meat Sci. 5: 261-266.

De Smet, S.M., Pauwels, H., De Bie, S., Demeyer, D.I., Callweier, J., and Eeckhout, W. 1996. Effect of halothane genotype, breed, feed withdrawl, and lairage on pork quality of Belgian slaughter pigs. J. Anim. Sci. 74: 1854-1863.

Dransfield, E. 1994. Modelling post-mortem tenderization - V: inactivation of calpains. Meat Sci. 37: 391-409.

Faustman, C. and Cassens, R.G. 1990. The biochemical basis for discoloration in fresh meat: a review. J. Muscle Foods 1: 217-243.

Garcia-Macias, J.A., Gispert, M., Oliver, M.A., Diestre, A., Alonso, P., Munoz-Luna, A., Siggens, K., and Cuthbert-Heavens, D. 1996. The effects of cross, slaughter weight, and halothane genotype on leanness and meat and fat quality in pig carcasses. Animal Science 63: 487-496.

Goodwin, R.N. 1994. Genetic Parameters of Pork Quality Traits. Ph.D. dissertation, Iowa State University, Ames.

Gornall, A.G., Bardawill, C.J. and David, M.M. 1949. Determination of serum proteins by means of the biuret reaction. J. Biol. Chem. 177: 751-766.

Grandin, T. 1994. Methods to Reduce PSE and Bloodsplash. Part IV, D in *Pork Chain Quality Audit*. p 115. National Pork Producers Council, Des Moines, IA.

Honikel, K.O. 1987. How to measure the water-holding capacity of meat? Recommendation of standardized methods. In: *Evaluation and Control of Meat Quality in Pigs*, P.V. Tarrant, G. Eikelenboom, and G. Monin (Eds.). p. 129. Martinus Nijhoff Publishers, Dordrecht, The Netherlands.

Honikel, K.O., Kim, C.J., and Hamm, R. 1986. Sarcomere shortening of prerigor muscles and its influence on drip loss. Meat Sci. 16: 267-282.

Joo, S.T., Kauffman, R.G., Kim, B.C., and Kim, C.J. 1995. The relationship between color and water-holding capacity in postrigor porcine longissimus muscle. J. Muscle Foods 6: 211-226.

Klont, R.E. and Lambooy, E. 1995a. Effects of preslaughter muscle exercise on muscle metabolism and meat quality studied in anesthetized pigs of different halothane genotypes. J. Anim. Sci. 73: 108-117.

Klont, R.E. and Lambooy, E. 1995b. Influence of preslaughter muscle temperature on muscle metabolism and meat quality in anesthetized pigs of different halothane genotypes. J. Anim. Sci. 73: 96-107.

Koohmaraie, M, Whipple, G., Kretchmar, D.H., Crouse, J.D., and Mersmann, H.J. 1991. Postmortem proteolysis in longissimus muscle from beef, lamb, and pork carcasses. J. Anim. Sci. 69: 617-624.

Leach, L.M., Ellis, M., Sutton, D.S., McKeith, F.K., and Wilson, E.R. 1996. The growth performance, carcass characteristics, and meat quality of halothane carrier and negative pigs. J. Anim. Sci. 74: 934-943.

LeRoy, P., Naveau, J., Elsen, J.M., and Sellier, P. 1990. Evidence for a new major gene influencing meat quality in pigs. Genet. Res. (Camb.) 55: 33-40.

Lindemann, M.D., Wood, C.M., Harper, A.F., Kornegay, E.T., and Anderson, R.A. 1995. Dietary chromium picolinate additions improve gain:feed and carcass characteristics in growing-finishing pigs and increase litter size in reproducing sows. J. Anim. Sci. 73: 457-465.

Lundstrom, K., Andersson, A., and Hansson, I. 1996. Effect of the RN gene on technological and sensory meat quality in crossbred pigs with Hampshire as terminal sire. Meat Sci. 42: 145-153.

Lundstrom, K., Essen-Gustavsson, B., Rundgren, M., Edfors-Lilja, I., and Malmfors, G. 1989. Effect of halothane genotype on muscle metabolism at slaughter and its relationship with meat quality: a within litter comparison. Meat Sci. 25: 251-263.

Lundstrom, K., Karlsson, A., Hakansson, J., Hansson, I., Johansson, M., Andersson, L., and Andersson, K. 1995. Production, carcass, and meat quality traits of F_2-crosses between European wild pigs and domestic pigs including halothane gene carriers. Anim. Sci. 61: 325-331.

MacDougall, D.B. 1982. Changes in the color and opacity of meat. Food Chem. 9: 75-88.

Mayo Rizo, J.M. 1995. Effects of Stress Genotype, Pre-slaughter Mixing, Pre-slaughter Resting Time, and Chilling Rate on Muscle Quality of Swine. M.S. thesis, Iowa State University, Ames.

Monin, G., Mejenes-Quijano, A.M., and Talmant, A. 1987. Influence of breed and muscle metabolic type on muscle glycolytic potential and meat pH in pigs. Meat Sci. 20: 149-158.

Mooney, K.W. and Cromwell, G.L. 1995. Effects of dietary chromium picolinate supplementation on growth, carcass characteristics, and accretion rates in growing-finishing swine. J. Anim. Sci. 73: 3351-3357.

NPPC. 1994. Consumer Quality Audit Summary. Part A in *Pork Chain Quality Audit*. p 16. National Pork Producers Council, Des Moines, IA.

Oliver, M.A., Gispert, M., and Diestre, A. 1993. The effects of breed and halothane sensitivity on pig meat quality. Meat Sci. 35: 105-118.

Page, T.G., Southern, T.L., Ward, T.L., and Thompson, D.L. 1993. Effect of chromium picolinate on growth and serum and carcass traits of growing-finishing pigs. J. Anim. Sci. 71: 656-662.

SAS. 1991. SAS User's Guide: Statistics (Version 6, 4th Ed.) Sas Inst. Inc., Cary, NC.

Sather, A.P., Jones, S.D.M., Tong, A.K.W., and Murray, A.C. 1991. Halothane genotype by weight interactions on meat quality. Can. J. Anim. Sci. 71: 645-658.

Sayre, R.N. and Briskey, E.J. 1963. Protein solubility as influenced by physiological conditions in the muscle. J. Food Sci. 28: 675-679.

Sensky, P.L., Parr, T., Lockley, A.K., Bardsley, R.G., and Buttery, P.J. 1997. Effect of the halothane mutation on the calpain-calpastatin system in porcine longissimus muscle. Presented at Nat. Anim. Sci. Mtg., Am. Soc. of Anim. Scientists, Nashville, TN, July 28-August 2.

Simpson, S.P. and Webb, A.J. 1989. Growth and carcass performance of British Landrace pigs heterozygous at the halothane locus. Anim. Prod. 49: 503-509.

van Laack, L.J.M., Faustman, C., and Sebranek, J.G. 1993. Pork quality and the expression of stress protein Hsp 70 in swine. J. Anim. Sci. 71: 2958-2964.

Wang, H., J.R. Claus, and Lindemann, M.D. 1994. Effect of supplemental dietary chromium on the characteristics of pork. (Abstr.) Institute of Food Technologists Annual Meeting 1994, Atlanta, GA, p. 90.

Warner, R.D. 1994. Physical properties of porcine musculature in relation to postmortem biochemical changes in muscle proteins. Ph.D Dissertation, University of Wisconsin, Madison.

Warner, R.D., Kauffman, R.G., and Greaser, M.L. 1997. Muscle protein changes postmortem in relation to pork quality traits. Meat Sci. 45: 339-352.

Webb, A.J. 1981. The halothane sensitivity test. Ch. 2 in *Porcine Stress and Meat Quality,* T. Froystein, E. Slinde, and N. Standal (Eds.) p 105. Agricultural Food research Society, As, Norway.

Zhang, W., Kuhlers, D.L. and Rempel, W.E. 1992. Halothane gene and swine performance. J. Anim. Sci. 70: 1307-1313.

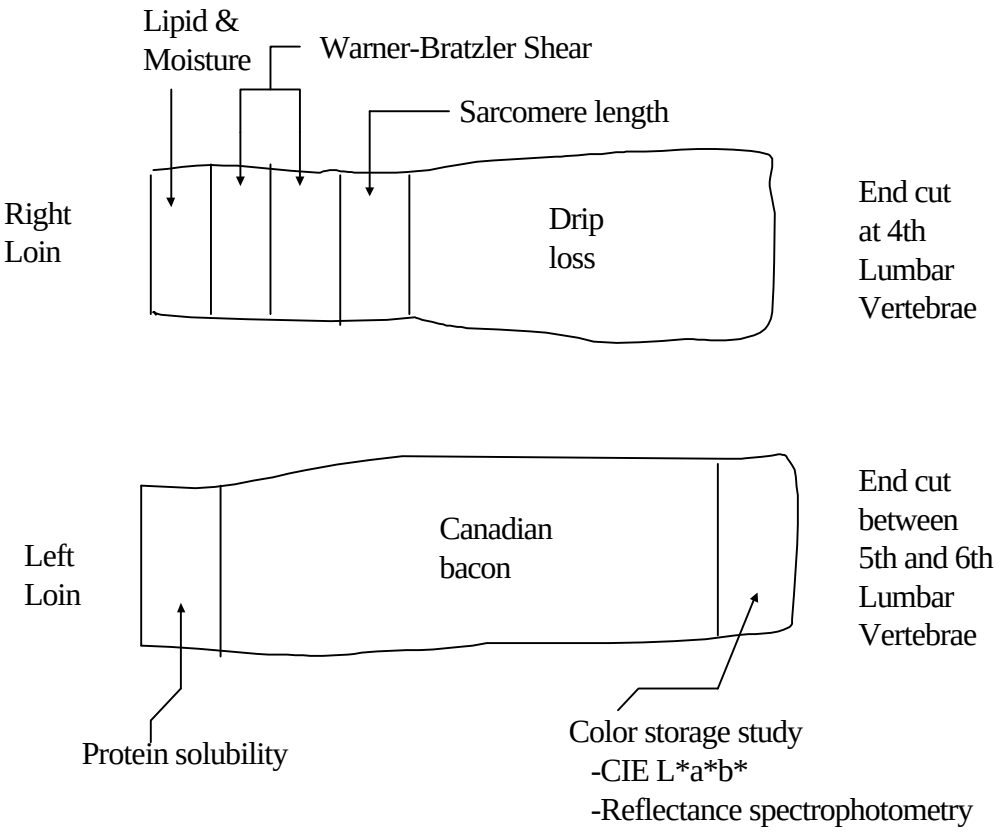

Figure 1. Loin sampling locations for various physical and chemical determinations. All samples were cut 2.54 cm thick except drip loss (5 cm) and canadian bacon (23 cm).

Table 1. Least squares means and standard errors (SEM) for halothane gene, chromium picolinate, and sex main effects on pH and temperature decline in pork *longissimus lumborum*[1]

	Halothane Gene		Chromium Picolinate, ppb		Sex	
Dependent variables[2]	NN	Nn	0	200	Barrow	Gilt
pH decline[3]						
.75 h	6.75^{ax}	6.46^{bx}	6.62^{ax}	6.59^{ax}	6.62^{ax}	6.60^{ax}
3 h	6.29^{ay}	5.85^{by}	6.10^{ay}	6.05^{ay}	6.07^{ay}	6.08^{ay}
24 h	5.21^{az}	5.13^{bz}	5.17^{az}	5.18^{az}	5.16^{az}	5.18^{az}
Temperature decline, C						
.75 h	37.9^{ax}	38.5^{ax}	38.1^{ax}	38.3^{ax}	38.4^{ax}	38.0^{ax}
3 h	22.8^{ay}	22.9^{ay}	23.0^{ay}	22.6^{ay}	23.2^{ay}	22.4^{ay}
24 h	2.6^{az}	2.6^{az}	2.6^{az}	2.6^{az}	2.8^{az}	2.4^{az}

[1]n = 160 pigs.
[2]Dependent variables: SEM for pH decline and temperature decline are 0.02 and 0.28, respectively.
[3]There was an interaction between the halothane gene and time for pH decline ($P < .001$).
[ab]Means with unlike superscripts within a main effect variable and row are different ($P < .05$).
[xyz]Means with unlike superscripts within a main effect variable and column are different ($P < .05$).

Table 2. Least squares means and standard errors (SEM) for halothane gene, chromium picolinate, and sex main effects on color characteristics of fresh pork *longissimus lumborum*[1]

	Halothane Gene			Chromium Picolinate, ppb			Sex			P - Values[2]		
Variable	NN	Nn	SEM	0	200	SEM	Barrows	Gilt	SEM	Hal	CrP	Sex
CIE values												
L*	52.62	57.03	.37	54.81	54.83	.37	55.48	54.16	.37	.001	.96	.02
a*	10.09	11.90	.17	10.72	11.26	.17	11.17	10.81	.17	.001	.04	.14
b*	7.64	9.96	.15	8.57	9.03	.15	9.12	8.47	.15	.001	.05	.005
Chroma C[3]	12.67	15.54	.21	13.75	14.45	.21	14.45	13.76	.21	.001	.03	.03
Hue angle[3]	36.93	39.88	.43	38.29	38.52	.43	39.08	37.72	.43	.001	.71	.04

[1]n = 160 pigs; determined 24 h postmortem at 10th thoracic vertebrae and 40 min after ribbing.
[2]Hal = Halothane gene; CrP = Chromium Picolinate.
[3]Chroma C and Hue angle calculated by $\sqrt{(a^*)^2 + (b^*)^2}$ and $h_{ab}=\tan^{-1}\left\{\frac{b^*}{a^*}\right\}$, respectively.

Table 3. Least squares means and standard errors (SEM) of halothane gene effects on color stability during storage of *longissimus thoracis et lumborum*[1]

	Halothane x Storage Day												
	Day 1			Day 3			Day 7			Day 10			Hal x Day[2]
Variables	NN	Nn	SEM	NN	Nn	SEM	NN	Nn	SEM	NN	Nn	SEM	P-Values
CIE values													
L*	53.35[b]	56.70[a]	.157	56.34[b]	59.30[a]	.157	58.36[b]	61.06[a]	.184	58.90[b]	61.46[a]	.184	.09
a*[3]	8.70[b]	9.46[a]	.131	9.14[a]	8.94[a]	.131	8.06[a]	7.17[b]	.154	7.20[a]	6.13[b]	.154	.001
b*	6.44[b]	7.99[a]	.101	8.57[b]	9.51[a]	.101	8.96[b]	9.80[a]	.119	9.03[b]	9.59[a]	.119	.001
Chroma C[4]	10.84[b]	12.41[a]	.139	12.55[b]	13.09[a]	.139	12.10[a]	12.29[a]	.164	11.62[a]	11.49[a]	.164	.001
Hue angle[4]	36.36[b]	40.10[a]	.384	43.29[b]	46.89[a]	.384	48.14[b]	53.94[a]	.452	51.64[b]	57.80[a]	.452	.002
Myoglobin[5]													
OMb	1.59[a]	1.56[a]	.009	1.67[a]	1.62[b]	.008	1.59[a]	1.50[b]	.013	1.54[a]	1.45[b]	.010	.007
DMb	1.19[a]	1.16[b]	.004	1.08[a]	1.06[b]	.003	1.05[a]	1.04[a]	.005	1.06[a]	1.04[b]	.004	.008
MMb[3]	.80[b]	.82[a]	.002	.83[b]	.85[a]	.002	.88[b]	.91[a]	.003	.92[b]	.94[a]	.002	.04

[1]n = 96 pigs.

[2]Hal x Day = halothane gene x storage day interaction.

[3]There was an interaction between the halothane gene, sex, and storage day ($P < .05$). See Tables 5 and 6.

[4]Chroma C and Hue angle calculated by $\sqrt{(a^*)^2 + (b^*)^2}$ and $h_{ab}=\tan^{-1}\left\{\frac{b^*}{a^*}\right\}$ respectively.

[5]Myoglobin forms were calculated as [follows]: %R 474nm/525nm for deoxymyoglobin, %R 572nm/525nm for metmyoglobin, and %R 610nm/525nm for oxymyoglobin.

[ab]Means with unlike superscripts within a storage day and row are different ($P < .05$).

Table 4. Least squares means and standard errors (SEM) of sex effects on color stability during storage of *longissimus thoracis et lumborum*[1]

	Sex x Storage Day												
	Day 1			Day 3			Day 7			Day 10			Sex x Day[2]
Variables	Barrows	Gilts	SEM	Barrows	Gilts	SEM	Barrows	Gilts	SEM	Barrows	Gilts	SEM	P-Values
CIE values													
L*	56.25[a]	53.81[b]	.157	58.91[a]	56.73[b]	.157	60.79[a]	58.64[b]	.184	61.19[a]	59.17[b]	.184	.64
a*[3]	9.12[a]	9.04[a]	.131	8.77[b]	9.30[a]	.131	7.18[b]	8.05[a]	.154	6.32[b]	7.01[a]	.154	.004
b*	7.62[a]	6.81[b]	.101	9.28[a]	8.80[b]	.101	9.64[a]	9.13[b]	.119	9.51[a]	9.11[a]	.119	.22
Chroma C[4]	11.92[a]	11.33[b]	.139	12.82[a]	12.82[a]	.139	12.17[a]	12.23[a]	.164	11.53[a]	11.57[a]	.164	.07
Hue angle[4]	39.66[a]	36.79[b]	.384	46.73[a]	43.46[b]	.384	53.33[a]	48.76[b]	.452	56.70[a]	52.74[b]	.452	.18
Myoglobin[5]													
OMb	1.56[a]	1.59[a]	.010	1.62[b]	1.67[a]	.008	1.52[b]	1.57[a]	.013	1.47[b]	1.52[a]	.010	.63
DMb	1.16[b]	1.19[a]	.004	1.07[a]	1.07[a]	.003	1.04[a]	1.05[a]	.005	1.04[a]	1.05[a]	.004	.04
MMb[3]	.82[a]	.80[b]	.002	.85[a]	.83[b]	.002	.91[a]	.89[b]	.003	.94[a]	.92[b]	.002	.59

[1]n = 96 pigs.

[2]Sex x Day = sex x storage day interaction.

[3]There was an interaction between sex, halothane gene, and storage day ($P < .05$). See Tables 5 and 6.

[4]Chroma C and Hue angle calculated by $\sqrt{(a^*)^2 + (b^*)^2}$ and $h_{ab}=\tan^{-1}\left\{\frac{b^*}{a^*}\right\}$ respectively.

[5]Myoglobin forms were calculated as follows: %R 474nm/525nm for deoxymyoglobin, %R 572nm/525nm for metmyoglobin, and %R 610nm/525nm for oxymyoglobin.

[ab]Means with unlike superscripts within a storage day and row are different ($P < .05$).

Table 5. Least squares means and standard errors (SEM) of sex x halothane gene x storage day effects on CIE a* values in fresh pork *longissimus thoracis et lumborum*[1]

	Sex			
	Barrows		Gilts	
	Halothane		Halothane	
Storage Day[2]	NN	Nn	NN	Nn
Day 1	8.67^{bx}	9.57^{aw}	8.73^{abwx}	9.35^{abw}
Day 3	8.98^{ax}	8.56^{ax}	9.29^{aw}	9.31^{aw}
Day 7	7.93^{axy}	6.42^{by}	8.18^{ax}	7.92^{ax}
Day 10	7.18^{ay}	5.46^{bz}	7.21^{ay}	6.81^{ay}

[1]Trial 1 only (n = 96 pigs).
[2]Standard errors are 0.19 for Days 1 and 3; 0.22 for Days 7 and 10.
[ab]Means within a row with unlike superscripts are different (P <.05).
[wxyz]Means within a column with unlike superscripts are different (P < .05).

Table 6. Least squares means and standard errors (SEM) of sex x halothane gene x storage day effects on metmyoglobin (MMb) values in fresh pork *longissimus thoracis et lumborum*[1]

	Sex			
	Barrows		Gilts	
	Halothane		Halothane	
Storage Day[2]	NN	Nn	NN	Nn
Day 1	.806^{bw}	.825^{aw}	.797^{bw}	.807^{bw}
Day 3	.827^{bx}	.871^{ax}	.827^{bx}	.836^{bx}
Day 7	.885^{by}	.928^{ay}	.883^{by}	.893^{by}
Day 10	.918^{bz}	.958^{az}	.914^{bz}	.923^{bz}

[1]Trial 1 only (n = 96 pigs).
[2]Standard errors are 0.003 for Days 1, 3, and 10; 0.004 for Day 7.
[3]Metmyoglobin calculated as %R 572nm/525nm.
[ab]Means within a row with unlike superscripts are different (P <.05).
[wxyz]Means within a column with unlike superscripts are different (P < .05).

Table 7. Least squares means and standard errors (SEM) for halothane gene, chromium picolinate, and sex main effects on quality characteristics of fresh pork *longissimus thoracis et lumborum*[1]

	Halothane Gene			Chromium Picolinate, ppb			Sex			P - Values[2]		
Variable	NN	Nn	SEM	0	200	SEM	Barrows	Gilt	SEM	Hal	CrP	Sex
Drip loss, %	3.50	5.76	.25	4.47	4.79	.25	4.79	4.48	.25	.001	.38	.41
Lipid, %[3]	5.99	5.01	.28	5.56	5.44	.28	6.08	4.92	.28	.03	.76	.008
Moisture, %[3]	70.21	70.40	.32	69.94	70.67	.32	69.53	71.08	.32	.69	.13	.003
Sarcomere length, μm[4]	1.90	1.95	.02	1.92	1.93	.02	1.93	1.92	.02	.08	.75	.88
Protein Solubility, mg/g[5]												
Myofibrillar	156.1	142.0	5.38	150.3	147.8	5.38	_	_	_	.09	.74	_
Sarcoplasmic	60.4	55.2	.96	59.2	56.5	.96	_	_	_	.002	.07	_
Total solubility	216.5	197.5	5.60	209.7	204.3	5.60	_	_	_	.03	.50	_
Shear force, kg[6]										.005	.43	.59
d 1	3.75[ax]	3.64[ax]	.07	3.78[ax]	3.61[ax]	.07	3.73[ax]	3.65[ax]	.07	_	_	_
d 10	2.94[by]	3.14[ay]	.04	3.08[ay]	3.00[ay]	.04	3.05[ay]	3.03[ay]	.04	_	_	_
Cooking loss, %[6]												
d 10	28.8	29.8	.3	29.4	29.3	.3	29.5	29.1	.3	.03	.86	.37

[1]n = 160 pigs.
[2]Hal = Halothane gene; CrP = Chromium Picolinate. Values are for main effects except for shear force and cooking loss, which are for main effects x day.
[3]There was an interaction between chromium picolinate and the halothane gene (P < .05). See Table 8.
[4]There was an interaction between chromium picolinate and sex (P < .05). See Table 9.
[5]Trial 1 barrows only (n = 48).
[6]Trial 1 only (n = 96).
[ab]Means with unlike superscripts within a row and main effect are different (P < .05).
[xy]Means with unlike superscripts within a column and main variable are different (P < .05).

Table 8. Least squares means and standard errors (SEM) of chromium picolinate x halothane gene effects on quality characteristics in fresh pork *longissimus thoracis et lumborum*[1]

	Chromium picolinate, ppb					
	0		200			
	Halothane		Halothane			Interaction
Variable	NN	Nn	NN	Nn	SEM	P-Values[2]
Drip Loss, %	3.15	5.79	3.85	5.73	.37	.31
Lipid, %	6.57[a]	4.56[b]	5.42[ab]	5.46[ab]	.40	.02
Moisture, %	69.32	70.56	71.10	70.24	.48	.04
Sarcomere length, μm	1.89	1.95	1.91	1.94	.03	.51
Protein Solubility, mg/g[3]						
Myofibrillar	164.3	136.4	147.8	147.7	7.98	.09
Sarcoplasmic	61.6	56.7	59.2	53.7	1.42	.84
Total solubility	226.0	193.4	207.0	201.5	8.31	.11
Shear force, kg[3]						.21
d 1	3.89[ax]	3.66[ax]	3.61[ax]	3.61[ax]	.10	_
d 10	2.97[aby]	3.20[ay]	2.91[by]	3.09[aby]	.06	_
Cooking loss, %[4]						
d 10	28.81	29.93	28.84	29.76	.46	.84

[1]n = 160 pigs.
[2]Value for shear force and cooking loss is for CrP x halothane gene x day effect.
[3]Trial 1 barrows only (n = 48).
[4]Trial 1 only (n = 96).
[ab]Means within a row with unlike superscripts are different (P < .05).
[xy]Means within a column and variable with unlike superscripts are different (P < .05).

Table 9. Least squares means and standard errors (SEM) of chromium picolinate x sex effects on quality characteristics in fresh pork *longissimus thoracis et lumborum*[1]

	Chromium picolinate, ppb					
	0		200			
	Sex		Sex			Interaction
Variable	Barrows	Gilts	Barrows	Gilts	SEM	P-Value[2]
Drip Loss, %	4.61	4.34	4.97	4.61	.37	.88
Lipid, %	6.42	4.70	5.74	5.14	.40	.18
Moisture, %	69.11	70.76	69.95	71.39	.47	.82
Sarcomere length, µm	1.96[a]	1.88[a]	1.90[a]	1.96[a]	.03	.01
Shear force, kg[3]						.25
d 1	3.85[ax]	3.71[ax]	3.62[ax]	3.60[ax]	.10	_
d 10	3.07[ay]	3.10[ay]	3.04[ay]	2.96[ay]	.06	_
Cooking loss, %[3]						
d 10	29.31	29.43	29.77	28.83	.48	.23

[1]n = 160.
[2]Value for shear force and cooking loss is for CrP x halothane gene x day effect.
[3]Trial 1 only (n = 96).
[xy]Means within a column and day are different (P < .05).
[ab]Means within a row with unlike superscripts are different (P < .05).

APPENDIX

Appendix Table 1. Least squares means and standard errors (SEM) of the main effects of the halothane gene, chromium picolinate, and sex on growth performance of individual pigs[a]

	Halothane Gene		Chromium Picolinate, ppb		Sex			P - Values[b]		
Variable	NN	Nn	0	200	Barrows	Gilts	SEM	Hal	CrP	Sex
Initial wt, kg	28.8	28.6	28.8	28.6	28.7	28.7	.7	.90	.89	.93
Final wt[c], kg	107.3	107.3	107.9	106.7	111.2	103.4	.8	.97	.31	.001
Daily gain, g	846.8	849.2	853.0	843.0	889.8	806.2	8.6	.85	.42	.001

[a]n = 160.
[b]Hal = Halothane gene; CrP = Chromium Picolinate.
[c]Represents the final weight measured at the farm.

Appendix Table 2. Least squares means and standard errors (SEM) of chromium picolinate x halothane gene effects on growth performance of individual pigs[a]

	Chromium picolinate, ppb					
	0		200			
	Halothane		Halothane			
Variable	NN	Nn	NN	Nn	SEM	P-Value
Initial wt, kg	28.7	28.8	28.8	28.4	1.0	.82
Final wt, kg[b]	107.5	108.2	107.1	106.4	1.1	.53
Daily gain, g	849.4	856.6	844.1	841.9	12.2	.71

[a]n = 160.
[b]Represents the final weight measured at the farm.

Appendix Table 3. Least squares means and standard errors (SEM) of chromium picolinate x sex effects on growth performance of individual pigs[a]

	Chromium picolinate, ppb					
	0		200			
	Sex		Sex			
Variable	Barrows	Gilts	Barrows	Gilts	SEM	P-Value
Initial wt, kg	28.8	28.7	28.6	28.6	1.0	.94
Final wt, kg[b]	111.8	103.9	110.6	102.9	1.1	.91
Daily gain, g	895.5	810.4	884.0	802.0	12.2	.91

[a]n = 160.
[b]Represents the final weight measured at the farm.

Appendix Table 4. Least squares means and standard errors (SEM) of sex x halothane gene effects on growth performance of individual pigs[a]

	Sex					
	Barrows		Gilts			
	Halothane		Halothane			
Variable	NN	Nn	NN	Nn	SEM	P-Value
Initial wt, kg	28.8	28.6	28.7	28.6	1.0	.93
Final wt, kg[b]	111.6	110.8	103.0	103.8	1.1	.45
Daily gain, g	892.3	887.2	801.2	811.2	12.2	.55

[a]n = 160.
[b]Represents the final weight measured at the farm.

Appendix Table 5. Least squares means and standard errors (SEM) of chromium picolinate x halothane gene effects on pH and temperature decline in pork *longissimus lumborum*[1]

	Chromium picolinate, ppb				
	0		200		
	Halothane		Halothane		
Variable	NN	Nn	NN	Nn	SEM
pH decline					
.75 h	6.77^{ax}	6.48^{bx}	6.73^{ax}	6.45^{bx}	.03
3 h	6.33^{ay}	5.87^{by}	6.26^{ay}	5.84^{by}	.03
24 h	5.21^{az}	5.12^{az}	5.22^{az}	5.14^{az}	.03
Temperature decline, C					
.75 h	37.7^{ax}	38.6^{ax}	38.2^{ax}	38.3^{ax}	.40
3 h	23.1^{ay}	22.8^{ay}	22.4^{ay}	22.9^{ay}	.40
24 h	2.6^{az}	2.6^{az}	2.5^{az}	2.6^{az}	.40

[1]n = 160 pigs.
[ab]Means within a row with unlike superscripts are different (P < .05).
[xyz]Means within a variable and column with unlike superscripts are different (P < .05).

Appendix Table 6. Least squares means and standard errors (SEM) of chromium picolinate x sex effects on pH and temperature decline in pork *longissimus lumborum*[1]

	Chromium picolinate, ppb				
	0		200		
	Sex		Sex		
Variable	Barrows	Gilts	Barrows	Gilts	SEM
pH decline					
.75 h	6.63^{ax}	6.62^{ax}	6.61^{ax}	6.58^{ax}	.03
3 h	6.11^{ay}	6.09^{ay}	6.03^{ay}	6.06^{ay}	.03
24 h	5.16^{az}	5.18^{az}	5.17^{az}	5.18^{az}	.03
Temperature decline, C					
.75 h	38.3^{ax}	38.0^{ax}	38.5^{ax}	38.1^{ax}	.40
3 h	23.5^{ay}	22.4^{ay}	22.8^{ay}	22.5^{ay}	.40
24 h	2.8^{az}	2.5^{az}	2.7^{az}	2.4^{az}	.40

[1]n = 160 pigs.
[ab]Means within a row with unlike superscripts are different (P < .05).
[xyz]Means within a variable and column with unlike superscripts are different (P < .05).

Appendix Table 7. Least squares means and standard errors (SEM) of sex x halothane gene effects on pH and temperature decline in pork *longissimus lumborum*[1]

	Sex				
	Barrows		Gilts		
	Halothane		Halothane		
Variable	NN	Nn	NN	Nn	SEM
pH decline					
.75 h	6.76^{ax}	6.48^{bx}	6.74^{ax}	6.45^{bx}	.03
3 h	6.29^{ay}	5.85^{by}	6.30^{ay}	5.85^{by}	.03
24 h	5.20^{az}	5.13^{az}	5.23^{az}	5.13^{az}	.03
Temperature decline, C					
.75 h	38.1^{ax}	38.7^{ax}	37.8^{ax}	38.2^{ax}	.40
3 h	22.7^{ay}	23.7^{ay}	22.8^{ay}	22.0^{ay}	.40
24 h	2.8^{az}	2.7^{az}	2.3^{az}	2.6^{az}	.40

[1]n = 160 pigs.
[ab]Means within a row with unlike superscripts are different (P < .05).
[xyz]Means within a variable and column with unlike superscripts are different (P < .05).

Appendix Table 8. Least squares means and standard errors (SEM) of chromium picolinate x halothane gene effects on color characteristics of fresh pork *longissimus thoracis et lumborum*[1]

	Chromium picolinate, ppb					
	0		200			
	Halothane		Halothane			Interaction
Variable	NN	Nn	NN	Nn	SEM	P-Values
CIE color						
L*	52.23[b]	57.38[a]	53.00[b]	56.67[a]	.5	.16
a*	9.65	11.80	10.52	12.00	.3	.19
b*	7.25	9.88	8.02	10.04	.2	.18
Chroma C[2]	12.10[c]	15.41[a]	13.24[b]	15.66[a]	.3	.14
Hue[2]	36.68[b]	39.89[a]	37.17[ab]	39.88[a]	.6	.69

[1]n = 160 pigs, determined 24 h postmortem at 10th thoracic vertebrae and 40 min after ribbing.

[2]Chroma C and Hue angle calculated by $\sqrt{(a^*)^2 + (b^*)^2}$ and $h_{ab}=\tan^{-1}\left\{\frac{b^*}{a^*}\right\}$ respectively.

[abc]Means with unlike superscripts within a row are different (P <.05).

Appendix Table 9. Least squares means and standard errors (SEM) of chromium picolinate x sex effects on color characteristics in fresh pork *longissimus thoracis et lumborum*[1]

	Chromium picolinate, ppb					
	0		200			
	Sex		Sex			Interaction
Variable	Barrows	Gilts	Barrows	Gilts	SEM	P-Values
CIE color						
L*	55.50	54.11	55.46	54.21	.5	.89
a*	10.89	10.56	11.46	11.06	.2	.90
b*	8.90	8.24	9.34	8.71	.2	.96
Chroma C[2]	14.09	13.42	14.81	14.10	.3	.94
Hue[2]	39.10	37.47	39.07	37.97	.6	.67

[1]n = 160 pigs, determined 24 h postmortem at 10th thoracic vertebrae and 40 min after ribbing.

[2]Chroma C and Hue angle calculated by $\sqrt{(a^*)^2 + (b^*)^2}$ and $h_{ab}=\tan^{-1}\left\{\frac{b^*}{a^*}\right\}$ respectively.

Appendix Table 10. Least squares means and standard errors (SEM) of sex x halothane gene effects on color characteristics of fresh pork *longissimus thoracis et lumborum*[1]

	Sex					
	Barrows		Gilts			
	Halothane		Halothane			Interaction
Variable	NN	Nn	NN	Nn	SEM	P-Values
CIE color						
L*	52.87[c]	58.09[a]	52.36[c]	55.96[b]	.5	.14
a*	10.35	12.00	9.82	11.80	.2	.49
b*	7.89	10.35	7.38	9.56	.2	.52
Chroma C[2]	13.03	15.87	12.31	15.20	.3	.93
Hue[2]	37.27[b]	40.90[a]	36.59[b]	38.86[ab]	.6	.28

[1]n = 160 pigs, determined 24 h postmortem at 10[th] thoracic vertebrae and 40 min after ribbing.

[2]Chroma C and Hue angle calculated by $\sqrt{(a^*)^2 + (b^*)^2}$ and $h_{ab}=\tan^{-1}\left\{\frac{b^*}{a^*}\right\}$ respectively.

[abc]Means with unlike superscripts within a row are different (P <.05).

Appendix Table 11. Least squares means and standard errors (SEM) of chromium picolinate effects on color stability during storage of fresh pork *longissimus thoracis et lumborum*[1]

	Chromium Picolinate x Storage Day												
	Day 1			Day 3			Day 7			Day 10			CrP x Day[2]
Variables	0	200	SEM	0	200	SEM	0	200	SEM	0	200	SEM	P-Values
CIE color													
L*	55.20	54.85	.157	57.91	57.73	.157	59.59	59.83	.184	60.16	60.19	.184	.33
a*	8.84	9.32	.131	8.88	9.20	.131	7.46	7.77	.154	6.55	6.78	.154	.82
b*	7.00[b]	7.43[a]	.101	8.90[a]	9.18[a]	.101	9.41[a]	9.36[a]	.119	9.15[a]	9.47[a]	.119	.15
Chroma C[3]	11.30[b]	11.94[a]	.139	12.61[a]	13.03[a]	.139	12.15[a]	12.24[a]	.164	11.35[a]	11.76[a]	.164	.31
Hue[3]	38.14	38.32	.384	45.15	45.04	.384	51.52	50.57	.452	54.69	54.75	.452	.51
Myoglobin[4]													
OMb	1.58	1.57	.009	1.64	1.65	.008	1.55	1.54	.013	1.50	1.49	.010	.65
DMb	1.17	1.17	.004	1.07	1.07	.003	1.05	1.04	.005	1.05	1.05	.004	.99
MMb	.81	.81	.002	.84	.84	.002	.90	.90	.003	.93	.93	.002	.53

[1]n = 96 pigs.

[2]CrP x Day = chromium picolinate x storage day interaction.

[3]Chroma C and Hue angle calculated by $\sqrt{(a^*)^2 + (b^*)^2}$ and $h_{ab}=\tan^{-1}\left\{\frac{b^*}{a^*}\right\}$ respectively.

[4]Myoglobin forms were calculated as follows: %R 474nm/525nm for deoxymyoglobin, %R 572nm/525nm for metmyoglobin, and %R 610/525 for oxymyoglobin.

[ab]Means with unlike superscripts within a storage day and row are different ($P < .05$).

Appendix Table 12. Least squares means and standard errors (SEM) of sex x halothane gene effects on quality characteristics in fresh pork *longissimus thoracis et lumborum*[1]

	Sex					
	Barrows		Gilts			
	Halothane		Halothane			Interaction
Variable	NN	Nn	NN	Nn	SEM	P-Value[2]
Drip Loss, %	3.56	6.01	3.44	5.51	.37	.61
Lipid, %	6.95[a]	5.22[b]	5.03[b]	4.81[b]	.40	.07
Moisture, %	69.03[b]	70.04[ab]	71.39[a]	70.76[ab]	.47	.09
Sarcomere length, μm	1.90	1.96	1.90	1.94	.03	.68
Shear force, kg[3]						.73
d 1	3.76[a]	3.71[a]	3.75[a]	3.56[a]	.10	_
d 10	2.90[b]	3.21[a]	2.99[ab]	3.08[ab]	.06	_
Cooking loss, %[3]						
d 10	29.07	30.00	28.57	29.69	.46	.85

[1] n = 160 pigs.
[2] Value for shear force and cooking loss is for CrP x halothane gene x day effect.
[3] Trial 1 only (n = 96).
[ab]Means within a row with unlike superscripts are different (P < .05).

Appendix Table 13. Least squares means and standard errors (SEM) of the halothane gene, chromium picolinate, and sex effects on subjective quality characteristics in pork[1]

	Halothane Gene		Chromium Picolinate, ppb		Sex			P - Values[2]		
Variable	NN	Nn	0	200	Barrow	Gilt	SEM	Hal	CrP	Sex
Sensory Panel										
Color	2.6	2.0	2.3	2.3	2.3	2.3	.06	.001	.58	.86
Moisture/Firmness	2.4	1.9	2.1	2.1	2.1	2.1	.09	.001	.91	.91

[1]Trial 2 only (n = 64); Sensory panel based on values found in *Procedures to Evaluate Market Hogs* (NPPC, 1991)
[2]Hal = Halothane gene; CrP = Chromium Picolinate.

Appendix Table 14. Least squares means and standard errors (SEM) of chromium picolinate x halothane gene effects on subjective quality characteristics of fresh pork[1]

	Chromium picolinate, ppb					
	0		200			
	Halothane		Halothane			Interaction
Variable	NN	Nn	NN	Nn	SEM	P-Value
Sensory Panel						
Color	2.6	2.0	2.5	2.1	.08	.36
Moisture/Firmness	2.4	1.9	2.4	1.9	.12	.91

[1]Trial 2 only (n = 64); Sensory panel based on values found in *Procedures to Evaluate Market Hogs* (NPPC, 1991).

Appendix Table 15. Least squares means and standard errors (SEM) of chromium picolinate x sex effects on subjective quality characteristics of fresh pork[1]

	Chromium picolinate, ppb					
	0		200			
	Sex		Sex			Interaction
Variable	Barrows	Gilts	Barrows	Gilts	SEM	P-Value
Sensory Panel						
Color	2.3	2.3	2.3	2.3	.08	.58
Moisture/Firmness	2.2	2.1	2.1	2.2	.12	.54

[1]Trial 2 only (n = 64); Sensory panel based on values found in *Procedures to Evaluate Market Hogs* (NPPC, 1991).

Appendix Table 16. Least squares means and standard errors (SEM) of sex x halothane gene effects on subjective quality characteristics of fresh pork[1]

	Sex					
	Barrows		Gilts			
	Halothane		Halothane			Interaction
Variable	NN	Nn	NN	Nn	SEM	P-Value
Sensory Panel						
Color	2.6	2.0	2.6	2.1	.08	.86
Moisture/Firmness	2.4	1.9	2.4	1.9	.12	.91

[1]Trial 2 only (n = 64); Sensory panel based on values found in *Procedures to Evaluate Market Hogs* (NPPC, 1991).

Appendix Table 17. Least squares means and standard errors (SEM) for halothane gene, chromium picolinate, and sex main effects on temperature decline in hams[1]

	Halothane Gene		Chromium Picolinate, ppb		Sex	
Dependent variables[2]	NN	Nn	0	200	Barrow	Gilt
Temperature decline, C						
.75 h	41.3^{ax}	41.7^{ax}	41.5^{ax}	41.5^{ax}	41.6^{ax}	41.5^{ax}
3 h	35.1^{ay}	35.4^{ay}	35.2^{ay}	35.3^{ay}	35.5^{ay}	35.0^{ay}
24 h	3.8^{az}	3.9^{az}	3.9^{az}	3.8^{az}	4.1^{az}	3.6^{az}

[1]n = 160 pigs.
[2]Dependent variables: SEM for temperature decline is 0.14.
[ab]Means with unlike superscripts within a main effect variable and row are different (P < .05).
[xyz]Means with unlike superscripts within a main effect variable and column are different (P < .05).

Appendix Table 18. Least squares means and standard errors (SEM) for halothane gene, chromium picolinate, and sex main effects on color characteristics of fresh pork *longissimus lumborum*[1]

	Halothane Gene			Chromium Picolinate, ppb			Sex			P - Values[2]		
Variable	NN	Nn	SEM	0	200	SEM	Barrows	Gilt	SEM	Hal	CrP	Sex
CIE values - GM[3]												
L*	51.73	54.57	.51	53.29	53.01	.51	53.92	52.39	.51	.001	.71	.05
a*	10.09	11.01	.22	10.50	10.60	.22	10.61	10.48	.22	.007	.76	.68
b*	6.03	7.56	.22	6.72	6.87	.22	7.07	6.52	.22	.001	.62	.10
Chroma C[4] - GM[3]	11.78	13.38	.27	12.49	12.67	.27	12.78	12.38	.27	.02	.73	.51
Hue angle[4] - GM[3]	22.54	24.70	.66	24.30	22.94	.66	23.87	23.37	.66	.03	.16	.60
CIE values - P[3]												
L*	46.06	47.20	.52	46.94	46.32	.52	47.07	46.18	.52	.14	.42	.24
a*	14.62	15.22	.23	14.79	15.05	.23	14.78	15.06	.23	.08	.44	.41
b*	6.10	7.04	.22	6.72	6.42	.22	6.58	6.55	.22	.007	.35	.93
Chroma C[4] - P[3]	15.87	16.81	.26	16.27	16.41	.26	16.22	16.46	.26	.001	.66	.31
Hue angle[4] - P[3]	22.54	24.70	.66	24.30	22.94	.66	23.87	23.37	.66	.03	.16	.60

[1]n = 160 pigs, determined 24 h postmortem at 10th thoracic vertebrae and 40 min after ribbing.
[2]Hal = Halothane gene; CrP = Chromium Picolinate.
[3]Ham muscles evaluated: GM = Gluteus medius; P = Psoas major.
[4]Chroma C and Hue angle calculated by $\sqrt{(a*)^2 + (b*)^2}$ and $h_{ab}=\tan^{-1}\left\{\frac{b*}{a*}\right\}$, respectively

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VITA

Brent Kenneth Green was born on May 28, 1971 in Lexington, Missouri, the son of Kenneth W. and Patricia K. Green. He graduated from Stet R-XV high school, in May, 1989. He studied Agricultural Economics for two years at Central Missouri State University before transferring to Kansas State University where he received a Bachelor of Science degree in Animal Science and Industry. In August of 1995, he began graduate studies at Virginia Polytechnic Institute and State University and completed his Master of Science degree in Animal and Poultry Science in conjunction with the Department of Food Science and Technology in August, 1997.

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