THE INFLUENCE OF PRE- AND POST-CHILL PROCESSING ON THE DEVELOPMENT AND STABILITY OF CURED MEAT PIGMENTS IN PORCINE MUSCLE

By

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CHAPTER I

INTRODUCTION

The meat packing industry is continually striving to find new innovations which will decrease its overhead costs. One such innovation is the pre-chill method used in the processing of pork products. One of the greatest cost to the pork processing industry today is refrigeration for the 24 hour chilling period now used in conventional processing plants. The pre-chill processing method was developed to reduce this chilling period and make it possible to market finished pork products in a shorter period after slaughter. This would decrease the cost of refrigeration and bring about a more rapid turnover of products. However, this pre-chill processing method must produce products of equal or superior quality and yield when compared to products processed by conventional methods.

Barbe and Henrickson (1966) concluded that the closer complete processing was to the time of slaughter, the less opportunity existed for undesirable bacterial growth to occur. Also, they found that the bacterial population studied in pre-chill processed ham revealed no significant bacteriological problems and that greater reductions in total bacterial numbers were obtained with pre-chill processing techniques.

Mandigo and Henrickson (1966) found essentially no difference in yield, tenderness and moisture content of the finished hams and that the color was more stable in the pre-chill cured hams. Also, they reported

no difference in the yields of sliced bacon and concluded that the curing and smoking process of ham and bacon could be satisfactorily completed prior to initial chilling of the product. Furthermore, they reported that pre-chill fresh pork loin could be processed with essentially the same yield, tenderness, and moisture content as the conventional loin. The findings of the researchers mentioned indicated that the pre-chill method produced products of equal yield and quality when compared to the conventionally processed products. Also, that no bacteriological problems arose when this method was used.

However, little emphasis has been placed on the development and stability of cured meat pigments in pre-chill processed pork. One of the most important salability qualities in cured meat is a bright, stable and uniform color. It is an accepted fact that there exists great variability in the color of cured pork products processed by conventional methods. Thus, there exists the possibility that pre-chill curing of pork may have advantages over the conventional methods in regard to the development, uniformity and stability of cured meat pigments. This thesis is concerned with the pre-chill curing method and its relationship to the development, uniformity, and stability of cured meat pigments.

CHAPTER II

LITERATURE REVIEW

The literature reviewed has been confined to, (1) the chemical and pigment changes occurring in non-chilled and chilled porcine muscle, (2) the curing ingredients and their functions, and (3) the development and stability of cured porcine muscle pigments.

The Changes Occurring in Non-Chilled and Chilled Porcine Muscle

Stoppage of blood circulation at death initiates a complex series of changes in muscle tissues. Anaerobic conditions develop and numerous physical, biochemical, and physiological reactions occur that singly or collectively, regulate the differentiation of muscles on the basis of color, exudation and gross morphology (Briskey 1963). These physio-chemical changes are features in or the result of post mortem anaerobic glycolysis, rigor mortis, and or temperature change.

Chemical Changes

The major chemical changes in muscle tissue after death are the production of lactic acid by anaerobic glycolysis, the breakdown of creatine phosphate and the resynthesis and breakdown of ATP (Briskey 1959). Both glycolysis and the breakdown of creatine phosphate are mechanisms for the resynthesis of ATP from ADP. One and one-half molecules of ATP are synthesized for every molecule of lactic acid formed.

Immediately post mortem there is a rapid drop in creatine phosphate, a slow and then rapid decrease in ATP, accompanied by a parallel drop in pH. The balance between the breakdown and resynthesis of ATP can be maintained only as long as the store of creatine phosphate lasts. Bate-Smith and Bendall (1956) stated that the creatine phosphate is reduced to less than 20% of its initial level before there is any appreciable loss of ATP. According to Briskey (1959) the disappearence of ATP, once started, proceeded at a steady rate until less than 30% of the initial amount remained. The post mortem chemical change most easily measured is the gradual acidification of muscle tissue, due to the production of lactic acid from glycogen through the glycolytic cycle. Bate-Smith (1948) reported that the initial and ultimate pH values of muscle tissue are critical in determining the time course of rigor. Lawrie et al. (1958) suggested that the initial pH is due mainly to the severity of the death struggle. Briskey et al. (1959a) reported that the initial pH value of fresh porcine tissue two minutes post mortem was similar for all muscles. Furthermore, results from a comparison study of eight pork muscles, Briskey et al. (1960) presented an initial pH range at time of slaughter from 6.1 to 7.1 and showed extreme variation among animals, but indicated no significant difference among muscles. The similarity of pH values of all fresh tissues regardless of ultimate muscle classification support the common contention that the pH of live tissue physiologically regulated within limits compatible with the biological system. McCarthy and MacKintosh (1953) proposed that muscle pH represented a balance between (1) the buffering capacity of muscle tissue and (2) the presence of acidic substances. The post mortem conversion of glycogen to lactic acid can be easily estimated by following the pH decline to

the ultimate pH. If post mortem glycolysis proceeds at an intermediate rate, which requires 6-12 hours for completion of rigor mortis, the muscles would appear normal in color, juice retention and firmness (Briskey and Wismer-Pedersen, 1961). Different rates of post mortem pH decline are easily illustrated in porcine muscle (Figure 1). The rates of pH decline are extremely variable, ranging from a slow gradual decline to an extremely rapid decline with an eventual slight elevation of pH to an ultimate value. The pH changes in any muscles that ultimately show variations in color, gross morphology, juice retnetion and firmness show wide fluctuation. Judge et al. (1958) reported that a correlation existed between ultimate pH, color and water binding capacity in pork muscle. The rate of post mortem decline has been classified into six distinct pH patterns by Briskey (1963). These patterns and their relationship to color, exudation and firmness are shown in Figure 1 and described below. The classifications are: (1) a slow gradual decrease to an ultimate (24 hr) pH of 6.0-6.5 or above (dark muscle); (2) a slow, graduate decrease to an ultimate pH of 5.7-6.0 (slightly dark muscle); (3) a gradual decrease approximately 5.7 at eight hours, with an ultimate pH of 5.3-5.7 (normal muscle); (4) a relatively rapid decrease to approximately 5.5 at 3 hour, with an ultimate pH of 5.3-5.6 (slightly pale); (5) a rapid to a slightly gradual decline, but extremely extensive decrease to an ultimate pH of approximately 5.0 (slightly dark to extremely pale, but in all cases extremely exudative); (6) a rapid decrease to a pH of 5.1-5.4 at 30 to 90 minutes and a retention of this low pH, or a slight subsequent elevation to 5.3-5.6 (extremely pale, soft and exudative). If the post mortem changes occurred under relatively high pH conditions, the meat remained dark red in color, firm in

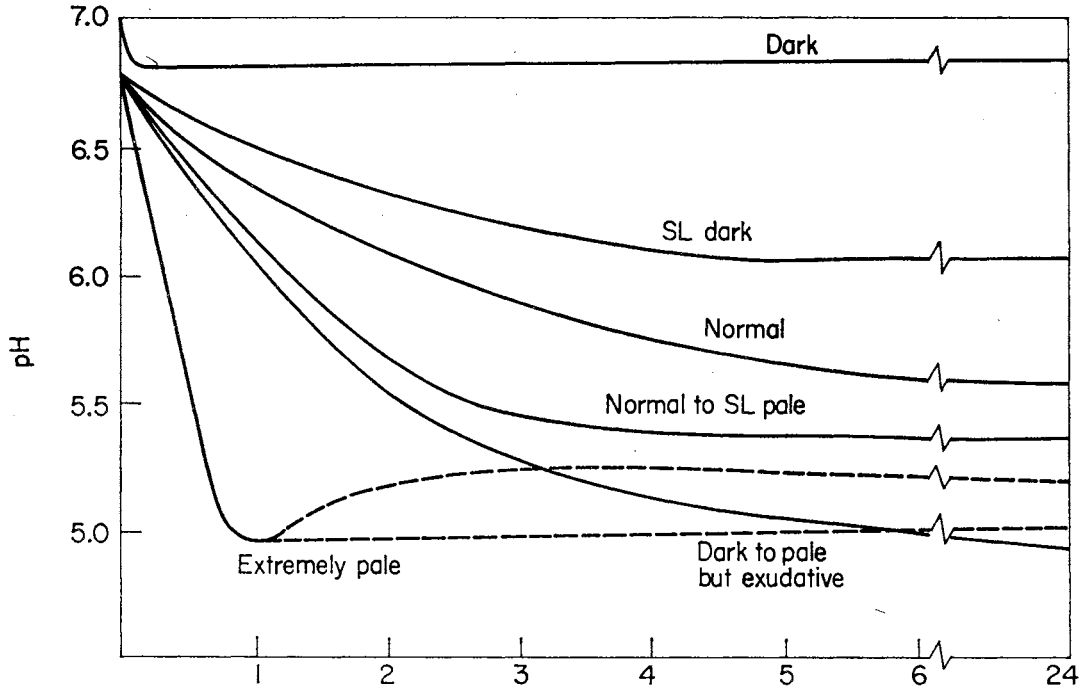

FIGURE 1. pH PATTERN VS STRUCTURAL CHANGE

(BRISKEY 1964.)

structure and dry in appearance (Briskey et al. 1962). Conversely, when these changes occurred at a rapid rate (30-90 minutes) under acid conditions and a high temperature the meat developed the very undesirable characteristics associated with pale, soft, and exudative porcine muscle (Kastenschmidt et al. 1964). Thus, as a correlation exists between the ultimate pH and color, the factors influencing the ultimate pH of muscle also affect the ultimate color of pork muscle. The relationship of the glycogen content of muscle to ultimate pH has been known since the first work by Callow (1938). Furthermore, Gibbons and Rose (1950) stated that the muscle glycogen stores at the time of slaughter determines the amount of lactic acid formed and thus influenced the ultimate pH. The quantity of glycogen stored at the time of death is important in determining post mortem chemical and physical properties of the muscle only if: (1) the glycogen is available or accessible for degradation (Lawrie 1955), and (2) the enzymes are not inhibited by a decreasing pH (Bate-Smith and Bendall 1949). Sayre et al. (1963abc) reported that the rate at which the glycogen is broken post mortem has been found to influence the properties of muscle more pronouncedly than does the total amount of glycogen present at the time of death. Larner et al. (1956) found that muscle phosphorylase preferentially degraded the larger glycogen molecules. Furthermore, Briskey and Lawrie (1961) stated that glycogen samples isolated from different bovine muscles at pre-rigor and post-rigor periods were broken down at unequal rates by phosphorylase. Sayre et al. (1963a) found marked differences in the amount and type of glycogen present in the muscles of pigs of different breeds. Briskey (1964) stated that these findings indicated that the branching characteristic of the glycogen molecule might differ under various nutritional

and hereditary conditions and may be a factor in the regulation of the rate and amount of post mortem glycolysis. This would then influence the ultimate pH of porcine muscle and indirectly influence the ultimate color of porcine muscle. Callow (1938) indicated that fatigue diminished muscle glycogen and elevated the ultimate pH of pork muscle. While, Wismer-Pedersen and Rieman (1960) and Ludvigsen (1960) demonstrated that the level of feeding and the degree of fatigue before death influenced the ultimate pH of pork muscle. McCarthy and MacKintosh (1953) stated that the immediate effect of exercise on muscle is a decrease in initial glycogen content and therefore, less glycogen is present to form lactic acid. According to Briskey et al. (1959c) a single and severe exercise just prior to slaughter produced post mortem conditions of a low glycogen supply, a high pH and dark colored muscles. Moreover, Gibbons and Rose (1950) demonstrated that pork muscle with a low ultimate pH could be produced by feeding 3 lbs of sugar prior to slaughter and Ludvigsen (1954) recognized that the kind of feed consumed had an influence on the post mortem chemical changes. Also Briskey et al. (1959b) reported that pigs on a high sucrose ration, for 7 days prior to slaughter had higher 2 minute post mortem glycogen concentrations and a significantly lower pH value 40 minutes post mortem than the single exhaustive exercise treatment pigs. The muscles of the sucrose feed pigs were pale, soft and extremely exudative. Furthermore, Moss (1962) demonstrated that the feeding of sucrose rations to large groups of pigs for 3, 2 or 1 day prior to slaughter resulted in a sharp increase in pale, soft and exudative muscle. Hupka (1953) reported that pigs on a low protein diet produced exudative muscle.

Work by Sayre et al. (1961) indicated that when the pigs' environ-

ment changed quickly from warm to cold there was in some muscles, a sharp reduction in muscle glycogen and the muscles were firmer and dryer. Also, Sayre et al. (1963b) stated that a warm environment prior to slaughter caused a sharp decrease in the post mortem pH of muscle from Poland China and Hampshire pigs, whereas, similar muscles from Chester White pigs had the capacity to withstand the heat. Furthermore, Forrest et al. (1963) observed a high incidence of pale, soft, and exudative tissue during periods of large daily temperature fluxations. Later, Kastenschmidt et al. (1965) reported a combined warm and cold air treatment reduced the initial glycogen content and decreased the rate of pH decline. Results from an extensive experiment with three breeds, Sayre et al. (1963c) indicated that fasting for 70 hours prior to slaughter lowered the initial glycogen content of the muscles and resulted in a slow rate of pH decline and color change during post mortem glycolysis.

Water Binding Capacity

Free water in muscle tissue is expressed as a total percentage of the total water in muscle. Hamm (1953) reported that as the pH declined the water binding capacity decreased and the expressible water ratio increased. Furthermore, Briskey et al. (1959a) stated that the expressible water ratio increased with increasing initial glycogen concentrations. Also, they found that pale, soft, and exudative muscles possessed a high expressible water ratio or a low water binding capacity. In addition, Briskey et al. (1959c) found that there were no significant differences among classes of muscles in terms of expressible water.

Color of Porcine Muscle

The color of pork muscle has little or no effect on its nutritive properties. However, the degree of pigmentation and pigment variation among muscles has an effect on the general appearance of the meat and may affect the ease with which it is merchandized. Color change in muscle is the most obvious visual alteration post mortem. In normal porcine muscle the color is converted from a relatively dark red to a lighter grayish-pink (Cassens 1966). Lawrie (1950) suggested that muscles with the same pigment content can vary in appearance depending upon the muscle tissue pH. He showed that myoglobin appeared darker at a high pH than at a low pH and that muscle consistency and pH are important determinates in muscle color formation. Furthermore, the relationship of muscle pH to the myoglobin content of muscle was reported in a study by Briskey et al. (1960) Table I. Hamm (1953) reported that with a low pH the water would be released, the structure would become more dense, and the light rays would be reflected from the surface areas and give the muscles a pale appearance. In addition, he suggested that the light rays penetrated deeply into the fresh hydrated muscle thus giving the muscle a dark appearance. Also, the Danish Meat Research Institute (1958) indicated that meat color was due to the interaction between pigment concentration and the transparency of the meat fibers. They reported that poor transparency is normally associated with pale color, but that a high pigment concentration may compensate for poor transparency resulting in apparent greater redness in the meat.

It is a generally accepted fact that muscle pigment concentrations vary from animal to animal and that contiguous muscles of pork frequently exhibit pronounced variation in color. These color differences are partially due to the muscle location and function. The darker-

TABLE I

COMPARISON OF CERTAIN PHYSICAL AND CHEMICAL CHARACTERISTICS OF EIGHT PORK MUSCLES[1]

Muscle Characteristic	Gluteus accessorius	Rectus femoris	Serratus ventralis	Terres major	Biceps femoris	Pectoralis profundus	Gluteus medius	Longissimus dorsi
pH (24 hr)	6.06	6.01	5.92	5.88	5.83	5.76	5.68	5.60
Myoglobin[2], mg./g.	8.66	7.48	8.77	6.69	4.64	2.75	2.88	2.17

[1]Briskey *et al.* (1960).

[2]Expressed on moisture-fat-free-basis.

colored muscles contain a higher myoglobin concentration than the lighter muscles (Briskey et al. 1960). Lawrie (1950) concluded that the principal factor contributing to myoglobin increase in muscles was the demand for oxygen as the result of increased activity, either by growth or exercise. Also, he stated that active pigs possess darker muscles with greater myoglobin concentrations than inactive pigs. This suggested one explanation for the wide variation in myoglobin concentration within muscle classes and also among individual muscles. In addition, he found that myoglobin content increased with age. In later work, Lawrie et al. (1963) compared myoglobin concentrations of muscles from the ham, loin, and shoulder regions of pigs slaughtered on a weight basis. The analyses indicated that the myoglobin content increased with body weight. The quantity of myoglobin in pale versus dark muscle is controversial. Hart et al. (1961) consistently noted a minor, but significantly lower pigment content in pale muscle and Briskey et al. (1959a) observed that myoglobin values appeared somewhat lower in pale muscles, but the differences were not significant. While, Meyer et al. (1963) reported a marked difference in myoglobin concentration between pale and dark muscles obtained from animals slaughtered at a commercial slaughtering plant. It was reported by Lawrie et al. (1958) that alternate light and dark areas appeared within the semimembranosus muscle of swine. Furthermore, Briskey et al. (1962) observed the occurrence of light and dark areas in the porcine semitendinosus, and Cassens et al. (1963) found that the dark sections contained three times as much myoglobin as did the light sections. In addition, Briskey (1964) observed that the outer area of the biceps femoris frequently showed a rapid loss of color upon cooling. Later work done by Arganosa (1969) showed a

TABLE II

MYOGLOBIN CONTENT OF PRE- AND POST-CHILLED UNCURED PORCINE MUSCLES[1]

Treatment	Muscle[2]			
	Biceps femoris	Longissimus dorsi	Semimembranosus	Semitendinosus
Pre-chilled	3.71	2.17	3.28	3.61
Post-chilled	3.66	2.09	2.94	3.49

[1]Arganosa (1968).

[2]Expressed as mg/g moisture-fat-free basis.

slight difference in the myoglobin content of muscle processed prior to chilling and muscles processed after a 24 hour chilling period (Table II).

Myoglobin

The bright red color of fresh meat and the pinkish-red color of cured meat, as well as various discolorations of meat and meat products, are due to the chemical state of the pigment called myoglobin (Schweigert 1956). The uniformity of color in fresh and cured pork depends upon the distribution of myoglobin in different muscles and the myoglobin concentration and distribution in different muscles has been shown to vary greatly. Myoglobin is an intracellular tissue pigment, occurring in the red muscles of vertebrates. It combines with oxygen to form complexes which serve as oxygen reservoirs within the fibers. Myoglobin is a conjugated protein that contains a heme moiety, an iron containing porphyrin compound attached to the protein, globin. The structure of the heme moiety is diagramed in Figure 2. The heme portion gives rise to the color of myoglobin although the protein or other constituents, which are in themselves, colorless modify the color considerably (Schweigert 1956). The chemical reactions involved in the development of desirable or undesirable color changes in fresh meats are shown in Figure 3. Oxygen is required for the oxygenation of myoglobin to oxymoglobin, a desired reaction in fresh meat, however, prolonged exposure at low oxygen pressures results in the undesirable formation of metmyoglobin. At all oxygen pressures there is a constant conversion of myoglobin to metmyoglobin, but the presence of reducing conditions which result from the oxidation of available substrates, primarily glucose, keeps myoglo-

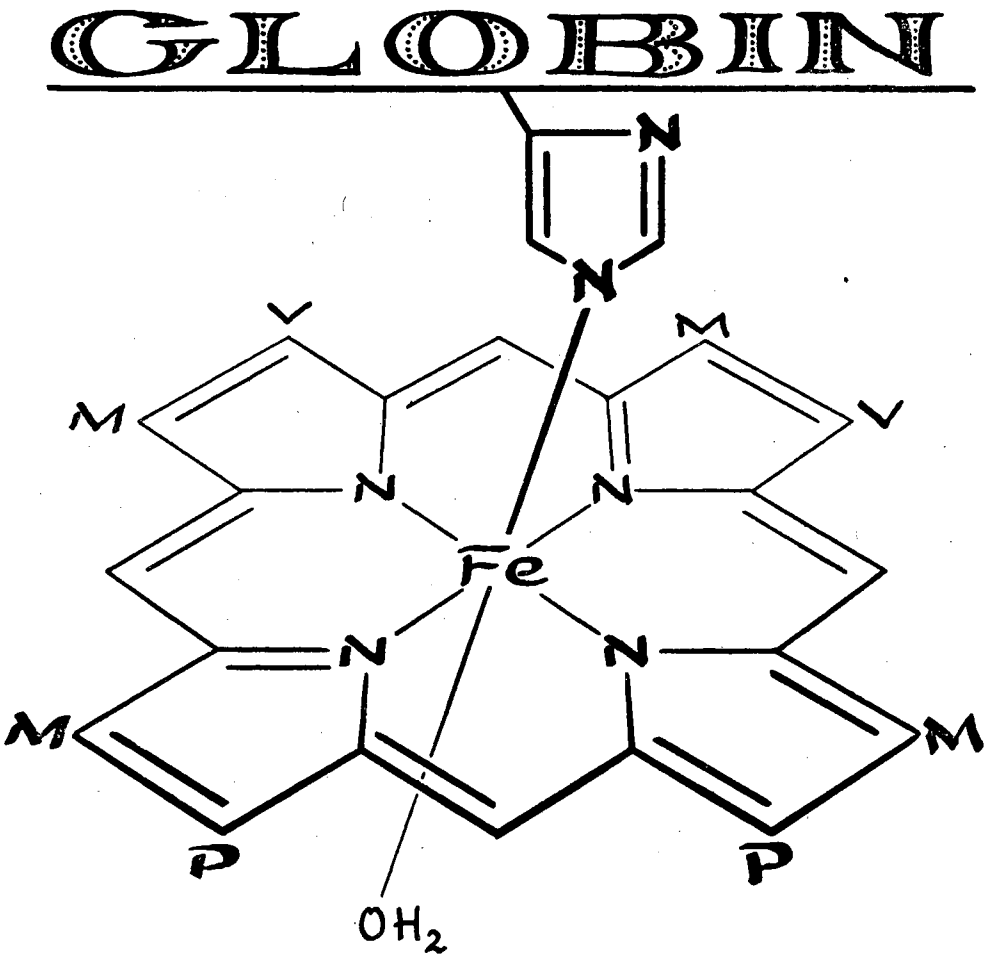

FIGURE 2. STRUCTURE OF MYOGLOBIN

(GIFFEE et. al. 1960.)

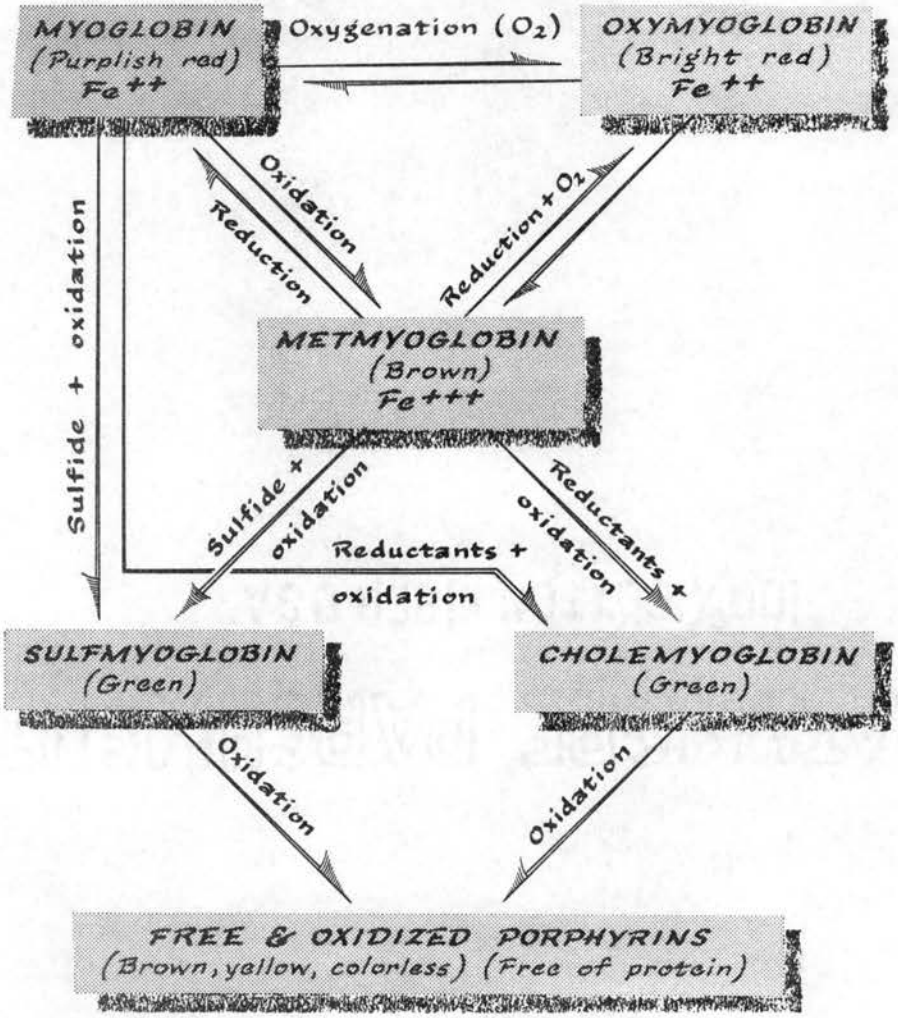

FIGURE 3. REACTIONS OF MYOGLOBIN

(GIFFEE et. al. 1960.)

bin in a reduced state and provides the co-enzymes capable of reducing metmyoglobin to myoglobin. When the supply of oxidizable substracts is depleted myoglobin is oxidized to metmyoglobin. Schweigert (1956) stated that when oxidation proceeds to the formation of green compounds, the reactions are irreversible. Also, he reported that the green compound formation and ultimate degradation to colorless compounds occurs on prolonged exposure to oxygen, by the action of peroxides, by the irradiation of gramma rays and the presence of light which catalyzes the rate of oxidation of these pigments. The exact chemical reactions and/or the mechanisms of these reactions are not fully understood.

Curing Ingredients and Their Functions

Meat curing is defined as the addition of salt, sugar, nitrate, nitrite and other adjuncts which are added for the purpose of preservation or flavor development. Fields and Dunker (1952) stated that each of the curing adjuncts used performed a specific function.

Water

Water is a constituent of all food and some foods contain substantial amounts and the water content of most food items range from 60 to 95% (Garner 1966). The behavior of water in food is closely related to its quality. Garner (1966) reported that moisture loss or gain during processing or storage accounted for many quality changes in food products and Dimarco (1963) stated that a greater water holding capacity usually resulted in a higher quality product. While Hamm (1960) reported that all processing and storage treatments affected the interaction between the water and muscle solids. Further work by Hamm

(1963) indicated that water was immobilized within the meshes of the protein network. Therefore, moisture control is an effective means of suppressing quality changes in foods.

Salt

Sodium chloride probably has the longest history of usefulness of all the preservatives used in foods. It is the most important constituent in the meat curing mixture. Salt is an effective dehydrating agent and when used alone in curing it will cause the meat to become dry and hard. This drying effect, according to Brady et al. (1949), decreases the rate of microbial growth. While, Niven and Chesbro (1960) stated that in sufficient concentrations salt inhibits microbial growth as the result of the increase in osmotic pressure of the medium.

The effectiveness of salt as a preservative for meat depends upon the penetration of the salt to all areas of the product. The rate of salt diffusion into muscular tissue is dependent upon: 1) the salt concentration of the solution and 2) the temperature of the solution and muscle. This was pointed out by Wistreich et al. (1960), when he stated that the salt diffusion rate into muscle varied linearly with the solution concentration. In addition, Wistreich et al. (1959) found that the diffusion rate increased with increased temperature in a non-linear manner. According to Callow (1947) the addition of salt to muscle increased the solubility of muscle proteins. Later, Wood (1966) reported that upon the addition of a curing solution to muscle there is an initial outward flow of water, protein and other organic materials from the muscle tissue. Furthermore, he stated that the slower the rate of diffusion of salt into the muscle tissue the greater the outward flow due

to osmosis and changes in protein structure. Work by DiMarco (1963) demonstrated that the addition of salt to meat increased the water holding capacity of muscle tissue. In addition, Callow (1956) reported that 80% of the water in uncured muscle could be expressed, but after curing only 40% could be expressed. The ideal combination of salt to sugar in the curing solution to provide maximum quality in cured products was found to be 2.5% salt and 1.1% sugar (Pearson et al. 1962).

Sugar

The two major functions of sugar are flavoring and reduction of the harshness caused by salt. However, Kraybill (1953) indicated that sugar content in most products was not sufficient to produce a sweet flavor. According to Greenwood et al. (1940) the presence of easily reduced sugars, such as; levulose and dextrose, produced significant changes in the type of bacteria and their actions in cured meat. Furthermore, they reported that the addition of these sugars produced color changes in meat pigments, while in the absence of microorganisms these sugars appeared to have no effect on the meat pigments. Also, they stated that sugar aided in improving the color of cured meat by establishing reducing conditions which helped in preventing the oxidation of the heme pigments. In addition, Kraybill (1953) proposed that sugars helped to maintain acid and reducing conditions, which are favorable to the development and stability of cured meat color. Sair (1965) stated that more acidic conditions accelerated cure development, whereas, Callow (1947) reported that sugar was acted upon by the microorganisms and changed to an acid compound. However, Urbain (1944) found that the use of excessive amounts of reducing sugars in curing resulted

in very dark colored meat during cooking. Also, he stated that the low pH values would oxidize the nitric-oxide heme pigments and this brought about the discoloration during cooking. Even though considerable work has been reported, the functions of sugars in curing are not completely understood.

Nitrate and Nitrite

Nitrate is widely used as a constituent of the meat curing mixture, but its functions in preservation are not fully understood. Many claims have been made that nitrate plays a rule as a reservoir for nitrite, thus maintaining a sufficient level in the meat for color fixation. However, Niven and Chesbro (1960) stated that nitrate reduction to nitrite is a bacterial process, and achieving significant reduction of nitrate would require reasonably large populations of nitrate reducing bacteria and such extensive bacterial growth in cured meat would be undesirable. White and Gibbons (1941) reported that the total number of microorganisms and number capable of reducing nitrate to nitrite were significantly correlated with the nitrite content of the cured meat. According to Tarr (1941) small amounts of nitrite had bacteriostatic action if the pH was below 7.0. Furthermore, Niven and Chesbro (1960) reported that the bacteriostatic action of nitrite was dependent on the pH of the meat and appeared to be associated with the undissociated nitrous acid concentration. Also, Jensen and Hess (1941) found that the addition of small quantities of nitrate to meat would reduce the incidence of bone marrow sours.

In early studies Haldane (1901) observed that when fresh meat was boiled in the presence of a small amount of nitrous acid a red color

developed, and color did not develop when nitrate was used. He suggested that nitrosohemoglobin was formed by the reaction of the nitrite with the hemoglobin in the muscle tissue. More recently, Niven and Chesbro (1960) stated that it is probable that a large quantity of the myoglobin is oxidized to metmyoglobin by the added nitrite, which then must be reduced again before the cured meat pigment is formed. They suggested that the metmyoglobin is then reduced and combines with nitric oxide to form the cured meat color. Sair (1962) stated that nitrate could be replaced by nitrite in the curing solution and that meat cured with nitrite: 1) cured more rapidly and 2) the nitrite content of the finished product was more uniform. Winkler et al. (1940) found that the red color of cured meats became more stable as the nitrite content increased, while Hanley et al. (1955) reported that the time required to produce the cured pink color could be reduced by the use of nitrite and higher temperatures in the curing process. The introduction of nitrites had a tremendous impact on the meat curing industry as it reduced the curing time for hams from 60 days to 15 days.

Ascorbate

The impact of ascorbate on the meat curing industry was not as far reaching as the introduction of nitrites, but nevertheless has resulted in many useful changes. Ascorbates have a twofold effect on curing as they accelerate the cure and stabilize the finished cured color (Sair 1962). Chang and Watts (1949) found that when ascorbic acid was added to hemoglobin solutions in the presence of nitrite; the ascorbic acid protected the red color of the nitrosohemoglobin from oxidation. Furthermore, Gibson (1943) observed that ascorbic acid reduced the oxidized

forms of myoglobin and hemoglobin to the reduced forms myoglobin and hemoglobin. Watts and Lehmann (1952a) found that the addition of ascorbic acid to meat during curing accelerated the production of cured meat color, while Henrickson et al. (1956) reported that hams pumped with a brine containing ascorbic acid developed deeper red color. In addition, Borenstein (1963) stated that cured meat developed superior flavor and greater color stability when ascorbate was used in curing. Earlier, work by Kelly and Watts (1957) demonstrated that ascorbic acid used as one of the reducing agents in curing catalyzed the production of nitrosomyoglobin and reduced the color fading in cured meats. Hollenbeck and Monahan (1953) found that the addition of sodium nitrite and sodium ascorbate to the curing solution increased the yields of available nitric oxide. While, DiMarco (1963) suggested that the action of sodium ascorbate, isoacorbate and ascorbic acid created reducing conditions which were favorable for a rapid reaction between nitrite and the heme pigments. Watts and Lehmann (1952b) postulated that the mechanism of the action of ascorbic acid in accelerating the formation of the nitrosomyoglobin complex was the reduction of metmyoglobin to myoglobin and the latter then reacted with nitric oxide. While, Hollenbeck and Monahan (1953) stated that another mechanism for the increased rate of nitrosomyoglobin complex formation in the presence of ascorbic acid would be: ascorbic acid reduces nitrous acid to nitric oxide with the exclusion of nitrogen dioxide and the nitric oxide reacts with the myoglobin.

Phosphates

The use of phosphates in curing has been widely adopted in the

United States. Various forms of phosphate have been used primarily to decrease the amount of skrinkage in cured products. McKernan et al. (1957) found that the incorporation of phosphate into the curing mixture resulted in: 1) increased moisture retention, 2) decreased loss of soluble proteins and 3) improved color and texture of the finished product. Bendall (1954) noted that meat cooked in a 1% salt solution retained only 75% of its original volume and that the addition of phosphate compounds increased the volume retained to 80% while the addition of pyrophosphates increased the cooked volume to 95% of the original volume. Hamm (1955) suggested that this could be explained by the ability of the phosphates to complex with the bivalent cations on the peptide chains and that the removal of the cations from the peptide chain made it possible for the hydration of the proteins to proceed more rapidly. Furthermore, the action of the phosphates was to increase the water holding capacity of the proteins. Swift and Ellis (1956) reported an improvement in cured meat texture upon the addition of phosphates to the curing ingredients and they postulated that this improvement was probably due to the increased water retention.

Heating and Smoking

Modern smokehouses are designed primarily to attain close control of the heating function, with only secondary consideration given to the smoking function (Wilson 1960a). While Draudt (1963) stated that the smoking operation is carried out only during part of the heating period and usually lasts from 2-8 hours. Furthermore, smoke does more than provide the desirable flavor and color to smoked products as it contributes substantially to preservation by acting as an effective antioxi-

dant and bacteriostatic and bactericidal agent as well as providing a protective film on the surface of smoked meat. Lea (1933) observed that smoking gave substantial protection against rancidity development on the surface of bacon. Later, Gibbons et al. (1954) demonstrated that smoke constituents were chiefly responsible for the bactericidal effect of the combined smoking, heating and drying processes. Also, Shewan (1949) found that cold smoking produced a 95% reduction in viable bacterial counts and that bacterial stability was a function of the phenolic compound content and smoking time. It is generally conceded that phenolic compounds are responsible for the smoke flavor of cured meat. Hanley et al. (1955) and Tilgner et al. (1962) stated that the total phenolic content of foods can be used as the index of the degree of smoking.

Draudt (1963) pointed out that the heating of cured meat was a very critical process, because all of the lean tissue must receive sufficient heat to develop and fix the red color of cured meat, yet the temperature reached must not be high enough to render the fat. Furthermore, he stated that for a given heating time there is only about 5-10°F difference between the temperature at which color fixation occurs and rendering starts. According to Wilson (1960b), nitrosomyoglobin in the presence of heat reacted with nitric oxide to form nitrosohemochrome. While Sair (1963) found that the best color development and stability occurred when the internal temperature of cured meat reached 152-155°F.

Development and Stability of Cured Porcine Muscle Pigments

The concentration and stability of the cured meat pigments, nitrosomyoglobin and nitrosohemoglobin are of great importance to all concerned with cured meat products. According to Hornsey (1964), the cured

meat color is due to the combining of myoglobin, with nitric oxide derived from nitrate or produced by bacteria from nitrite. While Sair (1962) defined the initial steps in cured color fixation to be: 1) nitrite in an acid medium is converted to nitrous acid, 2) two molecules of nitrous acid is then converted to one molecule of nitric oxide, nitrogen peroxide and water and 3) the nitric oxide reacts with myoglobin to yield nitrosomyoglobin the pink cured meat color. Figure 4 shows graphically the many pathways that the heme pigments may follow. Wilson (1960b) stated that when the cure is added to meat it is highly probable that a large part of the myoglobin is oxidized to metmyoglobin by the added nitrite. Furthermore, Sair (1962) reported that most of the evidence indicated that the nitric oxide reacted with the metmyoglobin to form nitric oxide metmyoglobin which is then reduced by the enzymes in meat to nitrosomyoglobin. In addition, Wilson (1960b) suggested that the nitrosomyoglobin is converted to nitrosohemochrome, which is the ultimate pink pigment desired, by heat. The step from changing from the oxidized to the reduced state of the meat pigments was a very critical one prior to the use of ascorbates. Sufficient time had to be given in the smokehouse for this reduction to occur before two much heat was added or the color development was unsatisfactory. Gibson (1943) and Vestling (1943) demonstrated that when nitrite was added to meat, a brown color, typical of metmyoglobin was formed and then on the addition of ascorbic acid the brown color was converted to a pink color indicating that the reduction step had taken place.

Under some conditions the nitrosohemochrome can be oxidized to green, yellow, or colorless prophyrin substances. The exact chemical nature of these oxidative reactions is not well understood, but it is

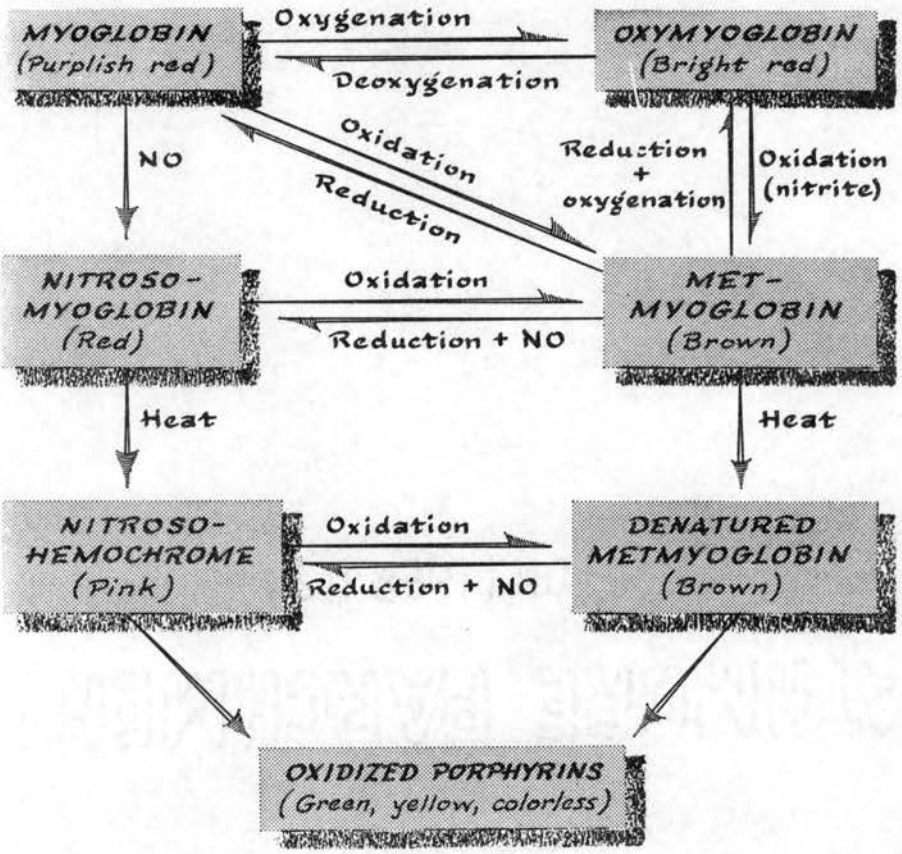

FIGURE 4. CHEMICAL CHANGES OF MYOGLOBIN THAT MAY OCCUR DURING THE CURING REACTION

(WILSON 1960b.)

believed that these represent a series of oxidative steps including the removal of the iron atom from the heme pigment and the ultimate rupture of the porphyrin ring.

Hornsey (1964) observed that the conversion of pigments to the cured form was the same for all muscles and that it increased linearly with temperature. Also, Winkler and Hopkins (1940) found that the maximum color intensity occurred at 70°C and that above 80°C there was a reduction in color intensity. Whereas, Hornsey (1964) stated that the highest rates of pigment conversion was between 54°C and 82°C and that underheating gave rise to a decreased stability.

Watts and Lehmann (1952a) pointed out the importance of pH on color fixation and stated that as the pH decreased the color developed more rapidly and total color development was greater. However, they emphasized that these results were mainly concerned with the rapidity and completeness of color development, and not with the stability of the color. Sair (1962) stated that there is a deficiency of information regarding the effect of pH on the stability of cured meat pigments.

According to Ramsbottom et al. (1951), the best color of cured meat is the pinkish red color observed immediately after cutting and upon exposure to light this color changed rapidly to a grayish-brown color. This color change was the result of the oxidation of nitrosomyoglobin and nitrosohemochrome. Furthermore, they reported that light acted as a catalyst and that the discoloration was proportional to the light intensity. Hockman (1946) found that light intensity had a greater effect on the pigments than the color of the light and that more fading occurred when cured meat was exposed to near ultraviolet and less yellow light. Ramsbottom et al. (1951) and Kraft and Ayres (1953) re-

ported that cured meat was not as severely discolored by ultraviolet light as it was by fluorescent light.

Sair (1963) stated that when a low level of nitrite was used the color development occurred more rapidly than when a higher level of nitrite was used, but these pigments faded rapidly when exposed to light. Furthermore, he reported that with increasing amounts of nitrite the color development was slower, but a progressive improvement in color stability was observed. Woodcock and White (1943) found that the presence of 50 ppm of nitrite in the meat appeared to be sufficient for complete cured color development, however, Sair (1962) reported that at this level color stability was very poor. He recommended using 120 ppm of nitrite in the meat to get maximum stability.

According to Hornsey (1964) if otherwise normally cured meat was found to possess either an abnormally high or low pigment concentration this could be attributed to an individual, which was deficient or over abundant in muscle pigments. While Briskey et al. (1959b) reported that the pigment differences observed in fresh meat were of the same magnitude in the cured product. Hornsey (1964) observed three categories of natural pigment variation: 1) normal pale muscles; 2) deep red colored or beef muscles and 3) two-toning and that these were commonly occurring faults which could be traced to the original pig.

CHAPTER III

MATERIALS AND METHODS

Two groups of barrows (10 and 12 each) were obtained from the Oklahoma Agricultural Experiment Station herd. Experiment I was conducted in August and September 1966 and Experiment II in August 1968. The barrows in each experiment were of mixed breeding, similar in age and weighed approximately 91 kg. when slaughtered. Slaughtering was according to the procedures established at the meat laboratory and consistent with methods and practices currently used in the industry. Following the slaughtering process the sides of the first carcass in each experiment were assigned at random to each treatment. The sides of the remaining carcasses in each experiment were alternately assigned to pre-chill and post-chill treatments. Post-chill processing (control) involved a 24 hour chilling period prior to wholesale cutting and curing. Pre-chill processing was defined as completing some or all of the fabrication steps prior to the initial chilling of the cuts. The pre-chill treatment involved the removal of the hams from the carcasses immediately after slaughter and completion of the curing process within 30 minutes post mortem. The post-chill treatment involved an initial 24 hour chilling of the carcass at 1.1^{o}C prior to the removal of the ham from the carcass and the completion of the curing process. In Experiment I two pigs were slaughtered every week for five weeks, while in Experiment II all twelve animals were slaughtered on the same day.

Experiment I

The hams of the pre-chill treatment sides were removed immediately post-slaughter, skinned, and trimmed free of excess fat. The semimembranosus, adductor, biceps femoris, and quadriceps, which included the vastus lateralis, rectus femoris, vastus intermedius and vastus medialis, were excised from the ham. Each muscle was then pumped to 112% of green weight with a 1.7°C (cold) curing brine (67° brine - consisting of salt, sugar, nitrite and ascorbate), placed in fibrous bags and heated in the smokehouse. The individually cased muscles were heated for 12 hours while slowly raising the internal temperature of the meat to 68°C and held at this temperature for one hour. Upon removal from the smokehouse the muscles were washed and placed in a 1.7°C cooler until color stability studies were completed. The post-chill hams were removed after an initial 24 hour chill period and the muscles were excised, cured, and cooked by the methods used in the pre-chill processing.

Experiment II

The hams of the pre-chill treatment were removed immediately post-slaughter, skinned and trimmed free of excess fat. The semimembranosus, semitendinosus, biceps femoris and quadriceps muscles were excised from ham. The muscles were then pumped to 112% of green weight with a 23°C (warm) curing brine (65° brine - consisting of salt, sugar, nitrite and ascorbate), placed in fibrous bags, and heated in a smokehouse. The smokehouse temperature was maintained at 36.1°C until all muscles were placed in the smokehouse. The muscles were heated for 12 hours while slowly raising the temperature to 68°C and held at this temperature for one hour. The muscles were removed from the smokehouse, washed and then

placed in a 1.7°C cooler until stability studies were completed. The post-chill treatment hams were removed after an initial 24 hour chill period and the muscles were excised, cured and cooked by the same methods used in the pre-chill processing.

Cured Color Stability

Experiment I

The cured muscles (from one ham each day) were then transferred to a darkened cooler (red photography lamp) with temperature of 1.7°C. All exposed surfaces and excess fat were trimmed away and the muscles were ground through a 1/4 in. grinder plate (Dormeyer homo-mixer grinder) and mixed thoroughly. Ten gram aliquots were weighed and placed in 9 cm petri dishes with tops (used to prevent excessive drying during the exposure period). Four plates for each of the six exposure times were weighed, two plates for total pigments and two for nitroso-pigments. The exposure periods studied were 0, 1, 3, 5, 7 and 24 hour. The samples were then placed in a light exposure cabinet for the designated period of time. The light intensity was regulated by a rheostat and set at 10 ft-c of light. After exposure to the light for the designated period the samples were removed to the darkened cooler. The samples were then transferred to erlenmeyer flasks containing a solvent (43 ml) and the flasks were attached to a mechanical shaker for 10 minutes. The mixtures were filtered twice through Whatman No. 1 qualitative filter paper into 50 ml erlenmeyer flasks and read on the Baush and Lomb Spectronic 20 spectrophotometer. The wavelength for total pigments was set at 512 and 640 mu and at 540 mu for nitroso-pigments. The solvents for nitroso-pigments were composed of 40 ml acetone, 3 ml of distilled water

and 7 ml of water derived from the meat sample. The solvents for total pigments contained 3 ml of concentrated hydrochloric acid in place of the 3 ml of distilled water. This method was outlined by Hornsey (1956).

Experiment II

The procedures in Experiment II were the same as those used in Experiment I except for the following changes: 1) only two plates for each of the exposure times were weighed, one plate each for total pigments and nitrosopigments; 2) the light intensity was increased to 100 ft-c, and 3) the 10 gm samples were maserated in a morter with the solvent.

The light exposure cabinet in Figure 5 was designed to study the stability of cured meat color. An adjustable, galvanized 1 and 1/4" expanded metal shelf 51 x 62" was positioned 42" from the floor and housed within walls constructed of 5/8" plywood painted flat white. An opaque plexiglass baffle was mounted 68" from the floor and a bank of lights 76" from the floor. Twelve fluorescent 40-watt deluxe cool white tubes were spaced 5" apart within the cabinet. The ceiling was located 88" from the floor with a 3" space between the ceiling and the top of the walls to allow for air flow. After selecting the proper shelf height the light intensity was maintained by use of a rheostat.

Statistical Analysis

A split plot analysis was used to determine the effects of animal, treatment, muscle and their interactions on the concentration and stability of total pigments and nitroso-pigments. Duncan's New Multiple Range test was used to determine significant differences among muscles

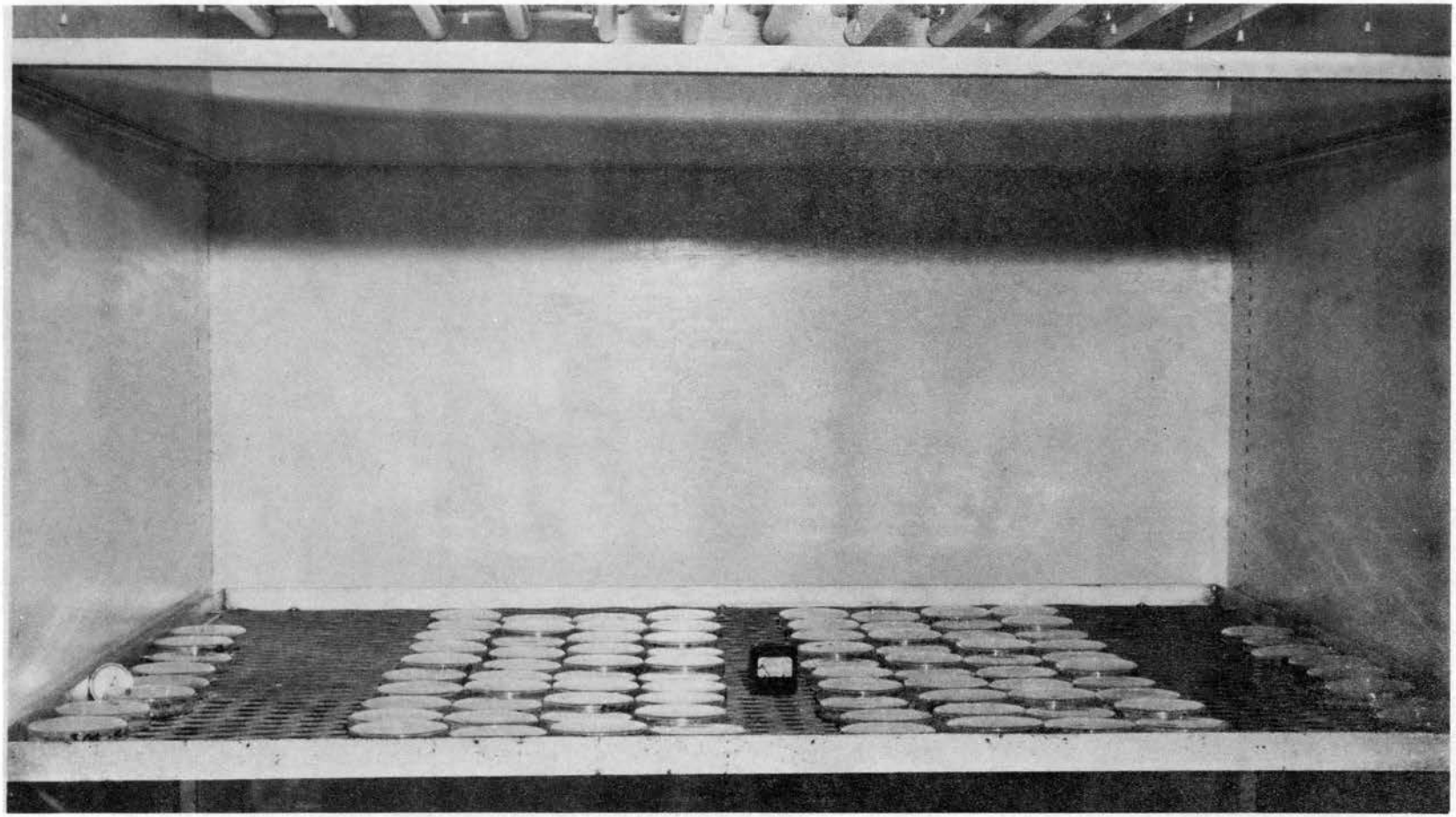

FIGURE 5. LIGHT EXPOSURE CABINET

(Steel and Torrie 1960).

A separate analysis was made for each measured pigment for the various light exposure time intervals. The analysis was such that differences among muscles and the effect of pre- and post-chill treatments on each muscle could be tested.

CHAPTER IV

RESULTS AND DISCUSSION

Pigment Development

Total Pigments

Experiment I - the concentration of total pigments in cured porcine muscle was found to be significantly ($P < .05$) different among animals and agreed with the work of Hornsey (1964) who reported that much of the total pigment variation of cured pork could be traced to the individual pig. Prior to any light exposure (zero hour), the post-chill cured muscles contained significantly ($P < .025$) more total pigments than the pre-chill cured muscles (Table III-A). After exposure to 10 ft-c of light for one through 24 hours, the post-chill cured muscles possessed higher concentrations of total pigments than the pre-chill muscles being non-significant at the one and 24 hour exposure intervals and $P \leq .025$ at the three, five and seven hour exposure intervals. The mean values of the total cured muscle pigments presented graphically in Figures 6 and 7 show that the pigment concentration for both the pre- and post-chill muscles was the highest in the quadriceps followed by the adductor, biceps femoris and semimembranosus. Duncan's New Multiple Range test indicated that the quadriceps muscles (pre- and post-chill cured) contained significantly ($P < .01$) more total pigments than the biceps femoris and semimembranosus, while the adductor possessed significantly ($P < .01$)

TABLE III-A

TOTAL PIGMENTS (ppm) IN CURED PORCINE MUSCLE REMAINING AFTER EXPOSURE TO 10 FT-C OF LIGHT

Time hr	Mean SM[1] Pre	SM[1] Post	A[2] Pre	A[2] Post	BF[3] Pre	BF[3] Post	Q[4] Pre	Q[4] Post	Treatment Effect
0	65.50	75.80	98.00	101.70	79.40	91.80	116.10	134.90	$P < .025$
1	64.50	76.35	99.90	98.50	79.40	90.90	115.80	132.20	$P < .10$
3	63.50	74.65	96.90	97.40	76.90	88.50	112.50	131.25	$P < .025$
5	61.60	73.10	94.90	95.10	73.80	87.10	108.10	123.75	$P < .025$
7	59.20	70.75	91.20	91.60	69.40	85.30	130.00	117.10	$P < .025$
24	28.30	32.05	42.70	42.90	34.10	38.30	49.50	55.10	$P < .10$

TABLE III-B

TOTAL PIGMENTS (ppm) IN CURED PORCINE MUSCLE REMAINING AFTER EXPOSURE TO 100 FT-C OF LIGHT

Time hr	Mean SM Pre	SM Post	ST[5] Pre	ST[5] Post	BF Pre	BF Post	Q Pre	Q Post	Treatment Effect
0	64.30	68.00	115.70	104.40	81.70	83.60	117.10	117.80	N.S.
1	63.20	65.60	116.50	103.10	78.10	85.70	114.70	114.90	N.S.
3	62.80	65.30	112.20	102.50	77.30	81.60	111.90	112.30	N.S.
5	61.20	61.30	111.40	100.30	77.30	81.20	108.70	111.10	N.S.
7	59.80	58.70	108.30	99.30	73.60	77.40	109.30	108.60	N.S.
24	51.60	53.60	99.30	93.60	64.10	69.40	97.00	99.00	N.S.

[1] SM = Semimembranosus

[2] A = Adductor

[3] BF = Biceps femoris

[4] Q = Quadriceps

[5] ST = Semitendinosus

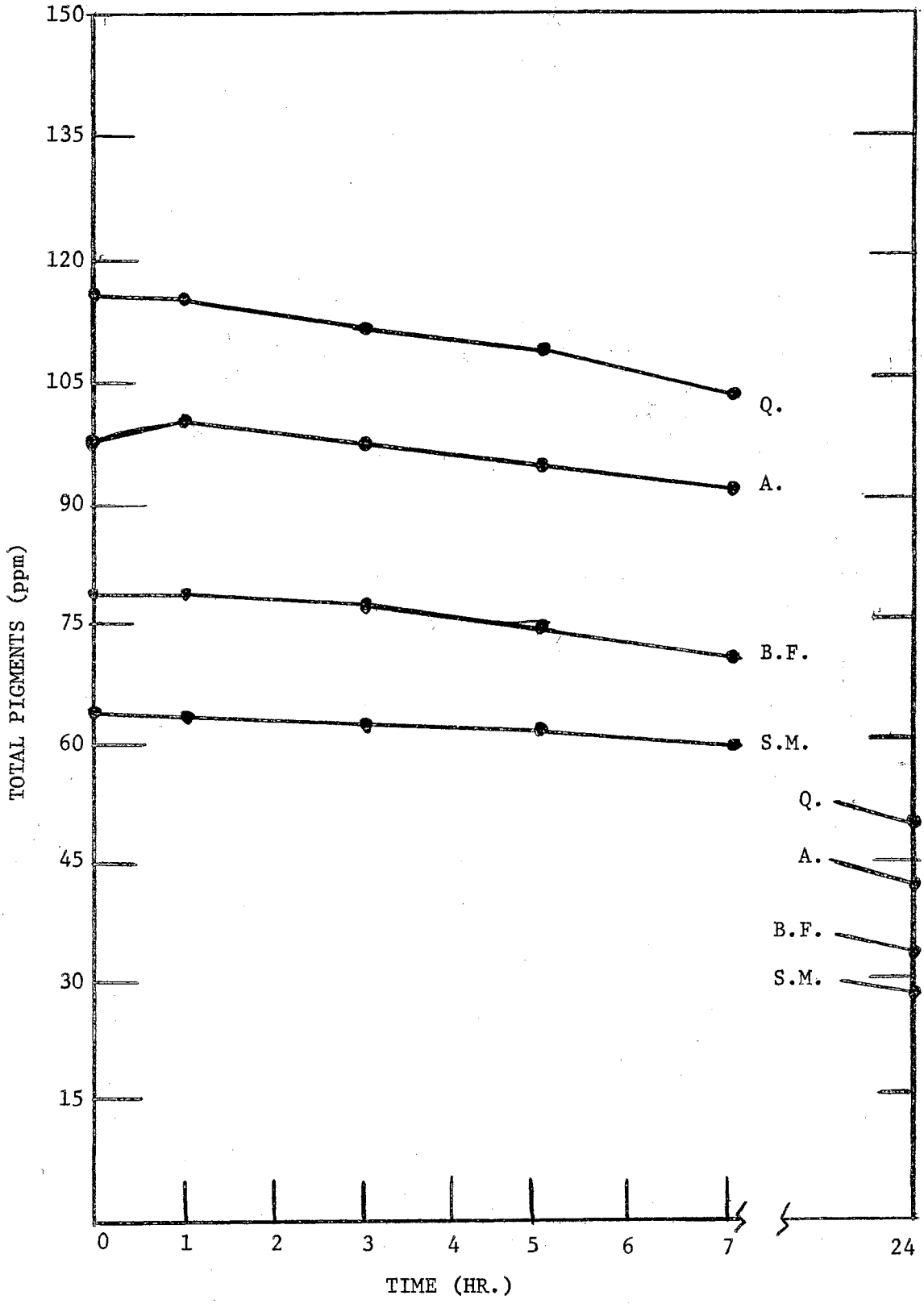

Figure 6. Remaining Total Pigment (Experiment I, Pre-Chilled)

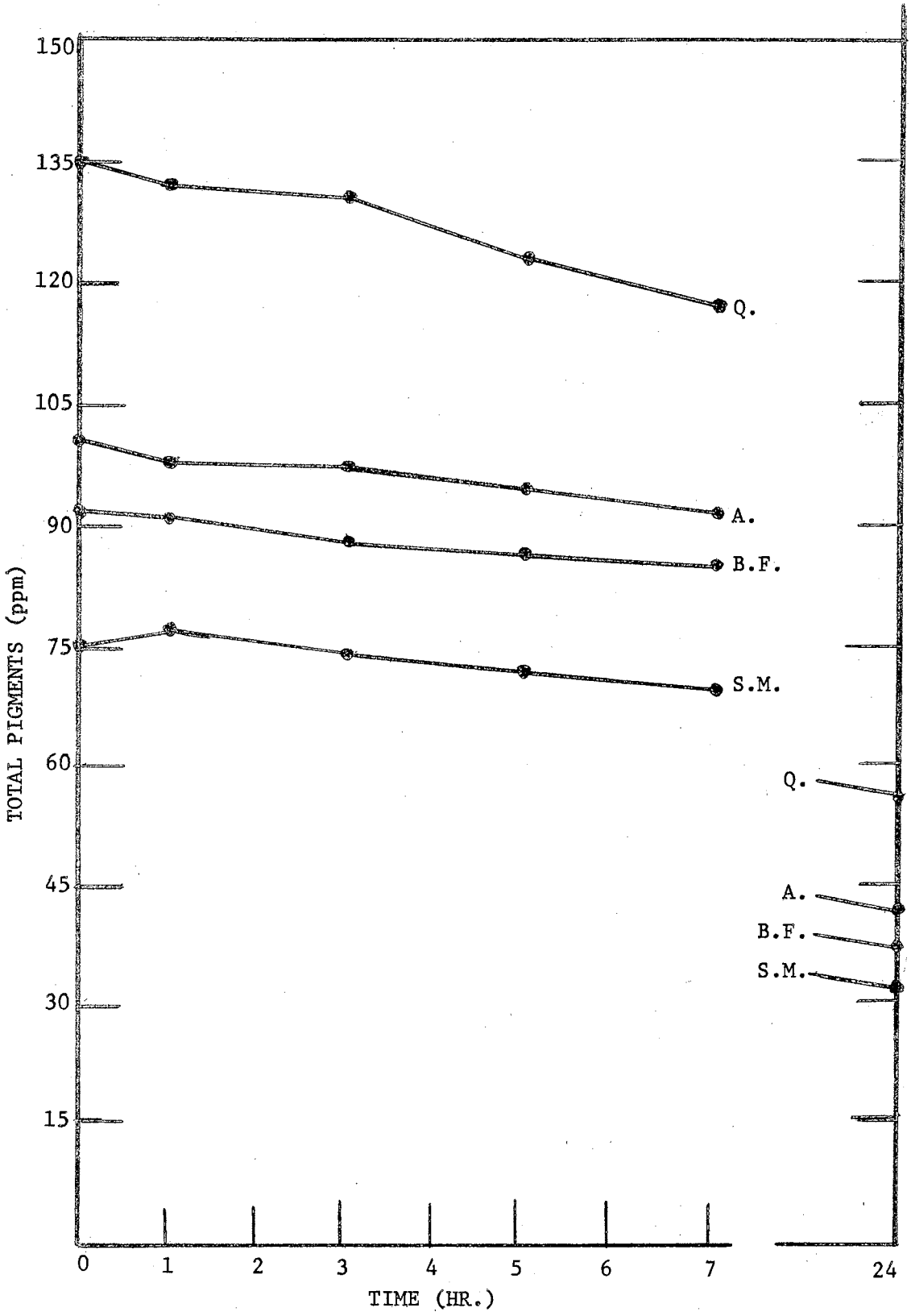

Figure 7. Remaining Total Pigments (Experiment I, Post-Chilled)

higher pigment concentrations than the semimembranosus. The pigment content of the pre-chill quadriceps exceeded that of the adductor and this observed difference decreased as the time of exposure increased as indicated in Figure 6 and by a change in the level of significance from $P < .01$ (zero and one hour) to $P < .05$ (three, five and seven hours) to no significant difference (24 hour). The post-chill quadriceps possessed significantly ($P < .01$) (zero through seven hour) and $P < .05$) (24 hour) more extractable pigments than the adductor. The pre-chill adductor contained higher pigment concentrations than the biceps femoris, and only at zero through seven hour exposure intervals was the observed difference significant ($P \leq .01$), while the difference in pigment content between the post-chill adductor and biceps femoris was non-significant. The biceps femoris (pre- and post-chill) pigment content exceeded that of the semimembranosus with the difference being significant ($P < .05$) at all exposure times except the 24 hour interval. This was in agreement with the work of Hornsey (1964) who observed wide differences in cured pigment concentration among muscles from the same ham.

The muscle by treatment interaction was significant ($P < .10$) and this indicated that the magnitude and direction of the response of pork muscles to pre- and post-chill curing depended upon which muscle was being cured. It can be observed from Table III-A that the response of the adductor muscle to the post-chill treatment was not of the same magnitude as the responses of the other three muscles. This interaction can be explained, in part, by an observation of Briskey's et al. (1960) that there was very little difference in the initial pH and color characteristics of muscles immediately post mortem, however, significant differences were observed 24 hours post mortem. The total pigment con-

centration of all muscles decreased gradually over the 24 hour exposure period.

Experiment II - the total cured pigment concentration was found to be significantly ($P < .005$) different among animals and agreed with the results of Experiment I. The differences in total pigment content between the pre- and post-chill cured muscles was non-significant. The post-chill semimembranosus, biceps femoris and quadriceps contained slightly higher pigment concentrations than the pre-chill muscles, while the pre-chill semitendinosus contained more cured pigments than the post-chill cured muscle (Table III-B). The differences in treatment response between Experiment I and Experiment II may have been due to the warm curing brine used in Experiment II. Figures 8 and 9 graphically illustrate that the concentration of total cured pigments of the pre-chill muscles is the highest in the quadriceps and semitendinosus, which were reversed in their order in total pigment concentration when exposed to light, followed by the biceps femoris and semimembranosus. However, the pigment content of the post-chill cured muscles was greatest in the quadriceps followed by the semitendinosus, biceps femoris, and semimembranosus. The pre- and post-chill quadriceps and semitendinosus possessed significantly ($P < .01$) more pigment than the biceps femoris and semimembranosus. The differences in pigment content between the biceps femoris (pre- and post-chill) and the semimembranosus was found to be statistically significant ($P < .01$). Essentially no difference was found in the pigment content of the pre-chill quadriceps and semitendinosus, while a significantly ($P < .01$) higher pigment content was found in the post-chill quadriceps than in the semitendinosus. The muscle by treatment interaction was significant ($P < .025$) and this was in agree-

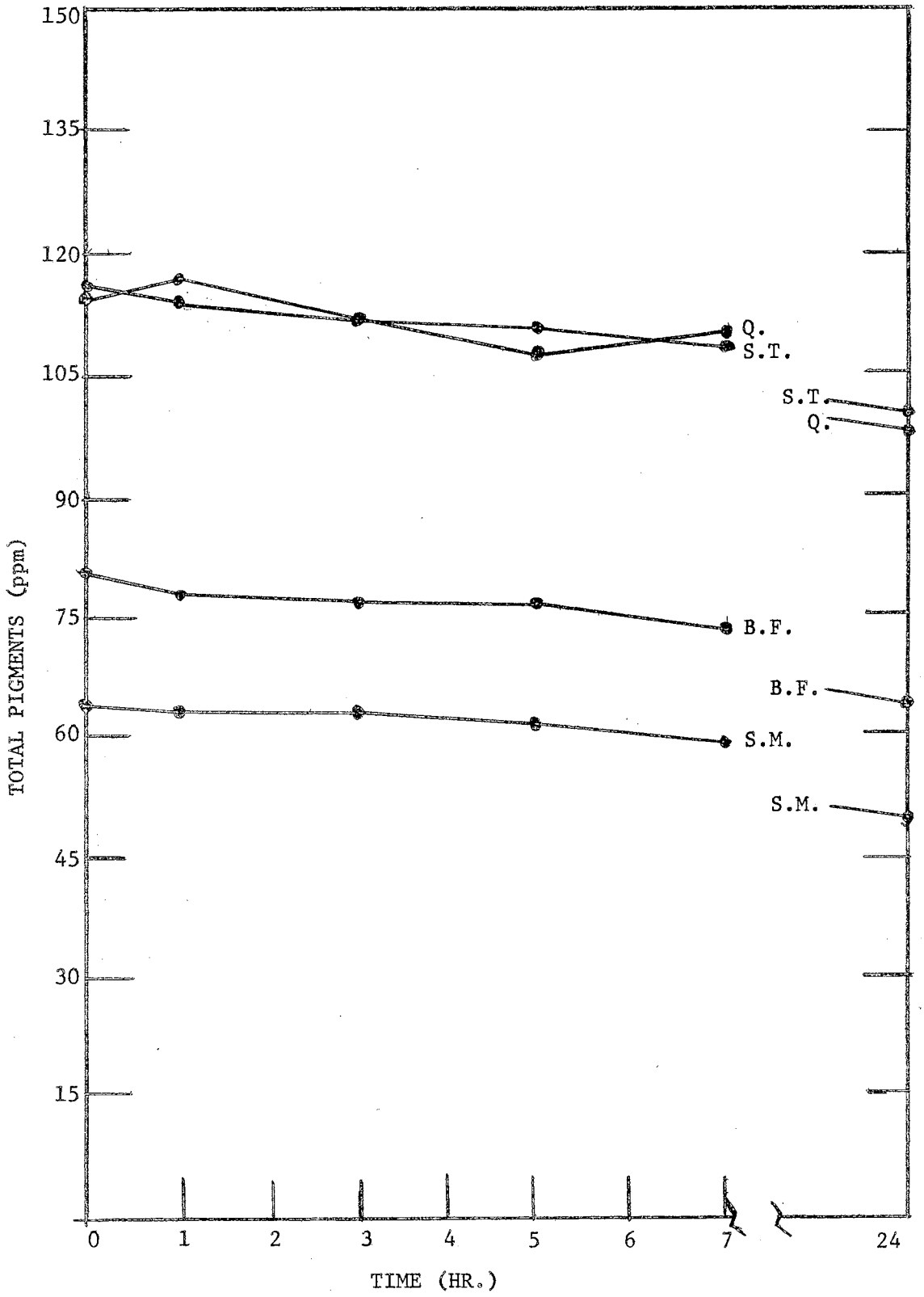

Figure 8. Remaining Total Pigments (Experiment II, Pre-Chilled)

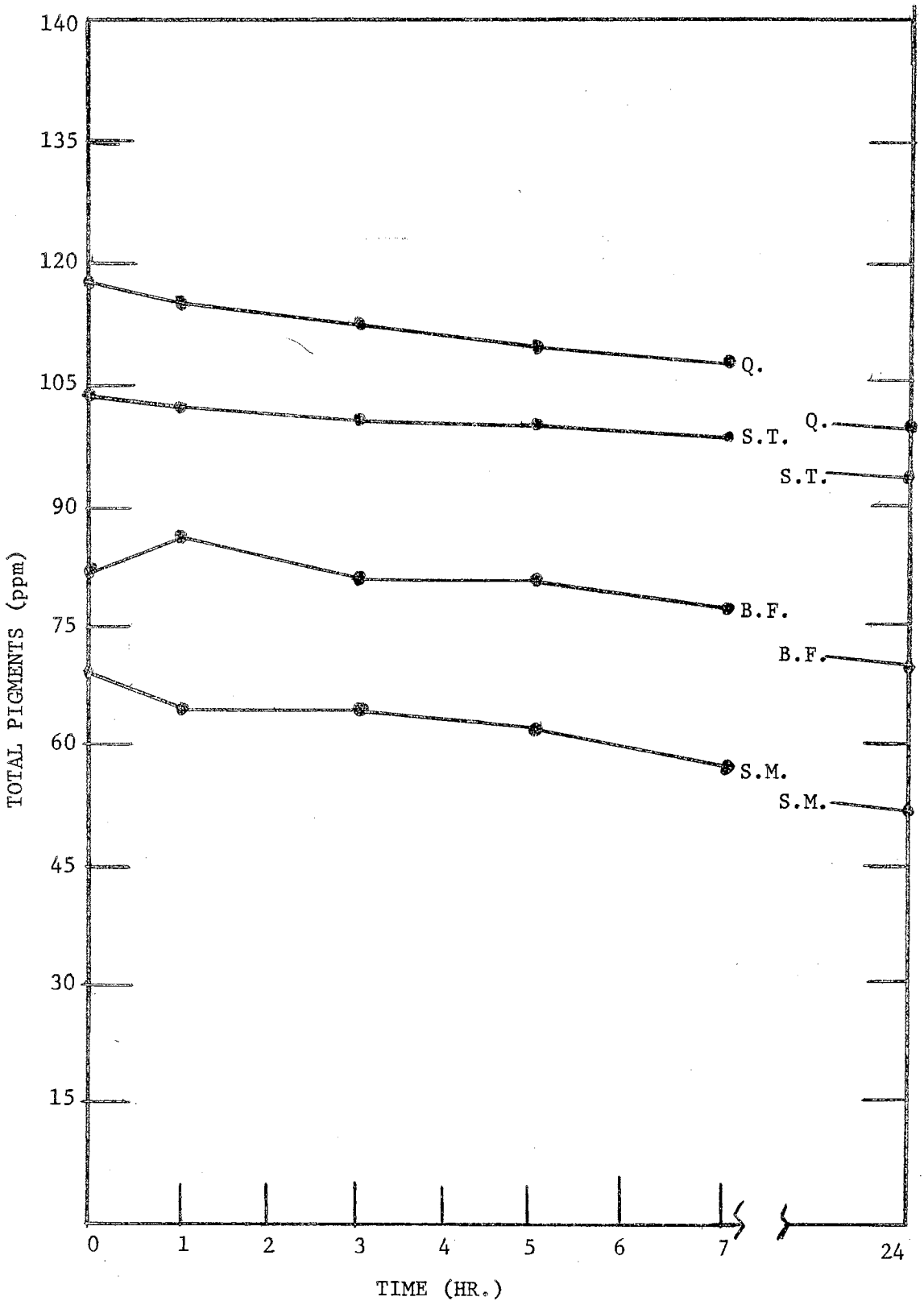

Figure 9. Remaining Total Pigments (Experiment II, Post-Chilled)

ment with the results of Experiment I, which indicated that the treatment effect was dependent upon which muscle was being cured. The failure of the semitendinosus to respond similar to the other three muscles can be partially explained by Briskey et al. (1962) who reported the occurrence of light and dark sections in the semitendinosus. Furthermore, Beecher et al. (1963) demonstrated that the light section was prone to rapid and severe glycolysis with a subsequent loss in color during rigor mortis. This would indicate that the pre-chill muscle, which was cured before the severe glycolysis and loss of color occurred, would possess higher pigment concentrations than the post-chill muscle, which was cured after severe glycolysis and color loss occurred. This suggested the possibility that pre-chill curing may help control some of the color variation among cured muscles by eliminating the losses of color which occur in some muscles due to severe glycolysis. The total pigment concentration for all muscles decreased at a uniform rate over the 24 hour exposure period.

Nitroso-pigments

Experiment I - the nitroso-pigment concentrations of cured porcine muscles was significantly ($P \leq .05$) different among animals. The nitroso-pigment content of the pre- and post-chill cured muscles was non-significant. The post-chill muscles contained slightly higher initial (zero hour) nitroso-pigment content while the pre-chill muscles possessed slightly higher pigment content at the 24 hour exposure interval. This was in agreement with the work of Watts and Lehmann (1952a) who reported that as the pH decreased which is what takes place in a chilled muscle a more rapid and complete development of nitroso-pigments occurred.

Furthermore, Arganosa and Henrickson (1969) found that the post-chill processed muscles had lower pH values than the pre-chill processed. This may be a possible explanation of the higher initial nitroso-pigment concentration in the post-chill cured muscles. The average ppm of nitroso-pigment extracted after exposure to light for a specified period of time are presented in Table IV-A. Figures 10 and 11 graphically illustrate that the nitroso-pigment content was the greatest in quadriceps (pre- and post-chill cured) followed by the adductor, biceps femoris and semimembranosus. The quadriceps (pre- and post-chill) possessed significantly ($P \leq .01$) higher concentrations of nitroso-pigments than the adductor, biceps femoris and semimembranosus while the adductor (pre- and post-chill) contained significantly ($P \leq .01$) more nitroso-pigments than the semimembranosus. The pre-chill adductor possessed significantly ($P \leq .01$) higher nitroso-pigment concentrations than the biceps femoris while the difference in the nitroso-pigment content between the post-chill adductor and biceps increased with time as indicated in Figure 11, the level of significance was $P \leq .05$ (zero through seven hour) and $P \leq .01$ (24 hr). The pre-chill biceps femoris contained a higher concentration of nitroso-pigments than the semimembranosus, with the difference being significant $P \leq .01$ at the zero through five exposure intervals (Figure 10). The difference in pigment concentrations between the post-chill biceps femoris and semimembranosus decreased with time, the difference being statistically significant ($P \leq .05$) at the seven hour exposure time. The muscle by treatment interaction was non-significant. The greatest reduction in nitroso-pigments came immediately after exposure to light and air. And was in agreement with the findings of Ramsbottom et al. (1951); and Hornsey, (1964).

TABLE IV-A

NITROSO-PIGMENTS (ppm) IN CURED PORCINE MUSCLE REMAINING AFTER EXPOSURE TO 10 FT-C OF LIGHT

Time hr	Mean								Treatment Effect
	SM[1]		A[2]		BF[3]		Q[4]		
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	
0	52.00	58.8	76.1	76.20	62.10	69.30	89.00	96.30	N.S.
1	46.90	53.40	69.2	68.40	56.00	61.80	79.00	86.50	N.S.
3	42.30	46.90	60.30	60.10	49.00	53.40	70.00	74.90	N.S.
5	36.70	40.70	54.50	51.60	43.30	46.60	63.30	66.30	N.S.
7	34.10	35.70	48.10	46.10	37.50	40.60	57.70	58.50	N.S.
24	21.60	18.10	29.50	25.60	21.50	20.10	37.70	33.4	N.S.

TABLE IV-B

NITROSO-PIGMENTS (ppm) IN CURED PORCINE MUSCLE REMAINING AFTER EXPOSURE TO 100 FT-C OF LIGHT

Time hr	Mean								Treatment Effect
	SM		ST[5]		BF		Q		
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	
0	58.30	49.80	94.90	56.30	72.20	62.20	101.60	88.30	$P < .005$
1	45.30	37.40	77.00	45.60	58.80	49.70	83.10	72.60	$P < .005$
3	33.70	27.30	63.40	33.40	44.20	35.30	67.50	53.80	$P < .005$
5	27.60	21.70	52.60	27.40	36.20	27.30	57.30	45.30	$P < .005$
7	21.90	17.60	42.30	22.20	29.80	22.70	46.10	37.40	$P < .005$
24	10.20	7.90	20.60	12.70	13.40	11.00	21.00	16.70	$P < .005$

[1] SM = Semimembranosus

[2] A = Adductor

[3] BF = Biceps femoris

[4] Q = Quadriceps

[5] ST = Semitendinosus

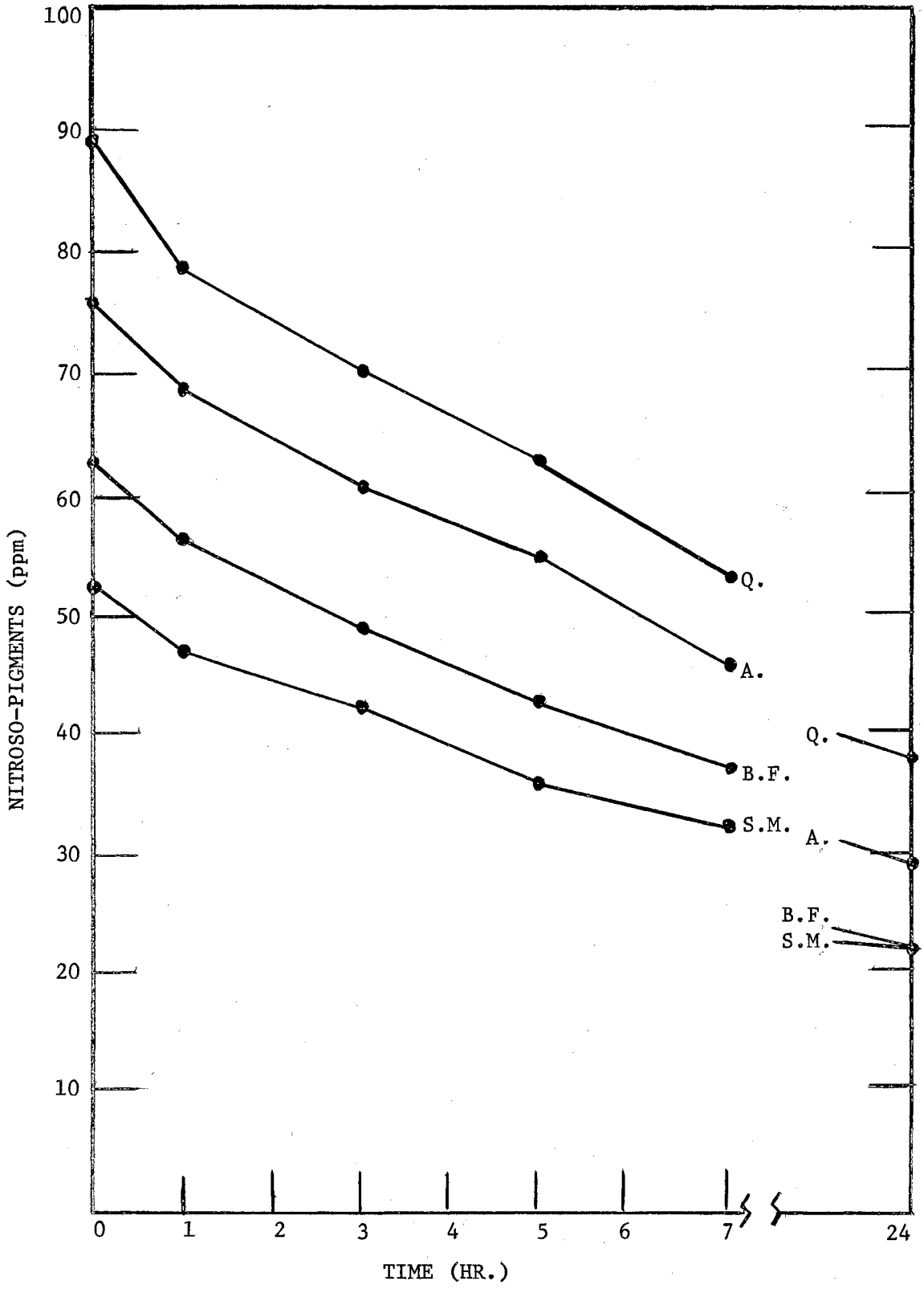

Figure 10. Remaining Nitroso-Pigments (Experiment I, Pre-Chill)

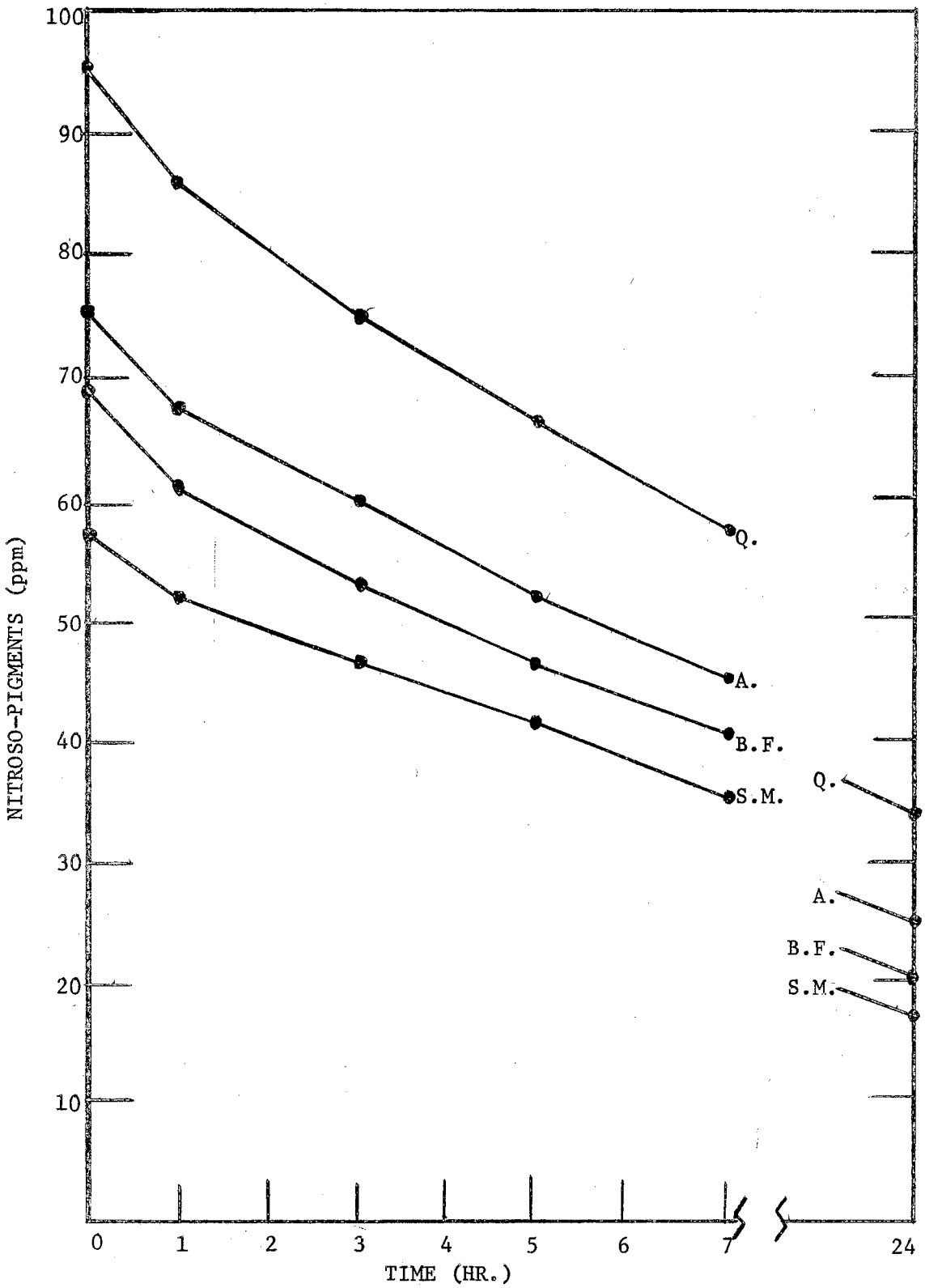

Figure 11. Remaining Nitroso-Pigments (Experiment I, Post-Chilled)

Experiment II - a difference in the nitroso-pigment content of cured porcine muscle was observed among animals, but it was not statistically significant. This was in agreement with the results from Experiment I. The pre-chill cured muscles possessed significantly ($P \leq .005$) higher concentrations of nitroso-pigments than the post-chill cured muscles (Table IV-B). This was not in agreement with the results of Experiment I which indicated no significant difference between treatments. This discrepancy can possibly be explained in that warm brine was used in curing all the muscles of Experiment II while a cold brine was used in Experiment I. This suggested the possibility that the combination of pre-chill curing and warm brine may be of use in producing cured pork products which possess brighter, more uniform color. Figures 12 and 13 show that the concentration of nitroso-pigments was the highest in the pre-chill quadriceps followed by the semitendinosus, biceps femoris, and semimembranosus. The post-chill quadriceps possessed the highest content of nitroso-pigments followed by the biceps femoris and semitendinosus, which reverse in order at the 24 hour interval, and semimembranosus. The pre-chill cured quadriceps and semitendinosus contained significantly ($P \leq .01$) greater amounts of extractable nitroso-pigments than the semimembranosus and the biceps femoris, which contain significantly ($P \leq .01$) more nitroso-pigments than the semimembranosus. At zero through seven hour exposure times the pre-chill quadriceps contained significantly ($P \leq .05$) greater amounts of nitroso-pigments than the semitendinosus; this observed difference decreased, as the exposure time increased, to the non-significant level. The post-chill quadriceps possessed significantly ($P \leq .01$) higher concentrations of nitroso-pigments than the biceps femoris, semimembranosus and the semitendinosus, which

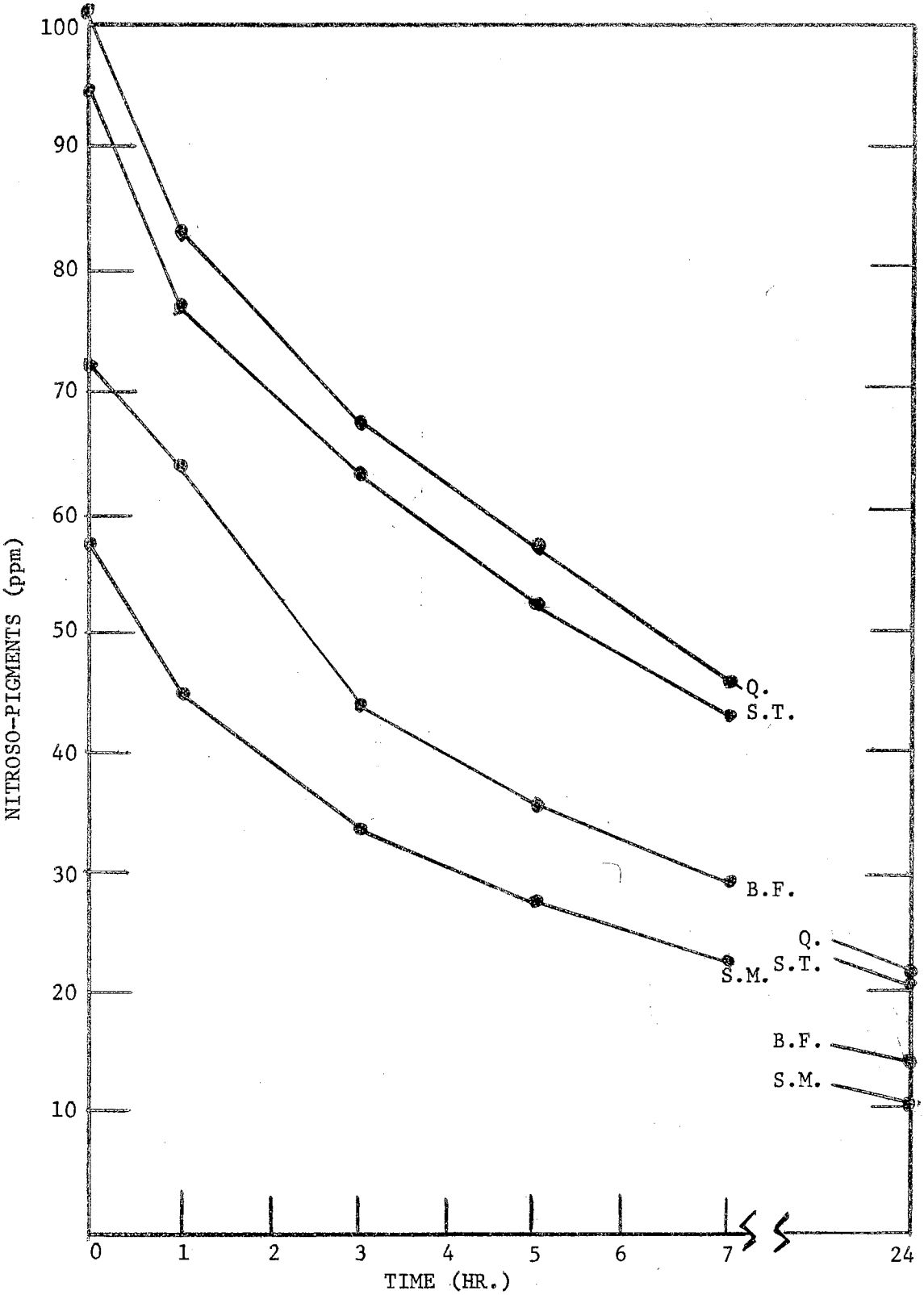

Figure 12. Remaining Nitroso-Pigments (Experiment II, Pre-Chilled)

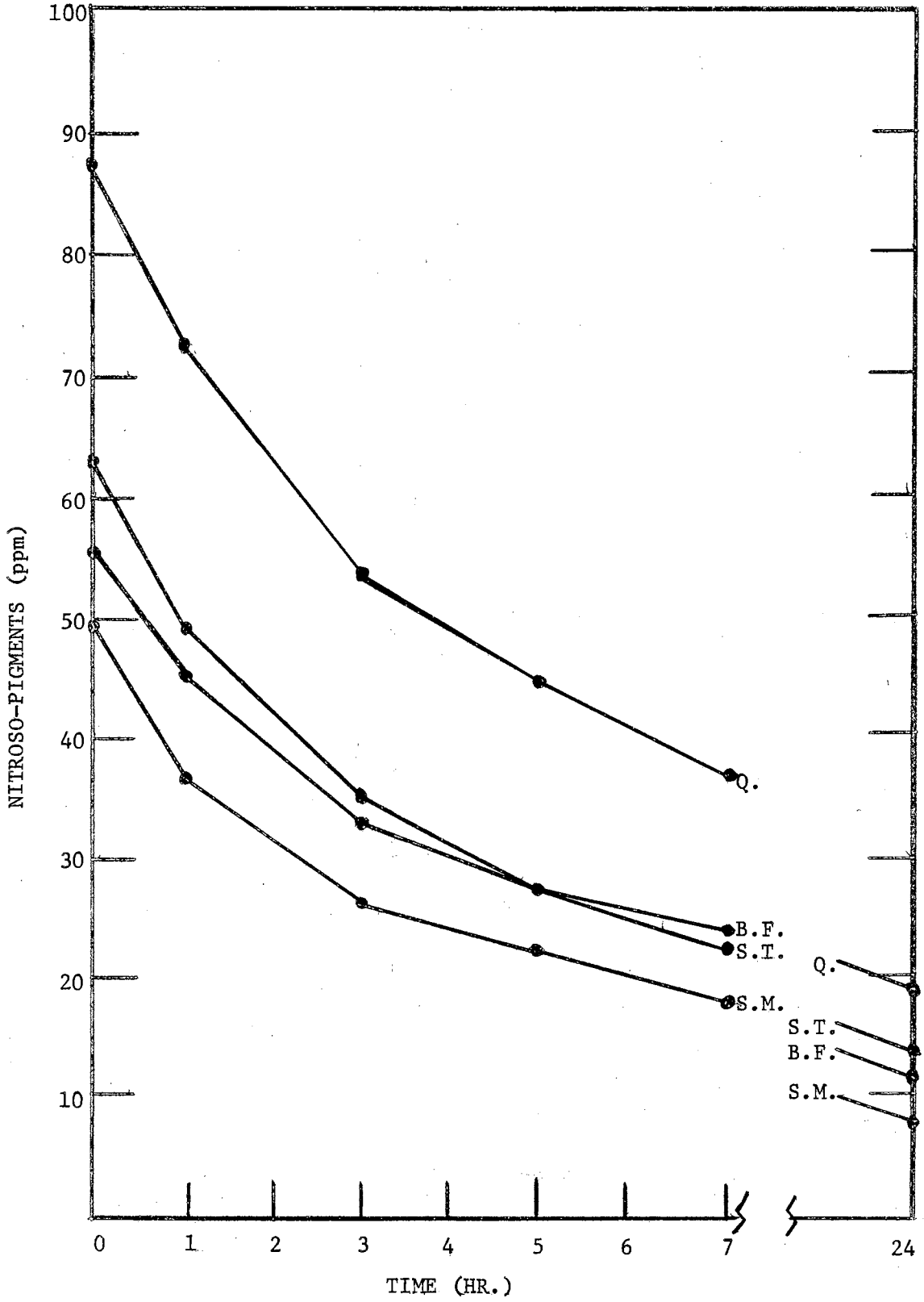

Figure 13. Remaining Nitroso-Pigments (Experiment II, Post-Chilled).

contained significantly ($P < .05$) greater concentrations of pigments than the semimembranosus. The difference in pigment content between the post-chill biceps femoris and semitendinosus was non-significant. The semimembranosus contained significantly ($P < .01$) lower concentrations of nitroso-pigments than the biceps femoris. Figures 12 and 13 graphically illustrates that the interaction was again due to the failure of the semitendinosus to respond like the other three muscles. These findings are in agreement with the results of Experiment II which indicated a severe loss of total pigments in the post-chill cured semitendinosus. The greatest loss in nitroso-pigment concentration occurred during the first hour of exposure to light and this was in agreement with the findings of Experiment I.

Color Stability

Experiment I - the zero exposure time interval was considered to be 100% of the nitroso-pigments, than the ppm of nitroso-extracted after a specified exposure time, was converted to percent of initial nitroso-pigments (zero hour). Table V-A presents the percent nitroso-pigments remaining after exposure to 10 ft-c of light. The percent nitroso-pigments remaining was found to be non-significant among animals. The pigment retention of the pre-chill cured muscles exceeded that of the post-chill cured muscles, with the observed differences being significant ($P < .05$) at the 24 hour exposure time. This suggested that the nitroso-pigments of the pre-chill muscles were more stable when exposed to light than the pigments of the post-chill muscles. After exposure to light for 24 hours the percent nitroso-pigments remaining in the pre-chill muscles was the highest in the quadriceps (42.1%) followed by the semimembranosus

TABLE V-A

NITROSO-PIGMENTS IN CURED PORCINE MUSCLE (PERCENT) REMAINING AFTER EXPOSURE TO 10 FT-C OF LIGHT

Time hr.	Mean								Treatment Effect
	SM[1]		A[2]		BF[3]		Q[4]		
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	
0	100	100	100	100	100	100	100	100	N.S.
1	90.20	90.60	91.1	89.8	90.1	89	88.9	90.0	N.S.
3	81.30	79.80	79.6	78.5	78.9	76.8	79.1	78.1	N.S.
5	70.90	68.90	71.4	67.4	69.7	65.8	70.7	69.0	N.S.
7	65.70	60.10	62.8	60.3	60.4	58.6	64.4	63.5	N.S.
24	42.0	30.40	38.8	33.6	34.5	29.1	42.1	34.9	N.S.

TABLE V-B

NITROSO-PIGMENTS IN CURED PORCINE MUSCLE (PERCENT) REMAINING AFTER EXPOSURE TO 100 FT-C OF LIGHT

Time hr.	Mean								Treatment Effect
	SM		ST[5]		BF		Q		
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	
0	100	100	100	100	100	100	100	100	N.S.
1	77.3	75.7	81.7	80.8	81.8	79.10	82.00	81.60	N.S.
3	57.9	55.4	67.0	59.9	62.0	56.80	66.70	61.10	$P < .005$
5	47.7	44.3	55.6	49.2	50.60	44.70	57.10	51.90	$P < .005$
7	37.4	35.5	44.8	39.8	41.80	36.60	47.80	42.50	$P < .005$
24	17.5	16.3	21.9	23.3	18.80	18.40	21.30	19.30	N.S.

[1] SM = Semimembranosus

[2] A = Adductor

[3] BF = Biceps femoris

[4] Q = Quadriceps

[5] ST = Semitendinosus

(42.0%), adductor (38.8%) and biceps femoris (34.9%) (Figure 14). The greatest retention of nitroso-pigments in the post-chill muscles was in the quadriceps (34.9%) followed by the adductor (33.6%), semimembranosus (30.4%) and biceps femoris (29.1%) (Figure 15). The difference in percent nitroso-pigments remaining between the pre-chill semimembranosus and biceps femoris was significant ($P < .05$) at the seven hour exposure period and $P < .01$ at the 24 hour exposure period. The 24 hour exposure period of the pre-chill quadriceps retained a significantly ($P < .01$) higher percentage of nitroso-pigments than the biceps femoris. Both the pre- and post-chill adductor muscles retained significantly ($P < .05$) greater percent of pigments after 24 hours of exposure to light than the biceps femoris. The seven hour exposure time of the post-chill quadriceps retained significantly ($P < .05$) more pigments than the biceps femoris and the percent nitroso-pigments remaining after exposure to light 24 hours was significantly ($P < .05$) higher than the percent retained by the biceps femoris and semimembranosus. The muscle by treatment interaction was non-significant.

Experiment II - the percent nitroso-pigments remaining after exposure to 100 ft-c of light was found to be significant ($P < .05$) different among animals. Three, five and seven hour exposures were significantly ($P < .005$) greater in retention of nitroso-pigments for the pre-chill cured muscles (Table V-B). According to Ramsbottom et al. (1951) the greatest reduction in cured meat color would be shortly after exposure to light. The results indicated that the nitroso-pigments of the pre-chilled cured muscles were less susceptible to the rapid and severe loss of color immediately after exposure to light than the nitroso-pigments of the post-chill cured muscles. Figures 16 and 17 show that the

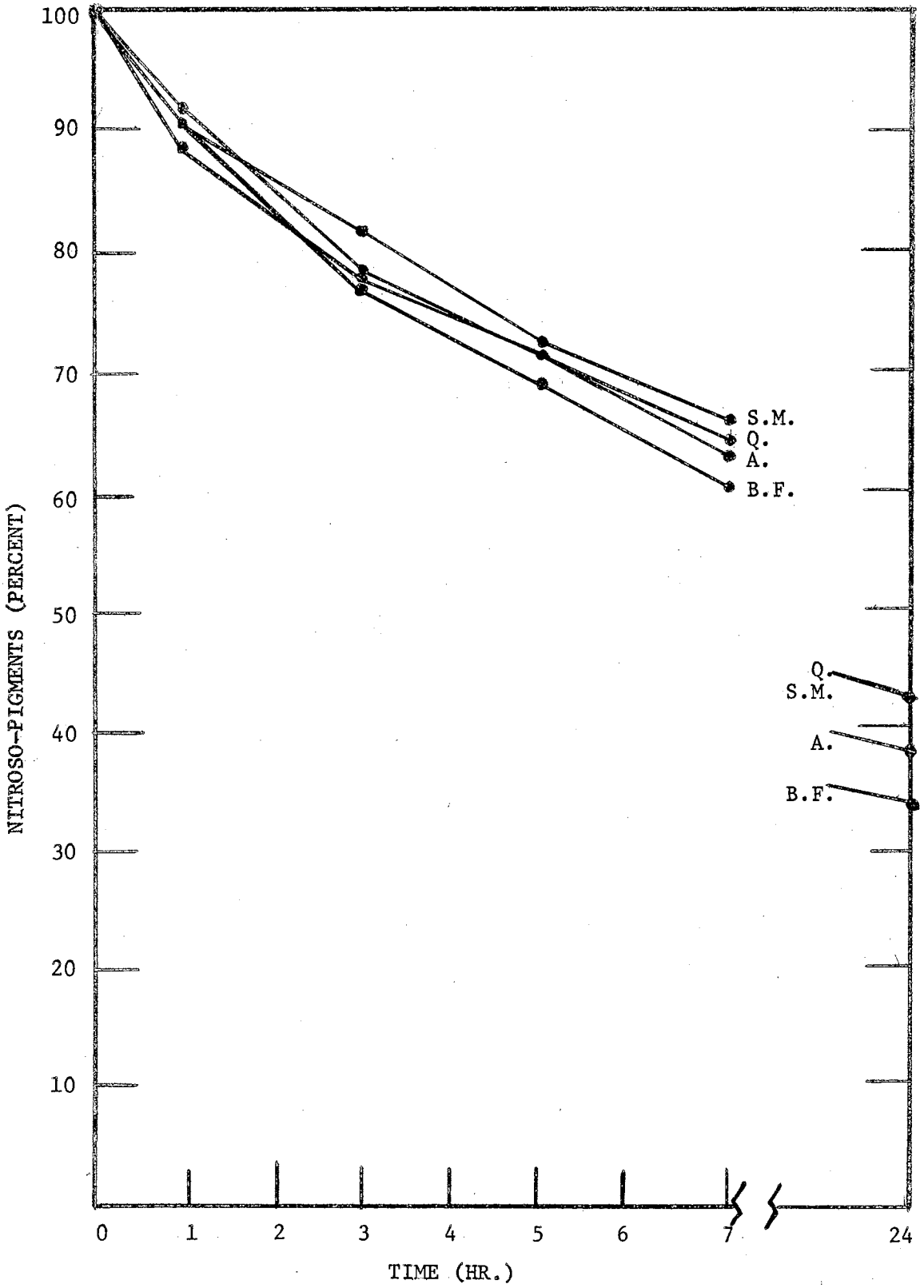

Figure 14. Remaining Nitroso-Pigments (Experiment I, Pre-Chilled)

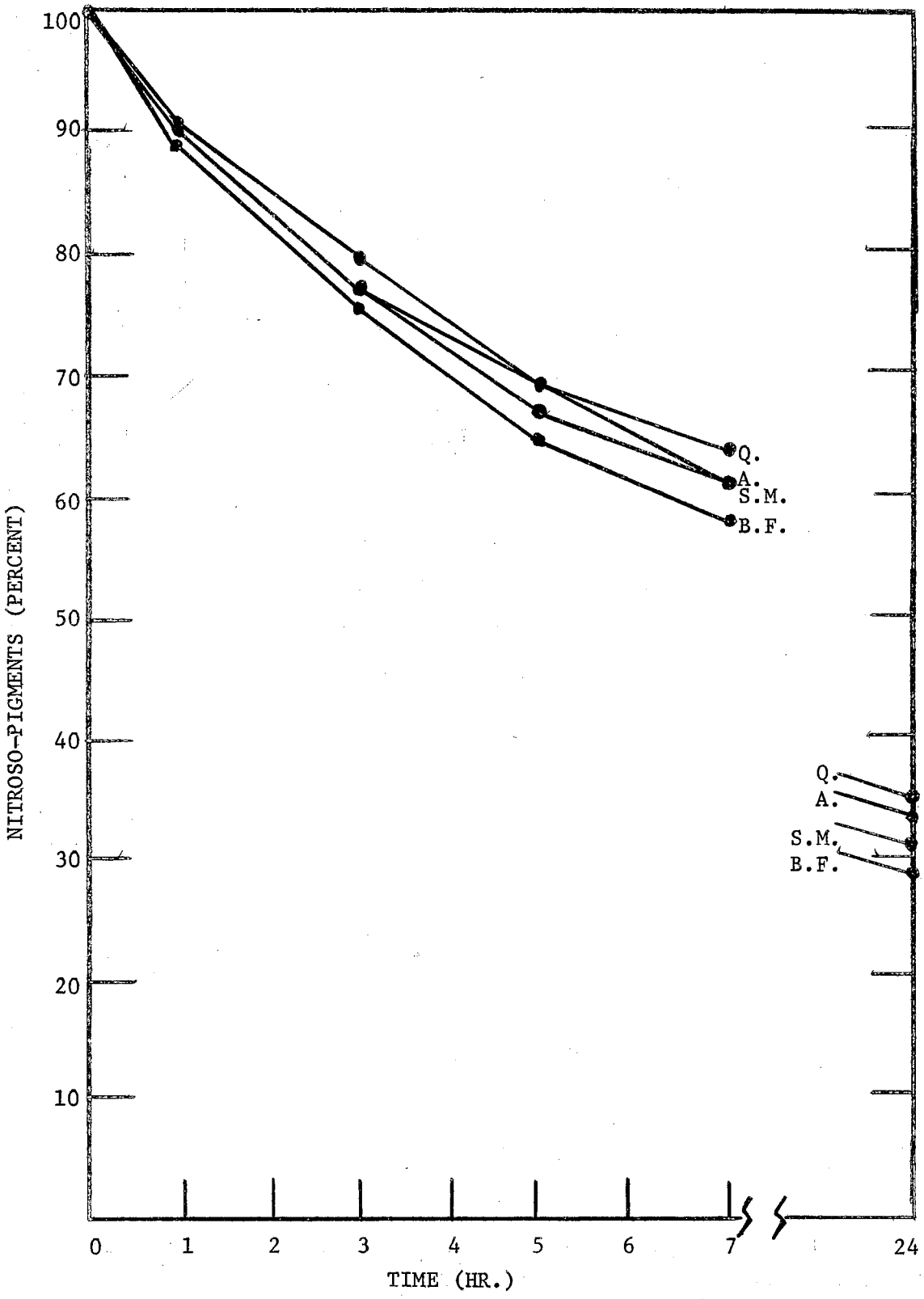

Figure 15. Remaining Nitroso-Pigments (Experiment I, Post-Chilled)

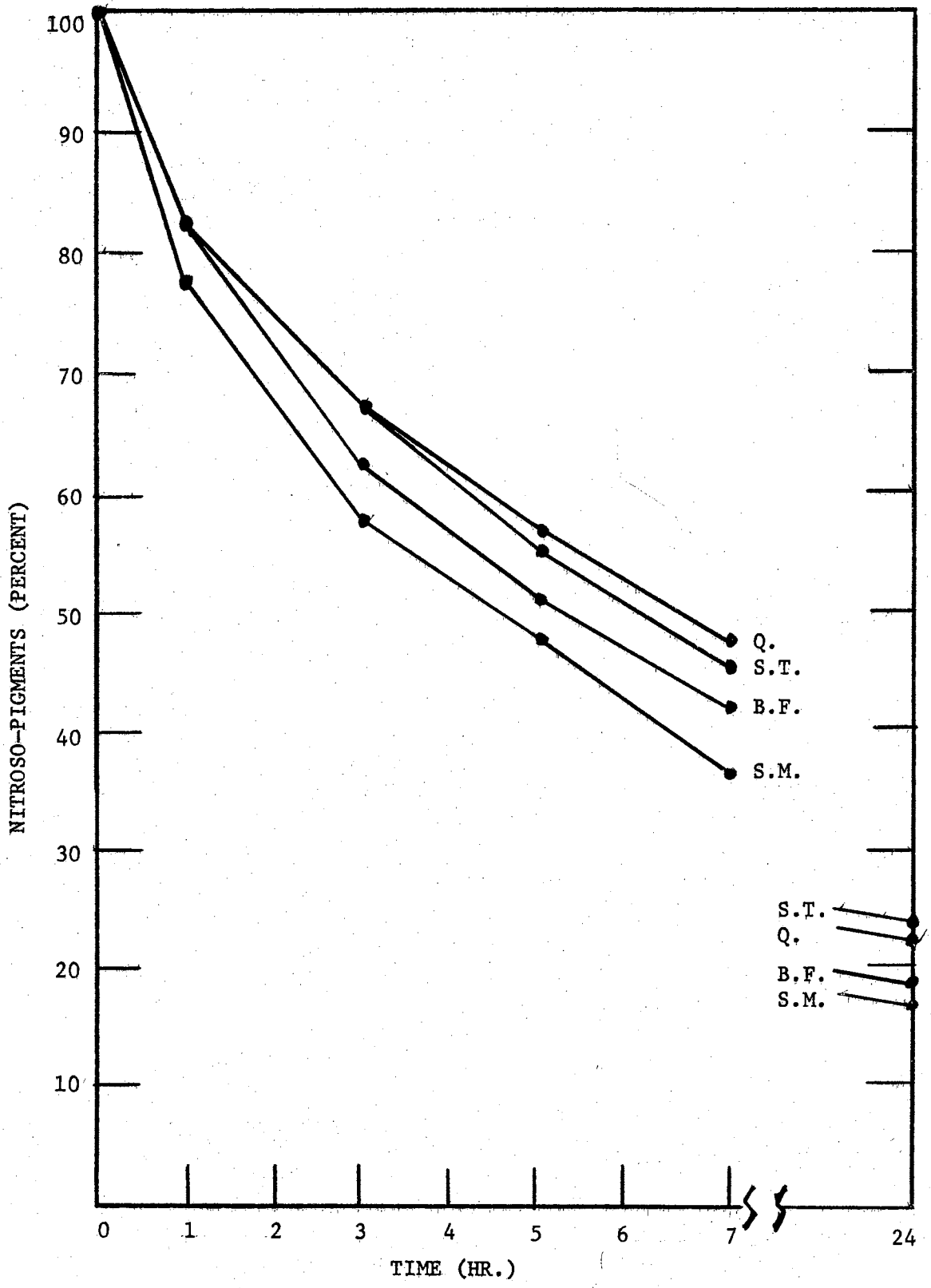

Figure 16. Remaining Nitroso-Pigments (Experiment II, Pre-Chilled)

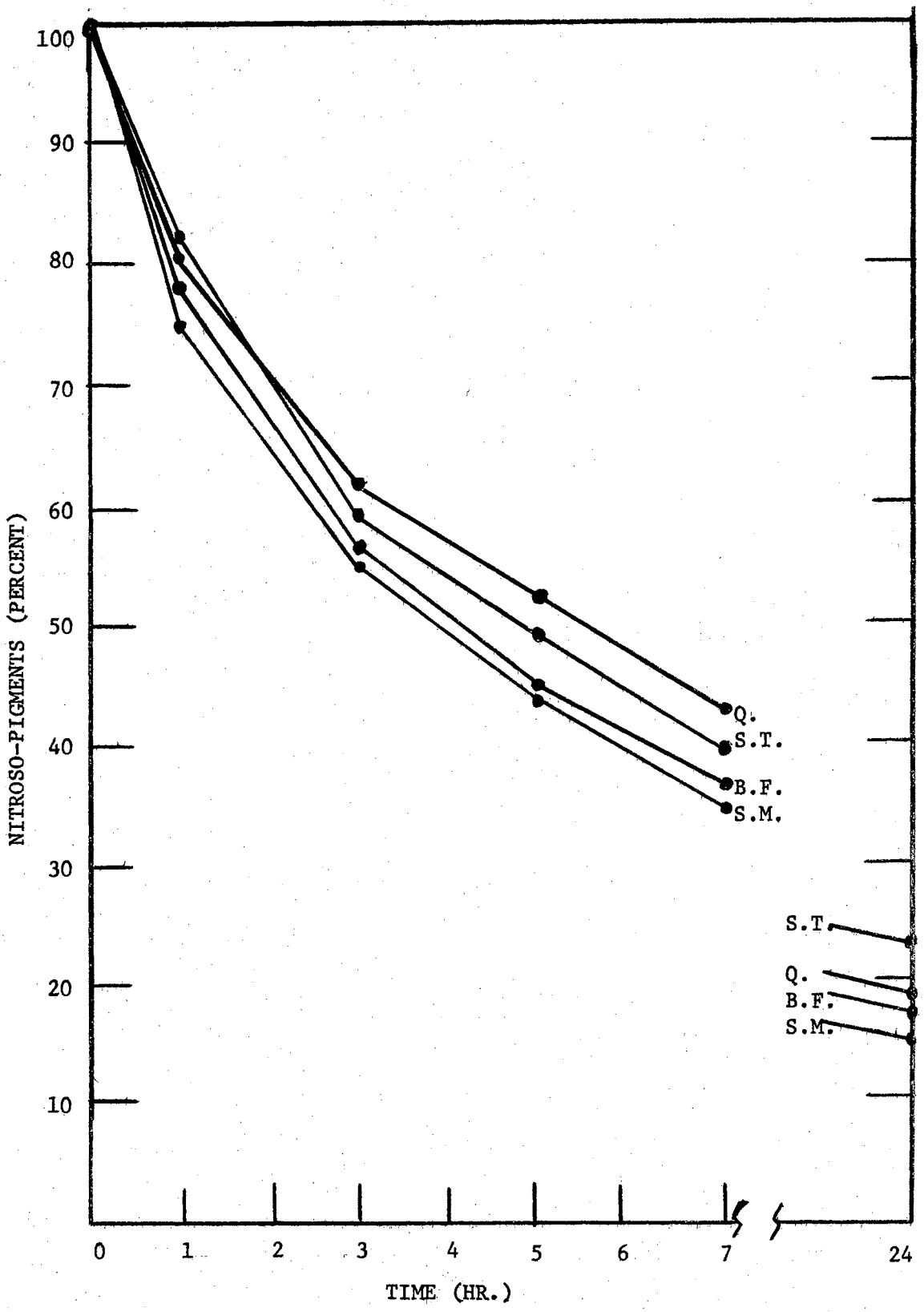

Figure 17. Remaining Nitroso-Pigments (Experiment II, Post-Chilled)

greatest pigment retention after exposure to 100 ft-c of light for 24 hours, occurred in the semitendinosus (21.1%) followed by the quadriceps (20.3%), biceps femoris (18.6%) and the semimembranosus (16.9%). The pre-chill quadriceps retained a significantly ($P < .01$) higher percent of nitroso-pigments at the three, five and seven hour exposure times and $P < .05$ at the 24 hour exposure time than the semimembranosus. The pigment retention was significantly ($P < .01$) greater at the three and five hour exposure times and $P < .05$ at the seven and 24 hour exposure times for the pre-chill semitendinosus than the semimembranosus. One, five and seven hour exposures were significantly ($P < .05$) greater in retention of nitroso-pigments for the post-chill cured quadriceps than in the semimembranosus. Also, the post-chill quadriceps retained significantly ($P < .05$) more nitroso-pigments at the five and seven hour exposures than the biceps femoris. At the 24 hour exposure time the post-chill semitendinosus retained significantly ($P < .05$) more pigments than the other three muscles. The evidence indicated that the retention of pigments is dependent upon the muscle being cured more than the curing method. This was substantiated by the non-significance difference in pigment retention between treatments at the 24 hour interval and by the significant differences in pigment retention among the four muscles. Furthermore, this gives evidence that the nitroso-pigment stability of the pre-chill cured muscles is as good or possibly better than the stability of the nitroso-pigments of the post-chill cured muscles. In both Experiment I and Experiment II the greatest reduction in nitroso-pigments was during the first hour of exposure to light and this held true for all muscles. This was in agreement with the findings of Rambottom et al. (1951), Hornsey (1964); and Mandigo and Henrickson (1966). The differ-

ence in total pigment and nitroso-pigment concentration between Experiment I and Experiment II after 24 hours of exposure to light can be explained by the difference in light intensity. In Experiment I the intensity was 10 ft-c while in Experiment II the light intensity was 100 ft-c. The 24 hour samples in Experiment I contained much lower pigment concentration and this is in agreement with the findings of Ramsbottom *et al.* (1951) who reported that the discoloration was proportional to the light intensity.

CHAPTER V

SUMMARY AND CONCLUSIONS

Two groups of barrows (10 and 12 each) were obtained from Oklahoma Agricultural Experiment Station herd. Experiment I was conducted in August and September 1966 and Experiment II in August 1966. The barrows in each experiment were of mixed breeding, similar in age and weighed approximately 91 kg. Post-chill processing (control) involved a 24 hour chilling period at 1.7°C prior to wholesale cutting and curing. The pre-chill treatment involved the removal of the hams from the carcasses immediately after slaughter and completion of the curing process within 30 minutes post mortem. In Experiment I the semimembranosus, adductor, biceps femoris and quadriceps were excised from the hams and cured with a cold brine (1.7°C). In Experiment II the semimembranosus, semitendinosus, biceps femoris and quadriceps were excised from the hams and cured with a warm brine (23°C). Total pigment and nitroso-pigment determinations were made on all muscles.

In Experiment I the post-chill cured muscles initial total pigment concentrations were significantly ($P < .025$) greater than the pigment concentration of the pre-chill cured muscles. While after 24 hours of exposure to light the differences were less. The initial total pigment concentration for both the pre- and post-chill cured muscles was the highest in the quadriceps followed by the adductor, biceps femoris and semimembranosus. In Experiment II the differences in total pigment

content between the pre- and post-chill cured muscles was non-significant. The initial total pigment content was the highest in the quadriceps, followed by the semitendinosus, biceps femoris, and the semimembranosus.

The differences in nitroso-pigment content between the pre- and post-chill cured muscles of Experiment I were non-significant. The nitroso-pigment concentrations were the highest in the quadriceps, followed by the adductor, biceps femoris and semimembranosus. The pre-chill cured muscles in Experiment II contained significantly ($P < .005$) higher concentrations of nitroso-pigments than the post-chill cured muscles. The pre-chill quadriceps, followed by the semitendinosus, biceps femoris and semimembranosus contained the highest concentrations of nitroso-pigments, while the post-chill semitendinosus and biceps femoris reversed in order.

The color stability was expressed as the amount of nitroso-pigments remaining after exposure to light. In Experiment I the pre-chill cured muscles retained significantly ($P < .05$) greater amounts of nitroso-pigments after 24 hours of exposure to light than did the post-chill cured muscles. While in Experiment II the nitroso-pigment retention was significantly ($P < .005$) greater in the pre-chill cured muscles for the three, five and seven hour exposure times than in the post-chill cured muscles. In Experiment I the greatest retention was in the quadriceps followed by the semimembranosus, adductor and biceps femoris while in Experiment II the greatest retention occurred in the semitendinosus followed by the quadriceps, biceps femoris and semimembranosus. The greatest loss of nitroso-pigments occurred immediately after exposure to

light. The results of the two experiments indicated that the development and stability of cured meat pigments in pre-chill cured pork is comparable to and superior to that of the post-chill cured pork.

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VITA

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