FACTORS AFFECTING SHOWCASE COLOR STABILITY OF FROZEN LAMB IN TRANSPARENT FILM

by

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Chapter 1

INTRODUCTION

The meat industry appears to be moving toward centralized processing of products for economic reasons. Retailing frozen products, rather than fresh products, seems to fit more logically into a central cutting system.

Consistent and acceptable meat quality, especially that manifested through color, is a primary determinant of product saleability. Attractive frozen meat color and an absence of frost and blood in packages are inherently critical since first impressions of any food are usually visual. Therefore, a positive or negative psychological response for acceptance is immediate for most potential consumers.

The fresh meat color most preferred by consumers results from the muscle pigment oxymyoglobin. Production of this bright red color in frozen meats seems logical to insure the meat industry a reasonable response to their frozen product. Variation from the oxygenated state may occur as the result of differing environmental conditions such as freezing rate, display temperature and time, packaging, display lighting, meat quality, degree of oxidative rancidity and microbial growth on the cut surface of the meat.

Although researchers have long been cognizant of the importance of meat color, objective methods of color measurement have been difficult and interpretations have been nearly

impossible. Of the various methods currently used for color determination, reflectance spectrophotometry offers promise as a nondestructive method of analysis. Reflectance ratios and/or reflectance at selected wavelengths may be indicative of color differences; however, further work is needed to quantitate this method.

Factors affecting color stability of fresh meat have been investigated by numerous researchers. Whether the recommendations for increasing shelf life of fresh products are applicable to frozen meat remains to be determined.

The purpose of this work was to study the effect of freezing rate, display temperature, packaging film permeability, display lighting type and marbling level on color stability, drip loss and weight loss of frozen lamb chops.

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Chapter 2

REVIEW OF LITERATURE

Importance of Color in Meat

Color, a definite component of food (Birren, 1963), is everywhere. He indicates color of foods can produce a physiological response related to appetite. Bright, warm colors tend to stimulate the autonomic nervous system including digestion. Soft, cool colors have a negative autonomic response. That is, the reds and yellows tend to excite hunger while the blues and greens tend to discourage hunger. The bloomed color of meat may, therefore, produce an unconscious stimulus to purchase retail meat products.

Consumers hold the key to the manner in which food products are prepared and placed on the market. Judd and Wyszecki (1963) agree that color of product greatly influences consumer acceptance.

Francis (1963) states that color in foodstuffs may be divided into two general problems. One concerns the addition of synthetic colors to foods to achieve desired appearances; the second involves the natural pigments and their appearances in food such as meat. The second problem presents special considerations as the processor usually has little or no control over the amount of colorant present. Hence, standardization is a very difficult problem yet extremely important. Two identical

meat cuts, equally wholesome and attractive but of different color, may make the consumer feel something is wrong with one of them.

Francis (1963) also indicates measurement of color in meat products involves two areas: that of color control during processing or storage and that concerned with color as a measurement of economic worth. Color control in foods has increased in significance because of new quality control programs and the development of instrumentation to make color measurement and control more practical. Modern frozen meat enterprises will likely utilize and improve recent advances in quality control.

Although meat color provides a criterion for wholesomeness and quality and even has some asthestic value, the significance of color to the meat industry is primarily related to consumer acceptance in the market place. Naumann et al. (1957) states consumer preference for meat involves two distinct preferences, visual and eating, which ultimately result in a single expression of preference. Visual appeal of any cut may be offset by low palatability. Conversely, potential eating satisfaction of meat is rarely realized if the cut is deficient in visual appeal. This in itself has profound implications for the entire meat industry.

Chemistry of Fresh Meat Pigments

The color of meat involves the chemistry of the heme pigments, hemoglobin and myoglobin. In muscle of living animals both pigments serve to complex oxygen required for metabolic

activity. Hemoglobin carries oxygen via the blood to the muscle; myoglobin serves as a storage complex for oxygen in muscle cells. Color mechanisms in post-mortem muscle tissue are dependent upon chemical reactions of these pigments.

Shenk et al. (1934) indicated more than 90% of the pigment in fresh meats was myoglobin rather than hemoglobin. Approximately 95% of the iron remaining after the bleeding process was in myoglobin molecules (Giffee et al., 1960). Fleming, Blumer and Craig (1960) analized over 150 beef rib eyes and found as high as 18% hemoglobin; however, the average was only 5%. On the other hand, Craig et al. (1966) found hemoglobin to be 12-15% of the total pigment in beef longissimus dorsi and in muscles of the foreshank. The data of Rickansrud and Henrickson (1967) indicated hemoglobin may influence the color of certain bovine muscles more than others. They found the longissimus dorsi muscle from 7 choice grading steers to average 20% hemoglobin and the psoas major to average nearly 38% hemoglobin. Nevertheless, the color of meat is primarily manifested through myoglobin.

Various research studies have found myoglobin concentrations within a specific muscle and from one muscle to another to vary directly with the physiological activity of the muscle. Variation is also related to species, breed, sex, age, plane of nutrition and training. Thus, a very important factor in the uniformity of meat color is the distribution of myoglobin in muscle tissue.

Myoglobin is a conjugated protein consisting of a heme moiety (iron containing porphyrin compound) attached to a globulin type protein (Schweigert, 1956). The heme portion consists of four pyrrole rings linked together by methene bridges and coordinated around a central atom of iron. Lemberg and Legge (1949) provide details of the chemistry of the muscle pigment. The chemical state of the iron and the constituents attached to it are responsible for the various colors of the pigment in meat. If denaturation of the protein moiety occurs, the heme is no longer able to complex oxygen; hence, it is not possible to obtain the desired colors of meat.

In the presence of oxygen the three pigments, myoglobin (reduced), oxymyoglobin and metmyoglobin, are constantly being interconverted (Fox, 1966). Myoglobin is purplish red when water is bonded to reduced iron. Oxygen bonded to ferrous iron converts the pigment to the bright red oxygenated state, oxymyoglobin. Oxidation of either oxymyoglobin or myoglobin results in brown metmyoglobin characterized by a hydroxyl radical attached to ferric iron. Brooks (1938) found this brown color was noticeable when about 60% of the pigment was in the metmyoglobin form. On heating any of these forms, the globin is denaturated, but the hematin nucleus remains intact as dull red globin haemichromogen and brown globin haemochromogen (Lawrie, 1966).

The relative proportion of myoglobin, oxymyoglobin and/or metmyoglobin in meat is dependent upon two opposing

reactions; oxidation of oxymyoglobin or reduced myoglobin to metmyoglobin and the subsequent re-reduction to myoglobin. This dynamic equilibrium is known to be related to partial pressure of oxygen and enzymatic reducing pathways in meat. Oxymyoglobin will persist as long as oxygen tension is sufficient to supply the need of both enzymatic activity and complexing of oxygen to myoglobin. Early work by Conont and Fieser (1924) and Neill and Hastings (1925) suggested the oxidation of oxyhemoglobin to methemoglobin was correlated with low oxygen pressure. Brooks (1938) found low oxygen tension (4 mm Hg) produced a maximum rate of methemoglobin formation. George and Stratmann (1952) indicated maximum rate of oxidation of myoglobin occurred at 1 to 1.4 mm. Hg oxygen pressure, but later suggested the rate of maximum conversion may range from 1 to 20 mm Hg of oxygen pressure depending on the pigment, pH and temperature. Similar reaction rates were reported by Snyder and Ayres (1961). Grant (1955), using enzyme inhibitors, demonstrated that respiratory enzymes in meat, especially succinic dehydrogenase, contributed to metmyoglobin formation by decreasing oxygen tension via oxidative phosphorylation. Data by Urbin and Wilson (1961) also indicated succinic dehydrogenase was an important competitor for oxygen in post-mortem bovine muscle. They stated oxygenation of myoglobin, dissolving of oxygen in meat solutions and enzymatic action accounted for the oxygen consumed during the

first 15 hours of uniform gas uptake. After 15 hours, oxygen uptake was due primarily to enzymatic activity.

Brown and Dolev (1963b) found beef metmyoglobin formation was actually accelerated at temperatures just below the freezing point of meat. Similar accelerated reactions between -8.5°C and -16.5°C were recorded by Lund, Fennema and Powrie (1969) as they studied the influence of freezing on acid hydrolysis of sucrose. Freezing of sucrose solutions resulted in a marked decrease in hydrolysis of sucrose catalyzed by invertase. The decrease was attributed to increased concentration of solutes resulting from ice formation and a temperature effect in excess of that predicted from the Arrhenius equation.

Reduction of metmyoglobin (Watts et al., 1966) and deoxygenation of oxymyoglobin to myoglobin (Schweigert, 1956) occurred when no oxygen was available. The oxymyoglobin to myoglobin cycle can clearly be demonstrated by vacuum packaging bloomed meat in oxygen impermeable film (Fox, 1966). Walters and Taylor (1963); Stewart et al. (1965a) and Watts et al. (1966) have shown the re-reduction of metmyoglobin to be involved with enzyme systems. Although the exact mechanism is not definite, Saleh and Watts (1968) state the rate of reduction of metmyoglobin is dependent upon the rate at which nicotinamide-adenine dinucleotide (NAD^+) is reduced.

Methods of Color Measurement in Meat

Mackintosh (1932) provided an early description of the

application of the Munsell spinning disk technique and Hiner (1954) described the application of color paddles to color measurement in meat. Neither of these methods, however, have been widely employed due to the lack of color stability and uniformity of the paddles and the time required to attain a good color match with spinning disks. Color comparisons are often made to colored photographs, e.g., pork color standards of University of Wisconsin (1963). Clydesdale (1969) provides a recent description of the International Commission on Illumination (I.C.I.) and Hunter Colorimetry methods of color measurement. These methods provide a means for accurately describing or matching colors; however, they do not appear useful for following rapid changes of color in meat.

Two methods, absorbancy and reflectance, have been used to estimate the percentages of myoglobin derivatives and/or follow changes in surface color of meat. The absorbancy method described by Austin and Drabkin (1935) and developed by Broumand, Ball and Stier (1958) to determine the percentage of all three myoglobin forms was dependent upon pigment extraction which has several disadvantages (Schweigert, 1954). Dean and Ball (1960a) demonstrated extraction procedures may allow myoglobin conversion from one form to another. Naughton, Zeiltin and Frodyma (1958) presented data for tuna hemoglobin indicating solubility of various heme pigments in water may differ. Sample destruction, failure to obtain clear solutions and standardization of depth to which

samples should be taken are other factors which have limited the use of the absorbancy method in meat color measurement.

Several reflectance methods have been described in the literature. Tappel and Maier (1957) stated reflectance spectra of hematin compounds possess enough maxima and minima through the visable wavelengths to allow identification of heme pigments and their derivatives. Kraft and Ayres (1954) expressed spectrophotometric measurements of packaged fresh beef as percent mean reflectance at eight wavelengths selected in the region 540 to 800 mu. Pirko and Ayres (1957) used reflectance at wavelengths of 555, 580 and 635 mu to relate changes in myoglobin, oxymyoglobin and metmyoglobin. This was compared to a KCl pigment extraction process which resulted in considerable variation. However, they were able to detect with reflectance data when pigment forms increased or decreased. Naughton, Frodyma and Zeitlin (1957) plotted the log of the recipiocal of reflectance, absorbance, rather than raw percent reflectance. They maintained that, for heme pigments, the wavelengths of absorption maxima from reflectance corresponded to those of transmission; hence, a complete interchange of data should be possible.

Dean and Ball (1960a) calculated ratios of K/S values at wavelengths 507/573 and 473/597 to estimate quantitative proportions of myoglobin forms. (K/S value is the ratio of absorption coefficient (K) to the scattering coefficient (S) per unit of sample thickness). Their reflectance data were unable to explain

the loss of redness of vacuum packaged beef. This may be explains by their selection of wavelengths which would not be expected to produce linear relationship between K/S ratios and proportion of pigment present (Stewart, Zipser and Watts 1965b).

Stewart et al. (1965b) refined the reflectance method as a measure of both total pigment and the ratio of metmyoglobin to ferrous pigments in ground beef. They found the reflectance, measured on absorbance scale, at the isobestic point, 525 mu, to have a nonlinear relationship to total pigment extract. However, when expressed as K/S at 525 mu the relationship was linear to total pigment. They also found the ratio of reflectance at 572/525 produced straight lines when plotted against total pigment. They assumed ratio K/S 572 / K/S 525 obtained from reflectance spectrophotometry would yield linear plots against varying pigment form concentrations. Stewart and coworkers (1965b) also made the important observation that K/S ratios from reflectance data were quite different from ratios of absorbancy coefficients at the same wavelengths calculated from transmission data.

Snyder (1965) suggested using reflectance data measured on the absorbancy scale for quantitative analysis of myoglobin derivatives rather than K/S ratios. He devised a model system of dried milk plus varying amounts of myoglobin derivatives. Results indicated reflectance values at two wavelengths was useful in differentiation of pigment types. Reflectance at 474 mu

indicated a change of oxymyoglobin or metmyoglobin to myoglobin while reflectance at 571 mu measured changes of myoglobin or oxymyoglobin to metmyoglobin. He further made an arbitrary adjustment of spectral curves to an absorbance value of 1.0 at 525 mu. He stated this method eliminated scatter of light due to factors other than myoglobin.

Snyder and Armstrong (1967) compared reflectance measured on the absorbance scale with K/S values. K/S values were found best suited for quantitative analysis of myoglobin derivatives since they were linear while raw reflectance was nonlinear in relation to concentration. They also found the arbitrary adjustment of spectra to eliminate scatter, suggested by Snyder (1965), to be unnecessary when using K/S ratios. Their work further revealed the nature of the blank was a critical factor when comparing K/S ratios calculated from reflectance (absorbance units) and K/S ratios from transmission data (absorbance units).

Allen et al. (1969) use reflectance data to study color changes in prepackaged bovine longissimus dorsi muscle at 26 time periods ranging from 0 through 240 hours. Decreasing reflectance values at 474 mu most closely followed color deterioration which occurred at 96 hours. Reflectance values at 525, 538, 568 and 571 mu were generally insensitive to color deterioration. A gradual decrease in reflectance at 600, 610, 620 and 630 mu did not indicate discoloration. Ratio 474/525 mu was observed to decrease as color brightened and increased as color

deteriorated.

According to Hansen and Sereika (1969) a ratio of reflectance (absorbance units) at wavelengths 582 mu/525 mu was an indicator of amount of oxymyoglobin present in frozen beef gluteus medius muscle; ratio of wavelengths 630 mu/525 mu indicated metmyoglobin presence. Larger values were recorded for each ratio as the particular form of myoglobin increased, hence, they found it necessary to consider both ratios to follow color change. Acceptable product color was characterisized by a value greater than 1.12 for ratio 582/525 and a value less than 0.55 for ratio 630/525.

Ockerman and Cahill (1969) report correlation coefficients above 0.85 between visual score and reflectance at 685 mu for beef and for pork (with a marbling adjustment for pork). They also found reflectance data transformed into tristimulus values did not correlate as well as raw reflectance to visual score nor did the transformation add significantly to color prediction equations.

Factors Affecting Color of Frozen Meat

Freezing Rate. Ramsbottom and Koonz (1939) used freezing temperatures of -12.2, -23.3, -34.4 and -45.6°C and observed a lighter color in beef with each decrease in temperature. Increased freezing rate yielded bright red colors in bovine muscle when comparing temperatures of 6.5, -18 and -40°C (Pearson and Miller, 1950). Brissey (1963) indicated rapidly frozen meat evinced

bright red color while slowly frozen meat was dark in color. Robertson (1950) reported slow freezing rates produced dark red colors, but a complete loss of color occurred when plate frozen at -46°C. Robertson further observed color stability to vary between muscles. Beef steaks frozen with liquid nitrogen at -18, -56.5, -101, -129 and -195.5°C produced lighter colors at the lower temperatures (Costello, 1964). However, he found no visual color difference after thawing. Refrozen meat (Rikert et al., 1957b; Townsend and Bratzler, 1958) was reported to be considerably darker in color.

Color stability of frozen meat is enhanced by freezing and storage treatments that produce and maintain intracellular ice crystals (Lawrie, 1966). Ramsbottom and Koonz (1941) compared freezing temperatures of -12.2°C and -34.4°C and found the slower frozen meat to be darker. Based on histological evidence, they attributed the darkening to large, mostly extracellular ice crystals resulting in less scattering of light.

Work with turkey and chicken indicated rapid freezing produces a lightening effect that was more desirable in appearance for that product (Baker, 1954; Spencer et al., 1956; Klose and Pool, 1956; Lentz and van den Berg, 1957; van den Berg and Lentz, 1958; Hamre and Stadelman, 1967). They stated the lighter color was due to opacity rather than a color change.

Display Temperature and Time. These factors relate to product color through inter-relationships of autoxidation, oxygen

tension, enzyme activity, micro-organism activity and oxidative rancidity. Early work by Richardson and Scherubel (1908), based on chemical, histological and bacteriological findings, indicated beef knuckles could be stored 554 days or longer at temperatures -9 to -12°C. Brooks (1938) stored frozen meat at -10°C for 16 weeks before oxidation caused discoloration. At -1.4°C he observed no discoloration in fresh meat for 40-50 days post-slaughter. Ramsbottom and Koonz (1941) found greater oxidation in frozen beef steaks stored at -12.2°C than -34.4°C. Ramsbottom (1947) compared frozen beef steaks packaged in du Pont 300 MSAT #87 cellophane and stored in darkness at -3.3, -6.5, -12, -18, -23 and -29°C ±0.83C°. He observed color to be good at 365 days when stored at -23 or -29°C, to be borderline-minus at -18°C, and to be poor in 240 days at -12°C, in 90 days at -6.5°C and in 30 to 60 days at -3.3°C. Ramsbottom (1947) found beef color more stable than that of pork or lamb and ground products much less stable than intact cuts.

Data compiled by Snyder (1964), comparing 6, 2 and -2°C storage temperatures for fresh meat, showed redness values to be higher at lower temperatures. The lower temperature also resulted in discoloration at a slower rate. Because of the short storage time involved, he discounted the role of bacteria in the discoloration, and concluded decreased respiratory activity as the major factor increasing color stability. Brown and Dolev (1963a); Snyder and Ayres (1961); Ball (1959); Kraft and Wan-

derstock (1950) and Cutaia and Ordal (1964) agreed that autoxidation was slowest at storage temperature just above the freezing point of meat.

Tressler and Evers (1947) stated that frozen meat changes from red to brown more rapidly at higher storage temperatures. Brown and Dolev (1963b) observed "supercooled" extracts of myoglobin not frozen at -10°C had very low rates of oxidation. They compared storage temperatures of 0, -5, -10, -15 and -18°C and found autoxidation to be logarithmic with decreasing temperature when the extract solidified (about -5°C).

Lawrie (1966) reviewed data which indicated decreasing frozen storage temperatures would delay both oxidative rancidity via slower lipolytic enzyme activity and myoglobin oxidation via slower respiratory enzyme activity. The latter also contributed to delayed rancidity by decreasing the catalytic action of ferric hemes on fat oxidation (Watts, 1954). Their data supported the results of Ramsbottom (1947) who observed that rancidity in beef, pork and lamb increased when stored at higher temperatures.

Microbial discoloration of fresh meat in display is well known. Haines (1937) found temperature to be the single most important factor governing microbial growth. Psychrophilic organisms (those which would affect frozen meat) have a temperature optima between -2 and 7°C (Jensen, 1945). Stanier, Doudoroff and Adelberg (1964) indicated rapidly frozen bacterial

suspensions can be kept at temperatures as low as -194°C for extented periods of time with little loss in viability; however, all microbial growth stops at approximately -10°C. Ramsbottom (1947) found all frozen steaks and chops to be in satisfactory bacterial condition; however, he recorded lower counts at 365 days for those stored at -29 and -23°C than at warmer storage temperatures. The possible devastating effect of micro-organisms on meat color can not be ignored; however, microbial discoloration of frozen meat should not be a serious problem provided -10°C or colder temperatures are maintained and sanitary processing conditions are employed.

Townsend and Bratzler (1958) found fluctuating storage temperatures to have a detrimental effect on frozen meat color, especially if thawing temperatures were reached. Cyclic defrost temperatures may produce similar results (Brissey, 1963). Hustruld, Winter and Nobel (1949) observed temperature fluctuations below -18°C to have no effect on color of ground beef or pork. Winter et al. (1952) states that constant storage at -18°C or fluctuating temperatures from -17.7 to -10°C had less effect on appearance, flavor, aroma or desiccation of ground pork or beef than storage time, wrapping material, or shape of package. Deterioration in quality, especially flavor, was found to increase from 4, 6, 8, and 10 months storage. Packages with larger exposed surface volume/mass accentuated deterioration as did non moisture-proof packaging materials.

Display Lighting. Color stability of frozen beef is related to foot-candle (ft-c) hours of illumination, display temperature and length of dark storage prior to display (Naumann, McBee and Brady, 1957). Marriott et al. (1967) observed lighting to have a profound effect on display life of beef steaks. Meat displayed at -1.0°C for 10 days in darkness changed only slightly in color while steaks illuminated continuously by 120 ft-c of soft white flourescent light discolored in 3 days. Steaks displayed under light after 3, 5 or 7 days of dark storage had lower undesirable visual scores than controls stored without illumination, and the differences became progressively worse as display period increased. These workers also recorded higher bacterial counts for steaks exposed to light; however, whether the presence of light or slight increase in surface temperature due to light radiation stimulated growth of bacteria was not determined. Townsend and Bratzler (1958) and M. M. Voegeli (unpublished data) noted discoloration in meat exposed to fluorescent lighting at 56 ft-c and 215 ft-c, respectively. P. E. Gould (unpublished data) observed high intensity incandescent lighting to increase surface temperature and subsequent discoloration in fresh pork chops. Ramsbottom, Goeser and Shultz (1951) found incandescent and several types of fluorescent lighting did not affect fresh beef, pork or lamb color in 3 days of display. Rather, they attributed later discoloration to increased microbe growth. They did note, however, the best color rendition for

meat was obtained with incandescent, deluxe cool white fluorescent and soft white fluorescent lights. Other researchers (Kraft and Ayres, 1954; Rikert et al., 1957b) have found fluorescent lighting did not greatly discolor fresh meat.

The literature reveals some evidence that certain portions of the electromagnetic spectrum may accelerate discoloration in meat. Ultraviolet light greatly increased fresh meat discoloration even though it controlled growth of micro-organisms (Kraft and Ayers, 1954). Haurowitz (1950) suggests ultraviolet light denatures the globin moiety in myoglobin. Frozen meat color was found by Townsend and Bratzler (1958) to deteriorate rapidly when exposed to wavelengths of light between 560 mu and 630 mu. They observed least metmyoglobin formation in steaks stored in darkness and under fluorescent light with a green filter, while discoloration was greatest with no filter and orange and red filters. Illumination was very low, 2-3 ft-c. Further work with colored fluorescent lights at 20 ft-c intensity revealed greatest color change with yellow and white lamps. Red and green lamps imparted less color change to the meat surface but more than control samples stored with no illumination. Lane and Bratzler (1961) found discoloration patterns in frozen extracts similar to those in steaks (Townsend and Bratzler, 1958) when exposed to 30-50 ft-c of fluorescent illumination.

Packaging. Urbin and Wilson (1958) listed four major parameters which influence color of meat: surface dehydration,

bacterial contamination, temperature and oxygen requirements of meat. They indicated surface dehydration may be prevented by packaging technique. Bacterial contamination should not be a limiting factor in the first several days of storage. Hence, they concluded that temperature and oxygen requirements were prime considerations in packaging. The role of oxygen tension on formation of metmyoglobin and its reduction was reviewed earlier. Packaging material directly affects oxygen availability in prepackaged meat. As previously reviewed, temperature regulates competition for oxygen in packaged meat by various oxidative enzymes, micro-organisms and oxygenation of myoglobin.

Skin tight, vacuum packaging of product, which will be frozen, appears to be necessary to reduce frost formation and product desiccation. This procedure largely removes oxygen and may result in the rapid loss of the bright red color of bloomed meat (Landrock and Wallace, 1955; Rikert, Ball and Stier, 1957a; Rikert et al., 1957b; Rikert et al., 1957c; Pirko and Ayres, 1957; Dean and Ball, 1960b; Fellers et al., 1963). Vacuum packaging appears to be necessary if the redness of color is to be later regenerated, but not for the initial decrease in redness score (Rikert et al., 1957c). Dean and Ball (1960b) observed vacuum packaged beef to discolor (decreased redness score) during the first day of storage at 2.2°C. However, a regeneration of redness which was relatively stable occurred in 2-4 days after packaging in a film of low gas permeability. They

noted the regenerated color was not the bright red color, but rather a purplish red which they felt was more appealing than the original color observed upon cutting. These researchers also found packaging films treated with an enzyme (a glucose oxidase system) to decrease the amount of oxygen available in the package was neither helpful nor deleterious to color. Pirko and Ayres (1957) observed meat packaged in gas impermeable film and stored for 14 days at 4.4°C would reoxygenate to oxymyoglobin when unpackaged. Meat packaged in films of medium or high gas permeability formed oxygyoglobin when unpackaged; however, it would only last 3 to 6 days before oxidation to metmyoglobin occurred. More stable color was observed in meat at 0°C packaged in Saran than in a highly permeable film (Fellers et al., 1963). Davis and Burns (1969) indicated vacuum packaging without good seals may yield misleading film permeability results. Landrock and Wallace (1955) compared films varying in permeability from 2,400 ml $O_2/m^2/24$ hrs. at 39°C to 13,000 ml O_2. They concluded permeabilities of 5,500 ml O_2 would retain or increase oxymyoglobin for 48 hours at display temperatures of 1.1-3.3°C. Film permeabilities of 2,400 or 4,400 ml O_2 were not satisfactory in maintaining bright red color for 1 day storage.

Very little data is available indicating color patterns of frozen meat. Ramsbottom (1947) found meat packaged in du Pont 300 MSAT #87 cellophane (high gas permeability rating) to be acceptable in color after a 1 year storage period at either

-23°C or -29°C.

Kraft and Ayres (1952) and Landrock and Wallace (1955) suggested highly permeable packaging films may create conditions more conducive to microbial growth. Cutaia and Ordal (1964) found an oxygen impermeable film to resist bacterial growth because of increased reducing potential. Marriott et al. (1967) observed meat had lower bacterial counts when packaged in low permeable film, and this resulted in more stable color.

Packaging films may aid in reducing discoloration by absorbing various wavelengths of light (Kraft and Ayres, 1954). They observed less discoloration in fresh meat whose package film absorbed ultraviolet light. Absorbance of ultraviolet and shorter wavelengths of light by packaging material may also reduce oxidative rancidity (Watts, 1954).

Reduction of metmyoglobin by vacuum packaging meat may at the same time reduce ferric heme catalytic activities in oxidation of lipids in meat (Watts, 1954). Data by Green (1969) indicates anaerobic packaging was effective in preventing oxidation of both myoglobin and lipids when the packaging process was executed rapidly and the meat contained sufficient reducing activity to assure complete reduction of metmyoglobin.

Effect of Freezing on Weight and Drip Losses

Data dealing directly with weight loss of frozen meat is very limited; however package film permeability appears a major factor. Ramsbottom and Koonz (1941) froze beef rib steaks unpro-

tected at either -12.2 or -34.4°C for 15 hours and packaged them in moisture-proof tin cans for storage at either -12.2 or -34.4°C. Regardless of treatment, they observed only small differences in weight losses after storage periods of 4 days vs. 1 year. Therefore, they concluded weight losses were greatest during the freezing process (about 1.56% of initial weight) while losses during frozen storage were negligible. Similar results were recorded for frozen wholesale ribs and rounds except the weight losses due to freezing decreased to about 0.33%. Brady, Frei and Hickman (1942) record data which indicated freezing of pork, lamb or beef steaks at -26.1°C had less weight loss than meat frozen at -17.8°C. These steaks were wrapped in double waxed freezer paper and double wrapped with butcher paper. Frozen beef, pork and lamb steaks packaged in du Pont 300 MSAT #87 cellophane had increased weight losses with increasing storage temperature; however, when stored at -23 or -29°C weight losses were negligible (Ramsbottom, 1947). Hustruld et al. (1949) and Winter et al. (1952) recorded weight losses from frozen meat stored in fluctuating temperatures (below -18°C and -18°C to -10°C, respectively) vs. constant 0°C storage. They found meat packaged in a moisture impermeable film (laminated foil) lost very little, if any, weight when stored at either constant or fluctuating temperatures. Meat packaged in waxed locker paper had weight losses of 1.8% at constant temperature storage while at fluctuating temperatures the loss was about 5.7%. Pirko and

Ayres (1957) investigated weight losses in fresh meat and reported losses about 6% of the initial weight after 2 weeks storage at 6°C when packaged in a film moderate to highly permeable to both gas and water vapor. Meat packaged in film of high gas and low water vapor permeability lost 2% of initial weight in 2 weeks, while meat packaged in films of low gas and water vapor permeability lost less than 1% weight loss. Marriott et al. (1967) found weight losses to be ten times greater in fresh meat packaged in a film permeable to water vapor than in a film of low moisture permeability.

The importance of various factors affecting drip losses in defrosted beef were investigated by Richardson and Scherubel (1908). They found slow thawing a means of reducing drip. According to Cook et al. (1926); Ramsbottom and Koonz (1940); Brady et al. (1942); Hiner, Madsen and Hankins (1945); Pearson and Miller (1950) and Callow (1952), the amount of drip loss from bovine muscle decreased when the freezing rate increased. Moran and Hale (1932) observed only a small amount of drip from small pieces of beef frozen in liquid nitrogen. However, Costello (1964) found liquid nitrogen freezing of beef at -18°C to yield no more drip than steaks frozen at -195.5°C.

Volume of meat in comparison to area of cut surface was a major factor in quantity of drip (Ramsbottom and Koonz, 1939). They found no significant difference in drip loss of wholesale ribs frozen at -12.2°C vs. -45.6°C. One inch steaks frozen at

-6.7, -23.3 and -45.6°C produced drip losses of 8.0, 6.3 and 4.9%, respectively. Increased or fluctuating storage temperatures were observed by Moran and Hale (1932) as very important factors increasing drip loss. They stated small ice crystals produced by rapid freezing will recrystalize on to larger crystals at relatively high storage temperatures. On the contrary, storage temperatures did not affect amount of drip loss (Ramsbottom and Koonz, 1941) nor did increased ice crystal size result in more drip (Ramsbottom and Koonz, 1940). Ramsbottom and Koonz (1941) reported drip losses of 7.4 and 7.6% when frozen at -34.4°C and stored 1 year at either -34.4 or -12.2°C. When frozen at -12.2°C and stored 1 year at -34.4 and -12.2°C, drip percentages were 9.6 and 9.9, respectively. These workers found drip losses increased 60% from 4 to 365 days of storage when the meat was frozen at -34.4°C. When frozen at -12.2°C, drip losses increased 70% from 4 to 365 days of storage. Other workers also report longer storage periods result in larger drip losses (Brady et al., 1942; Pearson and Miller, 1950; Awad, Powrie, Fennema, 1968).

Cook et al. (1926) and Sair and Cook (1938) observed a reduction in drip as the aging period increased. Ramsbottom and Koonz (1940) observed drip losses of 2.2% when beef steaks were frozen 6 hours after slaughter; while steaks frozen 1 day postslaughter had a drip loss of 5.3%. They stated the low drip at 6 hours was due to the state of rigor of the muscle. Ramsbottom and Koonz (1940) compared several aging periods ranging from 1 day through 5 weeks. They found less drip loss with

each increase in aging time. Concurrently, they noted an increase in ice crystal size when frozen after extended periods of aging, and pH did not vary with time.

Initial pH of meat prior to processing appears to affect quantity of drip (Empley, 1933; Sair and Cook, 1938). Their data indicated little or no drip resulted when muscle pH was between 6.2 and 6.4. However, drip volume gradually increased as pH decreased; maximum drip was recorded about pH of 5.0 to 5.2. Numerous workers have observed lower drip losses from dark cutting beef which has a pH in the range 6.2 to 6.5 (Lawrie, 1966).

Awad et al., (1968) studied drip losses from bovine muscle frozen and stored for 8 weeks at -4°C. They reported drip loss increased from 7.3ml/100g tissue (unfrozen control) to 15.9ml post-freezing. Drip at 8 weeks was 24ml. They also found protein content of the drip, expressed as percentage of total muscle protein, increased from 5.86% for unfrozen muscle to 17% for muscle frozen 8 weeks.

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Chapter 3

FACTORS AFFECTING SHOWCASE COLOR STABILITY OF FROZEN LAMB CHOPS IN TRANSPARENT FILM

The meat industry appears to be moving toward centralized processing of products for economic reasons. Frozen products, rather than fresh products, seem to fit more logically into a central cutting system. Retail markets, especially those in less populated areas, would be able to stock a variety of frozen lamb cuts throughout the year whereas presently the fresh lamb supply is seasonal or even absent.

Consistant and acceptable meat quality, especially that manifested through color, is a primary determinant of product saleability. Attractive frozen meat color and an absence of frost and blood in packages are inherently critical since first impressions of meat are usually visual.

The fresh meat color most preferred by consumers results from the muscle pigment oxymyoglobin. Production of this bright red color in frozen meats seems logical to insure the meat industry a reasonable response to their frozen product. Factors affecting color stability of fresh meat have been investigated by numerous researchers. Whether the recommendations for increasing shelf life of fresh products are applicable to frozen meat remains to be determined.

The purpose of this work was to investigate the effect of freezing temperature, display temperature, packaging film, display

lighting and marbling level on color stability, drip loss and weight loss of frozen lamb chops.

EXPERIMENTAL PROCEDURE

Sample Selection, Preparation and Display. Lamb carcasses were purchased at a commercial packing company. Each of three replications consisted of three carcasses with identical slaughter dates. Carcasses were selected for three quality levels based on longissimus dorsi marbling score at the 12th rib: Moderate or slightly abundant (Prime), slight or small (Choice) and practically devoid or devoid (Good). Sixteen loin chops, each 2.54 cm thick, were cut and randomly assigned (identity was maintained as to position) to one of 16 treatments which consisted of all possible combinations of 2 freezing temperatures (-40°C liquid nitrogen vs. -26°C circulating air blast), 2 display temperatures (-29°C vs. -21°C), 2 packaging films (Saran, oxygen impermeable; 0.033 mm vs. Cryovac L-300, oxygen permeability about 4,000-5,000 cc/m^2/24 hours at 1 atm and 23°C; 0.051 mm) and 2 lighting systems (deluxe cool white fluorescent vs. incandescent with a Holophane Prismatic Reflectance fixture, Holophane Company, Inc.). Chops were allowed to bloom at about 21°C for at least 30 minutes, individually vacuum packaged, clip sealed and heat shrunk for 2 or 3 seconds in a water dip tank at 88°C. Rapidly frozen chops were placed in a liquid nitrogen simulator freezer in an upright position to allow maximum exposure to the vapor. The freezing

chamber was pre-chilled and programmed to hold 0°C for 10 minutes and -40°C for 25 minutes. End point internal temperature of -29°C was reached in 35 minutes. Chops frozen at -26°C were placed upright in a blast freezer overnight. All chops remained in the dark at either -29°C or -26°C until placed in the predetermined display conditions. Display case temperatures (product level) of -29°C and -21°C were consistantly maintained in open topped cases except for twice daily defrost cycles. Product temperature never rose above -11.0°C during the defrost cycle, and 1.5 hours were required for the product to return to its prior temperature. Cases were operated in an air conditioned room at 22°C and extreme variation in room humidity was controlled. A light intensity of 1,076 lumens/meter^2 (100 foot-candles) at product level was maintained 24 hours/day for each lighting system; extraneous lighting was held at a minimum. Extreme care was taken to assure the same meat surface was evaluated and exposed to light throughout the study.

Color and Weight Determinations. Subjective color scores, objective color measurements and weight losses were recorded at 9 time periods: Fresh unpackaged (bloomed), fresh packaged, immediately post-freezing (day 0), and after frozen display for 1, 7, 21 and 42 days. Day 43 evaluations were made immediately after unwrapping the frozen chops and day 44 observations were after thawing on racks for 24 hours at 14.0°C and relative humidity about 90%. Color was visually evaluated under the

assigned lighting system to the nearest 0.5 point on the following scale: 1=very bright, 2=bright, 3=slightly dark, 4=dark and 5=extremely dark. Reflectance spectra were obtained from 400 mu to 700 mu at a recording speed of 250 mu/minute using a Bausch and Lomb 600 Spectrophotometer with reflectance attachment calibrated for 100% reflectance with $MgCO_3$. A black rubber gasket slightly larger than the reflectance aperature was placed between the package and the apparatus to insure a minimum effect from thawing during the color scan. Reflectance was determined by reading to the nearest 0.1% at wavelengths of 474, 525, 538, 568, 572, 600, 610, 620 and 630 mu. Ratios of reflectance readings 474/525 and 572/525 were calculated as suggested by Snyder and Armstrong (1967). Weights were determined to nearest 0.01 gram. Weight loss was expressed as percent of fresh packaged weight and drip loss as percent of frozen unpackaged weight (day 43).

Statistical Procedures. Either a split-plot or a split-split-plot design with carcass as the whole plot and the treatment combinations as sub-plots were utilized according to Cochran and Cox (1957). Analysis of variance and least significant difference procedures were used to detect differences in treatment means. Simple correlation coefficients were computed between visual score and all reflectance data.

RESULTS AND DISCUSSION

Interactions revealed by the statistical analysis in this

study were few in number and inconsistant in occurrence. Therefore, significance of interactions were eluded to the main effects in the results and discussion.

Packaging film. Mean visual score and percent reflectance at 630 mu for all fresh, unpackaged chops were 1.81 and 28.8%, respectively. Vacuum packaging in neither the oxygen permeable film (L-300) nor the impermeable film (Saran) maintained the bloomed color (table 1); however, the L-300 packaged chops possessed more desirable visual and reflectance values post-packaging than Saran packaged chops. These results are similar to vacuum packaging effects reported by Landrock and Wallace (1955); Rikert, Ball and Stier (1957a); Rikert et al. (1957b) and Dean and Ball (1960). A regeneration of redness in vacuum packaged fresh meat after 2 to 4 days storage has been described by Rikert et al. (1957a) and Dean and Ball (1960); but, these frozen meat data did not follow such a pattern.

Chops packaged in L-300 film were more desirable in visual score after 1 and 42 days of frozen display than chops packaged in Saran. Significantly ($P<.01$) lower values for reflectance ratio 474/525 were recorded for the L-300 film compared to Saran (1.06 vs. 1.22; 1.08 vs. 1.21; 1.10 vs. 1.17; 1.09 vs. 1.14; 1.12 vs. 1.19 at days 1, 7, 21, 42 and 43, respectively). Data by Snyder (1965), transformed from absorbance to reflectance, indicated oxymyoglobin and/or metmyoglobin existed when the value of ratio 474/525 was about 1.03; reduced myoglobin existed when the value was about 1.6. These data confirm the expected presence

TABLE 1. EFFECT OF FREEZING TEMPERATURE AND PACKAGING FILM ON MEAN VISUAL SCORE AND PERCENT REFLECTANCE AT 630mu OF FROZEN LAMB CHOPS AT SEVERAL TIME PERIODS

	Freezing temperature°C						Packaging film[b]					
	Visual score[a]			% Reflectance			Visual score			% Reflectance		
Time	-40		-26	-40		-26	L-300		Saran	L-300		Saran
Fresh packaged							2.40	**	2.61	26.1	**	24.2
Frozen, day												
0	2.29	**	2.66	29.0	**	22.6	2.42		2.52	25.9		25.3
1	2.31	**	2.74	27.6	**	21.6	2.42	**	2.63	24.8		24.4
7	2.37	**	2.93	26.8	**	21.0	2.62		2.68	23.2	*	24.5
21	2.48	**	3.01	24.7	**	21.3	2.70		2.79	22.0	**	24.0
42	2.65	**	3.13	24.0	**	22.2	2.81	*	2.97	22.4	**	23.8
43[c]	2.67	**	3.13	26.8		23.0	2.98		2.88	24.0	**	25.7
Thawed-44	3.18	*	3.34	16.2		16.0	3.32	*	3.19	15.6	**	16.6

[a] 1 = Very bright, 5 = Extremely dark.

[b] L-300 = oxygen permeable, Saran = oxygen impermeable.

[c] Unpackaged.

*(P<.05).

**(P<.01).

of a more reduced myoglobin state in the Saran packaged chops. Since metmyoglobin would reflect lesser amounts of light at 630 mu (orange-red) than either oxymyoglobin or reduced myoglobin, the lower reflectance for the L-300 film (table 1) at days 7, 21, 42 and 43 suggest the presence of metmyoglobin in the L-300 packages. Additional evidence for metmyoglobin presence in the L-300 packaged chops was found in significantly ($P<.01$) larger values of reflectance ratio 572/525 at days 7, 21, 42 and 43. Larger values for 572/525 ratio indicated samples contained proportionately more metmyoglobin (Snyder, 1965). Metmyoglobin would be present in oxygen permeable film packaged meat provided oxygen tension was sufficiently lowered (Fox, 1966). Brownish metmyoglobin was not detected by visual appraisal in this study; but, according to Brooks (1938), metmyoglobin was not visually detectable until approximately 60% of the pigment on the meat surface was in the oxidized form.

Saran packaged chops possessed more desirable visual and reflectance values after the thaw-bloom period than chops in L-300 film. Similar reoxygenation of myoglobin was observed by Pirko and Ayres (1957).

Increased reflectance at 630 mu from day 42 to 43 appeared to be an effect of packaging film. As display time increased, package film adherence to meat decreased; hence, true meat color reflectance may not have been measured when such conditions existed.

Surface desiccation may explain the marked decrease in

total reflectance of thawed chops.

Freezing temperature. The effect of freezing temperature on visual score and percent reflectance at 630 mu is presented in table 1. The more desirable visual scores which resulted from freezing at the lower temperature (-40°C) agreed with data of Ramsbottom and Koonz (1939, 1941); Pearson and Miller (1950) and Brissey (1963). Mean visual score of fresh chops packaged in L-300 and Saran film was 2.40 and 2.61, respectively. Hence, the -40°C freezing process had a brightening effect on chops regardless of package film. Severe "bleaching" noted with -46°C plate freezing (Robertson, 1950) was not observed in this study. Costello (1964) reported rapid freezing with liquid nitrogen produced "lighter" colors in beef steaks. Ramsbottom and Koonz (1941) attributed the lighter color of meat frozen at lower temperatures to very small surface ice crystals which reflect more light.

Data for thawed, day 44 samples indicated a beneficial visual color advantage for -40°C frozen chops; however, reflectance at 630 mu indicated no significant color difference. The color differences of beef steaks after freezing at conventional vs. rapid freezing rates were not apparent after thawing (Costello, 1964).

The improved visual scores due to freezing at -40°C were confirmed by higher reflectance readings, more red reflectance, in the 600-630 mu range. Decreasing differences between reflec-

tance at 630 mu indicated less advantage for -40°C freezing as display time increased.

Display temperature. Display of chops at -21°C resulted in more desirable visual scores at day 1 (table 2) compared to chops displayed at -29°C. These data suggest the higher frozen display temperature was sufficiently low to reduce enzyme competition for oxygen, thus allowing more myoglobin to remain oxygenated on the meat surface during the display period of 1 day. Reflectance at 630 mu, however, indicated a color advantage for -29°C display rather than -21°C.

Visual score indicated display temperature at -29 or -21°C did not critically affect visual color stability of lamb chops displayed for 3 weeks; however, a color advantage for -29°C display was visually apparent at day 42. The more desirable visual score at day 44 for -29°C display suggest a less oxidized state of myoglobin was maintained at that temperature. Lowering display temperatures should result in more desirable color due to decreased respiration of meat, hence increased depth of oxygen penetration, decreased autoxidation, increased amount of dissolved oxygen in meat fluids, and a shift of equilibrium, myoglobin + oxygen $\rightleftharpoons$ oxymyoglobin, to the right.

Reflectance data for display temperature (table 2) confirmed research by Ramsbottom and Koonz (1941); Ramsbottom (1947); Snyder and Ayres (1961); Brown and Dolev (1963); Snyder (1964) and Cutaia and Ordal (1964) that lower storage temperatures

TABLE 2. EFFECT OF DISPLAY TEMPERATURE AND LIGHTING ON MEAN VISUAL SCORE AND PERCENT REFLECTANCE AT 630mu OF FROZEN LAMB CHOPS AT SEVERAL TIME PERIODS

	Display temperature°C				Lighting[b]			
	Visual score[a]		% Reflectance		Visual score		% Reflectance	
Time	-29	-21	-29	-21	I	F	I	F
Frozen, day								
1	2.58 *	2.47	25.4 **	23.8	2.40	2.65	24.5	24.7
7	2.67	2.62	24.5 **	23.3	2.52 **	2.77	23.6	24.2
21	2.71	2.78	23.9 **	22.1	2.65 **	2.84	22.8	23.2
42	2.80 **	2.98	24.8 **	21.4	2.82 *	2.96	22.4 **	23.8
43[c]	2.80 **	3.01	26.2 **	23.6	2.82 *	2.99	24.3	25.5
Thawed-44	3.19 *	3.32	16.3	15.9	3.16 **	3.35	15.5 **	16.8

[a] 1 = Very bright, 5 - Extremely dark.

[b] I = incandescent, F = fluorescent.

[c] Unpackaged.

*(P<.05).

**(P<.01).

decreased autoxidation of myoglobin in fresh and frozen meat. The combination of lower reflectance values at 630 mu and significantly lower values for ratio 474/525 at day 7, 43 ($P<.01$) and 44 ($P<.05$) indicated more metmyoglobin in chops displayed at -21°C. This trend was apparent at all frozen time periods and after thawing. However, reflectance ratio 572/525 (indicates proportion of metmyoglobin) did not produce significant differences for display temperature.

Display temperature fluctuations, especially if thawing temperature was reached, had a critical effect on frozen meat color (Townsend and Bratzler, 1958). Product surface temperature for chops displayed at -29°C ranged from -26 to -15°C while product surface temperature fluctuations ranged from -18 to -11°C at -21°C display. These fluctuations did not appear to affect lamb chop color stability. Similar results were reported for temperature fluctuations below -18°C (Hustruld et al., 1949) and from -18 to -10°C (Winter et al., 1952).

Lighting. Chops displayed under incandescent lighting had lower (more desirable) visual scores at all frozen display time periods (table 2). Visual appraisal was conducted under the assigned lighting type; therefore, it was possible that the visual scores did not reflect true color deterioration or change in pigment state. Figure 1 presents the relative spectral distribution (General Electric, 1968) of both light sources and the percent transmission of wavelengths by the incandescent Holophane

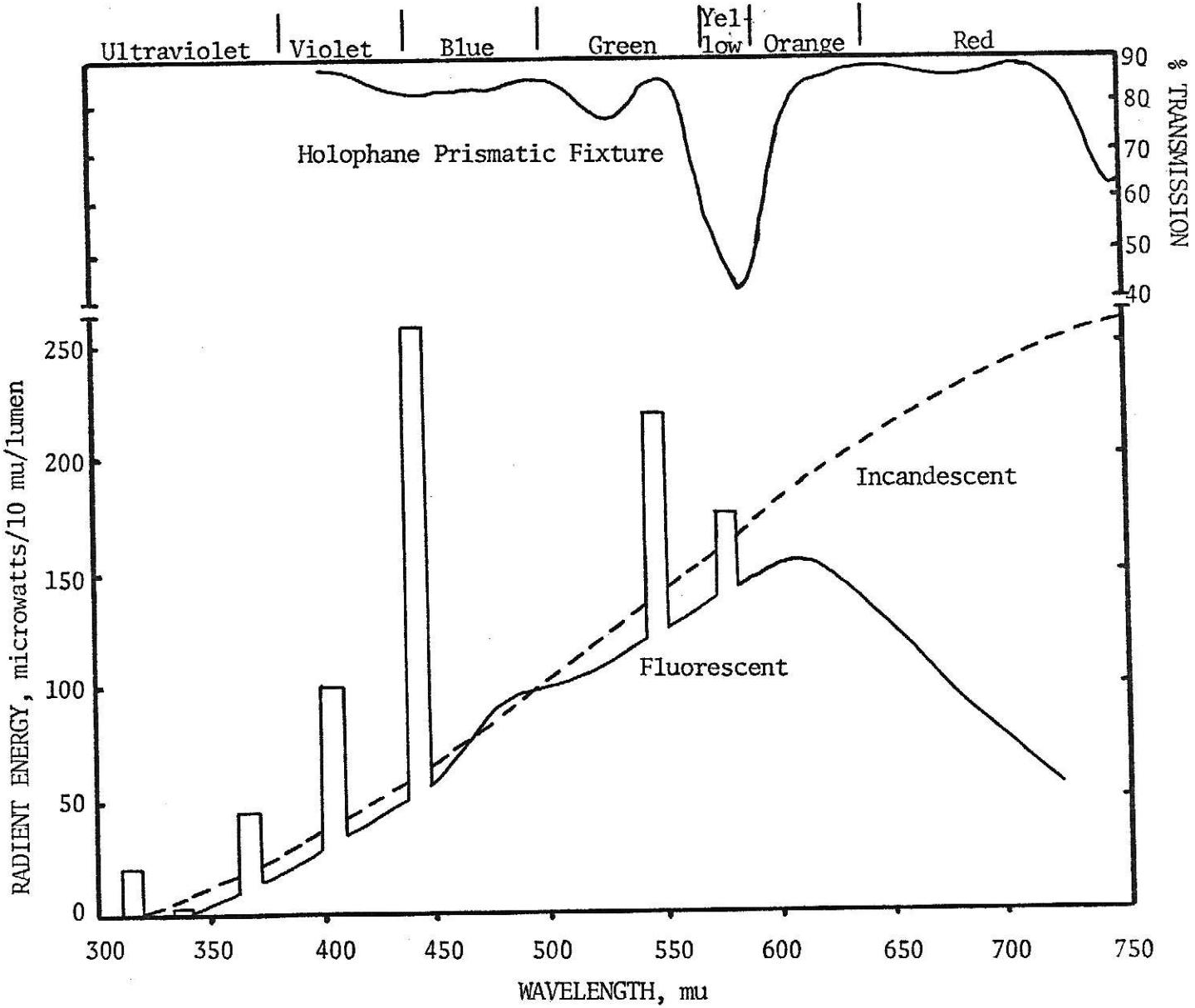

Figure 1. Approximate energy distribution of deluxe cool white fluorescent and incandescent lamps and percent transmission of light by Holophane Prismatic Reflectance Fixture (used with incandescent).

Prismatic Reflectance fixture (Holophane Company, 1963). Considerably more red wavelengths were emitted by the incandescent Holophane source; hence, these spectral data suggest the more desirable visual scores recorded for chops under incandescent light could have been due to the larger proportion of wavelengths greater than 600 mu.

Significantly lower values for ratio 474/525 were recorded for incandescent lighting at day 7 ($P<.05$), 21, 42 and 43 ($P<.01$). These lower values indicate the presence of more oxymyoglobin and/or metmyoglobin. Reflectance values at 630 mu were higher for the fluorescent lighting which indicate proportionately more reduced myoglobin or oxymyoglobin. Combination of these data (lower 474/525 and lower 630 reflectance) suggest more metmyoglobin in the chops stored under incandescent lighting. Significantly higher values for ratio 572/525 (indicates metmyoglobin) were recorded for incandescent lighting at days 42, 43 ($P<.01$) and 44 ($P<.05$). These reflectance data also indicated incandescent lighting caused more metmyoglobin formation in frozen lamb chops than fluorescent lighting. However, the differences in reflectance at 630 mu and the reflectance ratios were small and probably not of practical significance.

The Holophane fixture filtered out a large portion of incandescent wavelengths between 550 and 610 mu (figure 1); hence the fluorescent source emitted a markedly larger proportion of wavelengths from 540 to 610 mu. This band of light

apparently did not affect color stability if the reflectance measurements used accurately measured color deterioration. On the contrary, Townsend and Bratzler (1958) reported accelerated color deterioration in meat exposed to fluorescent wavelengths between 560 and 630 mu. Other researchers reported no difference between lighting systems (Ramsbottom, Goeser and Shultz, 1951; Hansen and Sereika, 1969).

Results of a separate study comparing effect of light on product temperature in display indicated both lighting systems at 1,076 lumens/m^2 raised the mean product temperature about 3 to 5°C; hence the additional heat produced by incandescent lighting was of little consequence. P. E. Gould (unpublished data) observed incandescent lighting to increase surface temperature and subsequent discoloration in fresh meat.

Spectral reflectance characteristics of each film were nearly identical. Therefore, the statement by Kraft and Ayres (1954) that certain packaging films may decrease discoloration in meat by absorbing various wavelengths of light, did not apply to films used in this study.

Although not a part of the formal study, random inspection of the bottom side of chops not exposed to light revealed consistantly brighter visual color that the side exposed to light. These observations support the work of Townsend and Bratzler (1958) and Marriott (1967) who found meat stored in darkness had more color stability.

Marbling. Degree of marbling in the longissimus dorsi did not significantly affect any subjective or objective measurements of color, weight or drip loss.

Weight loss. Figure 2 shows weight loss due to freezing was 0.29% while 0.42% additional loss occurred during frozen display (days 0 to 42), thus a total weight loss of 0.71% during frozen display up to 6 weeks was obtained in this study. Total weight loss from fresh unpackaged to frozen unpackaged (day 43) was about 0.90%. Weight loss was not significantly affected by any of the 16 treatments from one observation period to the next. However, the average total weight loss from day 1 to day 42 of the frozen chops packaged in the L-300 film was 0.23% compared to chops packaged in Saran (0.44%). High oxygen permeability and high water vapor transmission properties of packaging films do not necessarily coincide. However, more frost accumulated in the L-300 packages; hence, more water vapor may have passed into these packages and condensed as frost which was ultimately manifested as less weight loss for chops packaged in the L-300 film. Certain packaging films have been observed to actually gain weight (Hustruld et al., 1949). However, Hustruld et al., (1949); Pirko and Ayres (1957) and Marriott et al., (1967) recorded greater weight losses in meat packaged in films with greater water transmission ratings.

Drip loss. Mean drip loss was 5.34%. Chops frozen at -40°C exhibited less drip loss (4.93%) than those frozen at

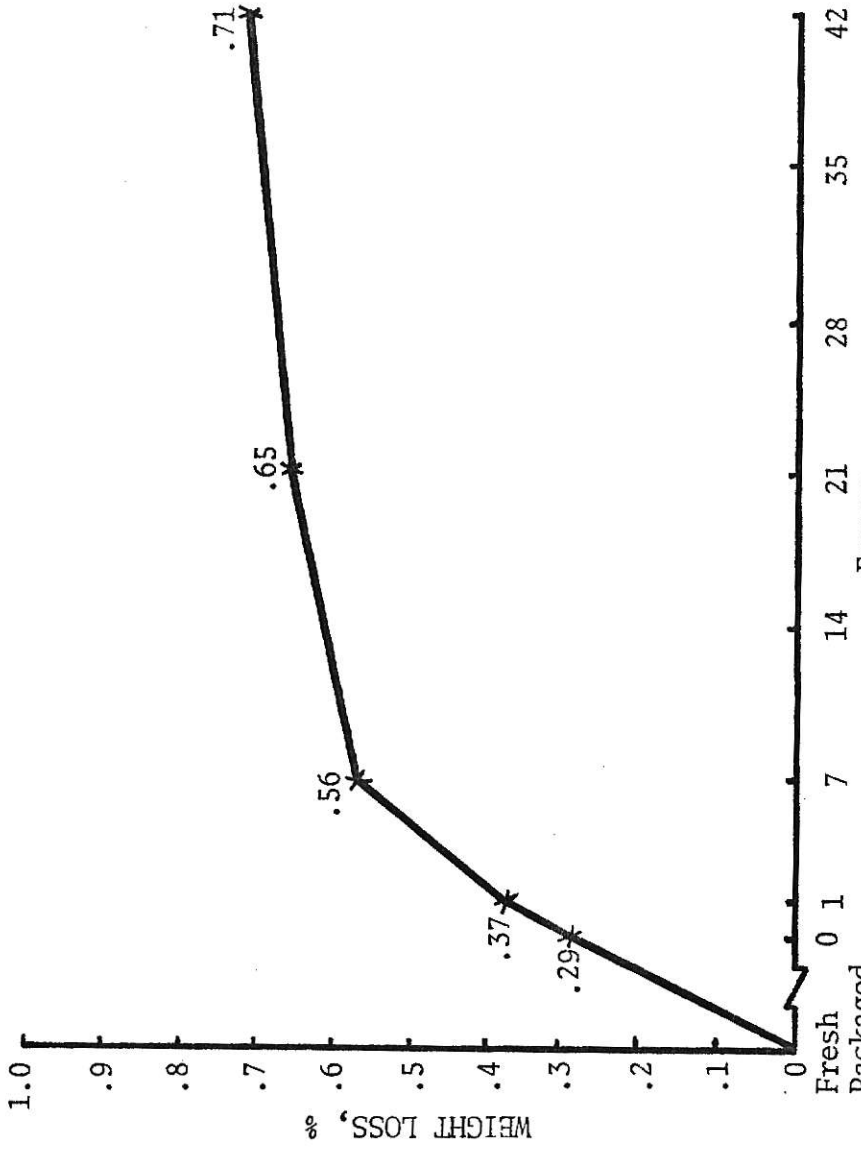

Figure 2. Percent weight loss of fresh packaged and frozen lamb chops at various time periods.

-26°C (5.76%). Ramsbottom and Koonz (1939) stated drip loss was a function of ice crystal size; the small crystals resulted from faster freezing rates, caused less tissue disruption and subsequently reduced drip loss. Display temperature, packaging film and lighting did not significantly affect drip loss.

Correlation of reflectance and visual score. Simple correlation coefficients between visual score and all objective color measurements are given in table 3. Overall pooled data contained both fresh and frozen chops, hence there was considerable variation in these data. These coefficients indicate the general relationship between visual score and the selected independent variables. Wavelength 630 mu appeared to be the best indicator of visual score (r= -.66). Since lower values of visual score were most desirable and higher values at 630 mu indicated more red reflectance, the negative correlations were expected.

Pooled data (frozen) involved chops from frozen day 1 to frozen day 42. Reflectance at wavelengths 610-630 mu had the highest relationship to frozen visual score (r= -.57).

Simple correlations for individual time periods tended to increase with time. Apparently, increased variation due to treatment effects improved the magnitude of the coefficients. Noteworthy is the increased coefficients from day 42 to day 43. The lack of package film to meat adherence at day 42 resulting in less accurate color scan is a possible explanation for the

TABLE 3. SIMPLE CORRELATION COEFFICIENTS BETWEEN LAMB CHOP VISUAL SCORE AND WAVELENGTH REFLECTANCE AND REFLECTANCE RATIOS AT ALL TIME PERIODS

Wavelength and ratios	Pooled[a] All	Pooled[b] Frozen	Fresh Unpkg.	Fresh Pkg.	Time Periods Frozen-day 0	1	7	21	42	43[c]	Thawed Day-44
474	-.23	-.33	-.11	0.03	-.28	-.31	-.48	-.34	-.37	-.61	-.56
525	-.24	-.32	-.09	-.04	-.34	0.37	-.49	-.39	-.30	-.64	-.52
538	-.09	-.23	-.10	0.05	0.21	-.24	-.42	-.32	-.26	-.61	-.48
568	-.12	-.30	-.09	-.02	-.34	-.36	-.45	-.40	-.32	-.65	-.40
572	-.08	-.27	-.09	0.01	-.29	-.31	-.44	-.36	-.31	-.65	-.41
600	-.41	-.52	-.13	-.15	-.57	-.55	-.59	-.58	0.44	-.70	-.61
610	-.55	-.57	-.13	-.19	-.62	-.58	-.66	-.61	-.48	-.68	-.64
620	-.62	-.57	-.14	-.21	-.60	-.55	-.68	-.60	-.48	-.67	-.63
630	-.66	-.57	-.16	-.21	-.60	-.55	-.66	-.58	-.47	-.64	-.63
474/525	0.01	0.08	0.09	0.19	0.18	0.17	0.02	0.19	0.04	0.26	-.14
572/525	0.48	0.16	0.02	0.23	0.21	0.27	0.10	0.04	-.13	0.07	0.27
r value *	0.06	0.08	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
r value **	0.08	0.11	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Observations	1296	576	144	144	144	144	144	144	144	144	144

[a] All fresh and frozen data.

[b] Frozen days 1, 7, 21, 42 data.

[c] Unpackaged.

*Correlation ≥ r value significant (P<.05).
** Correlation ≥ r value significant (P<.01).

increase. These correlation data suggest wavelengths 600, 610, 620 and 630 mu consistantly had the highest relationship of all reflectance variables to visual score. Ockerman and Cahill (1969) reported correlation coefficients above 0.85 between visual score and reflectance at 685 mu for beef and for pork (with a marbling adjustment for pork).

SUMMARY

Color stability of frozen lamb chops of three marbling levels was studied using all possible combinations of 2 freezing temperatures (-40°C vs. -26°C), 2 display temperatures (-29°C vs. -21°C), 2 packaging films (oxygen permeable vs. oxygen impermeable) and 2 lighting systems (fluorescent vs. incandescent). Weight, visual color and color by reflectance spectrophotometry were recorded for fresh chops, 7 post-freezing times up to 6 weeks and after thawing.

Freezing at -40°C produced more desirable visual color at all time periods post-freezing. This was confirmed by reflectance data. Bleaching of color was not a problem for chops frozen with liquid nitrogen at -40°C.

Chops displayed under incandescent lighting appeared more desirable in visual color; however, reflectance readings suggested less metmyoglobin formation in chops displayed under deluxe cool white fluorescent lighting.

Packaging in oxygen permeable L-300 film generally resulted in brighter visual scores in fresh and frozen chops, but chops

in Saran film evinced more desirable color after thawing and blooming. Reflectance data indicated more metmyoglobin in L-300 packages displayed 7 or more days.

Display at -29°C compared to -21°C improved visual color only after display for 3 weeks and after the thaw-bloom period. Reflectance values suggested more autoxidation of myoglobin occurred at -21°C display at all frozen display periods.

Marbling level did not affect weight loss or color stability.

Drip losses were less in chops frozen at -40°C than -26°C. Weight loss from fresh packaged to frozen at 6 weeks averaged 0.71%.

Simple correlations between visual score and reflectance of frozen chops were highest at wavelengths 610, 620 and 630 mu.

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APPENDICES

APPENDIX A

VISUAL SCORE SCALE, IDENTIFICATION OF TIME PERIODS AND VARIABLES

Visual Score

1. Very bright red
2. Bright red
3. Slightly dark
4. Dark
5. Extremely dark

Time Periods

1. Fresh unpackaged, full bloom
2. Fresh packaged
3. Frozen day 0
4. Frozen day 1
5. Frozen day 7
6. Frozen day 21
7. Frozen day 42
8. Frozen day 43, unpackaged
9. Thawed day 44

Variables

1. Weight, grams
2. Visual score
3. Reflectance 474mu
4. Reflectance 525mu
5. Reflectance 538mu
6. Reflectance 568mu
7. Reflectance 572mu
8. Reflectance 600mu
9. Reflectance 610mu
10. Reflectance 620mu
11. Reflectance 630mu
12. Reflectance ratio 474/525
13. Reflectance ratio 472/525

APPENDIX B

ORTHOGONAL COMPARISONS

1. Freezing temperature: $-40^{\circ}C$ vs. $-26^{\circ}C$
2. Display temperature: $-29^{\circ}C$ vs. $-21^{\circ}C$
3. Packaging film: L-300 vs. Saran
4. Lighting system: Fluorescent vs. Incandescent
5. Freezing X Display
6. Freezing X Packaging
7. Freezing X Lighting
8. Display X Packaging
9. Display X Lighting
10. Packaging X Lighting
11. Freezing X Display X Packaging
12. Freezing X Display X Lighting
13. Freezing X Packaging X Lighting
14. Display X Packaging X Lighting
15. Freezing X Display X Packaging X Lighting

APPENDIX C

TREATMENT COMBINATIONS

No.	Freezing temp.	Display temp.	Packaging	Lighting
1.	-40°C	-29°C	Saran	Fluorescent
2.	-40	-29	Saran	Incandescent
3.	-40	-29	L-300	Fluorescent
4.	-40	-29	L-300	Incandescent
5.	-40	-21	Saran	Fluorescent
6.	-40	-21	Saran	Incandescent
7.	-40	-21	L-300	Fluorescent
8.	-40	-21	L-300	Incandescent
9.	-26	-29	Saran	Fluorescent
10.	-26	-29	Saran	Incandescent
11.	-26	-29	L-300	Fluorescent
12.	-26	-29	L-300	Incandescent
13.	-26	-21	Saran	Fluorescent
14.	-26	-21	Saran	Incandescent
15.	-26	-21	L-300	Fluorescent
16.	-26	-21	L-300	Incandescent

APPENDIX D. VARIABLE MEANS FOR ALL EVALUATION TIME PERIODS

Variable[a]	Time[a] 1	2	3	4	5	6	7	8	9
1	108.51	112.05	111.72	111.63	111.42	111.32	111.26	107.50	101.76
2	1.81	2.50	2.47	2.52	2.61	2.71	2.89	2.90	3.21
3	10.0	14.5	14.6	14.1	13.8	14.0	14.9	14.4	7.8
4	8.9	11.5	13.0	12.4	12.1	12.5	13.5	12.5	7.2
5	6.3	9.9	11.5	11.1	11.0	11.5	12.7	11.4	6.0
6	7.1	9.7	12.3	11.8	12.0	12.3	13.4	12.6	7.4
7	6.4	9.5	11.9	11.5	11.7	12.1	13.4	12.4	6.9
8	15.8	14.9	18.9	18.0	17.8	17.2	17.9	18.4	12.9
9	21.1	18.8	21.8	20.9	20.2	19.6	20.0	21.1	14.8
10	25.8	22.6	24.4	23.2	22.3	21.6	22.0	23.6	15.7
11	28.8	25.1	25.8	24.6	23.6	22.7	23.1	24.9	15.8
12	1.12	1.26	1.12	1.14	1.13	1.13	1.12	1.16	1.08
13	0.72	0.82	0.91	0.93	0.95	0.97	0.99	0.99	0.95

[a]Appendix A.

APPENDIX E-1. EFFECT OF PACKAGING FILM, FREEZING TEMPERATURE, DISPLAY TEMPERATURE AND LIGHTING ON FROZEN LAMB CHOP MEAN VISUAL SCORE

Time[b]	Film				Freeze Temp.				Display Temp.				Lighting[a]			
	L-300		Saran		-40°C		-26°C		-29°C		-21°C		I		F	
2	2.40	**	2.61													
3	2.42		2.52		2.29	**	2.66									
4	2.42	**	2.63		2.31	**	2.74		2.58	*	2.47		2.40	**	2.65	
5	2.62		2.68		2.37	**	2.93		2.67		2.62		2.52	**	2.77	
6	2.70		2.79		2.48	**	3.01		2.71		2.78		2.65	**	2.84	
7	2.81	*	2.97		2.65	**	3.13		2.80	**	2.98		2.82	*	2.96	
8	2.92		2.88		2.67	**	3.13		2.80	**	3.01		2.82	*	2.99	
9	3.32	*	3.19		3.18	*	3.34		3.19	*	3.32		3.16	**	3.35	

[a]I = incandescent, F = fluorescent.

[b]Appendix A.

*(P<.05).

**(P<.01).

APPENDIX E-2. EFFECT OF PACKAGING FILM, FREEZING TEMPERATURE, DISPLAY TEMPERATURE AND LIGHTING ON FROZEN LAMB CHOP MEAN PERCENT REFLECTANCE AT 474mu

Time[b]	Film		Freeze Temp.		Display Temp.		Lighting[a]	
	L-300	Saran	-40°C	-26°C	-29°C	-21°C	I	F
2	13.9	15.0						
3	14.6	14.5	16.1 **	13.1				
4	13.3 **	14.9	15.4 **	12.7	14.7 **	13.5	13.9	14.3
5	13.2 **	14.8	15.3 **	12.7	14.4	13.6	13.9	14.1
6	13.6 **	14.8	14.7 **	13.6	14.7 **	13.6	14.0	14.3
7	14.6	15.3	15.3	14.5	16.1 **	13.8	14.6	15.3
8	14.1	14.8	15.8 **	13.0	15.4 **	13.4	13.9 **	14.9
9	8.0	8.1	8.0	8.1	8.2	7.9	8.4 **	7.7

[a] I = incandescent, F = fluorescent.

[b] Appendix A.

*(P<.05).

**(P<.01).

APPENDIX E-3. EFFECT OF PACKAGING FILM, FREEZING TEMPERATURE, DISPLAY TEMPERATURE AND LIGHTING ON FROZEN LAMB CHOP MEAN PERCENT REFLECTANCE AT 525mu

Time[b]	Film		Freeze Temp.		Display Temp.		Lighting[a]	
	L-300	Saran	-40°C	-26°C	-29°C	-21°C	I	F
2	11.6	11.5						
3	13.1	13.0	14.4 **	11.6				
4	12.6	12.3	13.7 **	11.2	12.9 **	12.0	12.3	12.6
5	12.4	12.4	13.7 **	11.2	12.6	12.2	12.4	12.4
6	12.5	12.8	13.2 **	12.1	13.0 *	12.2	12.7	12.6
7	13.4	13.5	13.8	13.1	14.5 **	12.4	13.4	13.6
8	12.6	12.5	14.0 **	11.1	13.2 **	11.8	12.4	12.6
9	7.4	7.5	7.4	7.5	7.5	7.3	7.2 *	7.7

[a]I = incandescent, F = fluorescent.

[b]Appendix A.

*(P<.05).

**(P<.01).

APPENDIX E-4. EFFECT OF PACKAGING FILM, FREEZING TEMPERATURE, DISPLAY TEMPERATURE AND LIGHTING ON FROZEN LAMB CHOP MEAN PERCENT REFLECTANCE AT 538mu

Time[b]	Film		Freeze Temp.			Display Temp.			Lighting[a]		
	L-300	Saran	-40°C		-26°C	-29°C		-21°C	I		F
2	9.6	10.2									
3	11.6	11.5	12.6	**	10.5						
4	10.8	11.3	12.0	**	10.2	11.6	**	10.6	10.9		11.3
5	11.0	11.4	12.1	**	10.3	11.5		10.9	11.2		11.2
6	11.4	11.8	12.0	*	11.3	12.0	*	11.2	11.6		11.6
7	12.6	12.8	13.0		12.4	13.7	**	11.7	12.6		12.8
8	11.5	11.4	12.8	**	10.1	12.1	**	10.8	11.3		11.6
9	6.3	6.1	6.2		6.2	6.3		6.1	6.0	*	6.4

[a]I = incandescent, F = fluorescent.

[b]Appendix A.

*(P<.05).

**(P<.01).

APPENDIX E-5. EFFECT OF PACKAGING FILM, FREEZING TEMPERATURE, DISPLAY TEMPERATURE AND LIGHTING ON FROZEN LAMB CHOP MEAN PERCENT REFLECTANCE AT 568mu

Time[b]	Film		Freeze Temp.		Display Temp.		Lighting[a]	
	L-300	Saran	-40°C	-26°C	-29°C	-21°C	I	F
2	9.8	9.6						
3	12.4	12.2	13.6 **	11.0				
4	12.4 **	11.3	13.0 **	10.7	12.3 *	11.4	11.7	12.0
5	12.6 *	11.7	13.3 **	11.0	12.4	11.9	12.1	12.1
6	12.6	12.2	13.1 **	11.7	12.8 *	12.1	12.6	12.3
7	13.5	13.3	13.9 *	12.9	14.4 **	12.4	13.5	13.3
8	12.9 **	12.2	14.2 **	10.9	13.1 **	12.0	12.7	12.4
9	7.7	7.3	7.6	7.5	7.6	7.4	7.4	7.7

[a] I = incandescent, F = fluorescent.

[b] Appendix A.

*(P<.05).

**(P<.01).

APPENDIX E-6. EFFECT OF PACKAGING FILM, FREEZING TEMPERATURE, DISPLAY TEMPERATURE AND LIGHTING ON FROZEN LAMB CHOP MEAN PERCENT REFLECTANCE AT 572mu

Time[b]	Film		Freeze Temp.		Display Temp.		Lighting[a]	
	L-300	Saran	-40°C	-26°C	-29°C	-21°C	I	F
2	9.4	9.6						
3	12.0	11.9	13.1 **	10.7				
4	11.7	11.4	12.6 **	10.4	12.0 **	11.0	11.3	11.7
5	12.1	11.6	12.9 **	10.8	12.2	11.5	11.8	11.9
6	12.4	12.1	12.8 **	11.8	12.8 **	11.8	12.3	12.3
7	13.4	13.3	13.8	12.9	14.4 **	12.3	13.4	13.3
8	12.7	12.1	14.0 **	10.8	12.9 **	11.8	12.5	12.3
9	7.2	6.8	7.1	7.0	7.1	6.9	7.0	7.1

[a]I = incandescent, F = fluorescent.

[b]Appendix A.

*(P<.05).

**(P<.01).

APPENDIX E-7. EFFECT OF PACKAGING FILM, FREEZING TEMPERATURE, DISPLAY TEMPERATURE AND LIGHTING ON FROZEN LAMB CHOP MEAN PERCENT REFLECTANCE AT 600mu

Time[b]	Film			Freeze Temp.			Display Temp.			Lighting[a]		
	L-300		Saran	-40°C		-26°C	-29°C		-21°C	I		F
2	15.7	**	14.2									
3	19.0		18.8	21.4	**	16.4						
4	19.4	**	15.6	20.4	**	15.6	18.7	**	17.3	17.8		18.2
5	18.9	**	17.3	20.4	**	15.7	18.4		17.7	18.0		18.2
6	17.7		17.2	18.9	**	16.0	18.0	**	16.8	17.6		17.3
7	17.9		17.8	18.7	**	17.0	19.2	**	16.6	17.8		17.9
8	18.6		18.1	20.4	**	16.3	19.2	**	17.5	18.6		18.2
9	13.1		13.2	13.3		13.1	13.3		13.0	12.9		13.5

[a] I = incandescent, F = fluorescent.

[b] Appendix A.

*(P<.05).

**(P<.01).

APPENDIX E-8. EFFECT OF PACKAGING FILM, FREEZING TEMPERATURE, DISPLAY TEMPERATURE AND LIGHTING ON FROZEN LAMB CHOP MEAN PERCENT REFLECTANCE AT 610mu

Time[b]	Film		Freeze Temp.		Display Temp.		Lighting[a]	
	L-300	Saran	-40°C	-26°C	-29°C	-21°C	I	F
2	19.8 **	17.8						
3	21.9	21.8	24.8 *	19.0				
4	22.1 **	20.0	23.7 **	18.1	21.7 **	20.1	20.8	21.0
5	21.0	20.1	23.2 **	17.8	21.1 *	20.0	20.4	20.7
6	19.8	19.9	21.5 **	18.2	20.6 **	19.1	19.9	19.8
7	19.9	20.2	21.0 **	19.1	21.6 **	18.6	19.8	20.3
8	20.9	21.3	23.2 **	18.9	22.1 **	20.1	21.0	21.2
9	14.8	15.4	15.2	14.9	15.3	14.8	14.6 **	15.5

[a]I = incandescent, F = fluorescent.

[b]Appendix A.

*(P<.05).

**(P<.01).

APPENDIX E-9. EFFECT OF PACKAGING FILM, FREEZING TEMPERATURE, DISPLAY TEMPERATURE AND LIGHTING ON FROZEN LAMB CHOP MEAN PERCENT REFLECTANCE AT 620mu

Time[b]	Film			Freeze Temp.			Display Temp.			Lighting[a]		
	L-300		Saran	-40°C	-26°C		-29°C	-21°C		I	F	
2	23.6	**	21.7									
3	24.5		24.4	27.6	**	21.4						
4	23.9	**	22.5	26.2	**	20.2	24.1	**	22.3	23.0		23.4
5	22.6		22.7	25.6	**	19.7	23.2	*	22.1	22.5		22.8
6	21.3	**	22.4	23.5	**	20.2	22.8	**	21.0	21.8		22.0
7	21.5		22.4	22.9	**	21.1	23.7	**	20.3	21.5		22.4
8	23.0	*	24.1	25.6	**	21.5	24.8	**	22.3	23.2		23.8
9	15.6	*	16.5	16.2		16.0	16.3		15.8	15.5	**	16.6

[a]I = incandescent, F = fluorescent.

[b]Appendix A.

*(P<.05).

**(P<.01).

APPENDIX E-10. EFFECT OF PACKAGING FILM, FREEZING TEMPERATURE, DISPLAY TEMPERATURE AND LIGHTING ON FROZEN LAMB CHOP MEAN PERCENT REFLECTANCE AT 630mu

Time[b]	Film				Freeze Temp.				Display Temp.				Lighting[a]			
	L-300		Saran		-40°C		-26°C		-29°C		-21°C		I		F	
2	26.1	**	24.2													
3	25.9		25.3		29.0	**	22.6									
4	24.8		24.4		27.6	**	21.6		25.4	**	23.8		24.5		24.7	
5	23.2	*	24.5		26.8	**	21.0		24.5	*	23.3		23.6		24.2	
6	22.0	**	24.0		24.7	**	21.3		23.9	**	22.1		22.8		23.2	
7	22.4	**	23.8		24.0	**	22.2		24.8	**	21.4		22.4	**	23.8	
8	24.0	**	25.7		26.8	**	23.0		26.2	**	23.6		24.3	**	25.5	
9	15.6	**	16.6		16.2		16.0		16.3		15.9		15.5	**	16.8	

[a]I = incandescent, F = fluorescent.

[b]Appendix A.

*(P<.05).

**(P<.01).

APPENDIX E-11. EFFECT OF PACKAGING FILM, FREEZING TEMPERATURE, DISPLAY TEMPERATURE AND LIGHTING ON FROZEN LAMB CHOP MEAN REFLECTANCE RATIO 474mu/525mu

Time[b]	Film				Freeze Temp.				Display Temp.				Lighting[a]			
	L-300		Saran		-40°C		-26°C		-29°C		-21°C		I		F	
2	1.21	**	1.31													
3	1.12		1.12		1.12		1.13									
4	1.06	**	1.22		1.13		1.14		1.14		1.13		1.13		1.14	
5	1.08	**	1.21		1.13	**	1.16		1.16	**	1.13		1.14	*	1.15	
6	1.10	**	1.17		1.13	*	1.15		1.15		1.13		1.12	**	1.16	
7	1.09	**	1.14		1.11		1.13		1.12		1.11		1.10	**	1.14	
8	1.12	**	1.19		1.13	**	1.18		1.17	**	1.14		1.13	**	1.19	
9	1.10		1.10		1.10		1.10		1.11	*	1.09		1.09		1.11	

[a]I= incandescent, F = fluorescent.

[b]Appendix A.

*(P<.05).

**(P<.01).

APPENDIX E-12. EFFECT OF PACKAGING FILM, FREEZING TEMPERATURE, DISPLAY TEMPERATURE AND LIGHTING ON FROZEN LAMB CHOP MEAN REFLECTANCE RATIO 572mu/525mu

Time[b]	Film		Freeze Temp.		Display Temp.		Lighting[a]	
	L-300	Saran	-40 C	-26 C	-29 C	-21 C	I	F
2	0.81 **	0.83						
3	0.92	0.92	0.91	0.92				
4	0.93	0.92	0.92	0.93	0.93	0.92	0.92	0.93
5	0.98 **	0.94	0.95	0.95	0.97	0.96	0.96	0.97
6	1.01 **	0.96	0.99	0.98	0.99	0.98	0.98	0.99
7	1.00 **	0.98	1.00 **	0.98	0.99	0.99	1.00 **	0.98
8	1.01 **	0.97	1.00 **	0.98	0.98 **	1.00	1.00 **	0.97
9	1.00 **	0.94	0.98	0.96	0.97	0.96	0.98 *	0.95

[a]I = incandescent, F = fluorescent.

[b]Appendix A.

*(P<.05).

**(P<.01).

APPENDIX F-1. F-VALUES[a] FOR POSITION AND TREATMENT EFFECTS ON WEIGHT OF FROZEN LAMB CHOPS

	Time[b]								
	1	2	3	4	5	6	7	8	9
Position[c]	25.91**								
Orthogonal[d]									
1									
2									
3									
4									
5									
6				4.18*	4.19*	4.19*	4.19*	4.25*	4.31*
7									
8									
9									
10									
11				4.57*	4.58*	4.58*	4.56*	4.70*	4.75*
12									
13									
14									
15									

[a]Only significant values listed. *(P<.05). **(P<.01).

[b]Appendix A.

[c]Right vs. left side of loin.

[d]Appendix B.

APPENDIX F-2. F-VALUES[a] FOR POSITION AND TREATMENT EFFECTS ON VISUAL SCORE OF FROZEN LAMB CHOPS

	Time[b]								
	1	2	3	4	5	6	7	8	9
Position[c] Orthogonal[d]									
1			11.74**	74.31**	111.87**	110.07**	63.04**	47.51**	6.68*
2				4.21*			9.22**	9.82**	4.47*
3		15.49**		17.99**			6.60**		4.47*
4				25.63**	22.65**	12.88**	5.45*	6.28*	10.82**
5									
6							4.42*		
7									
8									
9						4.88*			
10									
11									
12									
13									
14									
15									

[a]Only significant values listed. *(P<.05). **(P<.01).

[b]Appendix A.

[c]Right vs. left side of loin.

[d]Appendix B.

APPENDIX F-3. F-VALUES[a] FOR POSITION AND TREATMENT EFFECTS ON PERCENT REFLECTANCE AT 474mu OF FROZEN LAMB CHOPS

	Time[b]								
	1	2	3	4	5	6	7	8	9
Position[c] Orthogonal[d]									
1			9.67**	54.09**	37.42**	7.61**		58.67**	
2				9.67**		8.12**	33.79**	30.88**	
3				18.89**	13.94**	10.27**			
4								7.40**	7.00**
5									
6									
7									
8									
9						10.66**	5.32*	3.98*	
10									
11									
12									
13									
14									
15									

[a]Only significant values listed. *(P<.05). **(P<.01).

[b]Appendix A.

[c]Right vs. left side of loin.

[d]Appendix B.

APPENDIX F-4. F-VALUES[a] FOR POSITION AND TREATMENT EFFECTS ON PERCENT REFLECTANCE AT 525mu OF FROZEN LAMB CHOPS

	Time[b]								
	1	2	3	4	5	6	7	8	9
Position[c]									
Orthogonal[d]									
1			7.83**	49.12**	37.17**	9.64**		70.16**	
2				7.33**		5.11**	18.43**	15.00**	
3									
4									4.24*
5									
6									
7									
8							4.71*		
9						8.21**	4.01*		
10									
11									
12									
13									
14						5.51*			
15									

[a]Only significant values listed. *(P<.05). **(P<.01).

[b]Appendix A.

[c]Right vs. left side of loin.

[d]Appendix B.

APPENDIX F-5. F-VALUES[a] FOR POSITION AND TREATMENT EFFECTS ON PERCENT REFLECTANCE AT 538mu OF FROZEN LAMB CHOPS

	Time[b]								
	1	2	3	4	5	6	7	8	9
Position[c]									
Orthogonal[d]									
1			4.59**	27.41**	21.82**	4.21*		65.60**	
2				7.84**		6.12*	18.96**	14.98**	
3									
4									4.25*
5									
6									
7									
8							4.71*		
9						11.63**	4.54*		
10									
11									
12									
13									
14						5.30*			
15									

[a]Only significant values listed. *(P<.05). **(P<.01).

[b]Appendix A.

[c]Right vs. left side of loin.

[d]Appendix B.

APPENDIX F-6. F-VALUES[a] FOR POSITION AND TREATMENT EFFECTS ON PERCENT REFLECTANCE AT 568mu OF FROZEN LAMB CHOPS

	Time[b]								
	1	2	3	4	5	6	7	8	9
Position[c] Orthogonal[d]									
1			6.12**	44.65**	32.37**	15.61**	4.16*	81.48**	
2				6.14*		4.16*	15.84**	7.69**	
3				10.44**	4.95*			4.06*	
4									
5									
6									5.77*
7									
8					4.86*	5.11*	6.55*		
9						8.44**			
10									
11									
12									
13									7.63
14						5.25*			
15									

[a]Only significant values listed. *(P<.05). **(P<.01).

[b]Appendix A.

[c]Right vs. left side of loin.

[d]Appendix B.

APPENDIX F-7. F-VALUES[a] FOR POSITION AND TREATMENT EFFECTS ON PERCENT REFLECTANCE AT 572mu OF FROZEN LAMB CHOPS

	Time[b]								
	1	2	3	4	5	6	7	8	9
Position[c]									
Orthogonal[d]									
1			5.91**	37.48**	26.16**	8.21**		81.35**	
2				7.17**		7.01**	18.47**	10.11**	
3									
4									
5									
6									
7									
8					4.10*	6.42*	6.73*		
9						10.27**			
10									
11									
12						4.18*			
13									6.35*
14						6.57*			
15									

[a]Only significant values listed. *(P<.05). **(P<.01).

[b]Appendix A.

[c]Right vs. left side of loin.

[d]Appendix B.

APPENDIX F-8. F-VALUES[a] FOR POSITION AND TREATMENT EFFECTS ON PERCENT REFLECTANCE AT 600mu OF FROZEN LAMB CHOPS

	Time[b]								
	1	2	3	4	5	6	7	8	9
Position[c]	2.61**								
Orthogonal[d]									
1			19.08**	134.66**	82.50**	50.27**	11.26**	68.33**	
2				10.63**		8.21**	25.29**	11.79**	
3		25.39**		46.80**	9.49**				
4									
5									
6									5.51*
7									
8							4.04*		
9						4.19*			
10									
11									
12						5.23*			
13									
14									
15									

[a]Only significant values listed. *(P<.05). **(P<.01).

[b]Appendix A.

[c]Right vs. left side of loin.

[d]Appendix B.

APPENDIX F-9. F-VALUES[a] FOR POSITION AND TREATMENT EFFECTS ON PERCENT REFLECTANCE AT 610mu OF FROZEN LAMB CHOPS

	Time[b]								
	1	2	3	4	5	6	7	8	9
Position[c]	2.95**								
Orthogonal[d]									
1			25.74**	157.50**	118.31**	60.51**	12.94**	71.74**	
2				12.34**	5.39*	12.66**	33.45**	14.75**	
3		38.63**		22.66**					
4									7.10**
5									
6									4.21*
7									
8				4.73*					
9									
10									
11									
12						4.04*			
13									
14									
15									

[a]Only significant values listed. *(P<.05). **(P<.01).

[b]Appendix A.

[c]Right vs. left side of loin.

[d]Appendix B.

APPENDIX F-10. F-VALUES[a] FOR POSITION AND TREATMENT EFFECTS ON PERCENT REFLECTANCE AT 620mu OF FROZEN LAMB CHOPS

	Time[b]								
	1	2	3	4	5	6	7	8	9
Position[c]	3.20**								
Orthogonal[d]									
1			30.31**	158.47**	150.77**	61.37**	12.86**	64.77**	
2				12.77**	5.34*	17.88**	42.00**	22.39**	
3		25.43**		7.60**		7.15**		4.97*	5.54*
4									9.41**
5									
6									
7									
8									
9									
10									
11									
12						4.22*			
13									
14									
15									

[a]Only significant values listed. *(P<.05). **(P<.01).

[b]Appendix A.

[c]Right vs. left side of loin.

[d]Appendix B.

APPENDIX F-11. F-VALUES[a] FOR POSITION AND TREATMENT EFFECTS ON PERCENT REFLECTANCE AT 630mu OF FROZEN LAMB CHOPS

	Time[b]								
	1	2	3	4	5	6	7	8	9
Position[c]	2.81**								
Orthogonal[d]									
1			32.33**	160.92**	132.36**	59.78**	12.74**	56.06**	
2				12.12**	5.98*	19.06**	47.05**	26.30**	
3		21.32**			6.79*	20.28**	8.23**	10.70**	7.21**
4							6.88**	5.21*	9.92**
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									

[a]Only significant values listed. *(P<.05). **(P<.01).

[b]Appendix A.

[c]Right vs. left side of loin.

[d]Appendix B.

APPENDIX F-12. F-VALUES[a] FOR POSITION AND TREATMENT EFFECTS ON REFLECTANCE RATIO 474mu/525mu OF FROZEN LAMB CHOPS

	Time[b]								
	1	2	3	4	5	6	7	8	9
Position[c]	2.28**								
Orthogonal[d]									
1					8.58**	5.57*		45.54**	
2					11.96**			10.75**	4.00*
3		41.20**		435.14**	264.67**	58.04**	27.62**	70.12**	
4					5.06*	17.73**	18.50**	47.86**	
5				4.03*					
6								4.22*	
7									
8					16.36**	4.01*	14.52**	11.86**	
9									
10									
11									5.28*
12					8.06**				
13							4.34*		
14									
15									

[a]Only significant values listed. *(P<.05). **(P<.01).

[b]Appendix A.

[c]Right vs. left side of loin.

[d]Appendix B.

APPENDIX F-13. F-VALUES[a] FOR POSITION AND TREATMENT EFFECTS ON REFLECTANCE RATIO 572mu/525mu OF FROZEN LAMB CHOPS

	Time[b]								
	1	2	3	4	5	6	7	8	9
Position[c]									
Orthogonal[d]									
1					7.46**		9.26**	10.66**	
2								12.63**	
3		15.01**			22.66**	16.35**	5.71*	37.61**	15.84**
4							11.33**	29.11**	4.63*
5									
6					8.33**				
7									
8					4.72*	11.19**	11.92**	13.15**	
9									
10						6.72*			
11									6.08*
12									
13									
14									
15									

[a]Only significant values listed. *(P<.05). **(P<.01).

[b]Appendix A.

[c]Right vs. left side of loin.

[d]Appendix B.

FACTORS AFFECTING SHOWCASE COLOR STABILITY OF FROZEN LAMB IN TRANSPARENT FILM

by

MELVIN CHASE HUNT

B. S., Kansas State University, 1965

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

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MASTER OF SCIENCE

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KANSAS STATE UNIVERSITY
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Color stability of frozen lamb chops was studied by removing 16, 2.54 cm thick loin chops from each of nine carcasses representing three quality levels based on the marbling score of the longissimus dorsi at the 12th rib: Moderate or slightly abundant (Prime), slight or small (Choice) and practically devoid or devoid (Good). One chop per carcass was randomly assigned to one of 16 treatments which consisted of all possible combinations of 2 freezing temperatures (-40°C liquid nitrogen vs. -26°C air blast), 2 display temperatures (-29°C vs. -21°C), 2 packaging films (Saran, oxygen impermeable vs. Cryovac L-300, oxygen permeable) and 2 lighting systems (deluxe cool white fluorescent vs. incandescent with Holophane Prismatic Reflectance fixture, both at 1,076 lumens/m^2). Weight, visual score and color by reflectance spectrophotometry of each chop were obtained before and after packaging fresh, in frozen state at day 0, 1, 7, 21, 42 and 43 (unpackaged) and after thawing (day 44).

Freezing at -40°C produced significantly ($P<.05$) more desirable visual color at all time periods post-freezing. Higher reflectance at 630 mu confirmed color stability advantage ($P<.05$) for -40°C. Bleaching of color was not a problem for chops frozen in liquid nitrogen at -40°C.

Chops displayed under incandescent lighting appeared brighter ($P<.05$) in visual color at all time periods after day 1. However, reflectance data suggested more metmyoglobin

formation in chops displayed under incandescent lighting.

Brighter visual scores were generally found in fresh and frozen chops packaged in L-300 film; whereas, chops packaged in Saran possessed more desirable color ($P<.05$) after thawing and blooming. Reflectance data suggested more metmyoglobin in L-300 packages displayed 7 or more days.

Display at -21°C or -29°C did not critically affect color stability of chops displayed up to 3 weeks. Improved visual scores were noted in chops displayed at -29°C for 6 weeks display ($P<.01$) and after thawing of chops ($P<.05$). Reflectance data indicated more autoxidation of myoglobin ($P<.01$) occurred at -21°C display at all frozen display periods.

Drip losses were less in chops frozen at -40°C than -26°C. Weight loss from fresh packaged to frozen 6 weeks averaged 0.71%.

Marbling level did not affect weight loss or color stability