QUANTITATIVE MEASURES OF MARBLING AMOUNT, DISTRIBUTION AND TEXTURE AND THEIR RELATIONSHIPS TO MARBLING SCORE

by

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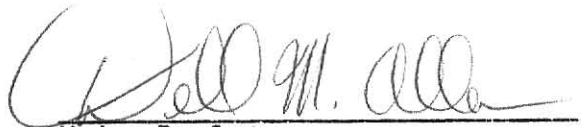
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REVIEW OF LITERATURE

Introduction

In current USDA beef grading standards, marbling is of key importance in determining quality grades. USDA beef carcass grades were initiated in 1927 largely from the efforts of the Better Beef Association Board. This group served as the initiator in response to satisfy the needs of an expanding market. Since that time USDA beef carcass grades have been used to predict the palatability traits of beef (tenderness, juiciness, flavor and overall palatability).

Since grading's inception, marbling has been identified as an important predictor of overall eating quality (Livestock and Meat Board, 1977). However, in numerous studies during recent years, the usefulness of marbling as a predictor of beef palatability has been seriously questioned.

Effect of Marbling on Beef Tenderness

Alsmeyer et al. (1959) found marbling accounted for 80% of the variation in federal beef quality grades, but only 5-6% of the variation in panel tenderness ratings. Zinn et al. (1961) reported marbling was responsible for only approximately 1% of the variation in panel tenderness, but was responsible for 80% of the final beef quality grade variation. Webb et al. (1964) and Maxwell et al. (1974) have reported

on even higher relationships between marbling score and USDA beef quality grade (r=.94).

Marbling has been considered important in predicting tenderness since it was theorized that fat cells within the muscle were supposed to distort the muscle fibers and make them more tender. Furthermore, fat supposedly spread strands of connective tissue apart between muscle fibers and muscle bundles making meat more tender since there were fewer strands of connective tissue per square inch of muscle (Moody et al., 1970). Nonetheless, in reality, USDA carcass grade has little practical relationship to the tenderness of connective tissue (Cover and Hostetler, 1960). Berry et al. (1974) also found a weak relationship between marbling score and connective tissue amount and softness.

Acceptance of the theory that marbling score is related to overall tenderness has been mixed and the focus of many studies. McBee and Wiles (1967) showed sensory tenderness increased linearly with additional marbling. Breidenstein et al. (1968) and Garcia de Siles et al. (1977) reported positive but nonsignificant trends towards greater tenderness acceptability with increasing marbling. Jennings et al. (1978), using an outside fat measure of the loin eye area in conjunction with modest and above marbling scores and slight and below scores, reported a significant ($p < .05$) increase in tenderness and a decrease in shear force values for modest and above marbling scores.

However, many researchers have stated contrary results and opinions. Cover et al. (1958) reported marbling, when measured as ether extract, only accounted for 11% of the shear force and taste panel variation and thus concluded that carcass grade was an

unsatisfactory indication of meat tenderness. Romans et al. (1965a), Walters et al. (1965) and Norris et al. (1971) reported marbling to have no significant effects on taste panel tenderness scores. Parrish (1974) stated the degree of marbling had little affect on tenderness; however, cooking loss did increase with increasing marbling score. Campion et al. (1975) reported that only 8% of the variation in taste panel tenderness could be attributed to marbling score.

Effect of Marbling on Beef Juiciness and Flavor

Marbling's effect on taste panel juiciness and flavor is also under controversy in the literature. Nelson et al. (1930) found flavor of lean much more desirable if additional fat was embedded within the musculature. Cover et al. (1962) stated juiciness comes from two components: 1) juice which is relatively free to run or be pressed out and may be lymph or any liquid remaining in the blood vessels and perhaps some capillary water; 2) juice which is absorbed water, who's availability is related to the degree of water binding properties of the meat. Goll et al. (1965) reported that juiciness and flavor were not significantly correlated to any measure of carcass fatness. This agrees with the findings of Tuma et al. (1962), Norris et al. (1971) and Parrish et al. (1974), who reported marbling had no significant effect on juiciness, flavor and overall acceptability. On the other hand, Romans et al. (1965a) reported that although flavor was not affected by marbling score, juiciness scores were significantly higher for moderately marbled steaks than for slightly marbled steaks. McBee and Wiles (1967) and Breidenstein et al. (1968) reported

that juiciness and flavor increased linearly with additional degrees of marbling. Jennings et al. (1978) stated that steaks with modest and above marbling scores were associated with higher panel juiciness scores than steaks with slight and below marbling scores. Many investigators have found slightly significant but low correlations between marbling score and panel juiciness and flavor (Field et al., 1966, 0.32 and 0.57, respectively; and Crouse et al., 1978, 0.22 and 0.27, respectively).

Effect of Marbling Score on Overall Palatability

The theory of marbling's effect on overall acceptability led Durham et al. (1961) to attempt a study which called for the injection of edible tallow directly into muscles to standardize degrees of marbling per pound of meat. Injected steaks required significantly fewer pounds of shear force when examined with the Warner-Bratzler shear apparatus. It was hypothesized that the decrease in required shear force was due to either expansion of the muscle, which reduced the number of muscle fibers per core, or possibly there was a physical tenderizing effect of the injection needle.

Francis et al. (1977) used a 806 member consumer taste panel to determine palatability differences between slight and modest marbled rib eye steaks. They concluded that the two distinct marbling levels were difficult for consumers to differentiate in steaks from young cattle, fed similarly. In an extensive study using 1,117 steers, Campion et al. (1975) reported a correlation coefficient of 0.29 between marbling and taste panel overall acceptability and came to

the conclusion that the predictive value of the current USDA Quality Grades for eating characteristics of young beef must be considered minimal.

Effect of Marbling Distribution and Marbling Texture on Beef Palatability

Little literature consideration has been given to affect of marbling distribution and texture on beef muscle eating qualities. Goll et al. (1965) showed finer textured, more evenly distributed marbling to be associated with greater tenderness. This agrees with the findings of Moody et al. (1970) who reported that finer marbling gave significantly lower Warner-Bratzler shear values. However, in the same study, Moody et al. (1970) found no significant differences in flavor, juiciness, sensory tenderness and overall satisfaction between rib eye steaks with fine and coarse textured marbling.

Effect of Marbling on Chemical and Cooking Properties

Chemical fat measures such as ether extract have been associated with marbling score. Blumer and Fleming (1959) found ether extract to be strongly related to total fat area within the loin eye steak and to the number of visible fat deposits on the steak's lean surface. Bray (1963) stated that ether extract was the most objective approach to estimating intramuscular fat, but recognized that ether extract fails to show lipid distribution and marbling texture within the muscle. Additionally, he cited that although marbling is the visible fat on the lean, ether extract includes marbling plus microscopic fat between the connective tissue strands and the intracellular lipids within the

muscle. Romans et al. (1965a) examined 80 beef rib eye steaks and found ether extract content significantly greater in steaks with moderate marbling than in steaks with slight marbling. Similar findings were reported by McBee and Wiles (1967) and Breidenstein et al. (1968) who found chemical fat values to significantly increase with increasing marbling score. Walters et al. (1965) reported a highly significant correlation coefficient of 0.91 between ether extract and marbling score. In a study examining 17 coarsely marbled rib eye steaks and 17 finely marbled rib eye steaks, both with modest marbling, Moody et al. (1970) reported no differences in ether extract amount or in percent moisture. In a more recent project, Cross (1977) found that percent chemical fat in the loin eye steak was not significantly ($p < .05$) affected by marbling, degree or by the distribution or the texture of marbling.

Cross (1977) also examined the cooking properties of these steaks. He stated that cooking time was affected by the three marbling constituents, with the fastest times associated with steaks of low amounts, uneven distributions and coarse texture. This contradicts Heldman (1975) who reported that although lean beef had a slightly higher thermal conductivity, higher marbled steaks have a lower specific heat and thus a faster heating or cooling rate. Cross (1977) reported no significant differences as to degree of doneness of the steaks regardless of amount, distribution and texture of marbling.

Effect of Marbling on Other Quality Traits

Color is an important consideration in the consumer acceptability of beef products. Romans et al. (1965b) reported a higher hue color score in steaks with moderate marbling than in steaks containing slight marbling. Moody et al. (1970) found that finer marbling was significantly ($p < .01$) associated with brighter colored lean.

Firmness of lean is also a consideration in the determination of beef eating qualities. Kropf and Graf (1959), Walter et al. (1965), McBee and Wiles (1967) and Breidenstein et al. (1968) agreed that muscle firmness significantly increased with increasing marbling degree.

Marbling Histology Within the Longissimus Muscle

Marbling amount, distribution patterns and texture have been found to vary greatly within the longissimus muscle. Carpenter et al. (1961) studied the longissimus muscle from paired pork loins and found that the right loin had a nonsignificantly lower extractable fat content than the left loin. He also cited that the loin chop at the 6th lumbar position had a $p < .05$ higher percent chemical fat than loin chops at the 7th and 13th thoracic positions. The ether extract in the 7th and 13th thoracic loin chops gave the most representative results when compared to the composite chemical fat of the whole loin. Blumer et al. (1962) compared $\frac{1}{4}$-inch cross sections of the longissimus muscle located in the 9-10-11 rib section and found that the average marbling score from a three member panel changed as much as 2 2/3 marbling degrees within the steaks from that rib section. Steaks

with the most, least, finest and coarsest marbling were, on the average, only separated by 1 3/4 inches. In addition, Blumer stated that the coarser and higher degrees of marbling were found opposite the rib, while the finer and lower amounts of marbling were located opposite those areas between the ribs. Cook et al. (1964) analyzed ½-inch longissimus steaks removed from the 6th thoracic vertebrae to the 5th lumbar vertebrae, and reported that the highest marbling scores and most uniform marbling patterns were between the 11th and 12th ribs and the marbling amount decreased and became less evenly dispersed anteriorly and posteriorly from these regions.

Similar findings were reported by Cross et al. (1975) who cited that marbling tended to be lower in amount and coarser in texture at the chuck and round than at the 12th and 13th rib cross section.

Marbling Histology Within Steaks

Blumer and Fleming (1959) reported that there was a nonsignificant, low correlation coefficient between the percent surface fat on one side of a ½-inch steak and the surface fat on the other side of the same steak. They concluded that the amount of marbling which a grader observes at the 12th rib is partially due to chance. This variation can be explained by the work of Blumer et al. (1962) who described marbling as being a tree-like structure, with the main trunk deposit being located close to or within heavy networks of blood vessels. These vessel networks are located opposite each rib. The branch deposits of the tree formation, originated at the trunk deposit and follow the capillary system into the rest of the

longissimus muscle. Reddy (1969) also cited that the number of blood vessels within a steak increase significantly with higher marbling levels. Moody and Cassens (1968) reported that fat cells accumulated and grew in close proximity to the circulatory system.

Using microscopic techniques, Carpenter et al. (1961) found that with an increase in extractable fat there was a highly significant increase in finely dispersed fat cells. Similarly, Breidenstein et al. (1968) and Cross et al. (1975) reported that an increase in marbling score corresponded to a more uniform dispersion of marbling throughout the lean surface. Additionally, Carpenter et al. (1961) reported that fat cell size was strongly related (.81) to total fat content. Moody and Cassens (1968) and Reddy (1969) agreed that an increase in marbling score corresponded to an increase in fat cell size and a greater number of fat cell masses within the muscle (deposit sites).

Romans et al. (1965a) and Covington (1968) revealed fiber diameter to be positively associated with higher degrees of marbling. However, neither researcher found any relationships between fiber diameter and tenderness measured by shear force.

Investigations examining distribution patterns within the lateral, central and medial sections of the loin eye steak have shown varying results. Moody and Cassens (1968) found that when examining steaks containing traces and small degrees of marbling that fat is deposited in the lateral region at a faster rate than within the central and medial regions. The central and medial deposits increase at a similar rate. However, as the marbling score increases from a small to a

moderate degree of marbling, the central section doubles in percent fat content while the quantities of marbling in the medial and lateral sections remained similar. Using a similar ocular grid to count fat deposit number and measure the area of fat within the 9th rib steak, as in the previous study, Reddy (1969) reported conflicting results. He found that as marbling increased from small to moderate marbling, histological fat content increased but did not change its distribution pattern. The lateral section had ($p < .05$) the highest amount of surface fat while the central section had the lowest marbling quantities of the three regions.

Subjectivity of Marbling

The large variation in marbling within the longissimus muscle and even within each steak has been cited in the literature as an obstacle in achieving homogeneous results for evaluating beef eating quality.

Other researchers have stated that the subjectivity of marbling, by itself, could account for the different results when comparing similar quality of beef.

In a 1978 Report to the Congress by the General Accounting Office, it was reported that in a survey of 29 meat packing plants visited in six USDA meat grading main station supervisory areas, 21% of the carcasses reviewed were incorrectly graded for yield grade, quality grade or both. This report also recognized the existence of differences in the interpretation of marbling levels between the six supervisory main station areas. This agrees with Maxwell et al. (1976) in which a highly ($p < .01$) significant location X trial interaction was reported

relative to quality grade. In this study, carcasses with the same quality factors received different grades.

Objective Measurements of Marbling

Realizing these inconsistencies exist among trained graders who grade carcasses on a daily basis, it is conceivable that even greater inconsistencies and inaccuracies exist between researchers who do not evaluate marbling on a continuous basis.

Because of this, there have been attempts to develop objective measurements of marbling score and its three constituents (amount, distribution and texture).

In 1957, Wellington and Stouffer made an attempt to standardize the degrees of marbling by taking four photographs (which ranged in distribution and texture of marbling) of each degree of marbling. Photographs ranged from devoid to extremely abundant degrees of marbling.

Lewis et al. (1958) used a photomicrographic technique to measure marbling in turkeys. However, this procedure seemed too tedious to be used in conjunction with the larger beef muscle.

Orme et al. (1958) reported that specific gravity was a successful measure of marbling and was highly related to steak chemical fat. However, this method fails to take into account marbling distribution and marbling texture. In a later study, Cole et al. (1960) found a -.77 correlation coefficient ($p < .01$) between marbling score and specific gravity. They also stated that specific gravity only accounted for 10-20% of the variation in beef eating quality characteristics.

Blumer and Fleming (1959) used a bacterial culture counter to measure the area of fat on the loin eye surface and to count the number of fat deposits which were visible on the muscle surface. They reported correlation coefficients of .81 and .82 ($p < .01$) between ether extract and fat area and number of fat deposits on the lean surface, respectively.

Cook and Bray (1961) developed a macrophotographic technique to measure marbling amount and marbling distribution. They used a positive transparency of a photograph taken of a rib steak and measured the light transmittance through the transparency. They obtained a correlation coefficient of .88 ($p < .01$) between percent light transmittance and marbling score and .83 ($p < .01$) between percent chemical fat and light transmittance. However, in this study, they only examined steaks with large differences in marbling degree.

Literature Cited

Alsmeyer, R.H., A.Z. Palmer, M. Koger and W.G. Kirk. 1959. The relative significance of factors influencing and/or associated with beef tenderness. Proc. Meat Ind. Res. Conf. 11:85.

Berry, B.W., G.C. Smith and Z.L. Carpenter. 1974. Beef carcass maturity indicators and palatability attributes. J. Anim. Sci. 23:1027.

Blumer, T.N., H.B. Craig, E.A. Pierce, W.W.G. Smart and M.B. Wise. 1962. Nature and variability of marbling deposits in longissimus dorsi muscles of beef carcasses. J. Anim. Sci. 21:935.

Blumer, T.N. and H.P. Fleming. 1959. A method for the quantitative estimation of marbling in the beef rib eye muscle. J. Anim. Sci. 18:959.

Bray, R.W. 1963. Symposium on Feed and Meats Terminology IV Quantitative Measures of Carcass Composition and Qualitative Evaluation. R.W. Bray.

Breidenstein, B.B, C.C. Cooper, R.G. Cassens, G. Evans and R.W. Bray. 1968. Influence of marbling and maturity on the palatability of beef muscle. J. Anim. Sci. 28:1532.

Campion, D.R., J.D. Crouse and M.E. Dikeman. 1975. Predictive value of USDA beef quality grade factors for cooked meat palatability. J. Food Sci. 40:1225.

Carpenter, Z.L., R.W. Bray, E.J. Brinskey and D.H. Traeder. 1961. Intramuscular fat distribution in the longissimus dorsi of paired pork loins. J. Anim. Sci. 20:603.

Cole, J.W., W.R. Backus and L.E. Orme. 1960. Specific gravity as a measure of beef eating quality. J. Anim. Sci. 19:167.

Cook, C.F. and R.W. Bray. 1961. A microphotographic technique for the quantitative determination of marbling and its relative distribution in meats. Food Technol. 15:540.

Cook, C.F., R.W. Bray and K.G. King. 1964. Variation in the quantity and distribution of lipid in the bovine longissimus dorsi. J. Anim. Sci. 23:329.

Cover, S. and R.L. Hostetler. 1960. Beef tenderness by new methods. Texas Agr. Exp. Sta. Bull. 947.

Cover, S., G.T. King and O.D. Butler. 1958. Effect of grade and fatness on tenderness of meat from steers of known history. Texas Agr. Exp. Sta. Bull. 889.

Cover, S., S.J. Ritchey and R.L. Hostetler. 1962. Tenderness of beef. II. Juiciness and softness components of tenderness. J. Food Sci. 27:476.

Covington, R.C. 1968. A study of various chemical and histological characteristics of beef muscle and their relationship to palatability. Master's Thesis. Kansas State University, Manhattan, Kansas.

Cross, H.R. 1977. Effect of amount, distribution and texture of marbling on cooking properties of beef longissimus. J. Food Sci. 42:182.

Cross, H.R., H.C. Abraham and Eunice M. Knapp. 1975. Variation in the amount, distribution and texture of intramuscular fat within muscles of the beef carcass. J. Anim. Sci. 41:1618.

Crouse, J.D., G.M. Smith and R.W. Mandigo. 1978. Relationship of selected beef carcass traits with meat palatability. J. Food Sci. 43:152.

Durham, R.M., H. Elliot and D.W. Zinn. 1961. Technique for marbling beef carcasses. J. Anim. Sci. 20:916. (Abstr.).

Field, R.A., G.E. Nelms and C.O. Schoonover. 1966. Effects of age, marbling and sex on palatability of beef. J. Anim. Sci. 25:360.

Francis, J.J., J.R. Romans and H.W. Norton. 1977. Consumer rating of two beef marbling levels. J. Anim. Sci. 45:67.

Dept. of Agr. Beef Grading: Accuracy and uniformity need to be improved. Comptroller General Report to the Congress of the U.S. CED 78-141. July 21, 1978.

Carcia-de-Siles, J.L., J.H. Ziegler and L.L. Wilson. 1977. Effects of marbling anc conformation scores on quality and quantity characteristics of steer and heifer carcasses. J. Anim. Sci. 44:36.

Goll, D.E., A.F. Carlin, L.P. Anderson, E.A. Kline and M.J. Walter. 1965. Effect of marbling and maturity on beef muscle characteristics. II. Physical, chemical and sensory evaluation of steaks. Food Technol. 19:163.

Heldman, D.R. 1975. Heat transfer in meat. Proc. Recip. Meat Conf. 1975:314.

Jennings, T.G., B.W. Berry and A.L. Joseph. 1978. Influence of fat thickness, marbling and length of aging on beef palatability and shelf life characteristics. J. Anim. Sci. 46:658.

Kropf, P.H. and R.F. Graf. 1959. Effect of grade, weight and class of beef carcasses on certain chemical and sensory evaluation of beef quality. Food Technol. 13:721.

Lewis, P.K., C.J. Brown and M.C. Heck. 1977. Fiber diameter, sarcomere length and tenderness of certain muscles of crossbred steers. J. Anim. Sci. 45:254.

Maxwell, D.R., M.P. Hoffman, H.C. Self, D.G. Topel and P.J. Berger. 1974. Beef quality grade: Factor analysis and estimation. J. Anim. Sci. 39:172.

Maxwell, D.R., M.P. Hoffman, D.G. Topel and H.L. Self. 1976. Effect of slaughter location and quality factors on quality grades. J. Anim. Sci. 42:565.

McBee, J.L., Jr. and J.A. Wiles. 1967. Influence of marbling and carcass grade on the physical and chemical characteristics of beef. J. Anim. Sci. 26:701.

Moody, W.G. and R.G. Cassens. 1968. A quantitative and morphological study of bovine longissimus fat cells. J. Food Sci. 33:47.

Moody, W.G., J.A. Jacobs and J.D. Kemp. 1970. Influence of marbling texture on beef rib palatability. J. Anim. Sci. 31:1074.

National Livestock and Meat Board. 1977. Meat Evaluation Handbook. National Livestock and Meat Board, Chicago, Illinois.

Nelson, P.M., B. Towe and M.D. Helser. 1930. Influence of the animal's age upon the quality and palatability of beef. I. Carcass yield and quality of meat cuts. II. The roast beef preparation. Agr. Exp. Sta. Iowa St. Col. of Ag. and Mech. Arts Bull. 272.

Norris, H.L., D.L. Harrison, L.L. Anderson, B. Von Welck and H.J. Tuma. 1971. Effects of physiological maturity of beef and marbling of rib steaks on eating quality. J. Food Sci. 36:440.

Orme, L.E., A.M. Pearson, L.J. Bratzler and W.T. Magee. 1958. Specific gravity as an objective measure of marbling. J. Anim. Sci. 17:693.

Parrish, F.C., Jr. 1974. Relationship of marbling to meat tenderness. Proc. Meat Ind. Res. Conf. 1974:117.

Reddy, B.G. 1969. The relationship of intramuscular fat and the vascular system to beef tenderness. Master's Thesis. Kansas State University, Manhattan, Kansas.

Romans, J.R., H.J. Tuma and W.L. Tucker. 1965a. Influence of carcass maturity and marbling on the physical and chemical characteristics of beef. I. Palatability, fiber diameter and proximate analysis. J. Anim. Sci. 24:681.

Romans, J.R., H.J. Tuma and W.L. Tucker. 1965b. Influence of carcass maturity and marbling on the physical and chemical characteristics of beef. II. Muscle pigment and color. J. Anim. Sci. 24:684.

Tuma, H.J., J.H. Vanalbe, P.R. Withier and R.L. Henrickson. 1962. Relationship of fiber diameter to tenderness and meatiness as influenced by bovine age. J. Anim. Sci. 21:33.

Walters, M.J., D.E. Goll, E.A. Kline, L.P. Anderson and A.F. Carlin. 1965. Effect of marbling and maturity on beef muscle characteristics. I. Objective measurements of tenderness and chemical properties. Food Technol. 19:841.

Webb, N.B., O.J. Kahlenberg and H.D. Nauman. 1964. Factors influencing beef tenderness. J. Anim. Sci. 23:1027.

Wellington, G.H. and J.R. Stouffer. 1959. Beef marbling--its estimation and influence on tenderness and juiciness. N.Y. (Cornell) Agric. Exp. Sta. Bull. 941.

Zinn, D.W., H. Elliott, D. Burnett and R.M. Durham. 1961. Evaluation of USDA beef grading methods. J. Anim. Sci. 20:922.

SUMMARY

Forty-eight rib steaks were used to analyze relationships between marbling score and measured marbling amount, distribution and texture.

These three measurements were calculated using a transparency of graph paper that had squares 1.27mm^2 in area. A dot was placed in each square, within the loin eye, which was at least one-half filled with fat (fat squares). The total area of fat squares was calculated giving a measurement of marbling amount. Distribution was measured by drawing a rectangle around the loin eye and then dividing the rectangle into eight equal sized parts (octants). The area of fat squares in each octant was measured out then divided by the loin eye area in each octant to provide a measure of marbling distribution. Marbling texture was measured by computing the average fat deposit size and counting the number of fat deposits on the loin eye surface. Average fat deposit size was measured by dividing the area of fat on the loin eye by the number of longissimus (LD) fat deposits.

Simple correlation coefficients between marbling score and measurements of marbling amount and texture were ($p < .0001$) 0.94 (percent surface fat/loin eye area), 0.84 (number of fat deposits) and 0.68 (average fat deposit size). Correlation coefficients between chemical fat and marbling score (0.83), percent surface fat (0.76), average fat deposit size (0.54) and total number of fat deposits (0.64) were all highly significant ($p < .0001$).

To study marbling distribution, marbling deposition rates and marbling amounts were measured in each octant of the loin eye. In carcasses with lower marbling scores there appears to be a trend towards a faster fat deposition rate and a greater amount of marbling in the octants of the medial half of the loin eye. However, after a small degree of marbling is reached, there tends to be a change towards a more rapid deposition and a higher percent of marbling in the lateral half of the loin eye.

With this information on marbling's three constituents, a regression equation, that predicts marbling score, was devised and tested. This prediction equation accounts for 92% of the variation in marbling score. That regression equation is:

-133.168 + 69.444 (Adjusted Fat Thickness)
+25.0244 (% Loin Eye Surface Fat)
+.29353 (Hot Carcass Wt.)
+1.107 (Number of Loin Eye Surface Fat Deposits).

INTRODUCTION

Quality grading of beef carcasses is and has been a highly subjective skill ever since the original beef grading standards were written. Yield grading of beef carcasses, although developed from objective measures, is also highly subjective due to the speed at which grading is done in standard commercial practice. With these facts in mind, Kansas State University began the design of an instrument which could provide a quick, reliable and objective measure of both quality and yield grades. The device consists of a video camera and a computer digitizer, which can differentiate between fat, muscle and bone. Although not yet fully developed, the computerized quality grading system has the capability of measuring percent loin eye surface fat, recognize marbling distribution patterns and calculate number of fat deposits and average fat deposit size on the cross-sectional loin eye surface. From this information the instrument will be able to arrive at a final marbling score and subsequent quality grade.

This study has a two-fold purpose:

1) develop an understanding of the relationships which exist between marbling score and marbling's three constituents (amount, distribution and texture) and

2) using this information, develop a prediction equation which can be used in conjunction with the grading instrument, to accurately, consistently and objectively measure marbling score.

EXPERIMENTAL PROCEDURE

Product Origin

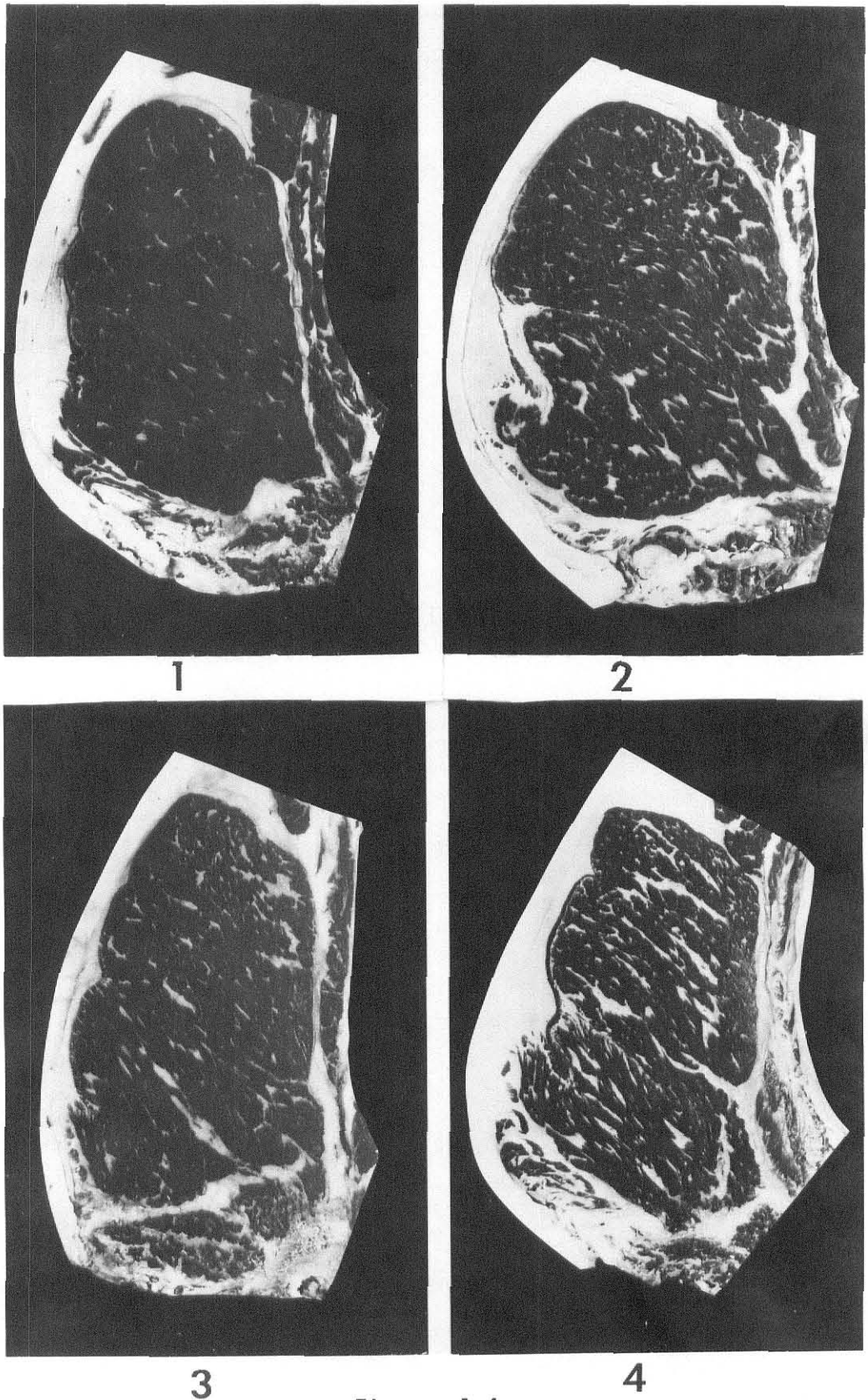
The 12th rib LD cross section from 48 beef carcasses were used in this study to analyze the singular and combined contributions of marbling amount, distribution and texture on the interpretation of overall marbling score.

A minimum of a ½-inch steak sample was removed from each 12th rib LD cross-sectional area. Each steak sample included the original lean surface presented for grading and this was used for taking measurements and scores of marbling amount, texture and distribution. Samples were chosen such that a large variation in marbling degree was included in the study.

Carcasses were conventionally chilled at 2°C, and at 48 hours postmortem a three member grading panel evaluated the carcasses' 12th rib longissimus cross-sectional lean surface for marbling degree and marbling texture. Panel members estimated the marbling score according to USDA marbling standards to the nearest 5% of a marbling degree. A subjective marbling texture score was placed on each steak using a scale of 1 (Fine) to 4 (Coarse) (Figures 1-4). 12th rib fat thickness and loin eye area were also measured. Additionally, adjusted 12th rib fat thickness, carcass bone maturity and percent kidney, heart and pelvic fat were estimated on each carcass

THIS BOOK CONTAINS NUMEROUS PICTURES THAT ARE ATTACHED TO DOCUMENTS CROOKED.

THIS IS AS RECEIVED FROM CUSTOMER.



Figures 1-4

Marbling Coarseness Scores

by an experienced grader. With the exception of marbling texture, carcass traits were evaluated as described in the 1973 USDA grading standards. Carcass maturity fell into the A and B (young) maturity groups (USDA, 1973). Bone maturity was estimated to the nearest 5% of a maturity level.

Marbling Amount

An adaption of the procedure described by Blumer and Fleming (1959) was used to objectively measure the amount of marbling present in each steak sample.

A transparency of graph paper with squares 1.27mm^2 in area was laid over each steak and the border of the longissimus muscle was traced as shown in Figure 5.

A measurement of the amount of visible fat within the loin eye was established by placing a dot in and counting each 1.27mm^2 square which was at least half filled with fat (Figure 5). To calculate the amount of marbling present on the 12th rib LD surface the formula

$$\text{Area of fat in the loin eye } (cm^2) = \frac{\text{Total number of fat squares}}{157.5 \text{ squares/cm}^2}$$

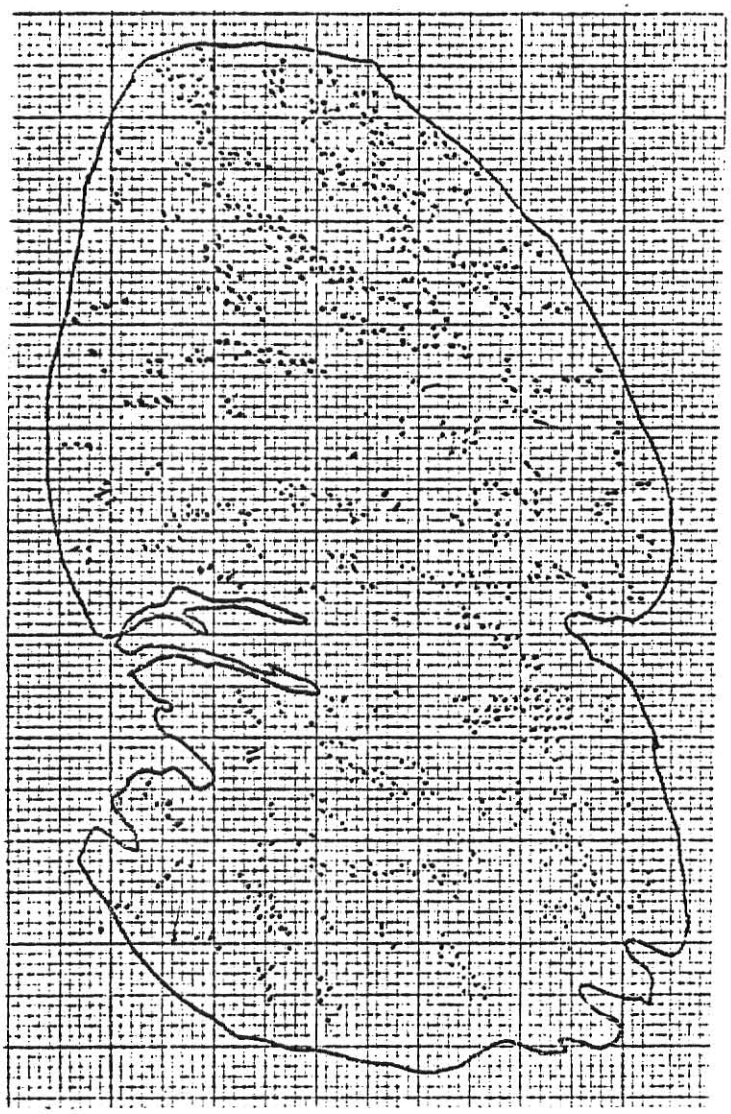
was used.

Marbling Distribution

To quantify marbling distribution and study its effect on marbling score, a rectangle was constructed such that the width and the length of the rectangle encompassed the maximum width and maximum length of the loin eye. The area of the rectangle was measured by multiplying

(LATERAL)

Fat Cover
(DORSAL)



Rib
(VENTRAL)

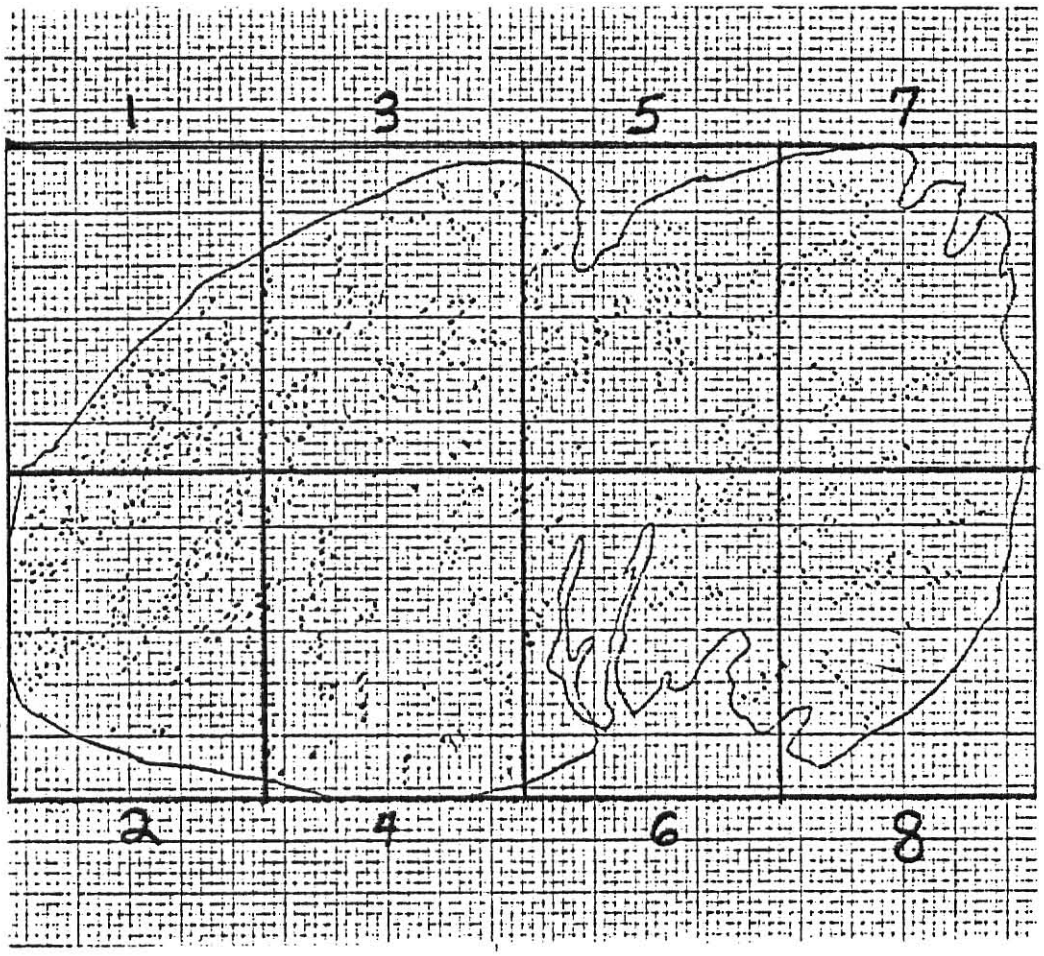
Spinous Process
(MEDIAL)

FIGURE 5

MARBLING AMOUNT DETERMINATION

Rib

(VENTRAL)



(MEDIAL)

(DORSAL)
Fat Cover

FIGURE 6

MARBLING DISTRIBUTION DETERMENATION

its length times its width. Then the rectangle was divided into eight equal sized units (an octant). The octant was developed by dividing the width of the rectangle in half and separating the length into four equidistant parts. An example of this procedure can be found in Figure 6. The area of fat present in each octant was measured using the same procedure used to calculate the total fat area in the entire LD.

$$\text{Fat area in the section} = \frac{\text{Number of fat squares in the section}}{157.5 \text{ squares/cm}^2}$$

Since the loin eye area was not constant in the eight octants (Figure 6), the quantity of marbling found in each section was weighted using the amount of loin eye present in that octant.

Marbling Coarseness (Figure 7)

An objective measure of the number of fat deposits and the average fat deposit size was measured within the entire loin eye and within each octant. The fat deposit number was computed by physically counting each visible fat deposit on the loin eye surface. The average fat deposit size is calculated by using the formula:

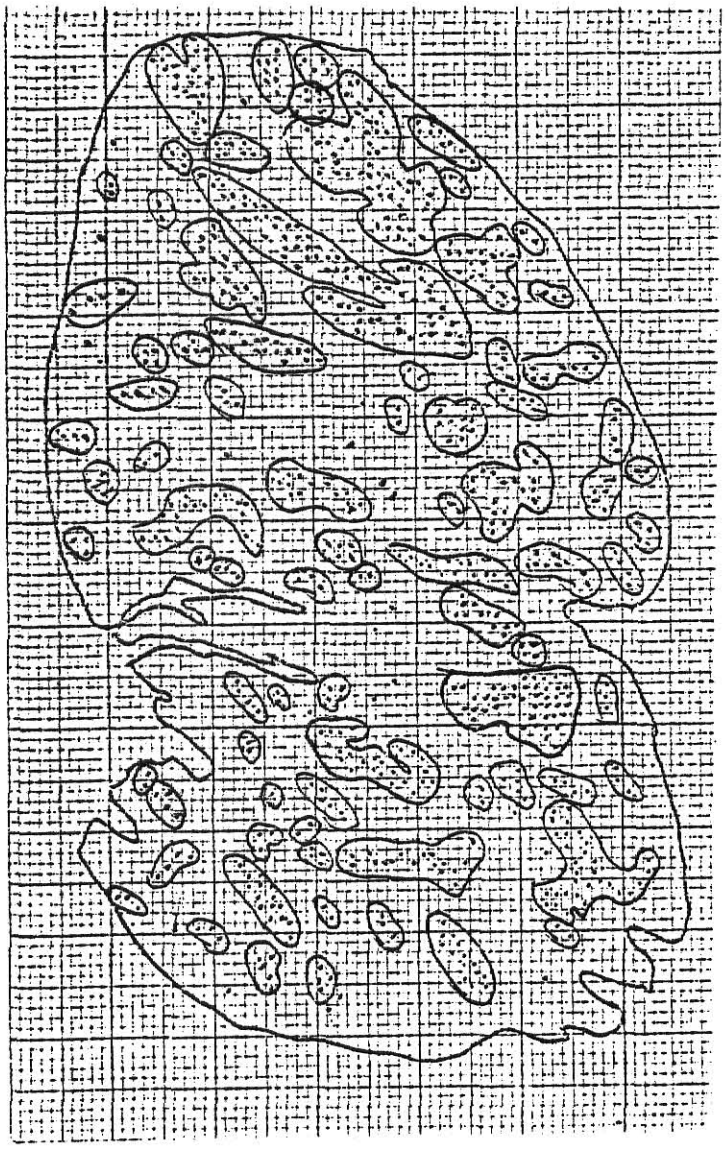
$$\text{Area of fat (cm}^2\text{)/number of fat deposits.}$$

Chemical Analysis

Many researchers have reported a large location variation in marbling content within the longissimus muscle (Blumer and Fleming,

(LATERAL)

Fat Cover
(DORSAL)



Rib
(VENTRAL)

(MEDIAL)
Spinous Process

FIGURE 7

MARBLING TEXTURE DETERMINATION

1959; Cook et al., 1964; Reddy, 1968). In order to limit this source of variation, a 1/10-inch slice was removed from each sample at the steak's original grading surface. This sample was then analyzed for chemical fat using the following procedure:

Each slice was finely minced with a hand knife and then the samples were frozen at -26°C until chemical analysis could be done. Ether extract and moisture determinations were done using AOAC (1980) procedures.

Statistical Analysis

Simple correlation coefficients were calculated to determine the relationships of marbling to other carcass traits studied. General linear modeling, Duncan's mean separation technique and contrast procedures were used to examine marbling distribution patterns. Multiple regression analysis combined with step-wise reduction procedures were used to establish and evaluate prediction equations for marbling. Means and standard deviations were calculated in order to compare chemical fat and measured loin eye surface fat. With the exception of Duncan's mean separation technique (Duncan, 1975), statistical procedures were done as described by Snedecor and Cochran (1967).

RESULTS AND DISCUSSION

Correlation Coefficients

All simple correlation coefficients between the carcass traits studied can be found in Table 1.

Marbling amount as objectively measured had a highly significant relationship to marbling score (0.94, $p < .0001$). Moody and Cassens (1968) reported a 0.57 ($p < .05$) correlation coefficient between the same two traits. Reddy (1969) similarly stated that the percent of histological fat on the loin eye surface increased with an increase from small to moderate marbling scores.

Marbling texture (fineness vs. coarseness) is a factor considered by graders when scoring marbling. Number of fat deposits on the total cross-sectional area of the loin eye surface as well as number per cm^2 and average fat deposit size and average fat deposit size per cm^2 of loin eye were measured to investigate marbling texture's relationship with marbling score. Simple correlation coefficients between marbling score and these measured traits were .84, .80, .68, and .66, respectively, all of which were highly significant ($p < .0001$). These results are in agreement with Moody and Cassens (1968) who stated that the fat deposit size within the loin eye becomes larger as marbling degree increases. However, a subjective marbling texture (fineness vs. coarseness) score was correlated with marbling score

TABLE 1

Correlation Coefficients Comparing Marbling Score and Related Traits

	1	2	3	4	5	6	7	8	9	10	11	12
1) Marbling Score	----											
	----											
2) L.E. Meas. Surface Fat %	.94	----										
	.0001	----										
3) Meas. No. of Fat Dep.	.84	.84	----									
	.0001	.0001	----									
4) Meas. No. of Fat Dep/LEA	.80	.83	.96	----								
	.0001	.0001	.0001	----								
5) Meas. Ave. Fat Dep. Size	.68	.75	.32	.28	----							
	.0001	.0001	.03	.06	----							
6) Meas. Ave. Fat Dep. Size/LEA	.66	.76	.34	.35	.94	----						
	.0001	.0001	.02	.02	.0001	----						
7) Marbling Texture	.26	NS	NS	NS	.41	NS	----					
	.08				.004		----					
8) Chemical Fat LD %	.83	.76	.64	.65	.54	.59	NS	----				
	.0001	.0001	.0001	.0001	.0001	.0001		----				
9) Moisture LD %	-.77	-.72	-.59	-.62	-.49	.55	-.26	-.93	----			
	.0001	.0001	.0001	.0001	.0004	.0001	.08	.0001	----			
10) Hot Carcass Weight	-.23	-.39	-.48	-.57	NS	NS	.30	NS	NS	----		
	.11	.006	.0006	.0001			.04			----		
11) Adj. Fat Thickness	.25	NS	NS	NS	.27	NS	.52	.26	-.25	.57	----	
	.09				.07		.0002	.08	.08	.0001	----	
12) Actual Fat Thickness	NS	NS	NS	NS	NS	NS	.42	NS	NS	.57	.94	----
							.003			.0001	.0001	----

at 0.26 ($p < .07$). Thus, it seems that graders are biased against coarse marbling and tend to discriminate against them to some extent when subjectively scoring marbling. This, despite the fact that the measured size of the fat deposit increases with increasing marbling score (0.68, Table 1), helps explain why total surface fat on the cross-sectional loin eye area is not perfectly related to marbling score.

Marbling score was correlated with percent ether extract at 0.83 and with percent moisture at -.77 ($p < .001$), respectively.

Many researchers have found similar findings between ether extract and marbling (Blumer and Fleming, 1959, 0.81, $p < .01$; Walters et al., 1965, 0.91, $p < .01$; Dikeman et al., 1972, 0.79, $p < .01$; and Campion et al., 1975, 0.78, $p < .01$).

Similarly, significant correlation coefficients were found between percent chemical fat and objective measures of marbling amount and marbling texture. The strongest relationship (0.76, $p < .0001$) was found between percent chemical fat and percent of measured surface fat on the loin eye. Number of fat deposits, number of deposits per cm^2 of loin eye area, average deposit size and average fat deposit size per cm^2 of loin eye correlation coefficients with percent ether extract were all highly significant ($p < .0001$) at .64, .65, .54 and .59, respectively. This agrees with Blumer and Fleming (1959) who reported a correlation coefficient ($p < .01$) between ether extract and fat area per square inch of loin eye surface of 0.81 and a 0.82 coefficient between chemical fat and number of measured fat deposits per square inch of loin eye surface area.

Marbling score was nonsignificantly related to hot carcass weight (-.23). This relationship was undoubtedly due to the fact that those carcasses with the higher marbling scores were also some of the lighter weight carcasses.

A positive correlation coefficient ($p < .10$) of 0.25 was found between adjusted 12th rib fat thickness and marbling score. Campion et al. (1975) reported a similar correlation coefficient of 0.27 ($p < .01$) between the two traits.

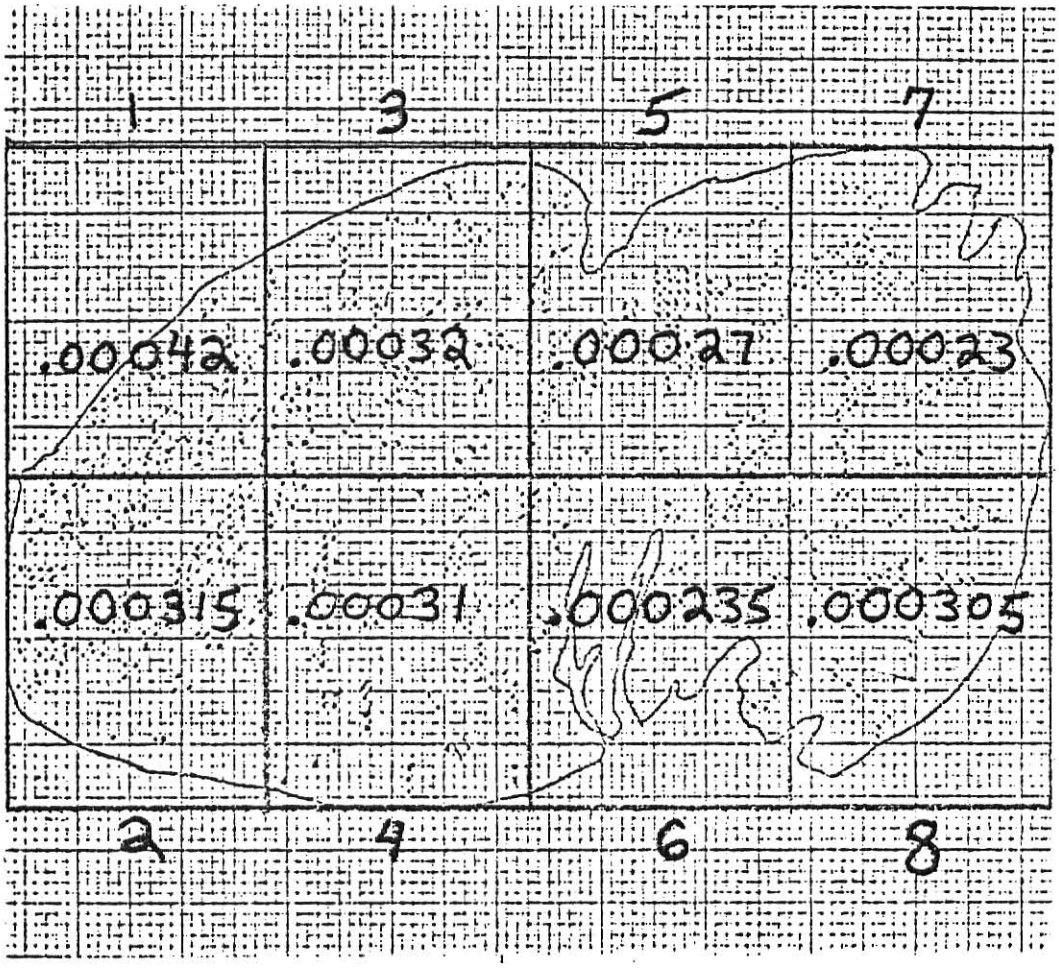
The total amount of measured fat on the loin eye surface showed the highest relationship with marbling score (0.94, $p < .0001$). Measured marbling amount was also strongly related to the number of fat deposits ($r=0.84$, $p < .0001$) and to the average fat deposit size, which increased with an increase in total percent fat on the cross-sectional loin eye surface ($r=0.74$, $p < .0001$).

Marbling Distribution Patterns

Figure 8 is an example of how each surface was divided into eight equal size sections (octants). The rate of fat deposition related to increasing marbling score on a linear slope is identified in each octant (Figure 8). It should be noted that the rate of deposition was significantly greatest ($p < .04$) in octant 1. There were no other significant differences among octants; however, there appears to be a trend towards a greater rate of fat deposition on the lateral half of the loin eye surface than on the medial half. To reinforce this hypothesis, marbling scores were separated into four categories: 1) slight and below, 2) small, 3) modest, and 4) moderate and above.

Rib

(VENTRAL)



(MEDIAL)

(DORSAL)
Fat Cover

FIGURE 8

FAT DEPOSITION RATES IN EACH LOIN EYE OCTANT

The percent of measured fat in each octant within marbling categories and the unit change of percent measured fat as marbling advances from one marbling group to the next is shown in Table 2. The percent of measured fat increased at a more rapid rate in the octants in the medial half of the loin eye than in those of the lateral half as marbling score increased from slight and below to small. However, as marbling degree increased from small to modest and from modest to moderate and above, there was a greater unit change in percent measured surface fat in the octants in the lateral half of the loin eye than those in the medial half of the surface.

In addition to deposition rate, the amount of fat found in each octant is also a part of marbling distribution. There were no significant differences ($p < .05$) in percent fat within the octants of loin eyes where marbling was scored as modest, small, or slight and below. But, in loin eyes with moderate and above marbling, a significantly greater amount of marbling was found in octant 1 than in octants 2, 5, 6 and 7.

The same trend which appeared for marbling deposition rate also can be found when comparing the amount of fat in each octant. Marbling amount seems to be found in large quantities in the medial half of the loin eye when the degree of marbling is small or slight and below (Table 2). However, as marbling reaches the modest level, there is a change towards a higher percent of measured fat found in the lateral half of the loin eye surface (Table 2).

From these similar trends which represent marbling deposition rate and marbling amounts it can be concluded that in the early stages

TABLE 2

Percent Measured Fat and Percent Unit Change of Measured Fat Among Four Marbling Categories

	Slight and Below	Unit Sl-Sm Δ	Small	Unit Sm-Mt Δ	Modest	Unit Mt-Me Δ	Moderate and Above
Number	13		13		9		14
	%	%	%	%	%	%	%
Octants Lateral Half							
1	4.8	1.8	6.6	3.1	9.7	8.0	17.7
2	3.2	2.3	5.5	2.2	7.7	5.9	13.6
3	5.2	0.5	5.7	3.0	8.7	6.3	15.0
4	4.2	1.4	5.6	3.2	8.8	5.5	14.3
Octants Medial Half							
5	4.1	3.6	7.7	0.2	7.9	5.1	13.0
6	5.4	2.2	7.6	0.1	7.7	5.4	13.0
7	3.9	1.1	6.0	2.7	8.7	3.0	11.7
8	4.7	2.5	7.2	2.8	10.0	4.8	14.8

Sl = Slight
Sm = Small
Mt = Modest
Me = Moderate
Δ = Change
Octants (see Figure 7)

of growth marbling is laid in the loin eye faster and in greater amounts in the medial half of the loin eye; however, as the animal reaches a small degree of marbling there is a trend towards more rapid deposition and a higher percent of marbling appearing in the lateral half of the 12th rib LD section. Reddy (1969) arrived at a similar conclusion when he examined steaks of small and moderate degrees of marbling and compared surface fat amounts in the medial, central and lateral portions of the LD surface. He reported that the lateral third contained a greater percent of surface fat than the medial third in both the small and moderate marbling levels. He cited that one explanation for this phenomenon was the presence of more functional blood vessels in the lateral portion of the loin eye. Some investigations have recognized that fat accumulates near the vascular system (Blumer et al., 1962; Moody and Cassens, 1968; and Reddy, 1969). Moody and Cassens (1968) arrived at a different conclusion when comparing surface fat on the medial, central and lateral sections of the LD surface of samples which ranged from traces to moderate marbling. As marbling increases from traces to small, there was a faster rate of deposition in the lateral section than in either of the other two sections and as marbling went from small to moderate there was no change in the percent of fat found in the lateral and medial sections.

Comparing Ether Extract and Percent Measured Surface Fat

The ether extract levels for slight through slightly abundant marbling levels are shown in Table 3. Campion et al. (1975) reported

TABLE 3

Means and Standard Deviations for Ether Extract and Total Percent Measured Fat Comparisons by Marbling Group

Marbling Degree	Number	% Ether Extract	Std. Dev.	% Measured Surface Fat	Std. Dev.
Slight	11	4.7	1.2	4.9	1.3
Small	13	6.1	1.5	6.6	1.5
Modest	8	6.7	1.1	8.2	1.5
Moderate	8	8.9	0.8	12.7	1.7
Sl. Abundant	5	10.2	1.8	16.2	1.8

Sl. = Slightly

percent chemical fat means of 3.5% (slight), 5.1% (small), 6.9% (modest), 8.7% (moderate) and 8.3% (slightly abundant).

It is also interesting to note that percent visible surface fat tends to be higher than percent chemical fat, especially in the higher degrees of marbling. Reddy (1969) found similar differences when comparing histological fat on the loin eye surface and ether extract. He concluded that the measured differences might be due to the basic differences of sample thickness for the two procedures and the marbling variability which exists on a location basis.

Prediction Equations for Estimating Marbling Score

Forty-eight rib steaks were used to develop and test several equations for predicting marbling score, using measured marbling criteria. Forty-two samples were used to derive the regression equation and six steaks representing a wide range in marbling score were selected to examine the predictability of each regression equation. The variables that were presented in the step-wise, maximum R-square and regression procedures can be found in Table 4.

The best model (Model A) which accounted for 97% of the variation in marbling score was a complicated formula which utilized thirteen separate variables and could not be practically used with the grading instrument. Therefore, it was thought that the second best model (Model B) which had the second lowest error mean square (1481) and still accounted for 92% of variation in marbling score, should be used. This regression equation is:

TABLE 4

Variables Used in Statistical Procedures to Arrive at a Regression Equation

1)	Actual 12th Rib Fat Thickness
2)	Adjusted 12th Rib Fat Thickness
3)	Carcass Bone Maturity
4)	Number of Fat Deposits in Octants 1-8
5)	Final Yield Grade
6)	Hot Carcass Weight
7)	Kidney, Pelvic and Heart Fat
8)	Loin Eye Area (LEA)
9)	Average Fat Deposits Size/LEA
10)	Average Fat Deposits Size
11)	Number of Fat Deposits/LEA (measured on surface)
12)	Number of Fat Deposits (measured on surface)
13)	Percent of Measured Loin Eye Surface Fat
14)	Percent of Measured Surface Fat in Octants 1-8
15)	Marbling Texture Score
16)	Number of Fat Deposits in Octants 1-8/LEA in Octants 1-8

Marbling Score = Adjusted Fat Thickness (69.444)
+ Percent Measured Surface Fat (2502.44)
+ Hot Carcass Weight (.29353)
+ Measured Number of Fat Deposits (1.107)
- 133.168

An even simpler but relatively accurate equation (Model C) for predicting marbling score (R^2 = .87, Error Mean Square = 2318) is:

Marbling Score = 152.312
+ Percent Measured Surface Fat (2980.317)

Table 5 shows the accuracy that the best, second best and simplest models showed when predicting the marbling score of six steaks with a wide range of marbling. It also gives the average marbling score that was placed on each steak by the three member grading panel. It is interesting to note that with these six steaks, the "second" best model (Model B) was a better predictor than Model A. Model B gave lower residuals than Model A.

TABLE 5

Predictability of Marbling Score by Regression Equations

	R^2	Sample Number					
		1	2	3	4	5	6
Actual Marbling Score		Tr^{90}	Sm^{32}	Sl^{70}	Sl^{80}	Mt^{75}	$SlAb^{50}$
Prediction Equations							
Model A	.97	Sl^{19}	Sm^{68}	Sl^{76}	Sl^{20}	Mt^{88}	$ModAb^{03}$
Model B	.92	Sl^{10}	Sm^{37}	Sl^{36}	Sm^{29}	Mt^{87}	$SlAb^{70}$
Model C	.87	Sl^{62}	Sm^{44}	Sl^{99}	Sm^{40}	Mt^{94}	$SlAb^{88}$

Model A = Best Model
Model B = 2nd Best Model
Model C = Simplest Model
Tr. = Traces
Sl. = Slight
Sm. = Small
Mt. = Modest
Me. = Moderate
Sl.Ab. = Slightly Abundant
Mod.Ab. = Moderately Abundant

Literature Cited

AOAC. 1980. Official Methods of Analysis (13th Ed.). Association of Official Agricultural Chemists, Washington, D.C.

Blumer, T.N. and H.P. Fleming. 1959. A method for the quantitative estimation of marbling in the beef rib eye muscle. J. Anim. Sci. 18:959.

Campion, D.R., J.D. Crouse and M.E. Dikeman. 1975. Predictive value of USDA beef quality grade factors for cooked meat palatability. J. Food Sci. 40:1225.

Cook, C.F., R.W. Bray and K.G. King. 1964. Variation in the quantity and distribution of lipid in the bovine longissimus dorsi. J. Anim. Sci. 23:329.

Dikeman, M.E., C.C. Melton, H.J. Tuma and G.R. Beecher. 1972. Biopsy sample analysis to predict bovine muscle palatability with emphasis on tenderness. J. Anim. Sci. 34:49.

Duncan, D.B. 1975. t-Test and Intervals for comparisons suggested by the data. Biometrics 31:339.

Moody, W.G. and R.G. Cassens. 1968. A quantitative and morphological study of bovine longissimus fat cells. J. Food Sci. 33:47.

Reddy, B.G. 1969. The relationship of intramuscular fat and the vascular system to beef tenderness. Master's Thesis. Kansas State University, Manhattan, Kansas.

Snedecor, G.W. and W.G. Cochran. 1967. Statistical Methods (6th Ed.). Iowa State College Press, Ames.

U.S.D.A. 1973. United States standards for grades of carcass beef. Title 7, Ch. 1, part 53, Sec. 53.100-53.105. Code of Fed. Reg.

Walters, M.J., D.E. Goll, E.A. Kline, L.P. Anderson and A.F. Carlin. 1965. Effect of marbling and maturity on beef muscle characteristics. I. Objective measurements of tenderness and chemical properties. Food Technol. 19:841.

APPENDIX

Definitions of Appendix Abbreviations

Actfat	Actual 12th Rib Fat Thickness
Adjfat	Adjusted 12th Rib Fat Thickness
Avmarb	Average Marbling Score 100-199 Traces 200-299 Slight 300-399 Small 400-499 Modest 500-599 Moderate 600-699 Sl. Abundant
Carmat	Carcass Bone Maturity
Fat Dep 1-8	Number of Fat Deposits in Octants 1-8
FYG	Final Yield Grade
HCarWt	Hot Carcass Weight
KPHF	Kidney Pelvic and Heart Fat
LEA	Loin Eye Area
LEASec 1-8	Loin Eye Area in Octants 1-8
LERecA	Loin Eye Area/Rectangle Area
Marb 1-5	Marbling Score Groups 1-5 1 Slight 2 Small 3 Modest 4 Moderate 5 Sl. Abundant
PctEE	Average Percent Ether Extract (wet)
PctF 1-8	Percent Measured Surface Fat in Octants 1-8
PctH2O	Average Percent Chemical Moisture
RecArea	Area of the Rectangle that Surrounds the L.E.
TAvFDSL	Average Fat Deposit Size/LEA
TDFSqF	Average Fat Deposit Size
TDFSqL	Number of Fat Deposits/LEA

TFDep	Number of Fat Deposits
TPctFat	Percent Measured Loin Eye Surface Fat

ILLEGIBLE DOCUMENT

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The Best Model for Predicting Marbling Score

MODEL: M1
DEP VARIABLE: AVMARB

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	15	657488	43832.513	52.785	0.0001
ERROR	26	21590.281	830.395		
C TOTAL	41	679078			

ROOT MSE	28.816583	R-SQUARE	0.9682
DEP MEAN	403.690	ADJ R-SQ	0.9499
C.V.	7.138286		

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	-102.459	63.988562	-1.601	0.1214
PCTF1	1	712.899	266.608	2.674	0.0128
PCTF2	1	1330.593	413.715	3.216	0.0035
PCTF3	1	1185.548	379.858	3.121	0.0044
PCTF4	1	982.899	456.073	2.155	0.0406
PCTF5	1	1417.356	451.535	3.139	0.0042
PCTF6	1	1048.002	389.265	2.692	0.0123
PCTF7	1	1199.423	322.373	3.609	0.0013
PCTF8	1	2262.308	481.390	4.700	0.0001
ADJFAT	1	92.366948	49.131736	1.880	0.0714
HCARWT	1	0.204716	0.108004	1.895	0.0692
TPCTFAT	1	-7475.687	2705.503	-2.763	0.0104
WGTSQDV	1	-192614	65764.811	-2.929	0.0070
FATDEP4	1	3.318695	1.285476	2.582	0.0158
DFSECSQ2	1	5.167815	2.208785	2.340	0.0273
AVCOAR	1	11.434489	7.285058	1.570	0.1286

Second Best Model (B) for Predicting Marbling Score

MODEL: M7
DEP VARIABLE: AVMARB

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	624264	156066	105.347	0.0001
ERROR	37	54813.559	1481.448		
C TOTAL	41	679078			

ROOT MSE	38.489577	R-SQUARE	0.9193
DEP MEAN	403.690	ADJ R-SQ	0.9106
C.V.	9.534428		

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	-133.168	79.832170	-1.668	0.1037
ADJFAT	1	69.443683	52.049536	1.334	0.1903
TPCTFAT	1	2502.443	283.928	8.814	0.0001
TFDEP	1	1.107076	0.377610	2.932	0.0058
HCARWT	1	0.293530	0.122415	2.398	0.0217

Simplist Model (C) for Predicting Marbling Score

MODEL: M2
DEP VARIABLE: AVMARB

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	619679	619679	267.271	0.0001
ERROR	39	90423.167	2318.543		
C TOTAL	40	710102			

ROOT MSE	48.151249	R-SQUARE	0.8727
DEP MEAN	399.695	ADJ R-SQ	0.8694
C.V.	12.04699		

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	141.126	17.512848	8.058	0.0001
TPCTFAT	1	3089.473	188.977	16.348	0.0001

Slope of A Line Which Represents Fat Deposition Rate

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PCNTFAT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	15	0.63764239	0.04250949	47.05	0.0001	0.657283	35.7481
ERROR	368	0.33247604	0.00090347		STD DEV		PCNTFAT MEAN
CORRECTED TOTAL	383	0.97011843			0.03005774		0.08408213

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
SECTION	7	0.01926173	3.05	0.0041	7	0.01285567	2.03	0.0499
AVMARB(SECTION)	8	0.61838066	85.56	0.0001	8	0.61838066	85.56	0.0001

CONTRAST	DF	SS	F VALUE	PR > F
SECTION7 VS SECTION8	1	0.00227275	2.52	0.1136
SECTION4 VS SECTION6	1	0.00232564	2.57	0.1095
SECTION2 VS SECTION6	1	0.00266596	2.95	0.0867

PARAMETER		ESTIMATE	T FOR HO: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		-0.03052242 B	-2.20	0.0285	0.01387836
SECTION	1	-0.03992436 B	-2.03	0.0427	0.01962696
	2	-0.02050005 B	-1.04	0.2969	0.01962696
	3	-0.01144851 B	-0.58	0.5600	0.01962696
	4	-0.01121327 B	-0.57	0.5681	0.01962696
	5	0.00581402 B	0.30	0.7672	0.01962696
	6	0.02177087 B	1.11	0.2681	0.01962698
	7	0.01350423 B	0.69	0.4919	0.01962696
	8	0.00000000 B	.	.	.
AVMARB(SECTION)	1	0.00041965	12.70	0.0001	0.00003304
	2	0.00031519	9.54	0.0001	0.00003304
	3	0.00032156	9.73	0.0001	0.00003304
	4	0.00030989	9.38	0.0001	0.00003304
	5	0.00026720	8.09	0.0001	0.00003304
	6	0.00023493	7.11	0.0001	0.00003304
	7	0.00023025	6.97	0.0001	0.00003304
	8	0.00030435	9.21	0.0001	0.00003304

Means Analysis of Ether Extract and % Measured Surface Fat
By Marbling Group

MARB=1

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
PCTEE	11	4.65054545	1.17152067	3.23900000	7.42200000	0.35322677	51.15600000	1.37246067	25.191
TPCTFAT	11	0.04900663	0.01292389	0.03571429	0.06745623	0.00389670	0.53907293	0.00016703	26.372

MARB=2

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
PCTEE	13	6.08053846	1.47378106	3.74900000	8.34100000	0.40875332	79.04700000	2.17203060	24.238
TPCTFAT	13	0.06600975	0.01511202	0.04287500	0.08903830	0.00419132	0.85812681	0.00022837	22.894

MARB=3

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
PCTEE	8	6.69650000	1.10902093	4.81600000	8.76500000	0.39209811	53.57200000	1.22992743	16.561
TPCTFAT	8	0.08151938	0.01514523	0.06286837	0.11497748	0.00535465	0.65215506	0.00022938	18.579

MARB=4

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
PCTEE	8	8.67762500	0.83896227	7.55500000	10.16000000	0.29661756	69.42100000	0.70385770	9.668
TPCTFAT	8	0.12693005	0.01744897	0.09575261	0.14899814	0.00616914	1.01544037	0.00030447	13.747

MARB=5

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
PCTEE	5	10.24780000	1.85114092	8.81900000	13.42400000	0.82785539	51.23900000	3.42672270	18.064
TPCTFAT	5	0.16162613	0.01851924	0.13492382	0.17988930	0.00828206	0.80813066	0.00034296	11.459

MARBLING SCORE AND MEASURED MARBLING AMOUNT AND MARBLING TEXTURE

11:38 TUESD

OBS	ANIMAL	AVMARB	TPCTFAT	AVCOAR	TFDEP	TDFSQL	TDFSQF	TAVFDSL
1	1	400.0	0.062868	2.33333	78	7.6621	0.0082051	0.00080600
2	3	350.0	0.048629	2.83333	69	5.9126	0.0082246	0.00070477
3	5	270.0	0.049094	1.83333	59	5.6244	0.0087288	0.00083211
4	6	580.0	0.115591	3.00000	109	8.3717	0.0138073	0.00106047
5	7	475.0	0.080989	3.00000	90	6.8441	0.0118333	0.00089987
6	8	505.0	0.095753	2.66667	136	10.1341	0.0094485	0.00070406
7	9	215.0	0.025760	2.50000	46	3.4099	0.0075543	0.00056000
8	10	332.5	0.064618	2.50000	78	7.5508	0.0085577	0.00082843
9	11	375.0	0.074212	2.33333	83	7.2680	0.0102108	0.00089412
10	12	190.0	0.037019	1.83333	40	3.8462	0.0096250	0.00092548
11	13	427.5	0.075064	3.16667	92	7.9038	0.0094973	0.00081592
12	14	305.0	0.044473	2.66667	67	5.7858	0.0086866	0.00066378
13	15	285.0	0.066056	3.50000	58	5.0000	0.0132112	0.00113890
14	16	362.5	0.075803	1.66667	93	8.5321	0.0088844	0.00081508
15	17	262.5	0.042996	2.00000	54	5.3838	0.0079861	0.00079622
16	18	227.5	0.037466	2.50000	54	4.8605	0.0077083	0.00069382
17	19	390.0	0.068610	3.66667	70	6.2780	0.0109286	0.00098014
18	20	235.0	0.040000	1.66667	48	4.3636	0.0091667	0.00083333
19	21	425.0	0.073219	2.66667	76	6.6843	0.0109539	0.00096341
20	22	280.0	0.063105	2.83333	57	5.0132	0.0125877	0.00110710
21	23	395.0	0.089038	3.83333	78	6.3570	0.0140064	0.00114152
22	24	305.0	0.042675	2.33333	59	5.9000	0.0072669	0.00072669
23	25	185.0	0.025208	1.83333	46	3.4875	0.0072283	0.00054801
24	26	250.0	0.035714	1.66667	50	4.0128	0.0089000	0.00071429
25	27	250.0	0.038522	1.50000	66	5.9299	0.0064962	0.00058367
26	28	390.0	0.063124	4.00000	74	7.3852	0.0085473	0.00085302
27	35	310.0	0.052563	1.33333	98	7.9096	0.0066454	0.00053635
28	36	275.0	0.067456	1.33333	72	7.4150	0.0090972	0.00093689
29	37	325.0	0.077426	2.50000	90	8.5633	0.0090417	0.00086029
30	38	285.0	0.061644	1.16667	81	7.3973	0.0083333	0.00076104
31	39	540.0	0.118074	2.50000	125	10.8225	0.0109100	0.00094459
32	40	435.0	0.081971	1.50000	135	11.6179	0.0070556	0.00060719
33	41	415.0	0.085227	3.16667	72	7.2727	0.0117188	0.00118371
34	42	345.0	0.070905	1.83333	75	7.5834	0.0093500	0.00094540
35	43	360.0	0.085852	1.50000	74	6.7766	0.0126689	0.00116016
36	44	405.0	0.077839	2.50000	108	8.2317	0.0094560	0.00072073
37	45	635.0	0.134524	3.16667	97	7.7787	0.0173454	0.00139097
38	46	520.0	0.138361	2.83333	142	14.5940	0.0094806	0.00057437
39	47	590.0	0.148598	2.83333	104	9.6925	0.0153726	0.00143267
40	48	640.0	0.162716	2.33333	124	10.2226	0.0159173	0.00131223
41	49	630.0	0.177489	3.83333	126	11.4027	0.0155655	0.00140864
42	50	650.0	0.153112	1.50000	134	13.4538	0.0113806	0.00114263
43	51	475.0	0.114977	1.33333	142	12.7928	0.0089877	0.00080970
44	52	515.0	0.140458	1.33333	138	11.3768	0.0123460	0.00101781
45	53	525.0	0.137533	4.00000	125	11.0914	0.0124000	0.00110027
46	55	520.0	0.120673	2.33333	149	14.3269	0.0084228	0.00080989
47	54	440.0	0.127347	2.83333	113	9.2245	0.0138053	0.00112696
48	56	650.0	0.179889	1.50000	131	12.0849	0.0148855	0.00137320

OBS	ANIMAL	PCTF1	PCTF2	PCTF3	PCTF4	PCTF5	PCTF6	PCTF7	PCTF8
1	1	0.080435	0.031250	0.067241	0.056738	0.026423	0.044118	0.072993	0.096552
2	3	0.026882	0.037109	0.038978	0.040000	0.075301	0.057018	0.044393	0.056897
3	5	0.083333	0.030000	0.076577	0.037143	0.049645	0.046584	0.028926	0.080420
4	6	0.036765	0.096983	0.142647	0.125622	0.074468	0.159459	0.134409	0.119863
5	7	0.102459	0.002101	0.112864	0.094231	0.066038	0.106209	0.099664	0.100962
6	8	0.115000	0.105769	0.078014	0.099781	0.094072	0.097772	0.083333	0.043354
7	9	0.014493	0.015244	0.020134	0.025000	0.048995	0.025785	0.025478	0.016949
8	10	0.060606	0.076087	0.058011	0.062030	0.077652	0.075820	0.064000	0.051095
9	11	0.083333	0.054598	0.070455	0.102381	0.099576	0.068820	0.058383	0.066384
10	12	0.039216	0.037313	0.032178	0.027778	0.080645	0.047445	0.009328	0.023707
11	13	0.080153	0.083333	0.077128	0.081250	0.080682	0.035256	0.094697	0.081439
12	14	0.041667	0.032946	0.050000	0.049435	0.046089	0.057059	0.030142	0.037791
13	15	0.032258	0.068182	0.168605	0.106855	0.031915	0.073684	0.035311	0.018405
14	16	0.093972	0.059140	0.076425	0.081288	0.105903	0.083929	0.012195	0.069149
15	17	0.031690	0.027778	0.032787	0.055380	0.029310	0.070690	0.034722	0.045082
16	18	0.053191	0.029197	0.033835	0.040984	0.031667	0.042857	0.030000	0.043548
17	19	0.041667	0.101351	0.045597	0.014423	0.140060	0.085294	0.045250	0.055921
18	20	0.097015	0.019397	0.043796	0.016369	0.024038	0.060897	0.028716	0.057554
19	21	0.022727	0.054745	0.074503	0.060345	0.090461	0.063910	0.093137	0.136870
20	22	0.031818	0.029310	0.040541	0.061905	0.015625	0.054196	0.036207	0.070356
21	23	0.076577	0.053241	0.077869	0.078025	0.111399	0.133117	0.092014	0.075581
22	24	0.021341	0.030488	0.048000	0.037356	0.036000	0.064453	0.018349	0.077083
23	25	0.020833	0.019737	0.033237	0.012136	0.030105	0.031065	0.031065	0.028443
24	26	0.020979	0.009524	0.057398	0.034031	0.044199	0.037500	0.015267	0.053819
25	27	0.039062	0.028846	0.036392	0.018571	0.058140	0.049213	0.037594	0.040179
26	28	0.044811	0.043103	0.061538	0.046667	0.079268	0.066929	0.078629	0.076923
27	35	0.060345	0.059659	0.032407	0.023810	0.050000	0.049051	0.056866	0.078378
28	36	0.102941	0.056250	0.027027	0.057927	0.036697	0.095588	0.080966	0.070699
29	37	0.116228	0.034574	0.055195	0.079658	0.084848	0.066898	0.074275	0.080435
30	38	0.052632	0.048387	0.071667	0.056497	0.054913	0.065693	0.068752	0.060403
31	39	0.126263	0.111446	0.091429	0.127095	0.145210	0.078244	0.118243	0.125731
32	40	0.076000	0.101124	0.090625	0.067647	0.075145	0.085172	0.078125	0.081081
33	41	0.107143	0.098901	0.035971	0.108156	0.061111	0.075630	0.082645	0.112245
34	42	0.083333	0.075397	0.069048	0.042683	0.031532	0.044828	0.118151	0.056429
35	43	0.108871	0.056985	0.056569	0.076087	0.064583	0.131890	0.084356	0.107595
36	44	0.104167	0.068841	0.043860	0.088235	0.036486	0.077941	0.110955	0.100000
37	45	0.224432	0.133871	0.141854	0.120283	0.127717	0.080882	0.125000	0.140511
38	46	0.125000	0.103846	0.201327	0.138199	0.117857	0.154851	0.172265	0.105392
39	47	0.238462	0.144643	0.138258	0.126603	0.129518	0.157643	0.181973	0.121622
40	48	0.320896	0.186047	0.168675	0.172500	0.205793	0.093750	0.104545	0.124031
41	49	0.300000	0.135185	0.240000	0.167582	0.149671	0.169255	0.071429	0.194712
42	50	0.182099	0.157563	0.181973	0.136503	0.123239	0.138060	0.127660	0.200000
43	51	0.138158	0.102740	0.130719	0.114706	0.123333	0.111868	0.085145	0.123047
44	52	0.107143	0.149573	0.139785	0.165230	0.150000	0.113208	0.113946	0.169421
45	53	0.120787	0.120130	0.136364	0.152695	0.089062	0.119427	0.114815	0.213503
46	55	0.205556	0.110656	0.126761	0.150915	0.081761	0.128906	0.070513	0.118750
47	54	0.162500	0.148844	0.152695	0.117718	0.148844	0.085058	0.081301	0.102174
48	56	0.200658	0.206204	0.157197	0.179487	0.196319	0.210993	0.102649	0.193277

OBS	ANIMAL	FATDEP1	FATDEP2	FATDEP3	FATDEP4	FATDEP5	FATDEP6	FATDEP7	FATDEP8
1	1	13	10	7	11	4	12	12	16
2	3	7	8	9	9	11	11	7	11
3	5	3	6	10	7	9	10	8	11
4	6	5	14	18	22	17	18	10	18
5	7	8	1	17	8	11	18	16	17
6	8	17	21	13	25	18	17	17	16
7	9	2	5	4	5	9	12	4	6
8	10	10	8	10	15	8	11	6	13
9	11	2	13	8	23	7	10	10	16
10	12	4	8	5	9	4	5	5	6
11	13	11	11	22	11	11	14	12	12
12	14	3	11	7	10	10	14	7	9
13	15	6	6	6	17	6	13	4	7
14	16	14	7	21	15	14	18	2	15
15	17	2	7	10	11	6	7	7	7
16	18	2	8	7	11	9	8	7	8
17	19	9	9	6	4	11	10	14	11
18	20	3	2	7	5	8	11	9	7
19	21	5	6	12	19	10	10	12	11
20	22	2	8	8	10	5	7	7	14
21	23	11	4	14	15	17	13	9	11
22	24	4	7	8	10	7	12	4	10
23	25	3	3	8	5	10	7	7	6
24	26	3	2	17	6	8	7	6	3
25	27	6	6	11	10	9	10	7	9
26	28	11	9	9	10	8	12	13	8
27	35	6	16	11	11	12	14	14	19
28	36	3	12	7	13	3	15	7	15
29	37	15	9	13	10	11	11	11	17
30	38	5	5	8	12	18	13	11	14
31	39	11	11	25	16	19	18	16	20
32	40	21	13	19	20	15	16	11	30
33	41	4	9	10	13	10	13	8	14
34	42	5	11	8	15	4	13	10	16
35	43	3	8	9	9	6	11	16	21
36	44	3	13	13	16	12	12	19	24
37	45	11	14	17	19	16	16	7	10
38	46	18	19	32	15	23	20	10	18
39	47	10	19	21	11	14	14	12	17
40	48	12	12	24	25	15	16	9	19
41	49	16	13	14	19	25	13	14	19
42	50	23	17	22	20	13	13	12	17
43	51	19	19	24	22	22	22	9	16
44	52	18	10	33	16	21	14	19	16
45	53	12	16	14	18	17	21	20	17
46	55	15	17	17	25	25	21	21	22
47	54	10	21	18	15	13	18	14	12
48	56	18	25	20	12	17	18	16	15

OBS	ANIMAL	LEASEC1	LEASEC2	LEASEC3	LEASEC4	LEASEC5	LEASEC6	LEASEC7	LEASEC8
1	1	1.15	0.96	1.45	1.41	1.23	1.53	1.37	1.45
2	3	0.93	1.28	1.86	1.75	1.66	1.71	1.07	1.45
3	5	0.39	1.25	1.11	1.75	1.41	1.61	1.21	1.43
4	6	1.02	1.16	1.70	2.01	1.88	1.85	1.86	1.46
5	7	1.22	1.19	2.06	1.30	1.59	1.53	1.58	1.56
6	8	1.00	1.82	1.41	2.28	1.94	2.02	1.35	1.58
7	9	0.69	1.64	1.49	2.10	1.99	2.23	1.57	1.77
8	10	0.99	0.92	1.81	1.33	1.32	1.22	1.25	1.37
9	11	0.18	1.74	1.10	2.10	1.18	1.78	1.67	1.77
10	12	0.51	2.01	1.01	1.53	1.24	1.37	1.34	1.16
11	13	1.31	0.93	1.88	1.60	1.70	1.56	1.32	1.32
12	14	0.48	1.29	1.25	1.77	1.79	1.62	1.41	1.72
13	15	0.62	1.54	1.29	1.24	1.88	1.90	1.77	1.63
14	16	1.41	0.93	1.93	1.63	1.44	1.40	0.82	1.41
15	17	0.71	1.35	1.22	1.58	1.45	1.45	1.08	1.22
16	18	0.47	1.37	1.33	1.83	1.50	1.75	1.25	1.55
17	19	1.26	1.11	1.59	1.04	1.66	1.70	1.38	1.52
18	20	0.67	1.16	1.37	1.68	1.56	1.56	1.48	1.39
19	21	1.10	1.37	1.51	1.74	1.52	1.33	1.53	1.31
20	22	0.55	1.45	1.11	2.10	1.44	1.43	1.45	1.87
21	23	1.11	1.08	1.83	1.57	1.93	1.54	1.44	1.72
22	24	0.82	1.23	1.25	1.74	1.25	1.28	1.09	1.20
23	25	1.20	1.14	1.73	2.06	1.91	1.69	1.69	1.67
24	26	1.43	1.05	1.96	1.91	1.81	1.60	1.31	1.44
25	27	0.96	1.30	1.58	1.75	1.72	1.27	1.33	1.12
26	28	1.06	1.16	1.30	1.50	1.23	1.27	1.24	1.17
27	35	0.58	1.76	1.62	1.68	1.70	1.58	1.67	1.85
28	36	0.51	1.20	1.11	1.64	1.09	1.36	1.42	1.45
29	37	1.14	0.94	1.54	1.52	1.65	1.27	1.38	1.15
30	38	0.76	0.93	1.50	1.77	1.73	1.37	1.49	1.49
31	39	0.99	0.83	1.75	1.79	1.67	1.31	1.48	1.71
32	40	1.25	0.89	1.60	1.70	1.73	1.57	1.28	1.48
33	41	0.77	0.91	1.39	1.41	1.35	1.35	1.21	1.47
34	42	0.48	1.26	1.05	1.64	1.11	1.45	1.46	1.40
35	43	0.62	1.36	1.37	1.64	1.20	1.27	1.63	1.58
36	44	0.96	1.38	1.71	2.04	1.85	1.70	1.78	1.65
37	45	0.88	1.55	1.78	2.12	1.84	1.70	1.32	1.37
38	46	0.68	1.30	1.13	1.61	1.40	1.34	1.19	1.02
39	47	0.65	1.40	1.32	1.56	1.66	1.57	1.47	1.11
40	48	0.67	1.72	1.66	2.00	1.64	1.36	1.65	1.29
41	49	1.05	1.35	1.50	1.82	1.52	1.61	1.19	1.04
42	50	0.81	1.19	1.47	1.63	1.42	1.34	0.94	1.05
43	51	0.76	1.46	1.53	1.70	1.50	1.43	1.41	1.28
44	52	1.19	1.17	1.86	1.74	1.85	1.59	1.47	1.21
45	53	0.89	1.54	1.76	1.67	1.60	1.57	1.35	1.09
46	55	0.90	1.22	1.42	1.64	1.59	1.28	1.17	1.20
47	54	1.00	1.73	1.67	2.06	1.73	1.77	1.23	1.15
48	56	0.76	1.37	1.32	1.56	1.63	1.41	1.51	1.19

OBS	ANIMAL	HCARWT	ACTFAT	ADJFAT	LEA	KPHF	FYG	CARMAT
1	1	812	0.90	0.90	10.18	3.0	5.1780	150
2	3	624	0.50	0.50	11.67	2.5	2.8868	60
3	5	546	0.30	0.30	10.49	2.5	2.4680	60
4	6	736	0.55	0.65	13.02	3.0	3.3554	65
5	7	800	1.05	1.05	13.15	2.5	4.4570	70
6	8	656	0.40	0.40	13.42	2.5	2.1584	100
7	9	675	0.60	0.55	13.49	2.0	2.5232	65
8	10	629	0.50	0.55	10.33	2.0	3.3596	95
9	11	649	0.65	0.65	11.42	2.0	3.3368	95
10	12	622	0.35	0.35	10.40	2.0	2.8106	110
11	13	650	0.55	0.55	11.64	2.0	3.0202	40
12	14	668	0.50	0.50	11.58	2.5	3.0828	80
13	15	631	0.60	0.65	11.60	2.5	3.3108	75
14	16	602	0.40	0.45	10.90	1.5	2.7246	50
15	17	641	0.45	0.50	10.03	2.0	3.3762	85
16	18	626	0.35	0.35	11.11	2.0	2.5986	120
17	19	706	0.55	0.60	11.15	1.5	3.4148	70
18	20	721	0.40	0.45	11.00	1.5	3.1448	65
19	21	736	0.70	0.60	11.37	2.0	3.5584	80
20	22	717	0.40	0.45	11.37	2.5	3.2112	70
21	23	720	0.50	0.55	12.27	2.0	3.0846	60
22	24	681	0.40	0.45	10.00	2.0	3.4128	70
23	25	702	0.30	0.35	13.19	1.5	2.1218	75
24	26	756	0.50	0.55	12.46	1.5	3.0606	80
25	27	709	0.50	0.50	11.13	2.5	3.3826	75
26	28	739	0.55	0.65	10.02	2.5	4.2268	65
27	35	677	0.65	0.60	12.39	2.0	3.0078	65
28	36	544	0.35	0.35	9.71	2.0	2.7350	65
29	37	628	0.35	0.40	10.51	2.5	3.0232	70
30	38	550	0.15	0.15	10.95	1.0	1.6610	55
31	39	658	0.35	0.35	11.55	1.5	2.4794	75
32	40	630	0.25	0.30	11.62	1.5	2.2256	70
33	41	629	0.50	0.50	9.90	2.5	3.4722	75
34	42	568	0.35	0.40	9.89	2.5	2.9936	70
35	43	702	0.40	0.40	10.92	1.5	2.9732	65
36	44	591	0.55	0.55	13.12	3.0	2.5224	70
37	45	644	0.50	0.65	12.47	2.5	3.0818	.
38	46	522	0.60	0.60	9.73	2.5	3.3700	.
39	47	611	0.55	0.55	10.73	2.5	3.2632	.
40	48	648	0.50	0.65	12.13	2.5	3.2058	.
41	49	616	0.55	0.50	11.05	2.5	3.0548	.
42	50	507	0.40	0.45	9.96	2.5	2.8644	.
43	51	503	0.40	0.40	11.10	2.5	2.3594	.
44	52	515	0.30	0.35	12.13	2.5	1.9504	.
45	53	613	0.40	0.60	11.27	2.5	3.2230	.
46	55	504	0.40	0.45	10.40	2.5	2.7122	.
47	54	612	0.60	0.60	12.25	2.5	2.9056	.
48	56	616	0.40	0.40	10.84	2.5	2.6720	.

OBS	ANIMAL	PCTEE	PCTH2O	RECAREA	LERECA
1	1	6.340	70.515	15.77	0.645529
2	3	8.341	70.056	16.07	0.726198
3	5	4.136	71.682	14.57	0.719973
4	6	8.402	70.011	19.02	0.684543
5	7	8.765	68.729	16.98	0.774441
6	8	7.975	69.907	21.05	0.637530
7	9	1.840	73.579	18.55	0.727224
8	10	7.464	67.976	14.79	0.658445
9	11	8.006	69.822	17.33	0.658973
10	12	7.422	70.176	14.36	0.724234
11	13	6.106	71.800	15.85	0.734385
12	14	3.749	72.096	17.58	0.658703
13	15	5.060	71.454	18.73	0.619327
14	16	6.830	69.026	15.59	0.699166
15	17	5.229	71.139	14.65	0.684642
16	18	3.474	73.414	16.54	0.671705
17	19	5.908	69.618	16.80	0.663690
18	20	4.299	71.889	15.15	0.726073
19	21	7.078	70.522	15.37	0.739753
20	22	5.615	70.794	17.40	0.653448
21	23	4.732	72.997	17.02	0.720917
22	24	7.281	69.608	15.90	0.628931
23	25	2.830	72.128	18.93	0.696778
24	26	4.512	72.991	16.90	0.737278
25	27	3.779	73.284	15.74	0.707116
26	28	6.769	69.130	15.07	0.664897
27	35	4.358	72.569	17.96	0.685866
28	36	4.391	72.416	14.75	0.658305
29	37	5.517	71.756	15.05	0.658339
30	38	3.239	72.910	15.81	0.692600
31	39	8.953	68.713	17.69	0.652911
32	40	6.609	71.195	17.12	0.678738
33	41	7.098	71.074	14.04	0.705128
34	42	5.317	73.037	14.73	0.671419
35	43	4.775	72.416	19.25	0.567273
36	44	6.761	70.168	15.41	0.651395
37	45	8.819	67.586	17.51	0.712164
38	46	8.148	68.808	13.50	0.720741
39	47	10.160	66.472	15.76	0.680838
40	48	9.484	67.313	16.00	0.758125
41	49	9.251	67.501	14.58	0.757888
42	50	13.424	64.697	14.61	0.681725
43	51	4.816	71.562	15.74	0.705210
44	52	7.555	69.635	16.56	0.732488
45	53	9.399	67.174	16.86	0.668446
46	55	8.829	66.869	14.70	0.707483
47	54	6.150	71.450	16.56	0.739734
48	56	10.261	67.451	14.08	0.769886

QUANTITATIVE MEASURES OF MARBLING AMOUNT, DISTRIBUTION AND TEXTURE AND THEIR RELATIONSHIPS TO MARBLING SCORE

by

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B.S., Kansas State University, 1979

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Forty-eight rib steaks were used to analyze relationships between marbling score and measured marbling amount, distribution and texture.

These three measurements were calculated using a transparency of graph paper that had squares 1.27mm^2 in area. A dot was placed in each square, within the loin eye, which was at least one-half filled with fat (fat squares). The total area of fat squares was calculated giving a measurement of marbling amount. Distribution was measured by drawing a rectangle around the loin eye and then dividing the rectangle into eight equal sized parts (octants). The area of fat squares in each octant was measured out then divided by the loin eye area in each octant to provide a measure of marbling distribution. Marbling texture was measured by computing the average fat deposit size and counting the number of fat deposits on the loin eye surface. Average fat deposit size was measured by dividing the area of fat on the loin eye by the number of LD fat deposits.

Simple correlation coefficients between marbling score and measurements of marbling amount and texture were ($p < .0001$) 0.94 (percent surface fat/loin eye area), 0.84 (number of fat deposits) and 0.68 (average fat deposit size). Correlation coefficients between chemical fat and marbling score (0.83), percent surface fat (0.76), average fat deposit size (0.54) and total number of fat deposits (0.64) were all highly significant ($p < .0001$).

To study marbling distribution, marbling deposition rates and marbling amounts were measured in each octant of the loin eye. In carcasses with lower marbling scores there appears to be a trend towards a faster fat deposition rate and a greater amount of

marbling in the octants of the medial half of the loin eye. However, after a small degree of marbling is reached, there tends to be a change towards a more rapid deposition and a higher percent of marbling in the lateral half of the loin eye.

With this information on marbling's three constituents, a regression equation, that predicts marbling score, was devised and tested. This prediction equation accounts for 92% of the variation in marbling score. That regression equation is:

-133.168 + 69.444 (Adjusted Fat Thickness)
+25.0244 (% Loin Eye Surface Fat)
+.29353 (Hot Carcass Wt.)
+1.107 (Number of Loin Eye Surface Fat Deposits).