Coupling of Image Analysis and Tenderness Classification to Simultaneously Evaluate Carcass Cutability, Longissimus Area, Subprimal Cut Weights, and Tenderness of Beef[1]

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ABSTRACT: The present experiment was conducted to determine whether image analysis of the 12th-rib cross-section used for tenderness classification could accurately predict carcass cutability, longissimus area, and subprimal cut weights. The right side of crossbred steer and heifer carcasses (n = 66) was fabricated, and the yield of totally trimmed retail product was determined. Following procedures that we have described for tenderness classification, a 2.54-cm-thick steak was removed from the 12th-rib region of the left side of each carcass, and image analysis was conducted using off-the-shelf technology. Image analysis accounted for more of the variation in retail product yield (RPYD; 89 vs 77%) and retail product weight (95 vs 90%) than did calculated yield grade. Also, image analysis accurately predicted longissimus area (R^2 = .88). For most subprimals, the combination of image analysis-predicted RPYD and hot carcass weight (HCW) accounted for more of the variation in subprimal weight than did the combination of calculated yield grade and HCW. Whereas HCW, by itself, accounted for only 30 to 34% of the variation in weights of round cuts, the combination of image analysis-predicted RPYD and HCW accounted for 78 to 82% of the variation in weights of round cuts. Hot carcass weight, the combination of calculated yield grade and HCW, and the combination of image analysis-predicted RPYD and HCW accounted for 54, 83, and 91% of the variation in the weight of 80% lean trimmings. Thus, image analysis could be used by the beef industry to more accurately predict individual subprimal weights. In turn, that information and appropriate price extensions could be used to more accurately estimate carcass value. Thus, image analysis could be used by the beef industry in combination with tenderness classification to accurately characterize beef carcasses for cutability and tenderness. These tools should help facilitate the development of value-based marketing systems.

Key Words: Beef, Carcasses, Cutability, Instrumentation, Tenderness

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Introduction

Image analysis has been shown to accurately predict 9-10-11th rib (r = .81; Cross et al., 1983) and carcass (r = .88; Jones et al., 1992) composition under controlled conditions. However, application of image analysis in high-speed beef processing plants (r^2 = .52 and .55 for Wassenberg et al., 1986 and Belk et al., 1996, respectively) has been less successful, partly because it is difficult with high-speed, on-line grading to consistently position a camera so that it can record an image of the entire longissimus and its surrounding fat cover (J. W. Wise, personal communication).

We have developed an accurate method of tenderness classification (Shackelford et al., 1997a,b). Because tenderness classification requires that a 12th-rib cross-section be removed from each carcass, it provides an easy opportunity to also assess carcass yield traits by image analysis of the cross-section. Thus, the present experiment was conducted to determine whether image analysis of the 12th-rib cross-section used for tenderness classification could accurately evaluate carcass cutability, longissimus area, and subprimal cut weights.

[1]Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of other products that may also be suitable. The authors are grateful to Patty Beska, Kathy Mihm, Pat Tammen, and Mike Thoesen for their assistance in the execution of this experiment and to Marilyn Bierman for her secretarial assistance.

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Materials and Methods

Animals. The Roman L. Hruska U.S. Meat Animal Research Center (**MARC**) Animal Care and Use Committee approved the use of animals in this study. Crossbred steers and heifers (n = 66) of 25, 50, or 75% Piedmontese inheritance were produced. Matings were such that approximately 25% of animals were expected to be homozygous normal for the "double muscling" gene, 50% of animals were expected to be heterozygous for the double muscling gene, and 25% of animals were expected to be homozygous for the double muscling gene (i.e., 0, 1, or 2 copies of the gene for double muscling). Animals were weaned at approximately 200 d of age and were given ad libitum access to corn-corn silage diets from weaning to slaughter at 12 to 15 mo of age. Following weaning, the energy concentration of the diet was steadily increased over a 90-d period until the steers reached the finishing diet (3.14 Mcal of ME/kg of dry matter). Animals were serially slaughtered to further increase the level of variation in carcass composition and marbling scores.

Carcass Grade Data. All cattle were slaughtered at the MARC abattoir and carcasses were chilled for 48 h (24 h at –1°C; 24 h at 1°C). The right carcass side was ribbed conventionally between the 12th and 13th ribs, USDA quality and yield grade data were recorded, and lean color (1 = very light cherry-red, 2 = cherry-red, 3 = slightly dark, 4 = moderately dark, 5 = dark red, 6 = very dark red, 7 = black) was scored. An outline of the perimeter of the longissimus was traced onto acetate paper and longissimus area was determined using a Microcomp PM morphometer (Southern Micro Instruments, Atlanta, GA). In subsequent discussion, that measurement is referred to as carcass longissimus area (**CLA**).

Image Analysis. A 2.54-cm thick steak was removed from the left carcass side using a double-bladed reciprocating saw as described by Shackelford et al. (1997a). Two straight, parallel cuts (2.54 cm apart) were made simultaneously through the posterior half of the 12th thoracic vertebra, longissimus, and adjacent fat perpendicular to both the long axis and split surface of the vertebral column. The cut proceeded to a point approximately 15 cm lateral to the lateral tip of the longissimus. A cut was then made perpendicular to the first two cuts to separate the lateral end of the steak from the carcass at a point 8 cm from the lateral tip of the longissimus. The cut surface of each steak, which was often smeared with fat during the cutting process, was scraped to improve fat/lean contrast.

For image analysis, steaks were placed flat on a nonglare black surface and illuminated with lights (RB 300, Kaiser®, Munich, Germany) equipped with 300-W halogen bulbs (Supershot® Model 64514, Osram, Munich, Germany). A light was placed on each of two opposing sides of the steak at a point where the lights' safety glass plate was approximately 65 cm from the center of the surface of the steak. Images were captured using a 3-CCD color video camera (DXC-970MD/1, Sony® Corp., Tokyo, Japan) equipped with a 25-mm f2.8 lens (Model C24184, Century Precision Optics), a software package (Image-Pro® Plus Version 3.0.1 for Macintosh, Media Cybernetics, Silver Springs, MD), and a 200-MHz personal computer (StarMax 4000/200, Motorola Inc., Chicago, IL) equipped with a RGB frame grabber (LG-3, Scion, Frederick, MD). With illumination as described, Macbeth® ColorChecker Chart (Munsell Color, Baltimore, MD) standards had the following red, green, and blue intensities, where 0 = no intensity and 255 = maximum intensity: red standard (red = 232.0 ± .0; green = 1.0 ± .0; blue = 30.0 ± .8), green standard (red = 75.4 ± .5; green = 195.0 ± .3; blue = 59.2 ± .5), and blue standard (red = 2.4 ± .4; green = 6.4 ± 1.0; blue = 203.4 ± 1.8).

Video capture translated a 24 × 32 cm area at the steak surface into a 480 × 640 pixel array for each RGB channel. Specifically, the camera was positioned such that the tip of the camera lens was 122 cm from the surface of the steak and the f-stop was set to 11. Images were captured and analyzed automatically using a macro computing program (http://shack.marc.usda.gov/MRU_WWW/protocol/image_analysis_macros.pdf), which was recorded and edited by the authors. The variables measured by image analysis (Figure 1) included total lean area (**LEAN**), total fat area (**FAT**), and total steak area (**TOTAL**). Histogram ranges used to identify each component are described in Table 1. The largest lean portion was identified by autoclassification, and its area (**EYEPIECE**), red intensity (**RED**), green intensity (**GREEN**), blue intensity (**BLUE**), and density (**DENSITY**) were determined. All components (LEAN, FAT, TOTAL, and EYEPIECE) were measured without the "fill holes" option selected. Thus, inter- and intramuscular fat pieces that were contained entirely within LEAN and EYEPIECE were not counted as a part of LEAN or EYEPIECE, respectively. All holes in EYEPIECE were counted (**NUMHOLES**), the sum of their areas was determined (**HOLEAREA**), and percentage hole area (**PERHOLE**) was calculated. Percentage lean (**PERLEAN**) was calculated for each steak as 100 × LEAN/(LEAN + FAT) rather than 100 × LEAN/TOTAL because preliminary analysis indicated that the former was more highly related to carcass cutability than the latter.

For each image analysis steak, an outline of the perimeter of the longissimus was traced onto acetate paper and longissimus area was determined using a Microcomp PM morphometer (Southern Micro Instruments). In subsequent discussion, that measurement is referred to as steak longissimus area (**SLA**).

Carcass Yield. The right side of each carcass was fabricated into boneless, totally trimmed retail product according to Wheeler et al. (1997). Each

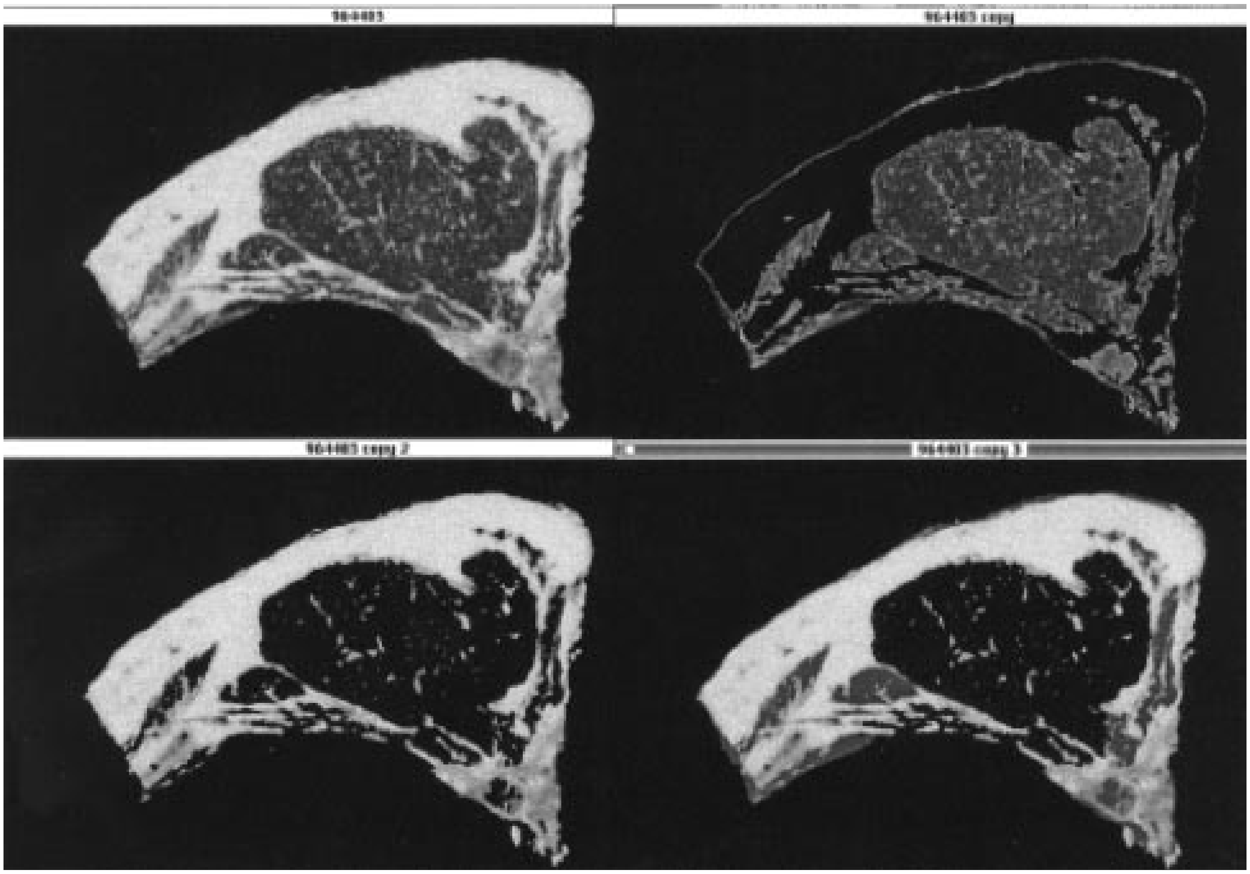

Figure 1. Images of a steak before analysis (top left), with the fat highlighted in black (top right), with the lean highlighted in black (bottom left), and with the biggest lean piece (EYEPIECE) highlighted in black (bottom right). Note that EYEPIECE is not necessarily limited to the longissimus.

wholesale cut (round, loin, rib, chuck, flank, and brisket/plate/foreshank) was individually dissected and the following components were weighed: 1) boneless, totally trimmed retail cuts, 2) fat trim, 3) lean trim, and 4) bone. Weights of lean and fat trim were adjusted to a constant 20% fat lean trim basis. Weights of boneless, totally trimmed retail cuts and 20% fat lean trim were summed to give retail product weight (**RPWT**). Retail product yield (**RPYD**) was expressed as a percentage of the sum of the parts (i.e., RPYD = 100 × RPWT/[RPWT + fat trim weight + bone weight]) rather than as a percentage of hot carcass weight (**HCW**) to overcome potential introduction of error that was due to shrink and(or) cutting loss.

Statistical Analysis. Carcasses were blocked by observed RPYD, and one-half of the carcasses were used to develop regression equations and one-half of the carcasses were used to validate the regression equations (Neter et al., 1989). Regression equations were developed for RPYD and SLA. Retail product weight was predicted by multiplying the best estimate of RPYD times HCW. All of the image analysis traits described above and HCW were included as potential independent variables. Regression equations were

Table 1. Histogram ranges for measuring lean area, fat area, and total steak area

	Brightness[a]					
	Red		Green		Blue	
Tissue	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Lean	50	218	1	108	1	130
Fat	221	254	129	254	114	254
Total	50	254	1	254	1	254

[a]0 = black; 255 = bright red, green, or blue.

selected using the RSQUARE procedure (SAS, 1988), which selects the single best (highest R^2) equation with a given number of variables. Thus, the RSQUARE technique differs from STEPWISE techniques in that the variables selected for higher-order equations do not depend on the variables used in lower-order equations. Equations were evaluated with respect to R^2, the C_p statistic (Mallows, 1973), and residual standard deviation (**RSD**). To more fully evaluate the ability of image analysis to predict carcass cutability, RPYD was regressed against yield grade, and RPWT was predicted by multiplying predicted RPYD times HCW.

Following collection of the aforementioned images, each steak was repositioned, and a second image was captured. The second image was not used in development or validation of regression equations. Those images were used to test the repeatability of the image analysis process. Retail product yield and SLA were predicted using the optimal equations described below, and repeatability of those prediction estimates was calculated using the VARCOMP procedure of SAS. For each trait, repeatability was calculated as $\sigma^2_{carcass}/(\sigma^2_{carcass} + \sigma^2_{error})$.

Results

Simple statistics of carcass traits and independent and dependent variables are presented in Table 2. On average, the carcasses used in the present experiment were lighter, had less fat thickness, larger longissimus area, lower yield grades, and lower marbling scores than are typical of the U.S. beef industry (Lorenzen et al., 1993; Boleman et al., 1998). This result was expected based on the high frequency of the double muscling allele in this population (Hanset, 1991; Casas et al., 1998; Wheeler et al., 1997).

Retail Product Yield. Regression equations are presented in Table 3. The single image analysis variable accounting for the greatest proportion of variation in RPYD was PERLEAN (R^2 = .77). The best five-variable equation (Equation 15, in Table 3) optimized R^2 (.88), C_p statistic, and RSD. The best four- and five-variable equations most precisely (R^2 = .91) predicted retail product yield in the validation data set. When data were pooled across development and validation data sets, the five-variable equation accounted for more (89 vs 77%) of the variation in RPYD than did yield grade (Figure 2).

Table 2. Simple statistics of carcass traits and independent and dependent variables (n = 66)

Variable	Abbreviation	Mean	SD	CV	Minimum	Maximum
Carcass traits						
Hot carcass weight, kg	HCW	295.8	34.2	12	222.9	374.5
Actual fat thickness, mm	—	6.4	3.5	55	1.3	15.2
Adjusted fat thickness, mm	—	5.8	3.3	57	1.3	12.7
Carcass longissimus area, cm^2	—	85.1	12.7	15	56.8	114.8
Kidney, pelvic, and heart fat, %	—	2.5	.9	36	.5	4.0
USDA yield grade	—	1.8	.9	50	−.4	3.6
Lean color score	—	3.0	.7	23	1.0	5.0
Lean maturity score[a]	—	155.2	13.5	9	130.0	190.0
Skeletal maturity score[a]	—	173.5	21.3	12	130.0	220.0
Overall maturity score[a]	—	164.5	13.9	8	135.0	190.0
Marbling score[b]	—	372.0	57.2	15	250.0	490.0
Independent variables[c]						
Total lean area, pixels	LEAN	49,408.0	6,794.8	14	33,869.0	65,742.0
Total fat area, pixels	FAT	28,911.0	8,176.3	28	12,036.0	44,219.0
Total steak area, pixels	TOTAL	89,333.0	9,604.8	11	68,551.0	111,731.0
Area of largest lean piece, pixels	EYEPIECE	39,990.0	7,992.7	20	22,413.0	60,884.0
Mean red intensity of EYEPIECE	RED	157.2	11.0	7	126.9	178.2
Mean green intensity of EYEPIECE	GREEN	37.6	9.6	26	20.5	65.7
Mean blue intensity of EYEPIECE	BLUE	44.1	9.5	21	27.8	71.5
Mean density of EYEPIECE	DENSITY	79.7	9.4	12	61.2	104.7
Number of holes in EYEPIECE	NUMHOLES	428.4	141.3	33	194.0	858.0
Area of holes in EYEPIECE, pixels	HOLEAREA	3,513.6	1,551.7	44	980.0	8,841.0
100 × HOLEAREA/(EYEPIECE + HOLEAREA), %	PERHOLE	7.6	2.8	37	3.2	15.2
100 × LEAN/(LEAN + FAT), %	PERLEAN	63.4	8.3	13	45.2	84.5
Dependent variables						
Retail product yield, %	RPYD	72.9	6.9	10	61.4	89.1
Retail product weight, kg	RPWT	203.1	29.5	15	146.2	259.9
Steak longissimus area, cm^2	SLA	83.9	12.8	15	58.7	109.7

[a]100 = A^0; 200 = B^0.
[b]200 = $Traces^0$; 300 = $Slight^0$; 400 = $Small^0$; 500 = $Modest^0$.
[c]Hot carcass weight (listed above with carcass traits) was included as a potential independent variable.

Table 3. Prediction equations for estimating retail product yield and longissimus area

Equation no.	Development R^2	Development C_p	Development RSD	Development Equation	Validation R^2
				Retail product yield, %	
11	.77	20.1	3.4	Predicted = 22.5 + (.79 × PERLEAN[a])	.86
12	.83	10.2	3.0	Predicted = 16.6 + (.76 × PERLEAN) + (.18 × BLUE)	.89
13	.85	7.9	2.8	Predicted = 34.7 + (.67 × PERLEAN) + (.015 × NUMHOLES) + (−.039 × HCW)	.87
14	.87	6.0	2.7	Predicted = 47.0 + (.65 × PERLEAN) + (.72 × BLUE) + (.014 × NUMHOLES) + (−.67 × DENSITY)	.91
15	.88	4.8	2.6	Predicted = 41.4 + (.70 × PERLEAN) + (.67 × BLUE) + (.022 × NUMHOLES) + (−.61 × DENSITY) + (−.00092 × HOLEAREA)	.91
				Longissimus area, cm^2	
21	.85	9.0	5.0	Predicted = −6.2 + (.0018 × LEAN)	.84
22	.88	3.8	4.6	Predicted = −3.6 + (.0016 × LEAN) + (.018 × NUMHOLES)	.85
23	.89	3.0	4.5	Predicted = 1.4 + (.0018 × LEAN) + (.017 × NUMHOLES) + (−.22 × PERLEAN)	.88
24	.90	.6	4.2	Predicted = 159.0 + (.0029 × LEAN) + (.019 × NUMHOLES) + (−2.7 × PERLEAN) + (−.0020 × FAT)	.85
25	.91	1.3	4.1	Predicted = 159.4 + (.0031 × LEAN) + (.020 × NUMHOLES) + (−2.7 × PERLEAN) + (−.0018 × FAT) + (−.052 × HCW)	.86

[a]Abbreviations are defined in Table 2.

Retail Product Weight. We (Shackelford et al., 1995) have shown that RPWT can be predicted more precisely by multiplying predicted RPYD times HCW rather than by predicting RPWT directly. Thus, we predicted RPWT by multiplying the results of Equation 15 times HCW. As with RPYD, RPWT could be estimated more precisely (R^2 = .95 vs .90) from image analysis data than from yield grade (Figure 3).

Longissimus Area. Traditionally, carcasses are ribbed between the 12th and 13th ribs following the natural curvature of the ribs. In practice, this leads to a large amount of variation in the angle at which the longissimus is transected, which, in turn, may lead to erroneous estimation of longissimus area. For tenderness classification, the angle (90°) at which the longissimus is transected must be controlled tightly (Shackelford et al., 1997a). Thus, we hypothesized that longissimus area would be more indicative of variation in carcass muscularity if longissimus area was measured on the steak removed for tenderness classification/image analysis rather than if longissimus area was measured on the conventionally ribbed side. Steak longissimus area was more highly related to retail product yield (R^2 = .37 vs .27) than was CLA. Thus, when evaluating the ability of image analysis to predict longissimus area, we predicted SLA rather than CLA.

The single image analysis variable that accounted for the greatest proportion of variation in SLA was LEAN (R^2 = .85). The best three-variable equation (Equation 23) optimized R^2 (.89), C_p statistic, and RSD and most precisely (R^2 = .88) predicted SLA in the validation data set.

Recently, some packers have begun to discount carcasses with extremely small or extremely large longissimus areas. However, it has been difficult for packers to accurately apply these discounts because of the difficulty in subjectively estimating longissimus area when carcasses are evaluated at rates of up to 400 carcasses per hour. Thus, the industry has sought an objective measure of longissimus area. The present image analysis system was quite accurate (Figure 4) at predicting whether a given longissimus area was within the longissimus area target of 71 to 90 cm^2 identified by Tatum (1992). For carcasses with predicted longissimus areas of less than 71 cm^2, the range in observed longissimus area was 58.7 to 76.8 cm^2. For carcasses with predicted longissimus areas within the range of 71 to 90 cm^2, the range in observed longissimus area was 71.6 to 94.2 cm^2. For carcasses with predicted longissimus areas greater than 90 cm^2, the range in observed longissimus area was 87.1 to 109.7 cm^2.

Subprimal Cut Weights. Because most beef carcasses are merchandised as boxed-beef subprimals and the subprimal yield of individual carcasses is usually not determined, the true value of most beef carcasses is never known. Thus, technology to measure or predict weights of individual subprimals would allow the beef industry to more accurately estimate true carcass value. To determine whether image analysis could be used to predict the weights of individual subprimals, we regressed predicted RPYD (Equation 15) and HCW against individual weights of each subprimal. Hot carcass weight, by itself, accounted for 23% (cube steak) to 74% (chuck roll) of the variation in subprimal weights (Table 4). Whereas HCW, by itself, only accounted for 30 to 34% of the variation in weights of round cuts, the combination of image analysis-predicted RPYD and HCW accounted for 78 to 82% of the variation in weights of round cuts. For most subprimals, the combination of image analysis-predicted RPYD and HCW accounted for more of the variation in subprimal weight than did the combination of calculated yield grade and HCW. For ribeye roll and striploin, the combination of calculated yield grade and HCW accounted for more of the variation in subprimal weight than did the combination of image analysis-predicted RPYD and HCW. Hot carcass weight, the combination of calculated yield grade and HCW, and the combination of image analysis-predicted RPYD and HCW accounted for 54, 83, and 91% of the variation in the weight of 80% lean trimmings. Thus, image analysis could be used by the beef industry to more accurately predict individual subprimal weights. In turn, that information and appropriate price extensions could be used to more accurately estimate carcass value.

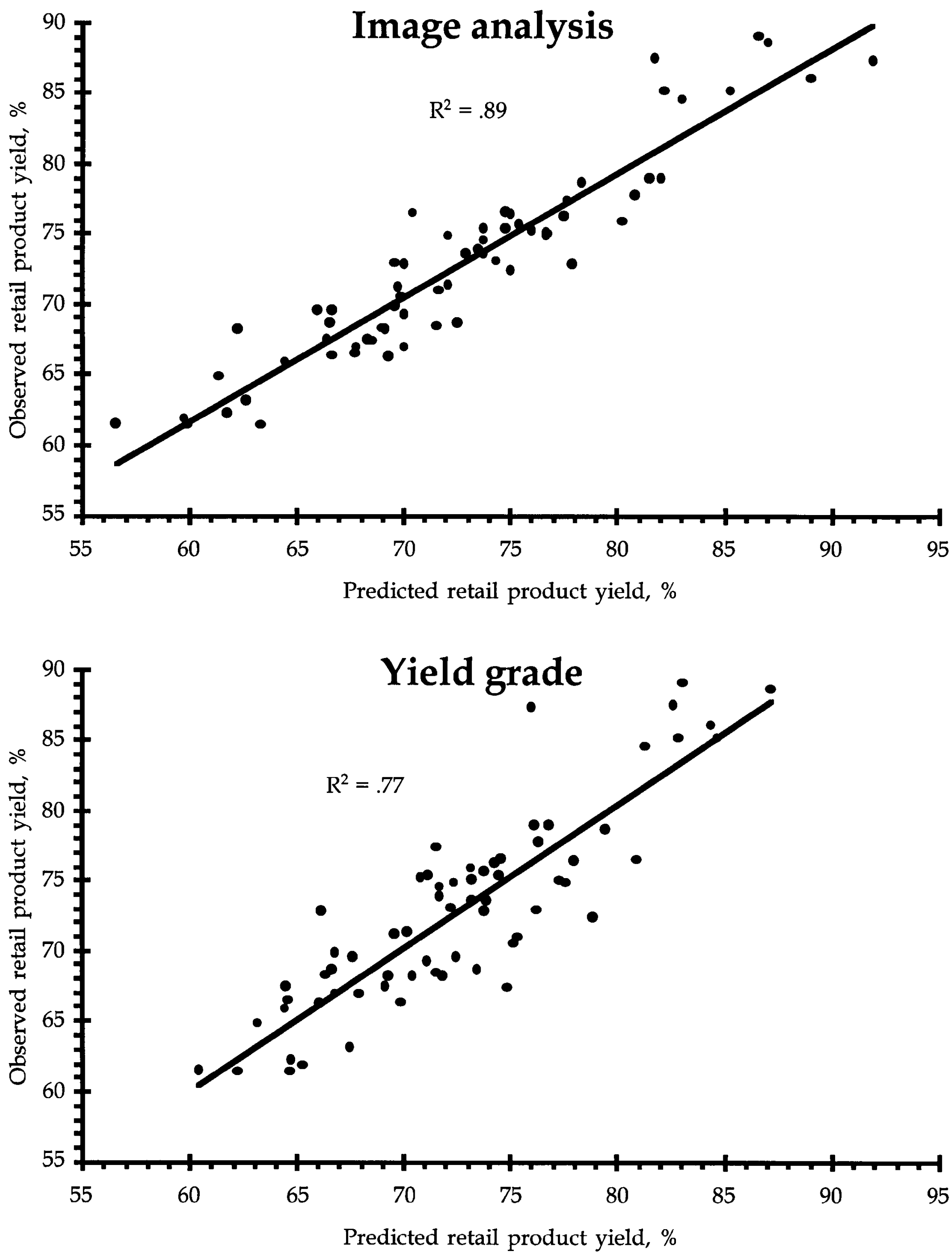

Figure 2. Comparison of the ability of image analysis and yield grade to predict retail product yield (n = 66).

Repeatability of Image Analysis. Repeatability estimates for predicted RPYD (R = .99) and predicted SLA (R = .99) were very high, which indicated that the process of collecting and analyzing the images was highly repeatable.

Discussion

At present, beef carcass value is a function of USDA quality grade, a subjective estimate of meat palatability, and USDA yield grade, a subjective estimate of carcass composition. Even though USDA yield grade is a relatively accurate (R^2 = .63 to .87) predictor of carcass composition (Cross et al., 1973; Crouse et al., 1975; Jones et al., 1990; Shackelford et al., 1995), producers continue to distrust use of yield grade in pricing formulas because of its subjectivity. Thus, it is widely believed that development of an accurate, objective method of estimating carcass composition would facilitate value-based marketing (Value Based Marketing Task Force, 1990; Cross and Savell, 1994).

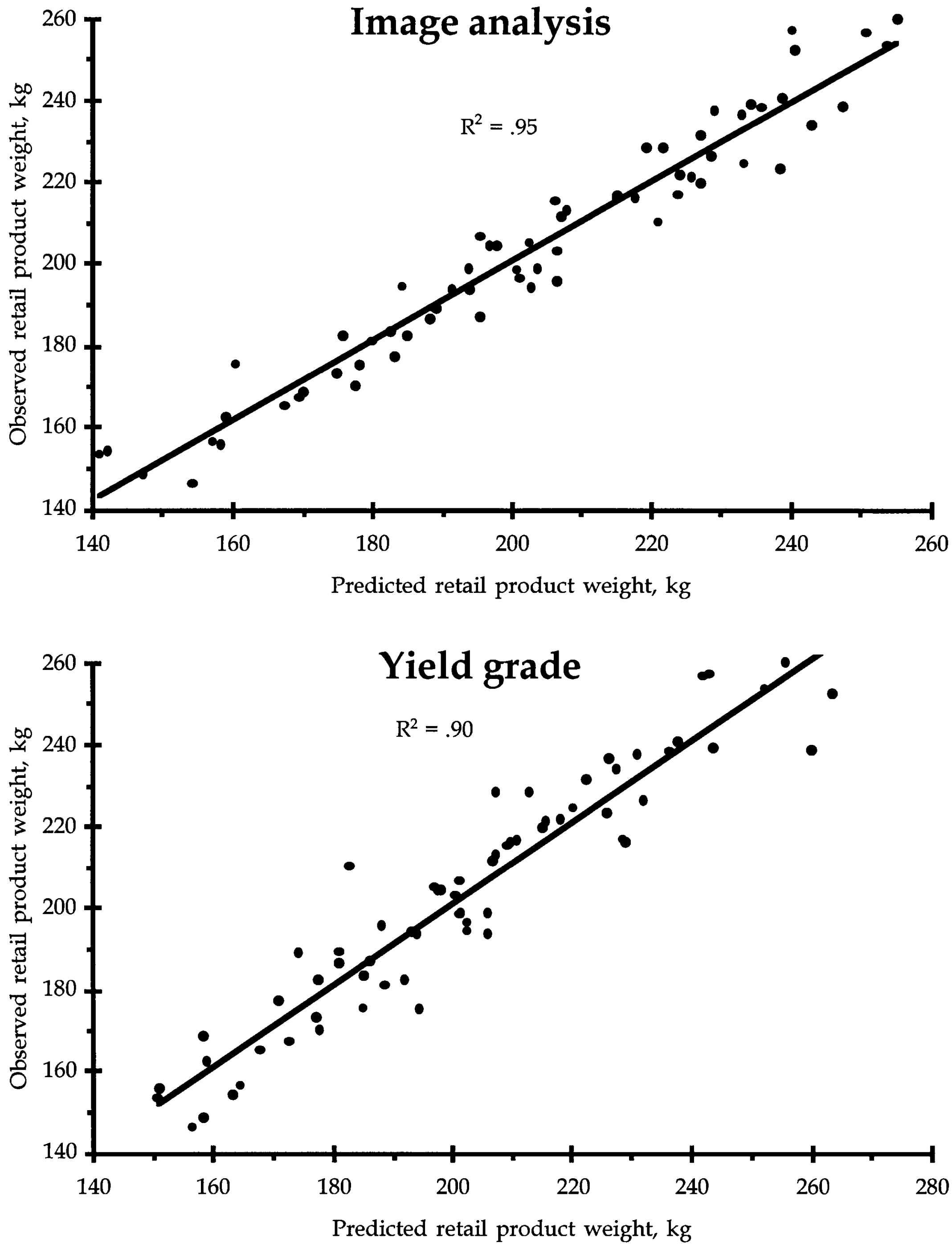

Figure 3. Comparison of the ability of image analysis and yield grade to predict retail product weight (n = 66).

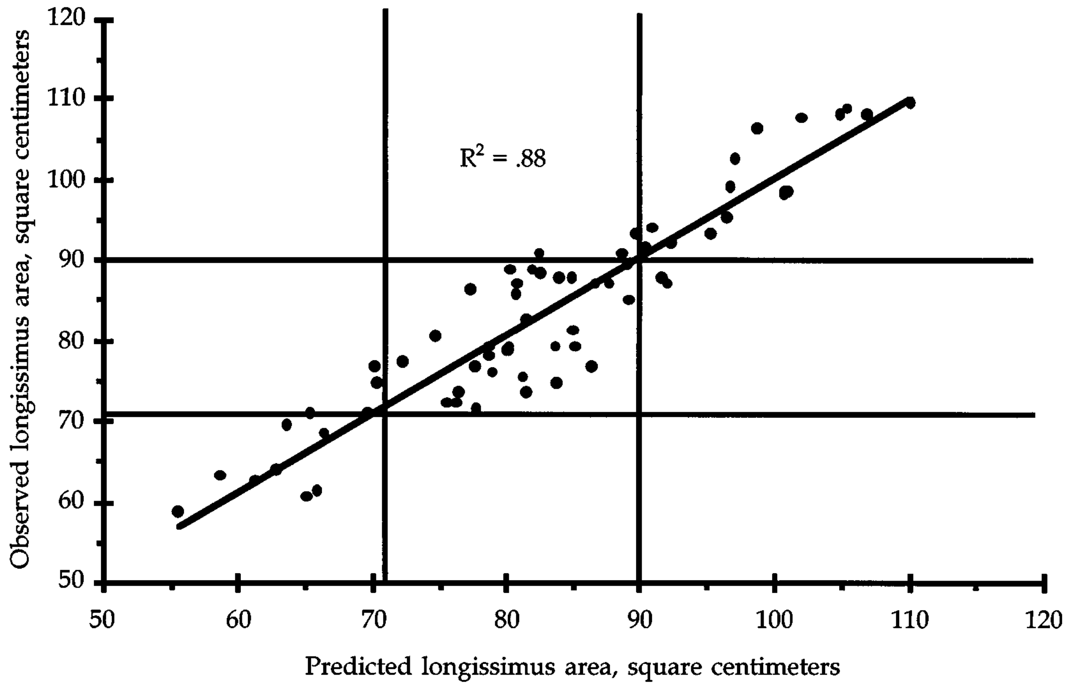

Figure 4. Use of image analysis to identify carcasses that meet a proposed “ideal” longissimus area target (n = 66). The ideal longissimus area target of 71 to 90 cm^2 was determined by Tatum (1992). For 89% of samples, image analysis correctly predicted whether the sample met the ideal longissimus area target.

Of the numerous technologies that have been proposed for objectively evaluating beef carcass composition, image analysis is believed to be the technology closest to commercial application (NLSMB, 1994). Recent experiments have indicated that current image analysis systems (R^2 = .55) are inferior to on-line USDA graders' (R^2 = .59) and off-line expert graders' (R^2 = .79) assessments of carcass cutability (Belk et

Table 4. Percentage of total variation in cut weights accounted for by carcass weight alone or in combination with yield grade or image analysis

Cut[a]	NAMP[b]	Hot carcass weight	Hot carcass + yield grade[c]	Hot carcass + image analysis[d]
Brisket, boneless, deckle-off	120	46	54	59
Shoulder clod	114A	54	77	86
Chuck tender	116B	41	73	79
Cube steak	1100	23	48	59
Chuck roll	116A	74	75	76
Ribeye roll	112	51	78	72
Short ribs	123A	45	50	46
Flank steak	193	40	53	55
Tenderloin, side muscle off	190	34	66	72
Strip loin	180A	50	84	74
Top sirloin butt	184	51	78	80
Full knuckle	167A	34	65	78
Top round	168	30	78	82
Gooseneck round	171A	33	82	81
80% lean trimmings	—	54	83	91

[a]All s.c. fat and any accessible intermuscular fat was trimmed from each cut.
[b]Beef product specification code (NAMP, 1997).
[c]Cut weights were calculated using a two-variable model that included hot carcass weight and calculated yield grade.
[d]Cut weights were calculated using a two-variable model that included hot carcass weight and predicted retail product yield, which was predicted from image analysis using Equation 15 (Table 3).

al., 1996). In the present experiment, image analysis more accurately predicted carcass cutability than did calculated yield grade.

Many image analysis systems have attempted to mimic the USDA yield grading process. That is, those systems have attempted to measure s.c. fat thickness and longissimus area. Our approach to estimating carcass cutability was much simpler and seems to be more effective. We simply measured the entire area of lean and fat in the surface of the 12th–13th rib steak (Figure 1) and calculated percentage lean. By itself, percentage lean as determined by image analysis accounted for as much of the variation in RPYD as did yield grade.

Because we measured total fat area in the surface of the steak rather than s.c. fat thickness, our measurement of fat included s.c. and inter- and intramuscular fat depots. Inclusion of inter- and intramuscular fat probably increased our ability to predict carcass cutability (Jones et al., 1990; Shackelford et al., 1995).

The precision of our system was likely increased by the size and composition of the steak sampled. Rather than limiting the steak to the length of the longissimus muscle, we left an 8-cm long tail on the steak (Figure 1). The tail, which is commonly referred to as the lower rib region of carcasses, is frequently evaluated by graders when adjusting fat thickness.

Frequently, when carcasses are dressed, a portion of the s.c. fat cover is torn or removed. Thus, a concern with the practical use of image analysis to predict carcass cutability is that fat tears will lead to erroneous results. Indeed, in reviewing a series of experiments designed to evaluate image analysis systems, Belk et al. (1996) concluded that the major limitation to current image analysis systems was that they were much less accurate than USDA graders at assessing carcass fatness because of errors induced by fat tears and other slaughter defects. Even though the carcasses analyzed in the present data set were not void of fat tears, the incidence and severity of fat tears on our carcasses was probably less than those typical of large-scale commercial packing plants. Therefore, one might speculate that the accuracy of this technology may decline in practical application. However, the inclusion of the 8-cm-long tail in the image analysis steak and measuring the combined area of all fat depots rather than s.c. fat thickness should help to minimize the error-inducing effects of fat tears.

Belk et al. (1998) determined that the biggest limitation to on-line determination of USDA yield grade was that graders cannot accurately ($R^2 = .23$) estimate longissimus area at chain speeds. Belk et al. (1998) demonstrated that yield grade could be determined accurately ($R^2 = .93$) by combining on-line USDA graders' assessments of fat thickness and kidney, pelvic, and heart fat with "gold standard" measurements of longissimus area and carcass weight. Belk et al. (1998) proposed a system in which an instrument would be used to measure longissimus area, on-line USDA graders would assess carcass fatness, and yield grade would be calculated using a computer. Our system was quite accurate at predicting longissimus area and, thus, could serve as the instrumental method of obtaining longissimus area for such a system. Even if fat tears and other slaughter defects interfere with this system's ability to assess carcass fatness under commercial conditions, this system would still be quite accurate at predicting longissimus area because LEAN, by itself, accounted for 85% of the variation in longissimus area.

The present data set did not contain sufficient variation in marbling or lean color to adequately investigate the ability of this technology to predict those traits. Given the economic importance of those traits to the beef industry, further research using cattle more typical of the U.S. fed-cattle slaughter population is needed.

We have developed a macro computer program that could be used in conjunction with the system we have described in this paper. Less than 9 s is required to capture the image, conduct image analysis, and output the data to a computer data base. Thus, this technology could be used to evaluate up to 400 carcasses per hour.

Implications

The technology described herein could be used by the beef industry in combination with tenderness classification to accurately characterize beef for carcass cutability, longissimus area, subprimal cut weights, and tenderness. These tools should help facilitate the development of value-based marketing systems.

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