Prediction Of Beef Palatability Using Instruments[1]

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Introduction

Prediction of cooked beef palatability has long relied on marbling scores assessed at the cross-sectional interface of the *longissimus* muscle at the 12^{th}-13^{th} rib, combined with physiological maturity. The decision to include marbling as a primary value-determining characteristic in beef carcass assessment was based on the premise that marbling is associated with eating quality (McBee and Wiles, 1967, Jennings *et al.,* 1978, Tatum *et al.,* 1980, Dolezal *et al.,* 1982). Smith *et al.* (1987) illustrated how marbling effectively sorts carcasses on the basis of expected eating quality when the sample population spans the entire range of possible quality grades experienced in the U.S. beef supply. However, over 80% of U.S. beef carcasses today grade USDA Select or low Choice (USDA Slight and Small degrees of marbling). Within this narrow range of marbling scores, marbling does not do an adequate job of sorting beef carcasses into palatability groups reflecting differences in value at the consumption level (Smith *et al.,* 1995). Despite the best efforts of industry and USDA to continually improve the Quality Grades, new technologies with the ability to more precisely sort carcass on the basis of cooked beef palatability are necessary, particularly as branded beef programs continue to become the marketing methodology of choice.

Instrument Technologies

As part of it's effort to implement value-based marketing, the beef industry began investigating use of instruments to improve characterization, sorting, and pricing of cattle and beef carcasses nearly three decades ago (Cross and Whittaker, 1992). In 1994, the National Livestock and Meat Board (now the National Cattlemen's Beef Association) convened a National Beef Instrument Assessment Planning (NBIAP) Symposium to assess state-of-the-art capabilities in carcass evaluation and to make recommendations as to which technologies new research should focus. The NBIAP Symposium determined that: (1) reliable, accurate tools for instrument assessment hold the promise of more accurately measuring factors that contribute to consumer satisfaction with beef, while reducing production costs and waste, (2) testing experimental technology under real-world conditions is critical to achieving commercial success, (3) VIA technology was ready for commercial testing and was the most promising technology for short-term implementation, and (4) ToBEC, Tendertec, Swatland's Probe and Real-Time Ultrasound for seedstock evaluation were ranked second through fifth in applied research priority, respectively (NLSMB, 1994).

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Opinions as to how instruments should be used in carcass assessment are diverse. They have ranged from those who would eliminate Federal USDA grading altogether and replace it with services provided by a private grading company that may, or may not, incorporate instruments into the system (Helming, 1996), to those who believe that technology should be used to augment the application of USDA grade standards (Belk *et al*., 1996). Supporters of augmenting USDA grades are excited about the possibility of increasing both the accuracy and repeatability of the current grade standards using instrument technology; however, they also realize that (1) privatization of the grading system would not prove to be a credible, third-party conformity assessment system, (2) the current system is voluntary and therefore, if grading were not desired by customers of beef packing companies, it could have already been eliminated, (3) eliminating USDA grades would require a change in the Agricultural Marketing Act of 1946, (4) current USDA grades are extremely important merchandising tools in the international market, and (5) elimination of USDA grades would have and adverse effect on other marketing services currently provided by USDA, such as certification and Process Verification programs (Belk *et al.* 1999).

Several instrument systems, some more effective than others, have been researched for use in sorting beef carcasses on the basis of expected cooked eating quality. Some of these systems are considered to be invasive (require the penetration or removal of muscle), while others are non-invasive. Invasive systems can result in lost yield to a packer or potential food safety concerns, while non-invasive systems result in no lost product and minimal food safety concerns. No system, to date, could be considered to be the "silver bullet" relative to perfect beef carcass sorting accuracy.

MARC Tenderness Classification System

Scientists at the Meat Animal Research Center (MARC) in Clay Center, NE advocate use of a system that measures slice shear force (a mechanical measure of cooked beef tenderness that could potentially run at chain speeds) of *longissimus* muscle steaks removed from carcasses after chilling (generally 36-48 hours post-mortem) to sort beef carcasses into groups described as "tender," "intermediate" or "tough." Shackelford *et al.* (1999) recently characterized this system as outlined in Table 1. Although Shackelford *et al.* (1999) showed the system to be effective, samples from carcasses in the study were obtained in a commercial packing plant and then transported to the MARC facility for slice shear force testing. Currently, an online system has not been developed. Furthermore, the MARC tenderness classification system has met with opposition from packers due to the invasive nature of the technology; removal of a steak from each carcass is costly to a packing plant that processes in excess of 5000 carcasses per day.

Tenderness Probes

Many researchers have attempted to develop probe systems that are moderately-invasive, believing that the industry would much more readily accept a system of this type. The first system of this type was the Armour Tenderometer (AT). This system utilized a group of probes that were inserted into the *longissimus* following carcass chilling and that measured the force required to penetrate the muscle and used this information to predict cooked meat tenderness. Carpenter *et al.* (1972) concluded that the AT effectively categorized USDA Choice beef carcasses into tenderness desirability groups, however Huffman (1974) reported that AT reading were related (R^2 = .22) to WBS values, but there was no relationship (P > .05) between AT readings and trained taste panel scores for tenderness taken from 192 carcasses ranging in USDA Quality Grade from Prime to Standard. Parrish *et al.* (1973) reported low correlations between AT values and both WBS and organoleptic tenderness ratings from *longissimus* steaks aged for 7 d (R^2 = .07 and .12, respectively). More recently, Harris *et al.* (1992) evaluated usefulness of Armour Tenderometer readings from 384 "A" maturity beef carcasses described in the study of Smith *et al.* (1984) and reported simple correlation coefficients of .10 (P < .05) and -.13 (P < .01) between AT readings and sensory panel tenderness ratings and WBS force values, respectively. Because of the low correlation to ultimate meat tenderness and palatability, and the apparent ineffectiveness of this technology, it has since been abandoned as a tenderness-predicting tool.

A second, moderately-invasive system was developed in Canada and is referred to as the "Connective Tissue Probe" (CT probe). This instrument uses an optical fiber probe and measures the reflectance of initially polarized light to predict the palatability of beef, predominantly by characterizing the connective tissue properties of the muscle (Swatland, 1991). Despite initial laboratory success, further improvements to the prototype system were needed to obtain more reliable results in commercial use. Later reports found that measurements (reflectance at 460 nm, fluorescence peak 3 and mean length disorder) collected using an optical-electrochemical probe accounted for 34% of the variation in perceived tenderness of 21 d aged *longissimus* steaks, but further work and improvements are needed to obtain more reliable predictions (Swatland *et al.,* 1998). Questions regarding durability of this particular instrument in the packing plant environment have been abundant, and it is clear that the instrument will require further development before it becomes commercially viable.

A third moderately-invasive system evaluated was the Tendertec Mark III Beef Grading Instrument, an Australian probe developed to measure the amount of connective tissue and other factors that contribute to the toughening of meat. In a study by George *et al.* (1997a), no statistical significance was found between the Tendertec outputs and Warner-Bratzler shear force values. Tendertec output variables were significantly correlated with sensory panel ratings for connective tissue amount and overall tenderness, but the coefficients were very low (George *et al*., 1997a). These results were similar to previous findings by Belk *et al.* (1996) for the Tendertec instrument's ability to predict beef carcass palatability.

Working with Lester Jeremiah (Agriculture Canada, Lacombe), George *et al.* (1997b) compared efficacy of Tendertec and Swatland's CT probes (on carcasses) and the Meat Industry Research in New Zealand (MIRINZ) Tenderometer (on raw muscle tissue) as predictors of WBS force values for beef loin steaks. The MIRINZ Tenderometer requires that a muscle sample be positioned on two concentric rings of probes which, when rotated counter to each other, measure the force associated with connective tissue toughness of the sample. Correlation coefficients for Tendertec, CT probe and MIRINZ Tenderometer with WBS force values for samples from more than 400 carcasses and/or muscles were not statistically different from zero (.19, .17, .00 to -.36, respectively).

Use Of Color

Due to the limited success of probes and industry opposition to invasive systems, researchers also have investigated the use of color as a palatability predictor. Hodgson *et al.* (1992) and Hilton *et al.* (1997) found that lean and fat color scores for mature cow carcasses were related to subsequent cooked beef palatability. The lean and fat color scores used in the Hodgson *et al.* (1992) and Hilton *et al.* (1997) studies were determined by personnel trained to evaluate such carcass traits, and did not represent the use of instruments to sort beef carcasses into specific palatability classes.

Belk *et al.* (1999) reported that the lean and fat color of beef carcasses can be used to measure several traits that are related to beef carcass palatability, including: (1) presence/absence of marbling, (2) physiological maturity of the lean, (3) muscle pH, (4) production and feeding management history, and (5) ultrastructural status of sarcomeres and connective tissue within the muscle. In addition, lean color has been shown to be related to calpastatin activity of postmortem muscle (Tatum *et al.*, 1997).

Wulf *et al.* (1997) utilized a Minolta Colorimeter (a portable colorimeter) to measure the Commission Internationale de l'Eclairage (International Commission on Illumination; CIE) values for L* (lightness; dark = 0, white = 100), a* (red = + values, green = - values), and b* (yellow = + values, blue = - values). Wulf *et al.* (1997) found that L*, a*, and b* values measured on the exposed *longissimus* muscle of beef carcasses were related to beef carcass palatability. Similarly, Tatum *et al.* (1997), found that L*, a* and b* values, measured using the HunterLab MiniScan portable spectrophotometer, could be used to decrease the variation that occurs in beef carcass palatability. Both of these studies used color measurement instruments with small aperture sizes to measure the lean and fat color of *longissimus* muscle cross sections. Therefore, information concerning lean color was only generated for a small portion of the exposed *longissimus* muscle, and was not representative of the variation in muscle color that occurs across the cross-sectional face of the *longissimus* muscle surface at the 12^{th} rib.

Color To Augment Application Of Quality Grades

A Quality Grade Augmentation system was developed by Wulf and Page (2000) who supplemented current USDA Quality Grade Standards with Minolta colorimeter readings (L*, a* and b*), pH and hump height (maximum dorsal protrusion of the rhomboideus muscle; measured as the distance from the dorsal edge of the *ligamentum nuchae* to the dorsal edge of the rhomboideus, not counting subcutaneous fat). When evaluated under "carefully-controlled" bloom times, it was reported that this augmentation system could predict *longissimus* WBS force (R^2 = .36) measures and a carcass palatability (R^2 = .46) index (additive measure of *longissimus, gluteus medius* and *semimembranosus* WBS shear force values and sensory panel attributes) following

7 days of postmortem aging. From this research, two proposed augmentation schemes were outlined for USDA Choice and Select beef carcasses (Table 2.)

Effectiveness of the two proposed South Dakota State University systems to segregate cattle into palatability groups are demonstrated in Figures 1 and 2. Augmentation of the current USDA grade standards with the proposed systems could reduce the chance of an unpleasant eating experience from 14% to 1% and 36% to 7% for USDA Choice and Select carcasses, respectively. It is evident that augmentation systems can improve the accuracy and precision of sorting beef carcasses into palatability groups.

BeefCam™

Researchers at Colorado State University have focused efforts toward developing video image analysis (VIA) systems to make color measurements on the entire exposed surface of the *longissimus* muscle at the 12th rib. Early work using VIA technology to measure beef muscle color was marginally successful (Li *et al.*, 1997). The early VIA systems used the computer compatible RGB color measurements computed from the video images to determine the lean color of beef *longissimus* muscle. While RGB colors were correlated to tenderness, attempts to sort beef carcasses into differing palatability classes using these color measurements were unsuccessful (Li *et al.,* 1997). Early VIA research did prove that computer software could be written that would accurately segment a video image of a ribeye--via image processing techniques--into fat, lean and connective tissue components and conduct analysis of color and other attributes generated by color measurements on each of these components, independently.

In 1996, Colorado State University initiated pilot work with Hunter Associates Laboratory (manufacturers of the HunterLab MiniScan portable spectrophotometer) to develop a VIA system that could measure beef carcass lean and fat color using the L*, a*, and b* color scale. A bench-top VIA system first was used to obtain images of beef *longissimus* steaks for the purpose of objective color analysis. When the VIA-derived color measurements were used, in conjunction with expert quality grade factors, the probability of encountering a tough (WBS $\geq$ 4.5 kg) steak after 14 to 21 d of aging was reduced from .18 to .25 and .15 to .02 for USDA Choice and USDA Select steaks, respectively (Belk *et al.*, 1997). Furthermore, Belk *et al.* (1997) reported that the pilot study data confirmed that (1) color is related to subsequent cooked palatability of beef carcasses, independent of differences in marbling or carcass maturity, and, (2) VIA technology is capable of ascertaining color attributes of beef ribeyes, using the color information to augment USDA quality grades, and thereby improve the accuracy of quality grades in sorting carcasses based on expected eating palatability across narrow ranges of marbling scores.

Based on the results of the pilot study, Colorado State University and Hunter Associates Laboratory began development of a prototype portable video imaging system (BeefCam™) which contained hardware and software that were specifically designed for the analysis of beef carcass lean and fat color in a packing plant environment. Researchers at Colorado State University tested the BeefCam™ system for its ability to sort beef carcasses based on the expected eating quality of subsequent cooked product. A study conducted by Wyle *et al.* (1999) used the BeefCam™ system, either alone (Model I), or in conjunction with USDA Quality Grade (Model II) to certify carcasses as being tender (WBS < 4.5 kg) or tough (WBS $\geq$ 4.5 kg). Use of Model I resulted in 51.9% of the carcasses evaluated being characterized as tender, and 92.2% of those that were certified were actually tender. Using Model II, 53.4% of the carcasses evaluated (n = 500) were certified as being tender and 94.4% of those certified were actually tender (Table 3).

To validate the effectiveness of the BeefCam™, researches at Colorado State University selected 292 beef carcasses from a commercial Colorado packing plant (Cannell et al., 1999; unpublished data), a different plant from those sampled in Wyle et al. (1999). The sample population evaluated contained carcasses that were assigned USDA quality grades ranging from U.S. Standard to U.S. Prime, with the greatest proportion of carcasses falling into the U.S. Select and U.S. Choice grades (mimicking the U.S. beef population). Sample carcasses were assigned USDA yield grades ranging between 1 and 5, and all carcasses were selected to reflect the normal variability in composition, dressing defects and quality attributes encountered by the facility on a daily basis. Data from that validation trial are presented in Table 4. From this validation, when tested on a separate and unique beef carcass sample population, relative to WBS force and trained taste panel ratings, BeefCam™ performed similarly (if not better) in accuracy to its performance on the initial population from which the sorting algorithms and regression equations were developed.

Conclusions and Implications

Video imaging systems and Wulf's system have been shown to perform at current chain speeds (over 300 hd/h) and accurately (over 90%) segment the cattle population into tender versus not tender categories, while doing so in a non-invasive fashion. In an industry where consumers are becoming more demanding of the end product and are willing to purchase "branded" or "certified" products in search of a consistently good eating experience, instrument technologies will be an integral part of identifying potentially tender carcasses and more effectively sorting and marketing beef products; these technologies show overwhelming potential as the next phase in USDA Quality Grade Standard improvement.

References

Belk, K.E., M.H. George, H.N. Zerby, J.A. Scanga, J.D. Tatum, J.W. Wise and G.C. Smith. 1996. An evaluation of HunterLab Color Vision System (a VIA system) for use in improving grading accuracy and for augmenting application of USDA quality and yield grades, and of the Tendertec Probe as an on-line testing device for use in sorting beef carcasses according to tenderness for use in development of a Palatability Assurance Critical Control Points (PACCP) model to reduce the incidence of beef palatability problems. Final report to the National Cattlemen's Beef Association. Colorado State University, Fort Collins, CO.

Belk, K.E., R.C. Cannell, J.D. Tatum and G.C. Smith. 1997. Video imaging systems for composition and quality. Paper presented at the Meat Industry Research Conf., October 28, Chicago, IL.

Belk, K.E. 1999. Techniques to identify palatable beef carcasses: HunterLab BeefCam™. Proc., The Range Beef Cow Symposium XVI, Greeley, CO.

Carpenter, Z. L., G. C. Smith, and O. D. Butler. 1972. Assessment of beef tenderness with the Armour Tenderometer. J. Food Sci. 37:126-129.

Cross, H.R. and A.D. Whittaker. 1992. The role of instrument grading in a beef value based marketing system. J. Anim. Sci. 70:984.

Dolezal, H.G., G.C. Smith, B.W. Berry and A.L. Carpenter. 1982. Comparison of subcutaneous fat thickness, marbling, and quality grade for predicting palatability of beef. J. Food Sci. 47:397.

George, M.H., J.D. Tatum, H.G. Dolezal, J.B. Morgan, J.W. Wise, C.R. Calkins, T. Gordon, J.O. Reagan and G.C. Smith. 1997a. Comparison of USDA quality grade with Tendertec for the assessment of beef palatability. J. Anim. Sci. 75:1538.

George, M.H., G.C. Smith, J.D. Tatum, K.E. Belk and L.E. Jeremiah. 1997b. Relationships of carcass measurements with Tendertec and Swatland's Connective Tissue Probe of beef carcass and raw muscle measurements with the MIRINZ Tenderometer to Warner-Bratzler Shear force measurements of beef loin steaks. Mimeograph Report. pp. 1-12. Colorado State University, Fort Collins and Agriculture Canada, Lacombe.

Harris, J. J.W. Savell and G.C. Smith. 1992. Armour Tenderometer readings and tenderness. Mimeograph Report. pp. 1-6. Department of Animal Science, Texas A&M University, College Station.

Helming, B. 1996. The time has come to shift the responsibility of beef quality grading from the government to the private sector (Parts 1 and 2). Report No. 442, 443. Bill Helming Consulting Services, Olathe, KS.

Hilton, G.G., J.D. Tatum, S.E. Williams, K.E. Belk, F.L. Williams, J.W. Wise and G.C. Smith. 1997. An evaluation of current and alternative systems for quality grading carcasses of mature slaughter cows. J. Anim. Sci. 76:2094.

Hodgson, R.R., K.E. Belk, J.W. Savell, H.R. Cross and F.L. Williams. 1992. Development of a quantitative quality grading system for mature cow carcasses. J. Anim. Sci. 70:1840.

Huffman, D.L. 1974. An evaluation of the Tenderometer for measuring beef tenderness. J. Anim. Sci. 38:287-294.

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.

Li, J., J. Tan, F.A. Martz. 1997. Predicting beef tenderness from image texture features. Paper presented at the American Society of Agricultural Engineering summer meeting, August 10, Minneapolis, MN.

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.

National Livestock and Meat Board. 1994. National Beef Instrument Assessment Plan-1994. National Livestock and Meat Board, Chicago, IL.

Parrish, F. C., D. G. Olson, B. E. Miner, R. B. Young, and R. L. Snell. 1973. Relationship of tenderness measurements made by the Armour Tenderometer to certain objective, subjective and organoleptic properties of bovine muscle. J. Food Sci. 38:1214-1219.

Shackelford, S.D., T.L. Wheeler and M. Koohmaraie. 1999. Tenderness classification of beef: II. Design and analysis of a system to measure beef longissimus shear force under commercial processing conditions. J. Anim. Sci. 77:1474.

Smith, G.C. Z. L. Carpenter, H.R. Cross, G.E. Murphey, H.C. Abraham, J.W. Savell, G.W. Davis, B.W. Berry and F.C. Parrish, Jr. 1984. Relationship of USDA marbling groups to palatability of cooked beef. J. Food Quality. 7:289-308.

Smith, G.C., J.W. Savell, H.R. Cross, Z.L. Carpenter, C.E. Murphey, G.W. Davis, H.C. Abraham, F.C. Parrish, Jr. and B.W. Berry. 1987. Relationship of USDA quality grades to palatability of cooked beef. J. Food Qual. 10:269.

Smith, G.C., J.W. Savell, H.G. Dolezal, T.G. Field, D.R. Gill, D.B. Griffin, D.S. Hale, J.B. Morgan, S.L. Northcutt, J.D. Tatum, R. Ames, S. Boleman, B. Gardner, W. Morgan, M. Smith, C. Lambert and G. Cowman. 1995. Improving the quality, consistency, competitiveness and market-share of beef – the final report of the second blueprint for total quality management in the fed-beef (slaughter steer/heifer) industry-1995. Colorado State University, Fort Collins, CO, Texas A&M University, College Station, TX, and Oklahoma State University, Stillwater, OK.

Swatland, H.J. 1991. Evaluation of probe designs to measure connective tissue fluorescence in carcasses. J. Anim. Sci. 69:1983.

Swatland, H. J., J. C. Brooks, and M. F. Miller. 1998. Possibilities for predicting taste and tenderness of broiled beef steaks using an optical-electromechanical probe. Meat Sci. 50:1-12.

Tatum, J.D., G.C. Smith, B.W. Berry, C.E. Montgomery, F.L. Williams and Z.L. Carpenter. 1980. Carcass characteristics, time on feed, and cooked beef palatability attributes. J. Anim. Sci. 50:833.

Tatum, J.D., M.H. George, K.E. Belk, and G.C. Smith. 1997. Development of a palatability assurance "critical control points" (PACCP) model to reduce the incidence of beef palatability problems. Final Report to the National Cattlemen's Beef Association. Colorado State University, Fort Collins.

USDA. 2000. National Carlot Meat Report, March 6, 2000. USDA-AMS, Livestock and Seed Program, Livestock and Grain Market News. Washington DC.

Wulf, D.M., S.F. O'Connor, J.D. Tatum, and G.C. Smith. 1997. Using objective measures of color to predict beef *longissimus* tenderness. J. Anim. Sci. 75:684.

Wulf, D.M., and J.K. Page. 2000. Using measurements of muscle color, pH and electrical impedance to augment the current USDA beef quality grading standards and improve the accuracy and precision of sorting carcasses into palatability groups. J. Anim. Sci. In-Press.

Wyle, A. M., R. C. Cannell, K. E. Belk, M. Goldberg, J. Hartnett, J. D. Tatum and G. C. Smith. 1999. Effectiveness of using the HunterLab BeefCam System to sort beef carcasses into differing product lines, across four different packing facilities and from both source verified and non-source verified fed cattle, based on projected tenderness of subsequently aged and cooked product. Final Report to National Cattlemen's Beef Association. pp. 1-14. Department of Animal Sciences, Colorado State University, Fort Collins.

Table 1. Effectiveness of the Meat Animal Research Center (MARC) tenderness classification system as determined via Warner-Bratzler shear force (WBS) and trained sensory panel (SP) evaluation (N = 483).

Item	Tender	Intermediate	Tough
Carcasses sorted into each category, %	47	48	5
Carcasses actually tender, % by WBS	100	89	36
Carcasses actually tender, % by SP	100	91	28
Mean WBS at 14 d, kg	3.5^{z}	4.2^{y}	5.7^{x}
Mean OT rating	7.3^{x}	6.4^{y}	4.4^{z}
Mean EOF rating	7.3^{x}	6.3^{y}	4.2^{z}
Mean CT rating	7.7^{x}	7.4^{y}	6.7^{z}
Mean FI rating	5.0^{x}	5.0^{x}	4.8^{x}

$^{x, y, z}$Means in the same row bearing differing superscript letters differ ($P < .05$).
Source: Shackelford et al. (1999).

Table 2. Proposed South Dakota State University beef carcass classification (color augmentation) system.

System #1	System #2
<u>Minimum requirement for Choice:</u>	**<u>Minimum requirement for Choice:</u>**
1. Must be “A” or “B” overall maturity	1. Must be “A” or “B” overall maturity
2. Must have a minimum marbling score of Small^{00}.	2. If L* is from 36.0 to 40.0 then must have a minimum marbling score of Small^{50}
3. Must have a minimum L* value of 36.0.	3. If L* is > 40.0, then must have a minimum marbling score of Slight^{50}
4. Must have a hump height < 8.9 cm	4. Must have a hump height < 8.9 cm
<u>Minimum requirement for Select:</u>	**<u>Minimum requirement for Select:</u>**
1. Must be “A” or “B” overall maturity.	1. Must be “A” or “B” overall maturity.
2. Must have a minimum marbling score of Slight^{00}.	2. Must have a minimum marbling score of Slight^{00}.
3. Must have a minimum L* value of 38.0.	3. Must have a minimum L* value of 36.0.
4. Must have a hump height < 8.9 cm.	4. Must have a hump height < 8.9 cm.

Source: Wulf and Page (2000).

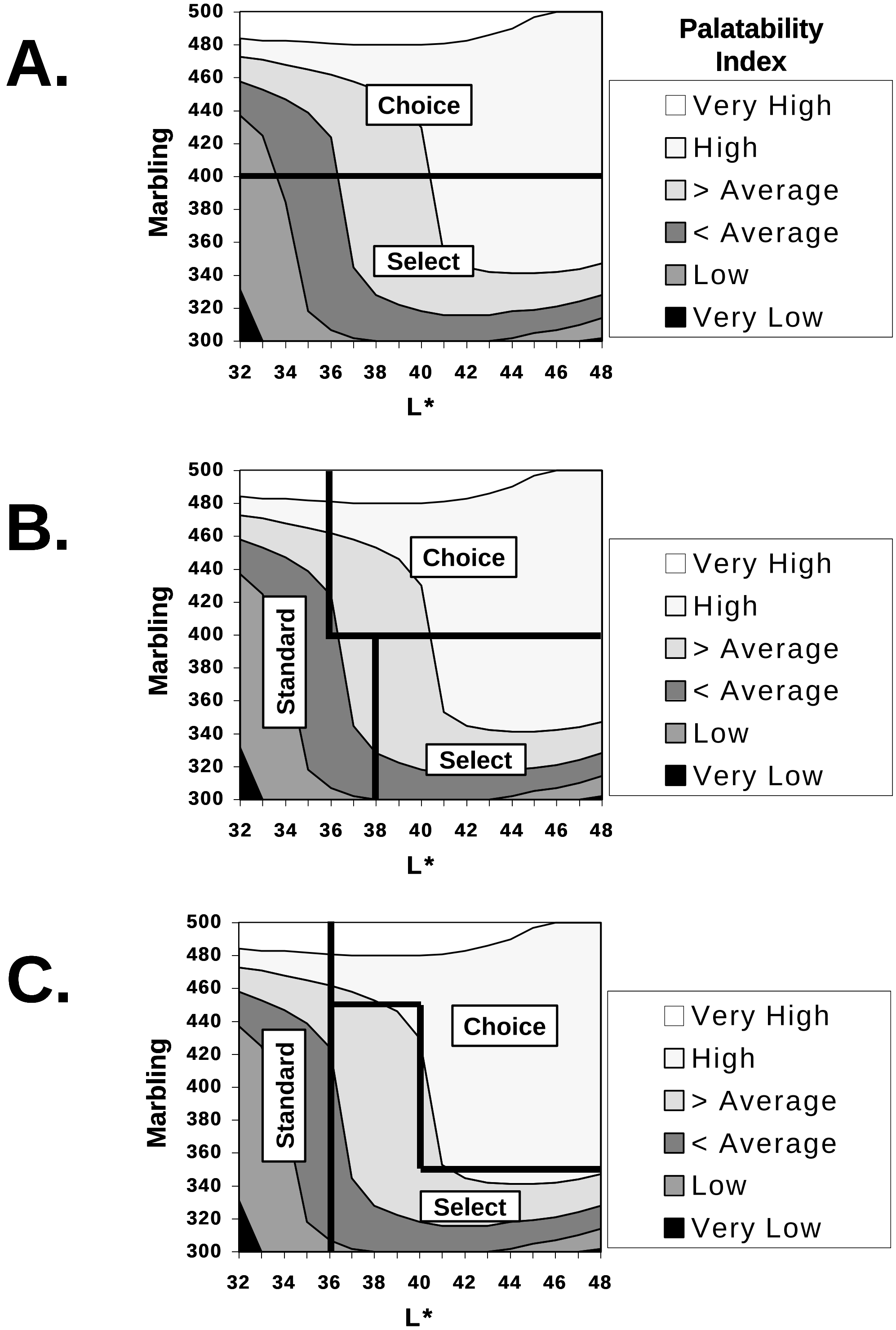

Figure 1. Surface response function for marbling score x lean color L* values and carcass segmentations using the current USDA Quality Grade Standards (A), and the SDSU proposed system No. 1 (B) or system No. 2 (C). Source: Wulf and Page (2000).

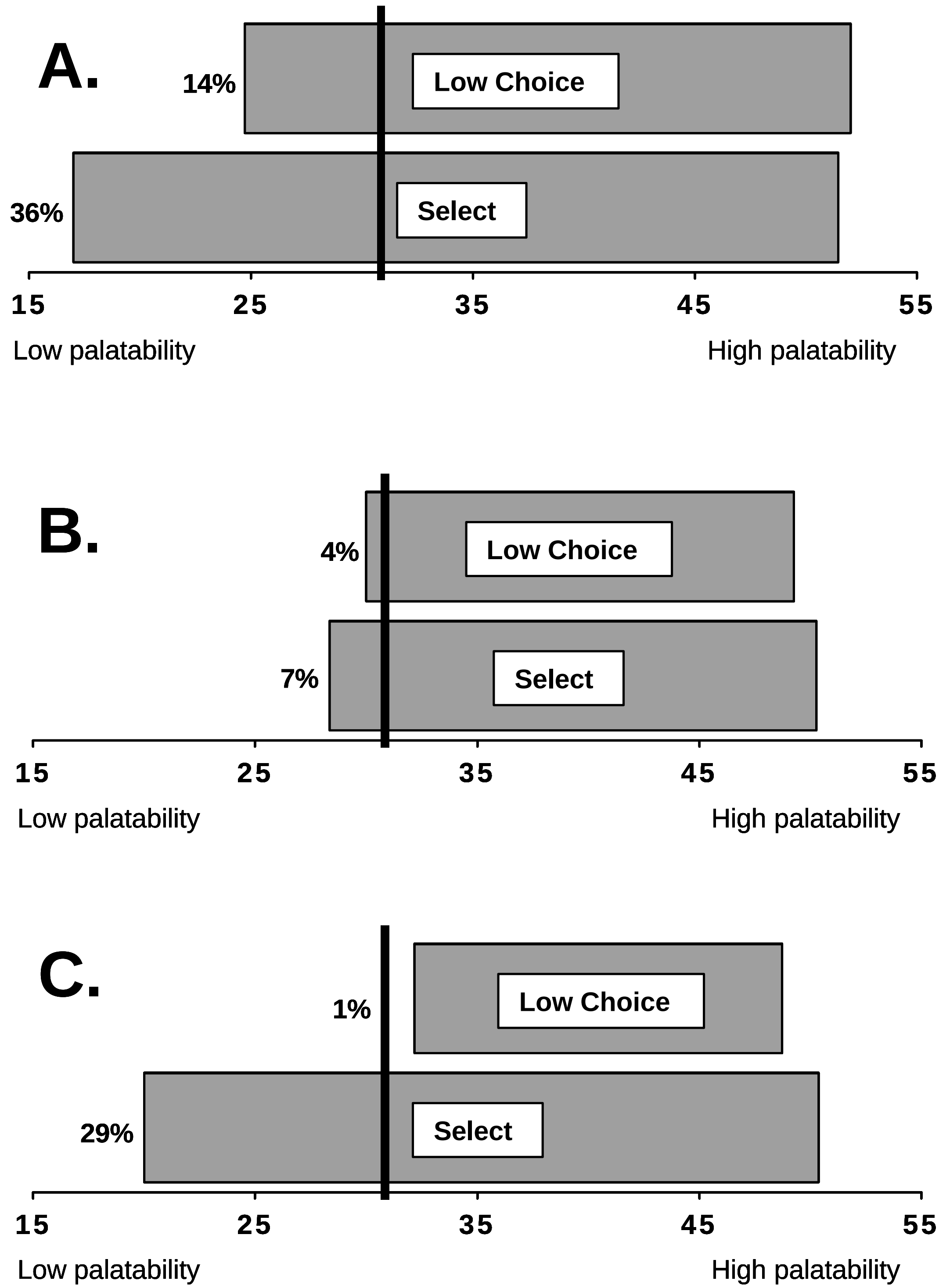

Figure 2. Beef carcass sorting effectiveness of the current USDA Quality Grade Standards (A), and the SDSU proposed system No. 1 (B) or system No. 2 (C). Percentages to the left of each bar reflect the number of unacceptable carcasses within each grade. Source: Wulf and Page (2000).

Table 3. Use of BeefCam™ alone (Model I), or to augment application of USDA Quality Grades (Model II), based on Warner-Bratzler shear force of cooked *longissimus* steaks (N = 769).

		Unacceptable Carcasses, %[a]		
Model/Grade	**% Carcasses Certified**	**Total Sample Population**	**Certified**	**Rejected**
Model I:				
All Carcasses	51.9	13.8[y]	7.8[x]	20.3[z]
Top Choice	57.3	7.9[xy]	4.3[x]	12.6[y]
Low Choice	58.5	10.3[x]	6.3[x]	16.0[y]
Select	37.5	24.7[y]	16.5[x]	29.6[z]
Model II:				
All Carcasses	53.4	13.8[y]	5.6[x]	23.2[z]
Top Choice	78.0	7.9[x]	4.8[x]	18.9[y]
Low Choice	59.1	10.3[xy]	6.7[x]	15.4[y]
Select	19.8	24.7[y]	4.4[x]	23.8[y]

[a] Percentage of carcasses in each classification group having *longissimus* steak Warner-Bratzler shear force values in excess of 4.5 kg after 10 d of postmortem aging.

[x, y, z] Percentages in the same row bearing different superscript letters differ ($P < .05$).

Source: Wyle et al. (1999).

Table 4. Validation of the BeefCam™ models developed by Wyle et al. (1999), based on Warner-Bratzler shear force of cooked *longissimus* steaks (N = 282) obtained from carcasses processed at a different packing plant.

Model/Grade	% Carcasses Certified	Unacceptable Carcasses, %[a]		
		Total Sample Population	Certified	Rejected
Model I:				
All Carcasses	45.7	7.1[y]	1.6[x]	11.8[y]
Top Choice	48.6	6.8[xy]	0.0[x]	13.2[y]
Low Choice	47.5	5.9[xy]	0.0[x]	11.3[y]
Select	42.1	8.4[x]	4.4[x]	11.3[x]
Model II:				
All Carcasses	42.6	7.1[y]	1.7[x]	11.1[y]
Top Choice	60.8	6.8[xy]	2.2[x]	13.8[y]
Low Choice	48.5	5.9[xy]	0.0[x]	11.5[y]
Select	24.3	8.4[x]	3.8[x]	9.9[x]

[a] Percentage of carcasses in each classification group having *longissimus* steak Warner-Bratzler shear force values in excess of 4.5 kg after 14 d of postmortem aging.

[x, y, z] Percentages in the same row bearing different superscript letters differ ($P < .05$)