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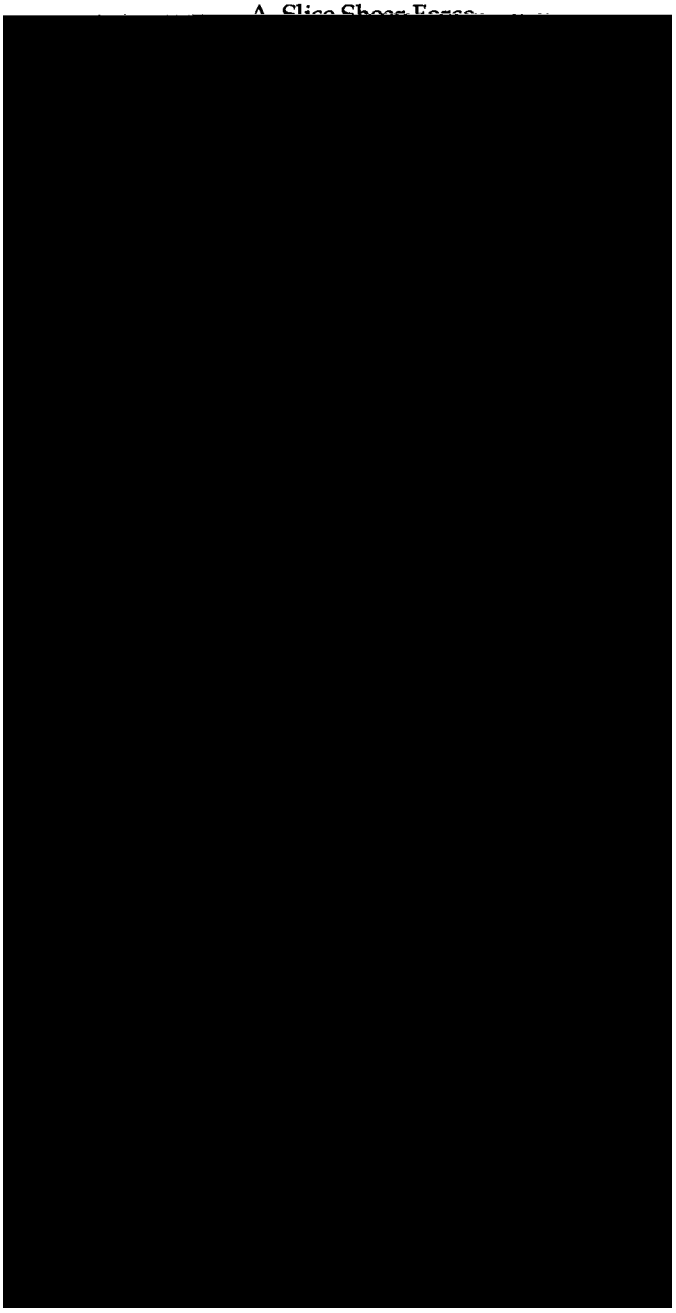
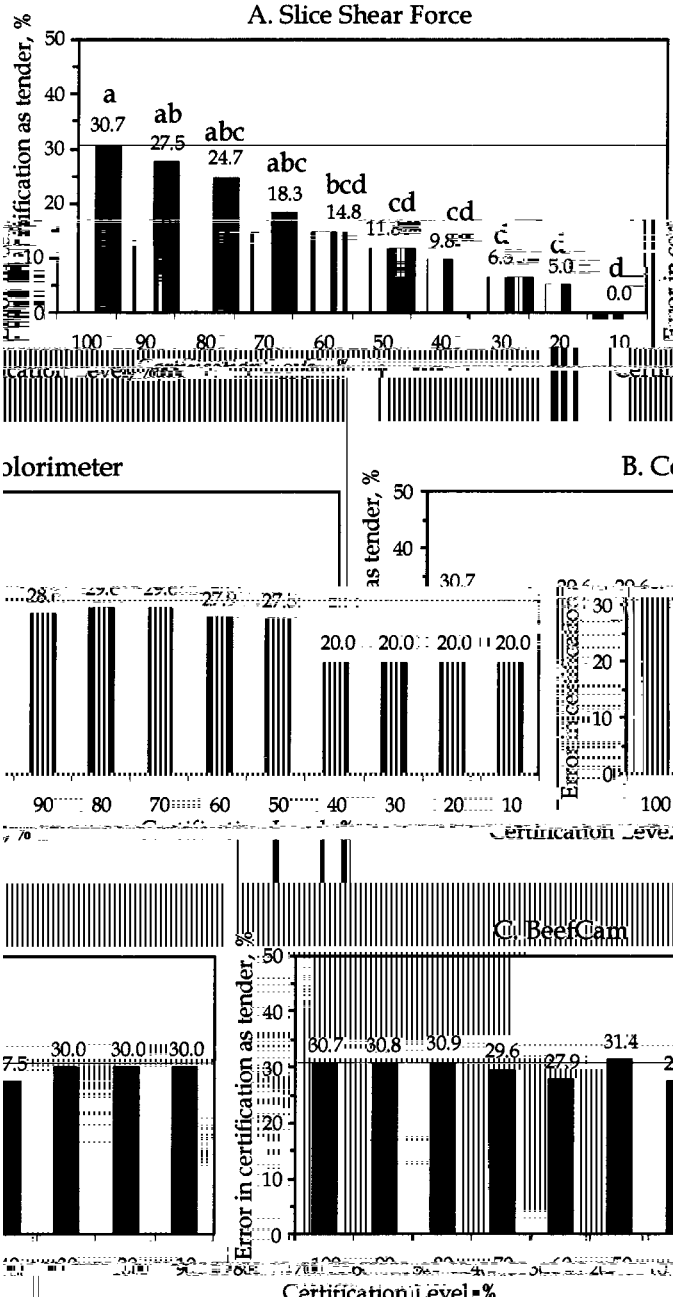
ABSTRACT: The objective of this study was to determine the accuracy of three objective systems (prototype BeefCam, colorimeter, and slice shear force) for identifying guaranteed tender beef. In Phase I, 308 carcasses (105 Top Choice, 101 Low Choice, and 102 Select) from two commercial plants were tested. In Phase II, 400 carcasses (200 rolled USDA Select and 200 rolled USDA Choice) from one commercial plant were tested. The three systems were evaluated based on progressive certification of the longissimus as "tender" in 10% increments (the best 10, 20, 30%, etc., certified as "tender" by each technology; 100% certification would mean no sorting for tenderness). In Phase I, the error (percentage of carcasses certified as tender that had Warner-Bratzler shear force of ≥ 5 kg at 14 d postmortem) for 100% certification using all carcasses was 14.1%. All certification levels up to 80% (slice shear force) and up to 70% (colorimeter) had less error ($P < 0.05$) than 100% certification. Errors in all levels of certification by prototype BeefCam (13.8 to 9.7%) were not different ($P > 0.05$) from 100% certification. In Phase I, the error for 100% certification for USDA Select carcasses was

with a belt grill (5.5 min), then a 5-cm-long, 1-cm-thick slice was removed from the lateral end of the steak parallel to the muscle fibers. This slice was sheared perpendicular to the fibers with a flat, blunt-end blade at 500 mm/min to obtain a slice shear force value.

Colorimeter. A portable Minolta Chroma Meter CR-310 (Minolta Corp., Ramsey, NJ) with a 50-mm-diameter measurement area and D65 illuminant was used to obtain L*, a*, and b* values on the longissimus cross section at the 12th rib from both sides 90 to 110 min after ribbing, as described by Wulf and Page (2000). Hump height was measured on both sides as the distance from the dorsal edge of the ligamentum nuchae to the maximum dorsal protrusion of the rhomboideus,



1. Error rates for certifying all carcasses as "tender" in increments of 10% of the sample (Phase I, n = 308). "Tender" was defined as longissimus Warner-Bratzler shear force of < 5 kg at 14 d postmortem. 100% certification means no tenderness sorting. [a,b,c,d]Means across certification levels within certification method lacking a common superscript letter differ ($P < 0.05$).

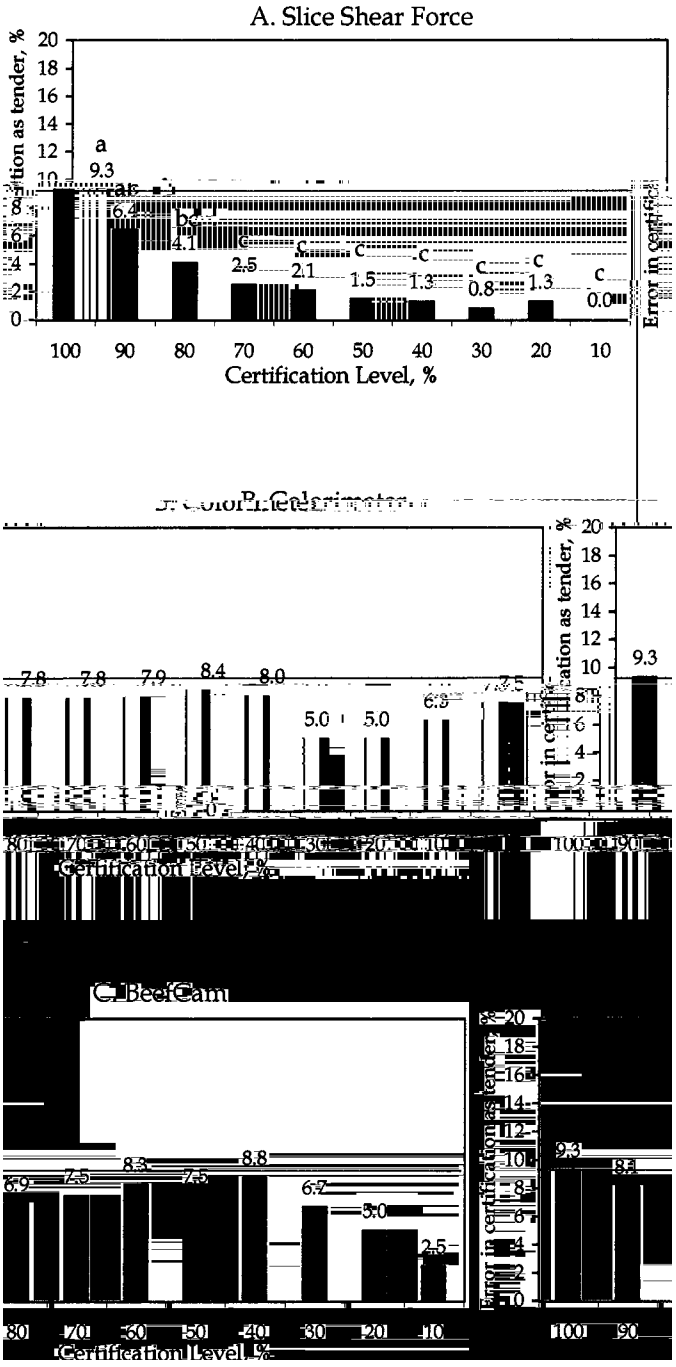


2. Error rates for certifying USDA Select carcasses as "tender" in increments of 10% of the sample (Phase I, n = 102). "Tender" was defined as longissimus Warner-Bratzler shear force of < 5 kg at 14 d postmortem. 100% certification means no tenderness sorting. [a,b,-c,d]Means across certification levels within certification method lacking a common superscript letter differ ($P < 0.05$).

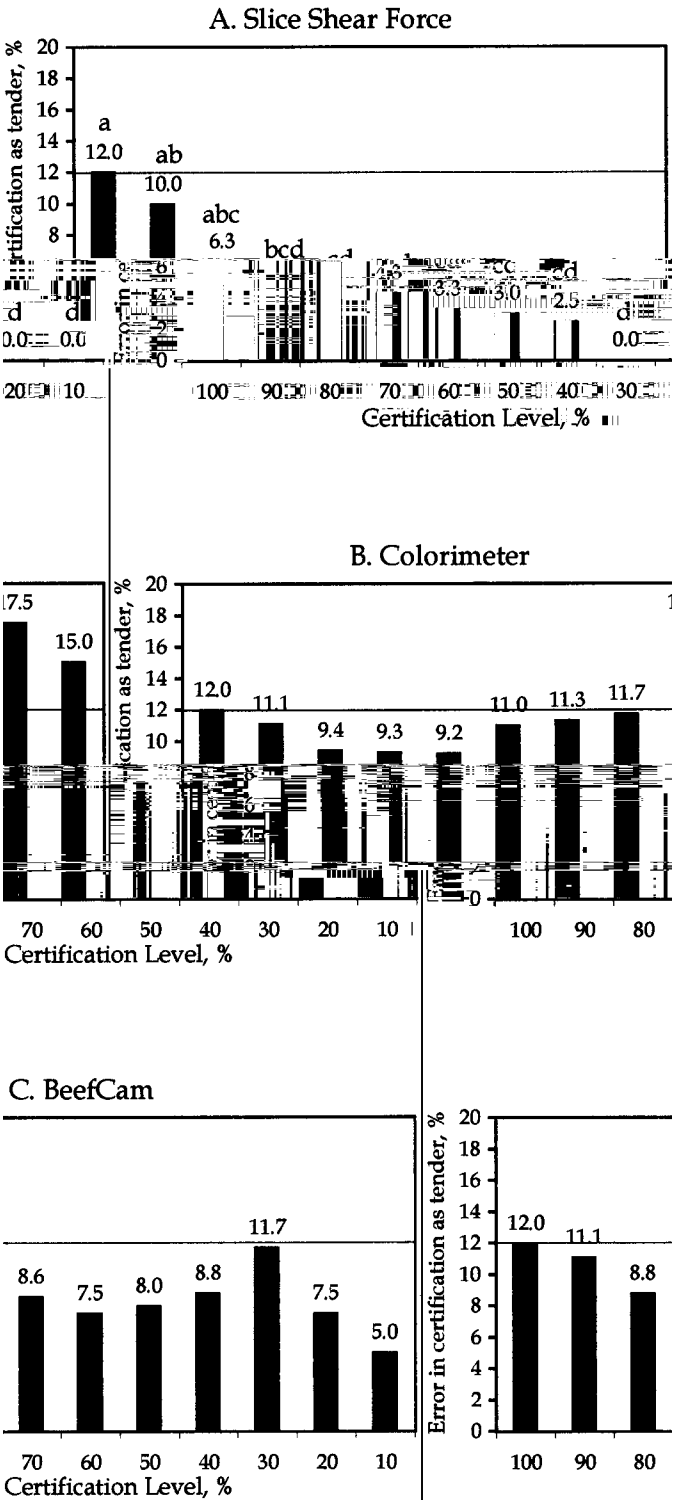
force value between certified "tender" and not certified was significant ($P < 0.05$) only for the 60% certification level. Results were similar for longissimus trained sensory tenderness rating, except the mean difference for 90% certification by colorimeter and 60% certification by prototype BeefCam was not ($P > 0.05$) significant (Table 2). Regardless of percentage certified, the difference in mean longissimus consumer tenderness like rating between certified "tender" and not certified was significant ($P < 0.05$) for slice shear force. For all certification levels except for 20, 50, and 90%, the difference in mean longissimus consumer tenderness like rating between certified "tender" and not certified was significant ($P < 0.05$) for colorimeter. The magnitude of the

. . . **2.** Effect of percentage certified as “tender” on longissimus 14-d Warner-Bratzler shear force, trained sensory panel tenderness rating, and consumer panel tenderness, Warner-Bratzlerpanelthre

a lower ($P < 0.05$) percentage of their longissimus with Warner-Bratzler shear force values that were at least 5 kg than did Select carcasses. In Phase II, mean Warner-Bratzler shear force value also was higher ($P < 0.05$) for longissimus from Select rather than from Low Choice carcasses. However, there was no difference ($P > 0.05$)



3. Error rates for certifying all carcasses as "tender" in increments of 10% of the sample (Phase II, n = 400). "Tender" was defined as longissimus Warner-Bratzler shear force of < 5 kg at 14 d postmortem. 100% certification means no tenderness sorting. [a,b,c,d]Means across certification levels within certification method lacking a common superscript letter differ ($P < 0.05$).



4. Error rates for certifying USDA Select carcasses as "tender" in increments of 10% of the sample (Phase II, n = 200). "Tender" was defined as longissimus Warner-Bratzler shear force of < 5 kg at 14 d postmortem. 100% certification means no tenderness sorting. [a,b,c,d]Means across certification levels within certification method lacking a common superscript letter differ ($P < 0.05$).

. . . . Effect of percentage certified as "tender" on longissimus 14-d Warner-Bratzler shear force for three certification methods (Phase II)

Percentage certified as "tender"	Slice shear force			Colorimeter			BeefCam		
	Certified "tender"	Not certified	Diff.[a]	Certified "tender"	Not certified	Diff.[a]	Certified "tender"	Not certified	Diff.[a]
	All carcasses, n = 400								
90	3.7	4.7	1.0*	3.8	4.3	0.5*	3.8	4.3	0.6*
80	3.6	4.5	0.9*	3.8	4.1	0.3*	3.7	4.2	0.4*
70	3.6	4.4	0.8*	3.7	4.0	0.3*	3.8	4.0	0.2*
60	3.5	4.3	0.8*	3.7	4.0	0.2*	3.7	3.9	0.2*
50	3.4	4.2	0.8*	3.7	3.9	0.2*	3.7	3.9	0.2*
40	3.4	4.1	0.7*	3.6	4.0	0.3*	3.7	3.9	0.2*
30	3.3	4.0	0.7*	3.7	3.9	0.2*	3.6	3.9	0.3*
20	3.4	3.9	0.6*	3.6	3.9	0.2*	3.5	3.9	0.4*
10	3.4	3.9	0.5*	3.6	3.9	0.3*	3.5	3.9	0.4*
	USDA Select carcasses, n = 200								
90	3.9	4.9	1.0*	3.9	4.3	0.4	3.9	4.4	0.5*
80	3.8	4.7	1.0*	3.9	4.4	0.5*	3.8	4.4	0.6*
70	3.7	4.6	0.9*	3.9	4.2	0.3*	3.8	4.3	0.5*
60	3.6	4.5	0.8*	3.9	4.1	0.2	3.8	4.1	0.3*
50	3.5	4.4	0.9*	3.9	4.0	0.1	3.9	4.0	0.2
40	3.5	4.3	0.8*	3.9	4.0	0.0	3.9	4.0	0.2
30	3.4	4.2	0.8*	3.9	4.0	0.1	3.9	4.0	0.1
20	3.4	4.1	0.7*	3.9	4.0	0.0	3.8	4.0	0.2
10	3.5	4.0	0.5*	3.8	4.0	0.1	3.7	4.0	0.3

[a]Diff. = The difference between means for not certified "tender" and certified "tender."
*The difference between certified "tender" and not certified "tender" was significant ($P < 0.05$).

between Select and Low Choice carcasses for percentage with at least a 5-kg longissimus Warner-Bratzler shear force value. Quality grade was more effective than prototype BeefCam or colorimeter for identifying tender beef. However, slice shear force could identify a subset of Select beef that would be similar in tenderness to Top Choice beef.

To meet consumer expectations, the beef industry has become increasingly interested in implementing

creased to 51% willing to pay an average premium of $4.06/kg ($1.84/lb) when the consumers were informed they were evaluating a "guaranteed tender" and a "probably tough" steak. In a study of Denver metropolitan area consumers, Shackelford et al. (2001) reported that 50% of consumers would be willing to pay a $1.10/kg ($0.50/lb) premium for guaranteed tender USDA Select loin steaks. They also found that 65% of consumers indicated that if a store carried a guaranteed tender line of beef, they would buy all their beef at that store (Shackelford et al., 2001). These data clearly indicate that some proportion of steak-eating consumers are willing to pay a premium for guaranteed tender steaks.

There have been many attempts to identify instrumental methods for predicting meat tenderness (reviewed by Pearson, 1963; Szczesniak and Torgeson, 1965). Most of these were intended for laboratory research tools and varied widely in their efficacies. In more recent investigations of objective predictions of meat tenderness, the goal has been to develop on-line systems for grading carcasses based on tenderness. The ideal system would involve an objective, noninvasive, tamper-proof, accurate, and robust technology. Technologies evaluated for their potential as on-line tenderness grading tools include Tendertec (George et al., 1997; Belk et al., 2001), connective tissue probe (Swatland, 1995; Swatland and Findlay, 1997; Swatland et al., 1998), elastography (Berg et al., 1999), near-infrared spectroscopy (Hildrum et al., 1994; Park et al., 1998), ultrasound (Park and Whittaker, 1991; Park et al., 1994), image analysis (Li et al., 1999, 2001), colorimeter (Wulf et al., 1997; Wulf and Page, 2000), and slice shear force (Shackelford et al., 1999a,b, 2001).

In studies investigating the use of color as a palatability indicator, Hodgson et al. (1992) and Hilton et al. (1998) found that lean and fat color scores for mature cow carcasses were related to subsequent cooked beef palatability. Davis et al. (1981) concluded from a comparison of grain- and forage-finished cattle that fat color could be used as an effective predictor of beef palatability. Although the relationship of lean and fat color with palatability in these three studies is likely greater than in A and B maturity grain-finished cattle, there is some indication that these traits also may be useful in youthful carcasses (Hilton et al., 1998). In other studies, lean and fat color of beef carcasses have been shown to be related to traits associated with palatability (our unpublished observations). Wulf et al. (1997) reported that b* values of the exposed longissimus at the 12th rib from a small-aperture colorimeter were correlated with 24-h calpastatin activity ($r = -0.28$) and trained sensory tenderness rating ($r = 0.37$). Furthermore, they found that a regression equation that included L*, a*, b*, and marbling score accounted for 19% of the variation in tenderness rating (Wulf et al., 1997). Li et al. (1999, 2001) have shown that lean color, marbling, and image texture features combined could account for up to 70% of the variation in trained sensory tenderness scores of longissimus lumborum. Collectively, this information led to the development of two noninvasive approaches to identify "tender" beef. One was an image analysis system, prototype BeefCam, used to obtain lean and fat color traits of the exposed surface of the longissimus at the 12th rib using the L*, a*,and b* color scale. The second was a palatability index (colorimeter) based on marbling, hump height, L*, and b* values that was intended as an augmentation system for USDA quality grade by changing the criteria for grading Choice or Select (Wulf and Page, 2000).

The amount a processor can spend on identifying "guaranteed tender" product depends on several factors, such as the amount of premium that product will generate, the proportion of carcasses that will qualify, potential reduction in value of nonqualifying product, and the weight of product (number of cuts) from each carcass that can be marketed as enhanced in tenderness. The method selected to identify "guaranteed tender" must be accurate enough to create a product that is recognizable by consumers as superior in tenderness. Furthermore, it would seem likely that tenderness certification would be applied to USDA Select carcasses because USDA Prime carcasses and most of the carcasses within the upper two thirds of Choice already receive premiums in the market. Thus, USDA Select carcasses would be logical candidates for increased value by identifying those that are "tender."

lished data) concluded that commercial BeefCam provided added assurance of acceptable tenderness over USDA quality grade, however, findings indicated that further refinement seems warranted to enhance the ability of BeefCam to segment carcasses that will yield acceptably tender meat. Thus, the prototype BeefCam performed poorly in this study, and after further development, the commercial BeefCam system appears to be only slightly improved.

The initial application of the colorimeter approach on 100 carcasses reduced the percentage of "low palatability" carcasses in Low Choice from 14 to 4% and in Select from 36 to 7% (Wulf and Page, 2000). From tests of its ability to identify "guaranteed tender" beef using an independent sample (Figures 1-4 of the present study), it appears that the "palatability index" from the colorimeter approach to tenderness sorting for carcasses may be useful when used over a broad range of marbling scores, but not within the narrow range of marbling in USDA Select carcasses. However, this approach may be useful to augment quality grade as demonstrated by Wulf and Page (2000), if validated on an independent sample.

The high level of accuracy of slice shear force for sorting carcasses into tenderness groups is in agreement with previous data (Shackelford et al., 1999a,b; 2001). Similar results have been obtained from classification at 2 or 3 d postmortem, as were obtained in this study from 3 d postmortem classification (Shackelford et al., 1999b). In agreement with our current results, it appears that accurate early-postmortem longissimus tenderness classification also would enable one to market sirloin and round cuts based on tenderness (Tatum et al., 1999; Wheeler et al., 2000).

This direct approach to tenderness grading of carcasses (slice shear force) is significantly more accurate than currently available noninvasive methods, allows certification of a greater proportion of carcasses, creates a "guaranteed tender" product that consumers recognize as superior, and enables marketing of multiple muscles, not Low not Low m2ni.1(in) TJT* (tendernes.s)58Wwhen 428(this 582(accuracy 568(is)58combained 428(

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Pearson, A. M. 1963. Objective and subjective measurements for meat tenderness. In: Proc. Meat Tenderness Symp., Campbell Soup Co., Camden, NJ. pp 135–160.