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PREDICTING MEAT QUALITY OF BEEF LONGISSIMUS MUSCLE USING ELASTOGRAPHY

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INTRODUCTION: Objective methods of predicting beef carcass quality and palatability have been examined to improve value assessment and to communicate quality. Ultrasound measurements of marbling have been used to predict beef quality (Park et al., 1994). Elastography, which uses images of the local variations in the elastic modulus of the tissue, was proposed to predict beef quality (Ophir et al., 1994). Changes in the muscle tissue elasticity could be related to changes in beef quality. Therefore, the objectives of this study were examine elastography as an automated, non-intrusive method to evaluate and predict meat tenderness based on the elasticity differences in the longissimus muscle of A-maturity beef carcasses.

MATERIALS AND METHODS: A-maturity beef carcasses (n=17; 3 High Choice, 5 Low Choice, 5 Select and 4 Standard) were selected at 48 h postmortem. Marbling score was determined and the longissimus muscle was removed from loin. A block, 8 cm x 8 cm x 5 cm with muscle fibers oriented parallel to the long axis, was obtained from the center for elastography analyses; two adjacent 2.54 cm-thick steaks were obtained for sensory analyses and shear force tests, respectively. The remaining muscle was used for chemical analyses. Samples for elastography analyses were vacuum-packaged, aged for 4 days and frozen (-10°C). The system of Ophir et al. (1994) was used for elastography. Each sample, after thermal equilibration to 30°C, was positioned on a digital scale for estimates of applied stress, with a standoff rubber pad placed between the scale and the piece of meat to minimize reverberation effects. The samples were preconditioned using a six cycle loading and unloading regimen (cross head speed=1 mm sec-1; peak strain=20%) to obtain sample linearity. On the last preconditioning cycle, the first radio-frequency (rf) frame (100 a-lines) was acquired at a compressing level of 17.5% and the second rf frame was obtained after 1% compression. Strain images (elastograms) were produced and the gray scale was linear between 0% (black) and 2% (white) strain. Three replicate scans were obtained from each sample at parallel planes separated by about 2 cm. Logarithmic compression was used in this study to reduce the amplitude and the noisy appearance of elastograms (Céspedes and Ophir, 1993). An image enhancement algorithm was developed to eliminate or reduce noise points within the image. Extraction of image texture features was preformed and 14 gray-level co-occurrence matrix statistical features (GCCM parameters; Haralick et al., 1973) were extracted at four angles (0, 45, 90, and 135) and 4 neighborhood distances (1, 2, 5, and 10). The base resolution for these elastograms was approximately .5 mm per resolution unit. For shear force and sensory analyses, steaks were broiled on a Farberware grill to an internal temperature reached 70°C and cooled to room temperature. About ten, 1.3 cm-diameter cores were taken from each steak and sheared using a Warner-Bratzler shear force device (John Chatillon & Sons, New York, NY) and measurements from each steak were averaged. After cooking, sensory steaks were cut into 1.27 cm cubes and served to an eight-member meat descriptive attribute trained sensory panel (Cross et al., 1978). Panelists rated each sample for juiciness (8 = extremely juicy; 1 = extremely dry), connective tissue amount (8 = none; 1 = abundant), muscle fiber and overall tenderness (8 = extremely tender; 1 = extremely tough). Sarcomere length was determined using a helium-neon laser (Spectra Physics, Eugene, OR). Myofibrillar fragmentation values were obtained using the procedure of Sams et al. (1991). Total collagen content and solubility were analyzed and calculated utilizing the hydroxyproline procedure (AOAC,1991; Cross et al., 1973). Fat content was determined using diethyl ether in a Soxhlet fat extraction unit (AOAC, 1991). Statistical analyses were performed according to the procedures of SAS (1991). Chemical, sensory and mechanical measurements were used as dependent variables and GCCM parameters were used as independent variables at $P<.15$ for regression equations.

RESULTS AND DISCUSSION: Collagen content, percentage fat, sarcomere length, Warner-Bratzler shear force and sensory attributes had means and standard deviations within expected ranges for longissimus muscle from A-maturity beef carcasses and therefore these data were an acceptable population to test the objectives of this study (Table 1). Correlation coeffiecients between GCCM parameters and chemical, sensory panel and mechanical data were calculated. Collagen content and fat correlated with f12 ($r=-.56$; $P<.02$) and f13 ($r=.63$; $P<.003$) at distances 1 and 2. However, f13 and f14 were the parameters that had high predictive value for collagen solubility ($R^2=.76$; Table 2). Collagen solubility was correlated to f10 ($r=.51$) at each distance, and to f1 at distance 5 ($r=.49$) and 10 ($r=.50$), and to f5d10 ($r=.48$). Collagen solubility was predicited using f10 and f14 ($R^2=.58$; Table 2). Prediction equations used f1, f10, and f14 to predict sarcomere length or fragmentation index ($R^2=.82$ and -.80, repectively.). Shear force was correlations for all the GCCM parameters, except f1, f12, and f14 at distances 1, f5 and f10 at distance 2, f10 and f12 at distance 5, and f12, f13 and f14 at distance 10. Elastography image structure explained 88% of the variation in Warner-Bratzler shear force. Juiciness or connective tissue amount were not correlated with the GCCM parameters. Muscle fiber tenderness and overall tenderness were correlated to most of the GCCM parameters except f1, f10, f12,and f13 ($r=.68$). Regression equations for these attributes accounted for a high amount of variability (.82 and .69 for

muscle fiber tenderness and overall tenderness, respectively). f6 was the GCCM parameter that accounted for the highest amount of variabiltiy in muscle fiber tenderness and overall tenderness. Collagen characteristics generally were predicted by f13 and f14. GCCM parameter f13d1 also played a major role in predicting percentage of fat, shear force and marbling score. Sarcomere length, juiciness and collagen solubility prediction were influenced by f14.

CONCLUSIONS: Elastograms had a low signal to noise ratio that could have influenced results. Noise in the elastogram is mainly due to two factors, the inherent variation of the strucuture of the subject analyzed, and the nonstationary relationship between the pre- and post-compression signals. The inherent variation was to have been analyzed throughout the imaging process to extract the textural information. The second source of noise is called elastography noise. Errors during the data processing obtained from the elastography procedure caused random noise in the local strain estimate, and ultimately noise in the elastogram. As signal to noise ratio reduction in the images was not available, elastograms represented a combination of the real variation and the artifactural noise; however, results were still postitive that elastography has the potential to be a non-invasive device for determining components of tenderness in beef longissimus muscle from young animals and continued validation of elastography for meat quality evaluation is needed.

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Table 1. Means and standard deviations for dependent variables.

Parameter[a]	Mean	SD
Collagen content, mg g-1;	3.2	.5
Collagen solubility, %	16.0	2.2
Fat, %	5.1	3.2
Fragmentation index	217.2	23.7
Sarcomere length, µm	1.8	.2
Warner Bratzler shear force, kg	9.0	2.3
Juiciness	5.3	.8
Muscle fiber tenderness	5.7	1.0
Connective tissue amount	6.6	.7
Overall tenderness	5.8	1.0

[a]Juiciness, Muscle fiber tenderness and Overall tenderness, and Connective tissue amount where 8 = extremely juicy, tender, tender and no connective tissue, and 1 = extremely dry, tough, tough and abundant.

Table 2. Regression equations for chemical, mechanical and sensory data for longissimus muscle from A-maturity carcasses (n = 17).

Dependent variable	Independent variable[a]	R^2	SEE[b]
Collagen content, mg g-1	f13d1, f14d2, f14d10	.76	.24
Collagen solubility, %	f14d2, f10d10, f14d10	.58	1.64
Fat, %	f12d1	.54	2.25
Fragmentation index	f12d1, f14d2, f1d5, f1d10, f14d10	.82	12.64
Sarcomere length, µm	f10d1, f6d5, f10d5, f14d5, f14d10	.74	.13
Warner-Bratzler, lbs	f1d1, f2d1, f8d1, f8d2, f14d2, f14d10	.88	1.0
Juiciness	f14d1	.19	.74
Muscle fiber tenderness	f6d2, f14d2, f6d5, f14d5, f6d10	.82	.53
Connective tissue amount	f6d5	.20	.67
Overall tenderness	f14d2, f6d5, f6d10	.69	.62

[a]GCCM parameters where f followed by a number indicates which GCCM paramenter from 1 to 14 and d followed by a number is the distance from the center of the texture kernel.

[b]SEE: Standard error of the estimate.