On-Line Prediction of Beef Tenderness Using a Computer Vision System Equipped with a BeefCam™ Module

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SUMMARY

Four experiments were conducted in two commercial packing plants to evaluate the efficacy of an on-line commercial video image analysis system, the Computer Vision System equipped with a BeefCam™ module (CVS BeefCam™) to predict beef longissimus steak tenderness using measurements obtained at chain speeds. A longissimus sample was obtained from each carcass for Warner-Bratzler shear force (WBS) evaluations following 14 days of aging. The CVS BeefCam™ output variable for ribeye area adjusted for carcass weight (in^2/lb) was correlated ($P < 0.05$) with WBS values in all experiments. The CVS BeefCam™ lean color measurements (a*, redness; and b*, yellowness), were effective ($P < 0.05$) in all experiments in segregating carcasses into groups that produced longissimus steaks differing in WBS values. Fat color measurements by CVS BeefCam™ were usually ineffective in segregating carcasses; however, in experiment 4, fat b* (yellowness) identified a group of carcasses that produced tough longissimus steaks. USDA quality grade factors accounted for 3, 18, 21 and 0% of the variation in WBS values among steaks in experiments 1 (n = 399), 2 (n = 195), 3 (n = 304), and 4 (n = 184), respectively; CVS BeefCam™ output variables accounted for 17, 30, 19, and 6% of the variation in WBS values among steaks in experiments 1, 2, 3, and 4, respectively. On-line measurements obtained by CVS BeefCam™ were related to beef longissimus tenderness and have potential for use as a beef carcass-sorting tool.

Key Words: Beef, Video Image, Color, Tenderness, Palatability

INTRODUCTION

In order to produce more consistently palatable beef there has been considerable effort to develop an objective measurement of beef palatability; this measure, converted technologically, could then be used to classify carcasses into groups with steaks of similar tenderness or palatability characteristics. One of these technologies, video image analysis or computer vision, has been reported to measure crude fat content, color and textural properties, that could explain differences in cooked beef palatability.

Belk et al. (2000) reported a prototype video imaging system (BeefCam™) identified carcasses that would yield steaks that would be "tender" after cooking. However, this prototype BeefCam™ had limitations that prevented its use in a commercial setting. Smart Machine Vision (Reston, VA) and Research Management Systems USA (RMS Inc., Fort Collins, CO) have recently integrated features contained in the prototype BeefCam™ into the Computer Vision System (CVS). The CVS, manufactured by RMS, has been proven useful in predicting the composition of beef carcasses under commercial conditions. In this paper, four independent experiments were conducted to determine the effectiveness of the CVS, equipped with a BeefCam™ module (CVS BeefCam™), to predict Warner-Bratzler shear force values of longissimus steaks from beef carcasses in a commercial setting.

MATERIALS AND METHODS

Four experiments were conducted, in two commercial packing plants that utilize electrical stimulation, to determine the effectiveness of the CVS BeefCam™ for predicting the Warner-Bratzler shear force (WBS) values of cooked longissimus steaks from carcasses. As carcasses were presented for grading, digital video images (3-CCD) of the 12th/13th rib interface were obtained using a CVS BeefCam™. These were processed via proprietary software (CVS version 1.5) to generate output variables that were evaluated for their relationship to beef tenderness. Carcasses moved by the grading stand at an approximate speed of 200 carcasses per hour for plant A and at approximately 380 carcasses per hour for plant B. A representative of USDA-AMS (Exp. 1) or Colorado State University personnel (Exp. 2, 3 and 4) collected carcass data on selected carcasses.

Sample Collection

Plant A. Beef carcasses (Exp. 1, n= 399; Exp. 2, n= 195; and Exp. 4, n= 184) were randomly selected following a 48-h chill over two days of production at Sam Kane Beef Processors, Corpus Christi, TX. Carcasses sampled for Exp. 1 and 2 were from the USDA Choice and Select quality grades, while carcasses chosen for Exp. 4 were from the USDA Select grade only. From one side of each carcass, a 2.4 in. thick rib steak from the 12th and 13th rib interface was removed and vacuum-packaged for transport to the CSU Meat Science Laboratory. Ribeye samples were aged at 35º F until 14 days postmortem, at which time they were frozen at -20º F and stored for later analysis. Frozen samples were removed from vacuum-packages, sawed into one-inch thick steaks and tempered for 24 hr at 35º F before cooking for WBS determination.

Plant B. Steers (Exp. 3, n = 304) representing diverse genetic backgrounds and quality grades were harvested on four separate days at ConAgra Beef Company, Greeley, CO. Following a 36-h chill, strip loins from the right side of each carcass were collected following fabrication, and immediately transported to the CSU Meat Science Laboratory. The strip loins were vacuum-packaged, aged at 35º F until 14-days postmortem and stored at -20º F. The strip loins were fabricated (in the frozen state) into steaks (1 in.). One steak from the anterior end of each strip loin was designated for WBS determination. Steaks were tempered for 24 hr at 35º F before cooking.

Warner-Bratzler Shear Force.

For Exp. 1 steaks were broiled on a Hobart Char Broiler (model CB 51, Hobart, Troy, OH) until reaching a final internal temperature of 160ºF. For Exp. 2, 3 and 4, steaks were cooked using a Magikitch'n belt grill (Magigrill model TBG-60; Magikitch'n Inc., Quakertown, PA) set to cook steaks to an endpoint temperature of 160° F. Cooked steaks were allowed to cool to room temperature (70° F) before removing 6 to 10 cores (0.5 in. in diameter) parallel to the muscle fiber orientation. Peak shear force was obtained for each core using a Warner-Bratzler shear force machine. Individual-core peak shear force values were averaged to assign a mean peak WBS value to each steak.

Statistical Analyses. Pearson's correlation coefficients were calculated between CVS BeefCam™ output variables and WBS within an experiment (SAS Inst. Inc., Cary, NC). Carcasses were classified into three groups (Low, Medium, and High; where Low < output variable mean – 1 SD, Medium = output variable mean ± 1 SD, and High > output variable mean + 1 SD) based upon each output variable except CVS marbling. Then, the effects of classification by each output variable were tested using Proc GLM, with expert marbling score as a linear covariate for experiments 1, 2, and 3 (covariate not significant for Exp. 4). Least squares means were separated using a protected pairwise t-test when a F-test was significant at á = 0.05 (SAS Inst. Inc.).

Linear regression models were developed to predict the natural log of WBS values using the forward model selection procedure with the confidence level for entry set at 85% (á = 0.15) (SAS Inst. Inc.).

RESULTS

Carcass Characteristics. The variation in marbling score depended upon experiment, because selection procedures between experiments differed. Lean color and fat color measurements varied comparably across experiments but the means for lean a* (redness), lean b* (yellowness) and fat a* (redness) values, among experiments were substantially different and could have resulted from differences in cattle type, carcass management, length of bloom at the time of imaging, CVS BeefCam™ systems or CVS BeefCam™ system color calibrations between the four experiments. Longissimus WBS indicated that all carcasses sampled would yield longissimus steaks that would result in a high percentage (>35%) of consumer dissatisfaction (WBS 10 lbs.) according to Shackelford et al. (1991).

Correlation Analyses. Simple correlations of CVS BeefCam™ output variables and WBS values are presented in Table 1. The CVS BeefCam™ output variable for ribeye area adjusted for carcass weight (in^2/lb) was positively correlated ($P < 0.05$) with WBS for all experiments. The correlation coefficient between CVS BeefCam™ marbling was negative in direction for all experiments and was correlated ($P < 0.05$) with WBS for all experiments except for Exp. 4; however, the carcasses sampled in Exp. 4 represented a much narrower range of expert marbling scores than did the other experiments. While not always significant, all correlation coefficients between lean color variables and WBS were negative in direction suggesting that higher WBS values were associated with darker colored lean. Correlations between WBS values and fat color measurements were variable in direction and magnitude among the experiments, but usually were not significant. Interestingly, fat b* was significantly correlated to WBS values among steaks in Exp. 4 while none of the lean color measurements were significantly correlated in this population of steaks.

Segregation Analyses. The effects of segregating carcasses into categories using CVS BeefCam™ output variables are presented in Tables 2, 3, 4, and 5 for Exp 1, 2, 3, and 4, respectively. Lean L* (lightness) was only successful ($P < 0.05$) in segregating carcasses in Exp. 2 and 3 as the Low lean L* groups contained steaks that were significantly tougher than the Medium or High lean L* groups. The output variables lean a* and lean b* were effective ($P < 0.05$) in segregating carcasses into groups differing in tenderness of their steaks (as determined by WBS) in all experiments. For both output variables, lower WBS values were associated with higher output variable values. Based on these results, either lean a* or lean b* could be used to identify (and, sort off) a group of carcasses likely to produce either tender or tough steaks. Although fat L* (lightness) was able to segregate carcasses ($P < 0.05$) for Exp. 3, across all experiments, fat L* appeared ineffective for identifying carcasses as likely to produce either tender or tough steaks. Similarly, fat a* failed to separate carcasses according to WBS values of their steaks across all experiments. In Exp. 4, fat b* (yellowness) was successful in identifying a group of carcasses that produced tough longissimus steaks; however, fat b* was ineffective in the other three experiments. Perhaps there is a fat b* (yellowness) threshold that could be used to identify carcasses likely to produce tough steaks. In Exp. 4, use of CVS BeefCam™ ribeye area adjusted for carcass weight (in^2/lb) identified a group of carcasses that produced tough steaks. Across all experiments, carcasses with larger ribeyes for their weight produced longissimus steaks that had numerically higher WBS values than did carcasses with smaller ribeyes for their weight.

Regression Analyses. For each experiment, equations were developed to predict WBS values using expert USDA quality grade factors and using output variables from the CVS BeefCam™. USDA marbling score entered into models for Exp. 1, 2, and 3 and accounted for 3, 11, and 13%, respectively, of the observed variation in WBS values. Lean maturity explained an additional 6 and 8% variation in WBS values for Exp. 2 and 3, respectively. The best equations for predicting WBS values, using only USDA quality grade factors, resulted in R^2 values of 0.03, 0.18, 0.21, and 0.00 for experiments 1 through 4, respectively.

In Exp. 1, Lean b*, singularly, accounted for 14% of the variation in WBS values and when combined with CVS BeefCam™ marbling plus fat b* accounted for 17% of the variation in WBS values. The best equation for predicting WBS values for Exp. 2, using only output variables from the CVS BeefCam™, included the variables lean a*, CVS BeefCam™ marbling, and lean b*, with lean a* being the strongest predictor as it accounted for 16% of the observed variation in WBS values. The best equation for predicting WBS values in Exp. 3 included the independent variables lean L*, CVS BeefCam™ ribeye area (in^2), lean b*, CVS BeefCam™ marbling and fat b* and accounted for 19% of the variation in WBS values. For Exp. 4, fat b* and lean b* were the only variables that entered the model and, when combined, resulted in a R^2 of 0.06. When carcasses varied little in amount of marbling in their ribeyes (e. g. in Exp. 1, 2, and 4), the amount of variation in WBS values accounted for by consideration of objective measurements (CVS BeefCam™ output variables) was greater than that explained by differences in USDA quality grades, while the opposite was true (in Exp. 3) when the carcass population differed more in ribeye marbling scores.

IMPLICATIONS

The CVS BeefCam™ captures and segments video images and produces useful output at commercial packing plant chain speeds. System output variables were useful in explaining observed variation in WBS values. Improvements in consistency of tenderness among steaks could be obtained by carcass segregation using information generated by CVS BeefCam™. Further development and refinement of the CVS BeefCam™ for use in predicting beef longissimus tenderness is warranted.

LITERATURE CITED

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Table 1. Correlation coefficients between Warner-Bratzler shear force (WBS), and output variables from a Computer Vision System equipped with a BeefCam™ module (CVS BeefCam™)

CVS BeefCam™ output variable	WBS			
	Exp. 1	Exp. 2	Exp. 3	Exp. 4
Marbling	-0.22*	-0.34*	-0.21*	-0.04
Adjusted ribeye area (in^2/lb)	0.13*	0.21*	0.15*	0.27*
Lean L*	-0.07	-0.25*	-0.31*	-0.05
Lean a*	-0.38*	-0.40*	-0.13*	-0.14
Lean b*	-0.38*	-0.23*	-0.25*	-0.12
Fat L*	-0.02	-0.06	0.17*	0.04
Fat a*	-0.16*	-0.12	0.04	-0.05
Fat b*	-0.08	0.08	0.05	0.22*

*Correlation differs from zero ($P < 0.05$).

Table 2. Results of carcass segregation, using output variables (mean ± 1 SD) from a Computer Vision System equipped with a BeefCam™ module (CVS BeefCam™) on Warner-Bratzler shear force (least-squares means are adjusted to a constant expert marbling score of Slight[72]) (Experiment 1)

CVS BeefCam™ output variable[a]	Low	Medium	High	*P*
Lean L*	4.1	4.0	4.0	0.570
Lean a*	4.6[b]	4.0[c]	3.6[d]	0.001
Lean b*	4.7[b]	4.0[c]	3.6[d]	0.001
Fat L*	4.2	4.0	4.1	0.206
Fat a*	4.3	4.0	4.0	0.050
Fat b*	4.0	4.0	4.0	0.489
Adjusted ribeye area (in^2/lb)	3.8	4.1	4.0	0.076

[a]CVS BeefCam™ Lean L*: Low = Lean L* 38.6; Medium = 38.6 < Lean L* < 43.2; High = Lean L* 43.2. CVS BeefCam™ Lean a*: Low = Lean a* 30.6; Medium = 30.6 < Lean a* < 34.0; High = Lean a* 34.0. CVS BeefCam™ Lean b*: Low = Lean b* 11.4; Medium = 11.4 < Lean b* < 13.8; High = Lean b* 13.8. CVS BeefCam™ Fat L*: Low = Fat L* 76.3; Medium = 76.3 < Fat L* < 81.7; High = Fat L* 81.7. CVS BeefCam™ Fat a*: Low = Fat a* 5.5; Medium = 5.5 < Fat a* < 8.5; High = Fat a* 8.5. CVS BeefCam™ Fat b*: Low = Fat b* 7.6; Medium = 7.6 < Fat b* < 10.6; High = Fat b* 10.6. CVS BeefCam™ Adjusted ribeye area (Adj. REA) (in^2/lb): Low = Adj. REA (in^2/lb) 0.016; Medium = 0.016 < Adj. REA (in^2/lb) < 0.022; High = Adj. REA (in^2/lb) 0.022.

[b, c, d]Least-squares means within a row lacking a common superscript letter differ (*P* < 0.05).

Table 3. Results of carcass segregation, using output variables from a Computer Vision System equipped with a BeefCam™ module (CVS BeefCam™) (mean ± 1 SD), on Warner-Bratzler shear force (WBS) (least-squares means are adjusted to a constant expert marbling score of Slight[63]) (Experiment 2)

CVS BeefCam output variable[a]	Low	Medium	High	*P*
Lean L*	5.1[b]	4.5[c]	4.2[c]	0.003
Lean a*	5.3[b]	4.5[c]	4.0[d]	0.001
Lean b*	4.9[b]	4.5[bc]	4.2[c]	0.043
Fat L*	4.6	4.6	4.3	0.398
Fat a*	4.8	4.5	4.3	0.234
Fat b*	4.2	4.6	4.8	0.140
Adjusted ribeye area (in^2/lb)	4.3	4.5	4.9	0.073

[a]CVS BeefCam™ Lean L*: Low = Lean L* 37.6; Medium = 37.6 < Lean L* < 42.2; High = Lean L* 42.2. CVS BeefCam™ Lean a*: Low = Lean a* 32.3; Medium = 32.3 < Lean a* < 35.1; High = Lean a* 35.1. CVS BeefCam™ Lean b*: Low = Lean b* 11.5; Medium = 11.5 < Lean b* < 13.1; High = Lean b* 13.1. CVS BeefCam™ Fat L*: Low = Fat L* 77.3; Medium = 77.3 < Fat L* < 82.7; High = Fat L* 82.7. CVS BeefCam™ Fat a*: Low = Fat a* 6.5; Medium = 6.5 < Fat a* < 9.1; High = Fat a* 9.1. CVS BeefCam™ Fat b*: Low = Fat b* 8.8; Medium = 8.8 < Fat b* < 12.0; High = Fat b* 12.0. CVS BeefCam™ Adjusted ribeye area (Adj. REA) (in^2/lb): Low = Adj. REA (in^2/lb) 0.015; Medium = 0.015 < Adj. REA (in^2/lb) < 0.021; High = Adj. REA (in^2/lb) 0.021.

[b, c, d]Least-squares means within a row lacking a common superscript letter differ (*P* < 0.05).

Table 4. Results of carcass segregation, using output variables from a Computer Vision System equipped with a BeefCam™ module (CVS BeefCam™) (mean ± 1 SD), on Warner-Bratzler shear force (WBS) (least-squares means are adjusted to a constant expert marbling score of Small^{49}) (Experiment 3)

CVS BeefCam™ output variable[a]	Low	Medium	High	*P*
Lean L*	4.9[b]	4.2[c]	4.0[c]	0.001
Lean a*	4.6[b]	4.2[c]	4.1[c]	0.008
Lean b*	4.8[b]	4.2[c]	3.9[d]	0.001
Fat L*	4.3[bc]	4.2[c]	4.7[b]	0.002
Fat a*	4.2	4.3	4.3	0.559
Fat b*	4.3	4.2	4.4	0.448
Adjusted ribeye area (in^2/lb)	4.2	4.2	4.6	0.081

[a]CVS BeefCam™ Lean L*: Low = Lean L*   37.7; Medium = 37.7 < Lean L* < 42.7; High = Lean L*   42.7. CVS   BeefCam™ Lean a*: Low = Lean a*   28.1; Medium = 28.1 < Lean a* < 31.7; High = Lean a*   31.7. CVS   BeefCam™ Lean b*: Low = Lean b*   8.3; Medium = 8.3 < Lean b* < 10.5; High = Lean b*   10.5. CVS   BeefCam™ Fat L*: Low = Fat L*   79.0; Medium = 79.0 < Fat L* < 84.2; High = Fat L*   84.2. CVS   BeefCam™ Fat a*: Low = Fat a*   2.8; Medium = 2.8 < Fat a* < 7.4; High = Fat a*   7.4. CVS   BeefCam™ Fat b*: Low = Fat b*   7.6; Medium = 7.6 < Fat b* < 10.2; High = Fat b*   10.2. CVS   BeefCam™ Adjusted ribeye area (Adj. REA) (in^2/lb): Low = Adj. REA (in^2/lb)   0.014; Medium = 0.014 < Adj. REA (in^2/lb) < 0.018; High = Adj. REA (in^2/lb)   0.018.

[b, c, d]Least-squares means within a row lacking a common superscript letter differ ($P < 0.05$).

Table 5. Results of carcass segregation, using output variables from a Computer Vision System equipped with a BeefCam™ module (CVS BeefCam™) (mean ± 1 SD), on Warner-Bratzler shear force (WBS) (Experiment 4)

CVS BeefCam™ output variable[a]	Low	Medium	High	*P*
Lean L*	4.4	4.9	4.5	0.062
Lean a*	5.2[b]	4.7[c]	4.5[c]	0.021
Lean b*	5.3[b]	4.7[c]	4.4[c]	0.026
Fat L*	4.7	4.8	4.7	0.790
Fat a*	4.9	4.7	4.8	0.369
Fat b*	4.6[c]	4.7[c]	5.4[b]	0.009
Adjusted ribeye area (in^2/lb)	4.4[c]	4.7[c]	5.3[b]	0.005

[a]CVS BeefCam™ Lean L*: Low = Lean L*   38.0; Medium = 38.0 < Lean L* < 42.6; High = Lean L*   42.6. CVS   BeefCam™ Lean a*: Low = Lean a*   27.7; Medium = 27.7 < Lean a* < 32.1; High = Lean a*   32.1. CVS   BeefCam™ Lean b*: Low = Lean b*   11.8; Medium = 11.8 < Lean b* < 14.2; High = Lean b*   14.2. CVS   BeefCam™ Fat L*: Low = Fat L*   76.1; Medium = 76.1 < Fat L* < 81.1; High = Fat L*   81.1. CVS   BeefCam™ Fat a*: Low = Fat a*   3.6; Medium = 3.6 < Fat a* < 8.4; High = Fat a*   8.4. CVS   BeefCam™ Fat b*: Low = Fat b*   9.6; Medium = 9.6 < Fat b* < 12.6; High = Fat b*   12.6. CVS   BeefCam™ Adjusted ribeye area (Adj. REA) (in^2/lb): Low = Adj. REA (in^2/lb)   0.016; Medium = 0.016 < Adj. REA (in^2/lb) < 0.022; High = Adj. REA (in^2/lb)   0.022.

[b, c]Least-squares means within a row lacking a common superscript letter differ ($P < 0.05$).