Published December 4, 2014

Relationships between fed cattle traits and Igenity panel scores[1]

E. A. DeVuyst,*[2] J. T. Biermacher,† J. L. Lusk,* R. G. Mateescu,‡ J. B. Blanton Jr.,† J. S. Swigert,† B. J. Cook,† and R. R. Reuter†

*Department of Agricultural Economics, Oklahoma State University, Stillwater 74078; †Agricultural Division, The Samuel Roberts Noble Foundation, Ardmore, OK 73402; and ‡Department of Animal Science, Oklahoma State University, Stillwater 74078

ABSTRACT: Although several previous studies have identified associations between cattle carcass characteristics and various SNP, comparatively little work has sought to validate the marker panels currently sold and marketed by commercial genotyping companies. Panels typically use a handful of SNP, but these range from as few as 2 to more than 100. Data from 764 commercially fed steers and heifers were used to assess the relationships of growth and carcass traits and Igenity panel scores for ADG, marbling (or percentage of USDA Choice), rib-eye area (REA), tenderness, fat thickness, and USDA Yield grade (YG). Results revealed statistically significant, but low, correlations between carcass measurements and corresponding Igenity panel scores. Genetic correlations were computed among the various Igenity panels and demonstrated either that several common markers existed across the panels or that markers across panels were in high linkage disequilibrium. Across all breeds, the genotypic correlations between the Igenity panel scores for ADG, REA, marbling, and YG with observed ADG, REA, USDA Quality grade, and YG at slaughter were 0.51, 0.38, 0.63, and 0.59 ($P < 0.01$), respectively. The partial effects of the Igenity marbling panel persisted in a multivariate regression model. Net return was significantly affected only by marbling panel score; a 1-unit increase in marbling panel score increased the net return by an estimated $7.53 per animal.

Key words: cattle, single nucleotide polymorphism, single nucleotide polymorphism panel

J. Anim. Sci. 2011. 89:1260–1269
doi:10.2527/jas.2009-2372

INTRODUCTION

Recent advances in sequencing of the cattle genome and genomic testing technology have the potential to revolutionize beef cattle breeding and marketing. The identification of associative and causative SNP allows for genetic improvement in selected traits. When coupled with economic analysis, the improvement in these traits can be weighed against potential deleterious effects in other traits. Numerous previous studies have identified SNP associated with economically important beef carcass characteristics (Kononoff et al., 2005; Nkrumah et al., 2005, 2007; Marques et al., 2009). Such knowledge has led to the commercialization of genetic testing technologies. Companies such as Merial Ltd./Igenity (Duluth, GA), MMI Genomics Inc. (Davis, CA), and Pfizer Inc. (New York, NY) have developed various SNP panels to predict phenotypic expression for quantitative traits such as tenderness, ADG, and marbling. These panels typically use a handful of SNP, but the number can range from as few as 2 to more than 100.

To date, few attempts have been made to validate the commercial marker panels. As such, little is known about the extent to which the commercial SNP panels actually predict the characteristics they purport to predict. The primary exceptions are reports by Van Eenennaam et al. (2007) and Hall et al. (2009). These researchers found mixed results when evaluating SNP panels for beef cattle. Over time, there have been changes in the ownership of panels, the number of panels, and the specific SNP composition of panels that are commercially available, indicating that additional information is needed to help producers accurately use the information provided by commercially available SNP panels.

This paper investigates the relationship of feedlot cattle growth and carcass traits, and Igenity panel scores. In addition, this research aims to assess the marginal impact of panel scores on ADG, feed efficiency (**FE**), days on feed (**DOF**), HCW, USDA Quality grade

[1]Partial funding for this research was provided by The Samuel Roberts Noble Foundation and the Oklahoma Agr. Exp. Stn., Oklahoma State University (Stillwater).

[2]Corresponding author: eric.devuyst@okstate.edu

Received August 5, 2009.
Accepted January 19, 2011.

Table 1. Summary statistics for cattle

	Steers				Heifers			
Variable	n	Mean	SD	Range	n	Mean	SD	Range
Placement wt, kg	460	307.3	35.0	212.3 to 394.2	304	293.8	30.8	217.3 to 401.4
Slaughter wt, kg	460	577.3	37.5	454.5 to 697.6	304	524.7	31.1	401.9 to 625.1
Days on feed, d	460	175.8	16.7	135 to 257	304	176.6	11.1	163 to 200
ADG, kg/d	460	1.5	0.2	0.7 to 2.2	304	1.3	0.2	0.6 to 1.9
Feed:gain	460	5.6	0.6	4.4 to 9.6	304	6.1	0.6	4.4 to 9.7
HCW, kg	460	368.7	26.7	279.4 to 448.1	304	331.3	23.8	261.4 to 390.1
USDA Quality grade[1]	460	2.5	0.7	1 to 5	304	2.5	0.6	1 to 4
USDA Yield grade[2]	442	2.4	0.8	1 to 5	297	2.4	0.8	1 to 5
Rib-eye area, cm^2	460	88.6	10.2	60.0 to 125.8	304	81.8	9.2	60.6 to 106.5
Igenity score								
ADG	434	5.2	1.0	2 to 8	280	5.0	0.9	3 to 7
Marbling	444	6.1	1.1	3 to 9	298	6.0	1.0	3 to 9
Percentage Choice	444	6.1	1.1	3 to 9	298	6.0	1.0	3 to 9
Yield grade	453	5.8	1.1	2 to 9	302	5.6	1.1	3 to 9
12th-rib fat thickness	453	5.1	1.0	2 to 8	302	5.0	1.1	3 to 8
Rib-eye area	443	5.1	1.0	3 to 8	300	5.1	0.9	3 to 7
Tenderness	453	5.6	1.8	1 to 10	298	5.3	1.8	1 to 10

[1]Grades: 1 = USDA Standard; 2 = USDA Select; 3 = USDA Choice; 4 = upper 2/3 of USDA Choice; 5 = USDA Prime.
[2]Carcasses that graded USDA Standard did not receive a USDA Yield grade.

(**QG**), USDA Yield grade (**YG**), rib-eye area (**REA**), and net return (**NR**) in feedlot cattle.

MATERIALS AND METHODS

All procedures involving live animals conformed to the guidelines outlined in the Guide for the Care and Use of Agricultural Animals in Research and Teaching (Federation of Animal Science Societies, 2010).

Animals

In the fall of 2007, a total of 764 feeder steers and heifers were selected from 11 commercial producers in Oklahoma and Texas according to the normal retained ownership management decisions of each producer, and were fed at a commercial feed yard in Oberlin, Kansas. Cattle were sired by Angus, Charolais, Limousin, Red Angus, or bulls of other or unknown breeds (106, 278, 280, 32, and 68 animals, respectively) and were born in the spring of 2007. Individual sires were identified by DNA match (Igenity, Merial Ltd.) for 620 of the animals. Dams were of mixed beef-type breeding. Cattle were fed a traditional balanced finishing diet containing steam-flaked and rolled corn. Steers were implanted with a combination implant (initial BW ≤340 kg: Revalor S; initial BW >340 kg: Revalor IS), as were heifers with initial BW >286 kg (Revalor 200; Intervet Schering-Plough Animal Health, Millsboro, DE). Heifers with initial BW >286 kg were implanted with 200 mg of trenbalone acetate (Finaplix-H, Intervet Schering-Plough Animal Health). Cattle were commercially slaughtered using industry-standard procedures. The feedlot used a commercial software program (Accutrac, Micro Beef Technologies Ltd., Amarillo, TX) to predict the day that the incremental cost of BW gain exceeded the incremental value of BW gain on an individual animal basis. Days on feed ranged from 135 to 237 d for cattle in this data set (Table 1). This software also estimated the FE of each animal (Tedeschi et al., 2004). Carcass data were reported by the processing facility and included HCW, QG, YG, and REA. Rib-eye area was determined by an electronic image capture and analysis system (VBG2000 Grading System, Vision-For-You Inc., Dakota Dunes, SD). The actual NR of each animal was calculated by subtracting actual veterinary and yardage expenses, and calculated feed expenses determined by the commercial software program mentioned above, from the actual revenue of each animal. The feed yard calculated this NR and included it in the data set. Descriptive statistics of cattle performance are presented in Table 1.

Igenity Scores

A small disk of tissue was collected from the distal-ventral edge of the pinnae of each animal on the ranch of origin and was sent for Igenity scoring. Scores were available for 714 to 755 animals, depending on the specific panel. Scores were available for ADG, tenderness, marbling, percentage of USDA Choice, 12th-rib fat thickness, YG, and REA. Scores were determined in the fall of 2008 and were reported on a scale of 1 to 10. Except for 12th-rib fat thickness and YG, a greater score indicates a more desirable phenotype. Descriptive statistics of Igenity scores by breed are presented in Table 2.

Analysis

Several analyses were conducted. The first step consisted of calculating bivariate phenotypic (Pearson)

Table 2. Igenity panel score summary statistics by breed

		Igenity panel score						
Sire breed	n	ADG	Marbling	Percentage Choice	Yield grade	12th-rib fat thickness	Rib-eye area	Tenderness
Angus breeds[1]	138							
Mean		5.7	6.4	6.4	6.1	5.1	4.9	6.1
SD		1.0	1.1	1.1	1.0	1.0	0.8	1.9
Range		3 to 8	3 to 9	3 to 9	4 to 9	3 to 8	3 to 8	1 to 10
Continental	558							
Mean		4.9	6.0	6.0	5.6	5.0	5.2	5.4
SD		0.9	1.0	1.0	1.2	1.1	1.0	1.7
Range		2 to 8	3 to 9	3 to 9	2 to 9	2 to 8	3 to 8	1 to 10
Other	68							
Mean		5.3	5.9	5.8	5.5	5.3	5.0	5.3
SD		0.9	1.2	1.1	1.0	1.0	1.1	1.7
Range		3 to 7	3 to 8	4 to 8	4 to 9	4 to 7	3 to 7	3 to 10

[1]Includes Angus and Red Angus-sired cattle. Panel scores range from 1 to 10. For most panels, 10 is preferred. However, 1 is preferred for Yield grade and 12th-rib fat panels.

correlations among the economically relevant traits and each of the Igenity panel scores. Second, genetic correlations among Igenity panels were calculated by a mixed model regression in PROC MIXED (SAS Inst. Inc., Cary, NC). Specific Igenity panel scores for each animal are modeled as

$$\mathrm{Y}_{ijk} = \mu + \mathrm{Ig}_i + \mathrm{S}_{ij} + \varepsilon_{ijk}, \quad [1]$$

where Y_{ijk} is the Igenity score for trait i on progeny k of sire j, Ig_i is the fixed effect of trait i (Igenity score), S_{ij} is the random effect of sire j for trait i, and ε_{ijk} is the random residual effect of progeny k of sire j for trait i. The estimate of sire variance, S(i,i), represents one-quarter of the additive genetic variance for trait i, and S(i,i') represents one-quarter of the additive genetic covariance between trait i and i'. Therefore, $\mathrm{V}_A = 4\sigma^2_{\mathrm{S}i,i}$ and $\mathrm{cov}_A = 4\sigma^2_{\mathrm{S}i,i}$; hence, $\mathrm{r}_A = \mathrm{cov}_A/(\mathrm{V}_{Ai}\mathrm{V}_{Ai'})^{1/2}$, where V is additive ($A$) genetic variance and r is the genetic correlation between 2 traits or panels (Falconer and Mackay, 1996).

The specific SNP included in each marker panel are unknown, so evaluations are limited to the correlations with Igenity panel scores directly, and not individual SNP. Analyses directly on the Igenity scores rather than on the individual SNP are meaningful because this is the information available to cattle breeders (molecular breeding values may also be provided but may be less meaningful to a lay audience than the panel scores). Given the likelihood that some panels share some of the same SNP and the potential for high linkage disequilibrium, the expectation was for some degree of correlation among Igenity panel scores.

Third, to measure the marginal impact of the Igenity panel scores on economically relevant traits, observed values for these traits were regressed using PROC MIXED (SAS Inst. Inc.) on panel scores and other explanatory variables that have the potential to affect cattle performance and carcass quality. A common functional form was estimated for each of 8 economically relevant traits:

$$\begin{aligned} trait_j &= c_1 + c_2 \times DOF_j + \sum_{i=3}^{6} c_i \times sire\_breed_{ij} + c_7 \\ &\times BW_{j0} + c_8 \times BW_{j0}^2 + c_9 \times sex_j + \sum_{i=10}^{20} c_i \\ &\times ranch\_identification + \sum_{i=21}^{27} c_i \\ &\times Igenity\_panel_{ij} + \varepsilon_j; \\ j &\in \{1,\ldots,764\}; \end{aligned} \quad [2]$$

where $trait_j$ is either ADG, DOF, FE, HCW, REA, YG, QG, or NR for animal j. Each equation intercept is given as c_1. The regression coefficients are as follows: c_2 is for DOF; c_3, c_4, c_5, and c_6 are sire breed indicators for Angus, Charolais, Limousin, and other breeds, respectively; c_7 and c_8 are the coefficients for feedlot placement BW and squared BW^2, respectively; c_9 is the coefficient for sex, where sex = 0 for steer and sex = 1 for heifer; c_{10} to c_{20} are random effects for the source ranch; and c_{21} to c_{27} are coefficients for the Igenity panels. The natural logarithm of HCW was taken to scale it to be similar to most of the explanatory variables. The null hypothesis of no random effect of ranch of origin was tested with the likelihood ratio test (**LR**) and rejected at $P \leq 0.001$ for all dependent variables. The LR (λ) was obtained as a ratio of the maximum likelihood value obtained when the mixed model was analyzed with and without the random constraint associated with ranch of origin. The LR depends on the restricted and unrestricted models, and under regularity, the test statistic ($-2\ln\lambda$) follows a χ^2 distribution with degrees of freedom equal to the number of restrictions imposed (Greene, 2005). The variable DOF was dropped from the DOF model. To avoid multicollinearity, Igenity panel scores for fat thickness and percentage

Table 3. Pearson and genetic correlation coefficients among Igenity panel scores, Angus breeds[1]

	Ingenity panel score						
Ingenity panel score	ADG	Marbling	Percentage of Choice	Yield grade	12th-rib fat thickness	Rib-eye area	Tenderness
Phenotypic correlation							
ADG	—						
Marbling	0.35***	—					
Percentage Choice	0.35***	1.00***	—				
Yield grade	0.32***	0.32***	0.32***	—			
12th-rib fat thickness	0.18*	0.42***	0.42***	0.57***	—		
Rib-eye area	0.06	0.01	0.01	−0.10	−0.13***	—	
Tenderness	0.23**	0.01	0.01	0.17	−0.02	0.09	—
Genetic correlation							
ADG	—						
Marbling	−0.54	—					
Percentage Choice	−0.54	1.00	—				
Yield grade	0.16	0.87	0.87	—			
12th-rib fat thickness	−0.28	0.93	0.93	0.95	—		
Rib-eye area	0.65	−0.05	−0.05	−0.43	−0.47	—	
Tenderness	0.38	0.93	0.93	0.49	0.39[1]	0.46	—

[1]Computed for Angus only. The model does not converge when Angus and Red Angus are jointly considered.
*$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$. Includes both Angus and Red Angus-sired cattle.

of Choice were not included as explanatory variables because of their high Pearson correlations with panel scores for YG (0.63, $P < 0.001$) and marbling (0.99, $P < 0.001$), respectively.

Two of our dependent variables of interest, YG and QG, were not continuous and were therefore not normally distributed. These variables were each coded as 1 through 5, with 1 representing a YG of 1 and 5 represented a YG of 5. For QG, 1 through 5 represented USDA Standard, Select, Choice, the upper 2/3 of Choice, and Prime, respectively. The effect of the independent variables on YG and QG were evaluated using an ordered logistic regression in PROC GLIMMIX (SAS Inst. Inc.), using a model similar to that described above.

RESULTS AND DISCUSSION

Given that the actual SNP in the various panels are confidential, the number of SNP that were common between panels is unknown. If 2 panels share a significant number of SNP or the panel SNP are in high linkage disequilibrium, multicollinearity could become an issue if both are included as explanatory variables in a regression. The greatest phenotypic correlation among panels was between the marbling and percentage of Choice panels, ranging from 0.94 to 1.0 (Tables 3, 4, and 5). It is likely that the marbling and percentage of Choice panels were identical. The correlation between marbling and percentage of Choice for other or unknown breeds (Table 5) was less than 1, but that seems likely because of errors in the data. The next greatest phenotypic correlations were between YG and 12th-rib fat thickness, ranging from 0.21 to 0.66 (Tables 3, 4, and 5). It seems reasonable that these 2 panels share SNP because YG is a function of fat thickness and other carcass traits. The 12th-rib fat thickness also showed some degree of correlation with the marbling and percentage of Choice panels, with correlations ranging from 0.26 to 0.42. These also suggest the possibility of shared SNP.

When compared across breeds, the ADG, marbling, percentage of Choice, and YG panels tended to have greater phenotypic correlations for the Angus breeds than for the other 2 breed types. Utrera and Van Vleck (2004) summarized heritability estimates from 72 studies and reported that a large amount of variability exists between these study estimates. Utrera and Van Vleck (2004) suggested that one possible cause of the observed variability between studies is breed differences. It appears that breed differences in genetic correlations might also exist, as can be seen by comparing Tables 3, 4, and 5.

Phenotypic correlations among the Igenity panel scores and cattle traits are reported in Tables 6, 7, and 8. In general, the Igenity panel scores showed low correlations with their corresponding performance traits. However, none of these correlations was negative. It is also instructive to calculate genetic correlations, but too few unique bulls were present in the data set to allow for their computation by breed. However, the genotypic correlations for the pooled data set (pooled across all sire breeds) are reported in Table 9. The genetic correlations tended to be greater than their corresponding phenotypic correlations. Genetic correlations had a large range across traits and panels. Days on feed showed low genetic correlations with the Igenity panels, ranging in absolute value from 0.11 to 0.46. Hot carcass weight had even smaller (absolute value) genetic correlations with the panels. Yield grade had some high genetic correlations with panels, including marbling (0.83) and percentage of Choice (0.80). Many moderate correlations are present in Table 9. These results

Table 4. Pearson and genetic correlation coefficients among Igenity panel scores, Continental breeds

	Igenity panel score						
Igenity panel score	ADG	Marbling	Percentage Choice	Yield grade	12th-rib fat thickness	Rib-eye area	Tenderness
Phenotypic correlation							
ADG	—						
Marbling	0.28***	—					
Percentage Choice	0.28***	1.00***	—				
Yield grade	0.17***	0.20***	0.20***	—			
12th-rib fat thickness	0.13**	0.26***	0.26***	0.66***	—		
Rib-eye area	−0.12**	0.00	0.00	−0.32***	−0.15***	—	
Tenderness	0.09*	−0.05	−0.05	0.08	−0.05	−0.05	—
Genetic correlation							
ADG	—						
Marbling	0.42	—					
Percentage Choice	0.42	1.00	—				
Yield grade	0.29	0.80	0.80	—			
12th-rib fat thickness	0.18	0.62	0.62	0.82	—		
Rib-eye area	−0.43	−0.66	−0.66	−0.82	−0.60	—	
Tenderness	−0.14	0.26	0.26	0.30	0.18	−0.06	—

*$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$.

suggest that SNP in the panels are associated with economically relevant traits.

Shackelford et al. (1994) reported genetic correlations (r_g) between shear force, IMF, and ADG. Shear force and ADG had r_g of −0.04, whereas r_g was −0.57 between shear force and IMF. The genetic correlation between the Igenity tenderness panel and ADG was 0.41 (Table 9), which is considerably greater than the estimate reported by Shackelford et al. (1994) when using an actual tenderness measure. Between the tenderness panel and QG, r_g was 0.13, which is much less than the estimate by Shackelford et al. (1994) with actual tenderness.

Heritabilities were also estimated for all breeds combined because too few observations were present to allow estimation by individual breed types. Estimates of heritabilities for ADG, marbling, REA, tenderness, and YG panels were 0.38, 0.21, 0.16, 0.15, and 0.33, respectively. Given that all heritabilities were less than one, the SNP in each panel were not additive. Our estimates for marbling, REA, and YG panel heritabilities were within the ranges of heritabilities for actual traits summarized by Utrera and Van Vleck (2004). The actual marbling score heritability ranged from 0.01 to 0.88 (μ = 0.37), whereas our estimate of marbling panel heritability was 0.21. The actual YG heritability ranged from 0.24 to 0.85 (μ = 0.64), whereas our estimate of YG panel heritability was 0.33.The marbling panel heritability (0.21) was outside the range of published estimates of actual marbling heritability (0.26 to 0.47, μ = 0.35; Marshall, 1994). Most of the panel heritabilities estimated here were less than the average heritabilities for the actual corresponding traits reported by Utrera and Van Vleck (2004) and Marshall (1994).

Shackelford et al. (1994) reported a heritability of 0.53 for tenderness (shear force), which was considerably greater than the tenderness panel heritability of 0.14. The ADG panel heritability estimate of 0.38 was greater than ADG heritabilities of 0.32 in Shackelford et al. (1994) and 0.28 in Arthur et al. (2001).

Because of the genetic correlations among panels and observed traits, the possibility existed that improvements in one trait would affect other traits (either positively or adversely). Regression analysis permitted an investigation into the effects of each panel while controlling for other factors, such as breed, that could af-

Table 5. Phenotypic (Pearson) correlation coefficients among Igenity panel scores, other or unknown breeds

	Igenity panel score						
Igenity panel score	ADG	Marbling	Percentage Choice	Yield grade	12th-rib fat thickness	Rib-eye area	Tenderness
ADG	—						
Marbling	0.13	—					
Percentage Choice	0.13	0.94***	—				
Yield grade	−0.14	0.27*	0.29*	—			
12th-rib fat thickness	−0.05	0.40***	0.32**	0.21***	—		
Rib-eye area	−0.20	−0.15	−0.21	−0.28*	−0.09	—	
Tenderness	0.17	−0.07	0.01	0.13	−0.02	0.00	—

*$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$. Genetic correlations were not computed because of the lack of sample size.

Table 6. Phenotypic (Pearson) correlation coefficients among feeder cattle traits and their Igenity panel scores, Angus breeds

	Igenity panel score						
Actual performance	ADG	Marbling	Percentage Choice	Yield grade	12th-rib fat thickness	Rib-eye area	Tenderness
Initial BW	−0.13	−0.39***	−0.39***	−0.26*	−0.37***	−0.11	−0.20**
Final BW	−0.03	0.07	0.07	−0.07	−0.21*	−0.09	0.00
Days on feed	−0.11	−0.05	−0.05	−0.03	0.11	0.07	−0.12
ADG	0.12	0.44***	0.44***	0.18*	0.09	0.00	0.21*
Feed efficiency	0.06	0.35***	0.35***	0.20*	0.25**	0.02	0.14
HCW	0.05	0.24**	0.24**	0.00	−0.03	−0.01	0.10
Quality grade[1]	0.09	0.25**	0.25**	0.14	0.10	0.12	0.14
Yield grade[2]	0.22*	−0.01	−0.01	0.12	0.04	0.01	0.05
Rib-eye area	−0.18*	0.11	0.11	−0.15	−0.05	0.03	−0.01

[1]Grades: 1 = USDA Standard; 2 = USDA Select; 3 = USDA Choice; 4 = upper 2/3 of USDA Choice; 5 = USDA Prime.
[2]USDA Yield grade, carcasses that graded USDA Standard did not receive a USDA Yield grade.
*$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$. Includes Angus and Red Angus-sired cattle.

fect cattle performance. Selected regression results are reported in Table 10. For conciseness, only the estimated coefficients and SE for the Igenity panel scores and DOF, placement BW, and sex are reported. In Table 10, the estimated effect on dependent variables from the Igenity panels are reported in each column, whereas each row shows the effect of an Igenity marker score on each measure of animal performance. By comparing the effects across each measure of performance, it can be determined whether improving the Igenity score might positively affect some phenotypes while adversely affecting others.

The only marker panel that exhibited a significant coefficient in the multivariate regressions for its corresponding feeder cattle trait was the marbling panel. Because QG was estimated using an ordered probit model, the coefficient could not be interpreted as a marginal increase in QG. Rather, the positive sign of the coefficient indicated that a 1-unit increase in the marbling panel would increase the probably of a greater QG ($P = 0.02$; Table 10; 1 = Standard, and 5 = Prime). In addition to marbling, the tenderness panel also increased the probability of greater QG ($P < 0.02$). This finding implies that other traits (such as ADG) might be improved without sacrificing QG.

However, improvement in some panels did affect other traits. The ADG panel had a positive effect on YG ($P \leq 0.05$). Improving the tenderness panel decreased DOF, and improving the marbling panel increased HCW. Either of these effects could be positive or negative, depending on the situation. Yield grade and REA panels did not significantly affect any of the dependent variables.

The tenderness Igenity score significantly affected observed ADG, but this raised the question of whether the effect was quantitatively large or economically important. Given a BW market price of $1.87/kg (or $85/cwt), it was estimated that for every 1-unit increase in the Igenity tenderness score, per-animal revenue would increase by $4.21 because of its influence on ADG.

Interestingly, the marbling panel was the only independent variable, whether a control variable or Igenity

Table 7. Phenotypic (Pearson) correlation coefficients among feeder cattle traits and their Igenity panel scores, Continental breeds

	Igenity panel score						
Actual performance	ADG	Marbling	Percentage Choice	Yield grade	12th-rib fat thickness	Rib-eye area	Tenderness
Initial BW	−0.21***	−0.07	−0.07	−0.12**	−0.04	0.11**	−0.03
Final BW	−0.04	−0.05	−0.05	0.00	−0.02	0.03	0.01
Days on feed	0.07	−0.10	−0.10	−0.04	−0.12	0.00	−0.06
ADG	0.08	0.05	0.05	0.12*	0.07	−0.06	0.06
Feed efficiency	0.17***	0.05	0.05	0.12*	0.08	−0.05	0.05
HCW	−0.07	−0.04	−0.04	−0.02	−0.01	0.07	−0.02
Quality grade[1]	0.07	0.08	0.08	0.06	0.00	−0.01	0.08
Yield grade[2]	0.02	0.06	0.06	0.13*	0.15***	−0.03	0.03
Rib-eye area	−0.02	0.02	−0.02	−0.06	−0.06	0.03	−0.02

[1]Grades: 1 = USDA Standard; 2 = USDA Select; 3 = USDA Choice; 4 = upper 2/3 of USDA Choice; 5 = USDA Prime.
[2]USDA Yield grade, carcasses that graded USDA Standard did not receive a USDA Yield grade.
*$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$. Includes Charolais and Limousin-sired cattle.

Table 8. Phenotypic (Pearson) correlation coefficients among feeder cattle traits and their Igenity panel scores, other or unknown breeds

	Igenity panel score						
Actual performance	ADG	Marbling	Percentage Choice	Yield grade	12th-rib fat thickness	Rib-eye area	Tenderness
Initial BW	−0.01	0.05	0.04	0.02	0.18	0.14	0.04
Final BW	−0.06	0.17	0.21	0.34	0.25	−0.02	0.16
Days on feed	−0.15	−0.13	−0.18	−0.19	−0.04	0.13	−0.24
ADG	0.00	0.21	0.27*	0.00	0.16	−0.15	0.16
Feed efficiency	−0.03	0.12	0.20	0.25*	0.01	−0.25	0.02
HCW	−0.1	0.19	0.24	0.25*	0.17	0.00	0.12
Quality grade[1]	0.30*	0.22	0.18	0.00	0.10	−0.12	0.14
Yield grade[2]	0.39**	0.10	0.11	0.02	0.05	−0.04	0.23
Rib-eye area	−0.21	0.08	0.16	0.22	0.16	−0.07	−0.12

[1]Grades: 1 = USDA Standard; 2 = USDA Select; 3 = USDA Choice; 4 = upper 2/3 of USDA Choice; 5 = USDA Prime.
[2]USDA Yield grade, carcasses that graded USDA Standard did not receive a USDA Yield grade.
*$P \leq 0.05$, **$P \leq 0.01$.

panel score, to have a statistically significant effect on actual NR. A 1-unit increase in marbling panel score improved NR by an estimated $7.53 per animal. An increase in marbling panel score was associated with an improved QG, but was also associated with an increase in HCW ($P = 0.01$) and a decrease in DOF ($P = 0.07$). All these factors would tend to increase NR, but the relationship of marbling panel score with HCW and DOF may not necessarily be expected biologically. It is likely that the full economic effect on NR of marbling panel score was not entirely due to improvements in QG.

Because the natural logarithm of HCW was taken as the dependent variable, the regression coefficient was interpreted as the percentage change in HCW. The logarithm of HCW had only 1 significant panel, marbling. A 1-unit change in the marbling panel score decreased HCW by 0.6%.

The tenderness panel did not have a significant effect on individual animal profit. The Igenity tenderness panel uses 2 SNP in calpain 1 (*CAPN1*) and 1 in calpastatin (*CAST*) SNP (Gill et al., 2009). Page et al. (2002, 2004) reported that the 2 *CAPN1* SNP

Table 9. Phenotypic (Pearson) and genetic correlation coefficients among feeder cattle traits and their Igenity panel scores, all breeds

	Igenity panel score						
Actual performance	ADG	Marbling	Percentage Choice	Yield grade	Fat thickness	Rib-eye area	Tenderness
Phenotypic correlation							
Initial BW	−0.16***	−0.12**	−0.12***	0.13***	−0.07*	0.07*	−0.16***
Final BW	0.02	0.02	0.02	0.05	−0.02	−0.01	0.05
Days on feed	−0.04	−0.13***	−0.13***	−0.09*	−0.11**	0.05	−0.11**
ADG	0.17***	0.18***	0.19***	0.20***	0.09**	−0.09**	0.17***
G:F	0.18***	0.13***	0.15***	0.17***	0.10**	−0.07	0.09*
HCW	0.00	0.05	0.06	0.03	0.00	0.04	0.03
Quality grade[1]	0.16***	0.16***	0.16***	0.10**	0.04	−0.03	0.13***
Yield grade[2]	0.17***	0.09*	0.09*	0.16***	0.13***	−0.05	0.09**
Rib-eye area	−0.11**	−0.01	0.00	−0.08*	−0.05	0.04	−0.05
Genotypic correlation							
Initial BW	−0.35***	−0.23***	−0.24***	−0.58***	−0.30***	0.35***	0.00
Final BW	0.05	0.49***	0.34***	0.17***	0.16***	−0.12**	0.36***
Days on feed	−0.30***	−0.46***	−0.42***	−0.16***	−0.33***	0.11*	−0.29***
ADG	0.51***	0.68***	0.64***	0.69***	0.56***	−0.44***	0.41***
G:F	0.46***	0.46***	0.46***	0.50***	0.46***	−0.47***	0.14**
HCW	−0.14**	0.21***	0.13**	−0.06	−0.07	0.04	0.21***
Quality grade[1]	0.61***	0.63***	0.61***	0.43***	0.12**	−0.50***	0.13**
Yield grade[2]	0.66***	0.83***	0.80***	0.59***	0.51***	−0.43***	0.29***
Rib-eye area	−0.71***	−0.61***	−0.64***	−0.51***	−0.32***	0.38***	−0.38***

[1]Grades: 1 = USDA Standard; 2 = USDA Select; 3 = USDA Choice; 4 = upper 2/3 of USDA Choice; 5 = USDA Prime.
[2]USDA Yield grade, carcasses that graded USDA Standard did not receive a USDA Yield grade.
*$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$.

Table 10. Estimated Igenity panel score coefficients for growth and carcass trait regression models

	Dependent variable							
Item	ADG, kg/d	Feed efficiency, kg of BW gain/kg of feed	Days on feed, d	Log(HCW), kg	Rib-eye area, cm^2	Yield grade	Quality grade	Net return, \$/animal
Independent variable								
Days on feed	−0.008***	−0.0004***	—	−0.0004	0.034	−0.035***	−0.038***	−0.122
	(0.001)	(0.00004)		(0.0002)	(0.034)	(0.008)	(0.008)	(0.277)
Placement BW, kg	−0.002*	−0.001***	−0.310	0.001	0.254	−0.041	0.016	0.76
	(0.003)	(0.0002)	(0.173)	(0.001)	(0.155)	(0.032)	(0.016)	(1.27)
Sex[1]	−0.237***	−0.019***	−5.09***	−0.092***	−7.198***	0.451**	0.036	2.273
	(0.014)	(0.0009)	(0.855)	(0.0054)	(0.785)	(0.170)	(0.035)	(2.530)
Igenity score								
ADG	−0.003	0.0003	−0.189	−0.0023	−0.650	0.195*	0.002	−0.274
	(0.007)	(0.0005)	(0.439)	(0.0027)	(0.393)	(0.085)	(0.088)	(3.195)
Tenderness	0.007*	0.0001	−0.486*	0.0012	−0.040	0.035	0.135**	0.678
	(0.004)	(0.0002)	(0.227)	(0.0014)	(0.204)	(0.043)	(0.046)	(1.655)
Marbling	0.010	0.0001	−0.773	0.0065*	0.739	−0.062	0.212*	7.532*
	(0.006)	(0.0005)	(0.430)	(0.0027)	(0.386)	(0.083)	(0.088)	(3.141)
Yield grade	−0.003	0.0001	−0.044	−0.0014	−0.441	0.035	−0.024	−1.046
	(0.006)	(0.0004)	(0.389)	(0.0024)	(0.348)	(0.074)	(0.079)	(2.835)
Rib-eye area	0.001	0.001	0.410	0.0037	−0.185	0.095	0.046	6.574
	(0.007)	(0.0004)	(0.432)	(0.0027)	(0.387)	(0.083)	(0.087)	(3.147)
N	709	709	709	709	709	684	709	709
Adjusted R^2 [2]	0.46	0.53	0.41	0.41	0.13	0.12	0.12	0.33

[1] In this analysis, steers were the base, and the coefficient estimates the heifer sex effect.

[2] As an aid to interpretation of the models, adjusted R^2 was reported. Adjusted R^2 was determined from a fixed-effects-only model in PROC REG (SAS Inst. Inc., Cary, NC). As such, the values presented here slightly overestimate actual adjusted R^2 of the mixed models.

*$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$; SE of coefficients are presented in parentheses.

(*CAPN*4751 and *CAPN*316) are associated with tenderness in crossbred cattle. Gill et al. (2009) also report improved tenderness associated with one of the *CAPN1* SNP (*CAPN*316). Schenkel et al. (2005) reported a relationship between tenderness and a *CAST* SNP.

Van Eenennaam et al. (2007) evaluated 2 marker panels for tenderness and quality grade from GeneSTAR (now owned by Pfizer Inc.) and the Igenity tenderness panel. These researchers concluded that the tenderness panels of both companies were indeed related to Warner-Bratzler shear force (**WBSF**). However, they found little to no correlation between the GeneSTAR quality grade panel and actual QG, a finding that emphasizes the need for continual validation of commercially available marker panels. In a study evaluating correlations between chute behavior and beef carcass quality, Hall et al. (2009) assessed the correlation between WBSF and Igenity tenderness and docility panels. In a somewhat surprising result, they reported a significant and positive correlation between the docility score and WBSF. The correlation between WBSF and tenderness score was found to be negative, as expected. Other economically relevant traits and relationships with Igenity panels were not evaluated in these studies.

It is encouraging for the beef industry that our regression results showed that improvement in Igenity tenderness scores was not detrimental to individual producer profits. Lusk et al. (2001) reported that consumers were willing to pay up to a \$1.80/kg (\$4/lb) for tender steaks and had an average willingness to pay \$0.58/kg (\$1.23/lb) for tender steaks. If individual animal profits are not affected by an improvement in Igenity tenderness scores (Table 10), an improvement in Igenity tenderness panel scores improves tenderness (Van Eenennaam et al. 2007), and consumers are willing to pay more for tender steaks (Lusk et al. 2001), the use of this panel for selection decisions will increase beef demand and industry profits.

Marbling may be another area with potential for a win-win scenario. Several studies have found a relationship between SNP known to be in the Igenity marbling panel, for example, leptin SNP. Kononoff et al. (2005), Nkrumah et al. (2005), Schenkel et al. (2005), and others have reported relationships between leptin markers and marbling. The National Beef Cattle Evaluation Consortium (2009) has validated the relationship between the Igenity marbling panel and measures of marbling and QG. Our results showed that individual animal profit increased with increases in Igenity marbling panel score. On the consumer side, studies (e.g., Platter et al., 2003) reported that consumer acceptance of steak increased with marbling or QG. Hence, again it appears that the use of this panel would benefit individual producers, the industry, and consumers.

One of the biggest challenges in any feeding program is to select feeder calves with a subset of desirable traits while minimizing the adverse effect on other economically relevant traits. With the mapping of the cattle genome, feeders have another tool available to help them achieve their objectives. Although the challenge of improvement with minimal adverse effects remains, commercially available SNP panels enable researchers and producers to measure the effects of SNP-assisted selection. This study analyzed the association between the Igenity SNP panels on fed cattle traits.

In general, our results showed a low, although highly significant, correlation of Igenity panel scores with the corresponding fed cattle performance traits they were designed to predict (mean Pearson correlation coefficient of these correlations is 0.13). Further, all these correlations had the expected sign. Genetic correlations were, in general, much larger than phenotypic correlations. These results would seem to support the concept of SNP-based selection and that improvement or refinement of the panels should improve correlation. Additionally, one of the Igenity panels (marbling) tested did influence its corresponding traits in a rigorous multivariate regression. Some of the relationships examined here may be statistically weak, but at the same time can be economically meaningful. For example, an improvement in the marbling panel score from 6 to 7 would be expected to improve NR by almost \$7.53 per animal under the market conditions of these data. However, this would also be expected to affect other traits of interest. With the estimated effects of changes in Igenity panels, economic tradeoffs can be evaluated. The specific tradeoffs will vary across producers and market conditions.

Our models are limited to fed cattle, which partially limits recommendations on marker-assisted selection. Upstream and downstream considerations are likely. For example, how does selection using the Igenity ADG panel affect fertility rate or tenderness? How does the selection of sires based on their Igenity panel scores affect the performance of their offspring, and how do these relationships change in different market circumstances? Additional research is needed to address these questions.

LITERATURE CITED

Arthur, P. F., J. A. Archer, D. J. Johnston, R. M. Herd, E. C. Richardson, and P. F. Parnell. 2001. Genetic and phenotypic variance and covariance components for feed intake, feed efficiency, and other postweaning traits in Angus cattle. J. Anim. Sci. 79:2805–2811.

Falconer, D. S., and T. F. C. Mackay. 1996. Introduction to Quantitative Genetics. 4th ed. Longmans Green, Harlow, Essex, UK.

Federation of Animal Science Societies. 2010. Guide for the Care and Use of Agricultural Animals in Research and Teaching. 3rd ed. Fed. Anim. Sci. Soc., Champaign, IL.

Gill, J. L., S. C. Bishop, C. McCorquodale, J. L. Williams, and P. Wiener. 2009. Association of selected SNP with carcass and taste panel assessed meat quality traits in a commercial population of Aberdeen Angus-sired beef cattle. Genet. Sel. Evol. 41:36.

Greene, W. 2005. Econometric Analysis. 5th ed. Prentice Hall, Upper Saddle River, NJ.

Hall, N. L., V. L. Anderson, K. R. Carlin, J. C. Galbreath, and E. P. Berg. 2009. Working chute behavior of feedlot cattle can be an indication of cattle temperament and beef carcass composition and quality. J. Anim. Sci. 87(E-Suppl. 3):72.

Kononoff, P. J., H. M. Deobald, E. L. Stewart, A. D. Laycock, and F. L. S. Marquess. 2005. The effect of a leptin single nucleotide polymorphism on quality grade, yield grade, and carcass weight of beef cattle. J. Anim. Sci. 83:927–932.

Lusk, J. L., J. A. Fox, T. C. Schroeder, J. Mintert, and M. Koohmaraie. 2001. In-store valuation of steak tenderness. Am. J. Agric. Econ. 83:539–550.

Marques, E., J. D. Nkrumah, E. L. Sherman, and S. S. Moore. 2009. Polymorphisms in positional candidate genes on BTA14 and BTA26 affect carcass quality in beef cattle. J. Anim. Sci. 87:2475–2484.

Marshall, D. M. 1994. Breed differences and genetic parameters for body composition traits in beef cattle. J. Anim. Sci. 72:2745–2755.

National Beef Cattle Evaluation Consortium. 2009. Home page. Accessed Jul. 16, 2009. http://www.nbcec.org/.

Nkrumah, J. D., J. A. Basarab, Z. Wang, C. Li, M. A. Price, E. K. Okine, D. H. Crews Jr., and S. S. Moore. 2007. Genetic and phenotypic relationships of feed intake and measures of efficiency with growth and carcass merit of beef cattle. J. Anim. Sci. 85:2711–2720.

Nkrumah, J. D., C. Li, J. Yu, C. Hansen, D. H. Keisler, and S. S. Moore. 2005. Polymorphisms in the bovine leptin promoter associated with serum leptin concentration, growth, feed intake, feeding behavior, and measures of carcass merit. J. Anim. Sci. 83:20–28.

Page, B. T., E. Casas, M. P. Heaton, N. G. Cullen, D. L. Hyndman, C. A. Morris, A. M. Crawford, T. L. Wheeler, M. Koohmaraie, J. W. Keele, and T. P. L. Smith. 2002. Evaluation of single-nucleotide polymorphisms in *CAPN1* for association with meat tenderness in cattle. J. Anim. Sci. 80:3077–3085.

Page, B. T., E. Casas, R. L. Quaas, R. M. Thallman, T. L. Wheeler, S. D. Shackelford, M. Koohmaraie, S. N. White, G. L. Bennett, J. W. Keele, M. E. Dikeman, and T. P. L. Smith. 2004. Association of markers in the bovine *CAPN1* gene with meat tenderness in large crossbred populations that sample influential industry sires. J. Anim. Sci. 82:3474–3481.

Platter, W. J., J. D. Tatum, K. E. Belk, P. L. Chapman, J. A. Scanga, and G. C. Smith. 2003. Relationships of consumer sensory ratings, marbling score, and shear force value to consumer acceptance of beef strip loin steaks. J. Anim. Sci. 81:2741–2750.

Schenkel, F. S., S. P. Miller, X. Ye, S. S. Moore, J. D. Nkrumah, C. Li, J. Yu, I. B. Mandell, J. W. Wilton, and J. L. Williams. 2005. Association of single nucleotide polymorphisms in the leptin gene with carcass and meat quality traits of beef cattle. J. Anim. Sci. 83:2009–2020.

Shackelford, S. D., M. Koohmaraie, L. V. Cundiff, K. E. Gregory, G. A. Rohrer, and J. W. Savell. 1994. Heritabilities and phenotypic and genetic correlations for bovine postrigor calpastatin activity, intramuscular fat content, Warner-Bratzler shear force, retail product yield and growth rate. J. Anim. Sci. 72:857–863.

Tedeschi, L. O., D. G. Fox, and P. J. Guiroy. 2004. A decision support system to improve individual cattle management. 1. A mechanistic, dynamic model for animal growth. Agric. Syst. 79:171–204.

Utrera, A. R., and L. D. Van Vleck. 2004. Heritability estimates for carcass traits of cattle: A review. Genet. Mol. Res. 3:380–394.

Van Eenennaam, A. L., J. Li, R. M. Thallman, R. L. Quaas, M. E. Dikeman, C. A. Gill, D. E. Franke, and M. G. Thomas. 2007. Validation of commercial DNA tests for quantitative beef quality traits. J. Anim. Sci. 85:891–900.