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日 本 畜 産 学 会 報　第63巻　第2号　別 刷
1992（平4）年2月
Reprinted from
Animal Science and Technology,　Vol. 63,　No. 2
February 1992

Evaluation of Meat Quality in Japanese Beef Cattle by Computer Image Analysis

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(Received July 1, 1991)

Abstract Beef carcass grade is an important factor in determining the quality and price of beef in Japan. Currently the grade is mainly estimated visually by standardized Beef Marbling Scores. The size and form of intramuscular (I/M) fat particles also influence meat quality. This study was conducted to develop a method which expresses numerically the marbling score and the form of the I/M fat via Computer Image Analysis. Progeny testing records and images of the rib-eye muscle (M. longissimus thoracic) between the 5th and 6th rib of Japanese Black (JB) and Japanese Shorthorn (JS) were used to estimate heritabilities, genetic and phenotypic correlations for growth, and carcass and meat quality traits. These data were collected from the Aomori, Akita, Iwate, and Miyagi prefectural Animal Husbandry Experimental Stations, and the Ohu National Livestock Breeding Station, for 14 years from 1975 to 1988. The mean values of the I/M fat ratios within the rib-eye muscle were 7.88% and 5.18% for JB and JS, respectively. No significant differences were detected between breeds for the area score and form score of marbling. Genetic parameters were calculated by Harvey's least squares analysis program of LSMLMW. The heritability estimates of I/M fat ratio via image analysis were 1.09 (JB), and 0.45 (JS). Genetic correlations between daily gain and marbling score by grading or I/M fat ratio via Image Analysis of JB were 0.02 and 0.01, respectively, but those of JS were 0.52 and −0.67, respectively. The phenotypic correlations between the marbling score and I/M fat ratio were comparatively high (0.63 in JB) and low (0.14 in JS). This might indicate difficulty in grading the marbling score in breeds having a low I/M fat ratio.

Anim. Sci. Technol. (Jpn.) 63 (2) : 121-128, 1992

Key words : image analysis, genetic parameters, Japanese Black, Japanese Shorthorn

Techniques for objectively measuring intramuscular (I/M) fat within the rib-eye muscle would greatly contribute to genetic improvement, as this trait is economically very important in Japan. NEWMAN[8] reported techniques to estimate the I/M fat ratio using retail-slices of boneless beef, and NAKAI *et al.*[7], HOSHINO[2] also reported on image analysis method. But image data from progeny testing cattle have not been reported previously. The first object of this study was, therefore, to develop an Image Analysis method to estimate the I/M fat ratio and the form of the marbling particles. The second aim was to obtain genetic parameters for growth, carcass and meat quality traits estimated by Image Analysis using the progeny testing records of Japanese Black and Japanese Shorthorn breeds. Differences in the marbling characteristics between the two breeds were also investigated.

Materials and Methods

Image Analysis System and Computer Program : The image analysis was caried out by the Computer Image Analysis system (NEC Ltd., Tokyo) at the Computer Center of Tohoku University. The main components of this system were a Host computer (ACOS-2000), Mini computer (MS-135), Image display control equipment (N 7835-12) and Color video camera (N 7836-63). Image data from pictures taken by color video camera was linked to the Image Analysis System, and saved in a computer image memory. The data were composed of column (corresponds to X-axis), line (Y-axis) and band (Red, Green and Blue component).

The computer program was developed in FORTRAN program language using SPIDER and RSIPS-II which are sub-routine packages for image analysis.

The image data of the rib-eye muscle were inputted by Color Video Camera equipment and transformed into digital signals : 0 (lean) and 1 (fat). The inputted image data included some unnecessary outside area of the rib-eye muscle. It was therefore necessary to remove this part. In this study, the boundary of the rib-eye muscle was detected by the KIRSCH[3] method and the outside area of the boundary was excluded. The I/M fat ratio was calculated as follows :

$$FR = Pf/Pr * 100$$

where, FR : the I/M fat ratio,
Pf : the number of pixels of I/M fat,
Pr : the number of pixels of rib-eye muscle.

Pictures of the rib-eye muscle between the 5th and 6th ribs, taken during grading, were used as the image data.

The size and form of I/M fat particles are important factors in deciding meat price and grade. Thus, an objective method of estimating them via Image Analysis was investigated. The mean of the area of each I/M fat particle represents its coarseness. This was defined as 'area score' in this study. The area score was calculated as follows :

$$AS = Pf/Nf/Pr * 10000$$

where, AS : the area score,
Pf : the number of pixels of I/M fat,
Nf : the number of I/M fat Particles,
Pr : the number of pixels of rib-eye muscle.

As the area of the rib-eye muscle images were different, these were adjusted by dividing by the number of pixels of rib-eye muscle.

The circumference length of I/M fat particles, when compared to their area score, can be used as an estimate of the marbling form. The circumference length and 'the form score' which describes the form of I/M fat were calculated as follows :

$$CL = Sc/Nf/Pr * 100$$

where, CL : the circumference length,
Sc : the sum of circumferences of individual marbling particles,
Nf : the number of I/M fat particles,
Pr : the number of pixels for rib-eye muscle.

$$FS = \sqrt{AS/CL * 100}$$

where, FS : the form score,
AS : the area score,
CL : the circumference.

A high form score for I/M fat indicates a circular form, and a low score indicates an elliptical form.

Image analysis of progeny testing data : Progeny testing records of Japanese Black (JB) and Japanese Shorthorn (JS) were used in this study. These data were collected from 244 (JB) and 350 (JS) steers for 14 years from 1975 to 1988. Data from steers with inferior picture quality was discarded. These cattle were sired by 34 (JB) and 56 (JS) bulls raised at the Aomori, Akita, Iwate, and Miyagi Prefectural Animal Husbandry Experimental Stations and the Ohu National Livestock Breeding Station. The number of steers and sires by year and

Table 1. Number of steers and sires by breed and station

Breed	Station					Total
	Aomori	Akita	Iwate	Miyagi	Ohu	
Japanese	—	5[a]	17	12	—	34
Black	—	37[b]	101	106	—	244
Japanese	25	—	17	—	14	56
Shorthorn	154	—	104	—	92	350

a): Upper row-number of sires,
b): Lower row-number of steers.

station are shown in Table 1.

In the analysis, carcass grades were converted into the following indices ; Tokusen to 100, Gokujo to 80, Jo to 60, Chu to 40 and Nami to 20. Marbling scores were coded similarly "1 +" to 1.33, "2 −" to 1.67, "2" to 2.00 and so on. Analysis was done by the least squares analysis of variance procedure of HARVEY[1]. Estimates of heritability, and genetic or phenotypic correlations were calculated from paternal half-sib. The mathematical model is as follows :

$$Y_{ijk} = \mu + YS_i + s_{ij} + a_1(x_{ijk} - \bar{x}) + a_2(x_{ijk} - \bar{x})^2 + e_{ijk}$$

where, Y_{ijk} : the k^{th} observation for the j^{th} sire within the i^{th} year-station,

μ : the population mean,

YS_i : effect of the i^{th} year-station,

s_{ij} : effect of the j^{th} sire, within the i^{th} year-station,

a_1 : partial regression coefficient on initial age (linear),

a_2 : partial regression coefficient on initial age (quadratic),

x_{ijk} : the continuous independent variable age,

$\bar{x}$: the arithmetic mean of the x_{ijk},

e_{ijk} : the residual error.

Sire and residual error were treated as random and the other sources of variance were considered as fixed effects. This model was adopted because the quadratic effect of age at the start of the test was significant ($p<0.05$) for dressing percentage.

Results and Discussion

Compared to red and white paper standards, the error of estimation of Computer Image Analysis was less than 4 percent. Therefore, this method is more exact than the judgement of marbling score by visual grading[7].

The quality of the picture around the rib-eye muscle is important for exact estimation. In particular, the contrast between the lean and fat areas has a great influence on the Image Analysis measurement.

Analyses of variance were performed to examine the differences between the two breeds. Table 2 shows the least-squares means and their standard errors for growth and carcass traits of JB and JS steers in progeny testing. The significant differences between the two breeds in daily gain, dressing percentage, rib-eye muscle, subcutaneous fat thickness at the withers, marbling score and carcass grade were examined. Dressing percentage, rib-eye muscle, marbling score and carcass grade of JB were significantly higher than those of JS. These results of JB were similar to previous reports by YANG *et al.*[12] and MUKAI *et al.*[6], and the results for JS were nearly consistent with results of MATSUKAWA *et al.*[5]. Table 3 shows the least square means and their standard errors for I/M fat ratio, area score and form score. I/M fat ratio of JB was significantly ($p<0.01$) higher than that of JS. This was consistent with the results of grading score from the progeny testing. No differences

Table 2. Least squares means and their standard errors for growth and carcass traits of Japanese Black and Japanese Shorthorn steers

Traits	Japanese Black	Japanese Shorthorn
Daily gain(kg/day)	0.816*±0.06	1.001*±0.05
Final body weight(kg)	523.0 ±3.14	533.0 ±2.22
Dressing percentage(%)	63.6* ±0.13	61.3* ±0.09
Rib eye area(cm^2)	49.3* ±0.36	38.5* ±0.27
Fat thickness(cm)	1.29* ±0.03	1.68* ±0.02
Marbling score[a]	3.20* ±0.04	1.04* ±0.03
Carcass grade[b]	76.0* ±0.88	35.0* ±0.64

a) : "0+" ···0.33; "1−" ···0.67; "1" ···1.00; "1+" ···1.33
b) : TOKUSEN···100; GOKUJO···80; JO···60; CYU···40; NAMI···20
*) : Significantly ($p<0.05$) different in each row

Table 3. The least squares means and their standard errors for three traits concerning Image Analysis of I/M fat

Traits	Japanese Black	Japanese Shorthorn
I/M fat ratio	7.88*±0.3	5.18*±0.2
Area score	96.8 ±4.2	93.4 ±3.5
Form score	26.3 ±0.4	27.2 ±0.4

*) : Significantly ($p<0.05$) different in each row.

were detected between the two breeds for area nor form score. The attention should be given in comparison with these traits for two breeds, because the testing term for JB was 364 days while that of JS was 308 days.

According to the results from this study, the I/M fat ratios calculated by Image Analysis for JB and JS were 7.88% and 5.18%, respectively. Marbling scores assessed by grading were 3.20 and 1.04 for JB and JS, respectively. This result indicated that the relationship between I/M fat ratio and marbling score was not in proportion. NAKAI *et al.*[7] have calculated the fat ratio within the rib-eye muscle using picture standards to judge marbling score. The method used the Carcass Grading Standard (former standard) revised by the Nippon Meat Grading Association in 1979. It appears that the relationship between the marbling score judged by this standard and the I/M fat ratio calculated by Image Analysis was not linear. All data used in this study were judged by the former standard. This could cause differences in the results for marbling score and I/M fat ratio. In the new standard revised the same association in 1988, the relationship between the marbling score and the I/M fat ratio was defined to be linear.

The results of analysis of variance on meat quality are given in Table 4. In JB, dressing percentage, subcutaneous fat thickness (not shown in the table), marbling score, I/M fat ratio, area score and form score were significantly affected by year-station, and all traits were significantly affected by sire within year-station. In JS, the effects of year-station were significant for all traits except carcass grade (not shown in the table). Similarly, sire effects were significant for all traits.

The effects of year-station on dressing percentage, subcutaneous fat thickness, marbling score, I/M fat ratio, area score, form score in JB, and on all traits in JS, were highly significant. The progeny testing programs were standardized with respect to the facilities and the feeding condition. But these programs were operated independently at each station and used progeny produced from different original maternal populations which deviated from each other in body size[11]. Moreover, weather conditions were greatly different among stations. Therefore, the effect of sire

Table 4. Mean squares for meat quality traits of Japanese Black and Japanese Shorthorn steers

Breed	Source of variation	Degree of freedom	Marbling score	I/M fat ratio	Area score	Form score
Japanese Black	Year-Station	12	3.912**	123.00**	27560**	303.3**
	Sire within Year-station	19	2.655**	31.96**	20304**	213.1**
	Regression on age(linear)	1	0.001	0.00	1640	8.2
	Regression on age(quadratic)	1	0.000	0.00	1736	7.4
	Error	210	0.533	8.77	4794	12.8
Japanese Shorthorn	Year-Station	25	1.406**	66.89**	4037**	312.9**
	Sire within Year-station	29	0.928**	17.56**	3400*	103.0**
	Regression on age(linear)	1	0.222	4.18	1554	36.5
	Regression on age(quadratic)	1	0.199	4.43	1520	59.7
	Error	293	0.280	5.01	2145	38.8

*; $p<0.05$, **; $p<0.01$

within year-station could be confounded with the station effect. Hence, in order to estimate better sire performance for all stations, it might be useful to use a reference sire to adjust the differences in dam and circumstance.

Linear and quadratic effects of age at the start of the test were not significant except for dressing percentage in JB.

Table 5 gives estimates of heritability for meat quality traits. Genetic and phenotypic correlations between meat quality traits and other traits are given in Table 6. The estimates of heritability for JB were over 1.00 for most traits. This might be caused by the fact that sire variances in JB for most traits were greater than those in JS[4,6,12]. The heritabilities in JS were moderate for I/M fat ratio and area score, and high for form score. The phenotypic correlation between marbling score at grading and I/M fat ratio calculated by Image Analysis was relatively high (0.63) in JB, but fairly low (0.14) in JS. KUCHIDA *et al.*[4] reported that JS was lower for marbling score and narrower for its range than JB.

Table 5. Heritability estimates and their standard errors for meat quality traits of Japanese Black and Japanese Shorthorn steers

	Heritability±S.E.	
Traits	Japanese Black	Japanese Shorthorn
Marbling score	1.30±0.31	0.88±0.20
I/M fat ratio	1.09±0.32	0.45±0.20
Area score	1.05±0.32	0.31±0.19
Form score	–	0.81±0.24

Such differences could cause the difference in phenotypic correlations seen here between the breeds. The heritability estimates for marbling score and I/M fat ratio were similarly high. The heritability for marbling score in JS was also high, but the estimate for I/M fat ratio was moderate.

The genetic correlations between daily gain and either marbling score or I/M fat ratio in JB were estimated to be positive and near 0. These estimates are in good agreement with the results of YANG *et al.*[12], and MUKAI

Table 6. Genetic and phenotypic correlations for meat quality traits of Japanese Black and Japanese Shorthorn steers

Breed			Marbling score	I/M fat ratio	Area score	Form score
Japanese Black	Daily gain	G[a]	0.02±0.28[b]	0.01±0.31	0.06±0.31	−0.05±0.27
		P	−0.01	0.01	0.00	0.07
	Final body weight	G	−0.21±0.27	−0.17±0.32	0.16±0.32	−0.10±0.28
		P	−0.10	−0.10	−0.00	0.09
	Dressing percentage	G	0.29±0.30	0.47±0.35	0.59±0.34	−0.21±0.34
		P	0.08	0.03	0.06	−0.07
	Fat thickness	G	−0.24±0.25	−0.33±0.28	0.28±0.28	−0.23±0.25
		P	−0.08	−0.14	0.06	−0.09
	Rib-eye area	G	0.67±0.22	0.64±0.28	0.00±0.35	0.34±0.28
		P	0.17	0.45	−0.13	0.25
	Carcass grade	G	1.15±0.30	0.64±0.19	−0.63±0.26	0.40±0.23
		P	0.80	0.46	−0.25	0.18
	Marbling score	G		0.64±0.19	−0.63±0.26	0.40±0.23
		P		0.63	−0.13	0.25
	I/M fat ratio	G			−0.20±0.30	0.52±0.22
		P			0.14	0.14
	Area score	G				−0.65±0.23
		P				−0.42
Japanese Shorthorn	Daily gain	G	0.52±0.23	−0.67±0.46	−0.38±0.53	0.03±0.40
		P	0.16	0.40	0.16	0.19
	Final body weight	G	0.21±0.24	−0.67±0.39	0.13±0.45	−0.42±0.33
		P	0.14	−0.06	0.04	−0.03
	Dressing percentage	G	0.09±0.26	−1.35±2.73	−0.70±1.78	−0.18±0.98
		P	0.06	−0.10	−0.05	−0.06
	Fat thickness	G	−0.11±0.23	−0.66±0.33	−0.06±0.38	−0.41±0.27
		P	0.14	−0.14	0.01	−0.14
	Rib-eye area	G	0.30±0.24	0.26±0.36	−0.36±0.44	0.23±0.30
		P	0.01	0.06	−0.15	0.23
	Carcass grade	G	1.10±0.02	0.49±0.32	0.49±0.38	−0.18±0.31
		P	0.82	0.15	0.14	−0.07
	Marbling score	G		0.23±0.35	0.47±0.35	−0.17±0.30
		P		0.14	0.23	−0.11
	I/M fat ratio	G			0.28±0.43	0.24±0.33
		P			0.42	0.56
	Area score	G				−0.79±0.42
		P				−0.13

a): G=genetic, P=phenotypic correlations
b): Genetic correlation and its standard error

et al.[6], WILSON *et al.*[10] reported the genetic correlation between daily gain and marbling score in Herefords to be negative. The genetic correlation between daily gain and marbling score by grading in JS was positive and 0.52, but that between daily gain and I/M fat ratio by Image Analysis was − 0.67.

From the results of low phenotypic correlation (0.14) and the difference in genetic correlations for JS, it was suggested that judgement of marbling score for a low marbling breed such as JS is very difficult.

The phenotypic correlations of area score with growth and meat quality traits were generally low or around 0 except for I/M fat ratio in JS. Phenotypic correlations of form score with growth and meat quality traits were low except for area score in JB and I/M fat ratio in JS. These results indicate that the large size of marbling particles in JS are associated with a high fat ratio in the rib-eye muscle. Generally, the marbling particles are rougher in JS than those in JB. This might influence the phenotypic correlations between meat quality traits and area or form score.

The genetic correlations between area score and meat quality traits were negative ($-0.63 \sim -0.20$) in JB and positive ($0.28 \sim 0.49$) in JS. Similar correlations of form score with carcass grade and marbling score were positive (0.40) in JB and negative ($-0.18 \sim -0.17$) in JS. These genetic correlations were contrary in sign in the two breeds. Selection for increased I/M fat ratio should lead to small marbling particles in JB, but to large ones in JS. Genetic correlations between area score and form score were highly negative in both breeds. In both breeds, selection for small marbling particles should therefore lead to a more circular form of marbling.

Thus, for evaluating the I/M fat ratio, the method of Image Analysis was useful especially in regard to the breed having the lower marbling level. It might be important for genetic improvement to develop a method for estimating the I/M fat ratio within the rib-eye muscle via Image Analysis.

Acknowledgments

The authors thank the Aomori, Akita, Iwate and Miyagi Prefectural Animal Husbandry Experimental Stations and the Ohu National Livestock Breeding Station for supplying the progeny test data. Dr. S. Matsuzawa provided technical advice on Image Analysis. We wish to thank Dr. S. Barwick, Dr. B. Sundstrom and Dr. T. Oikawa for their helpful advice.

This study was supported in part by the Ito Foundation in 1988.

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コンピュータ画像解析による和牛肉質の評価

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牛枝肉規格は，牛肉の価値を判断する上で重要な指標となるが，その判定は，スタンダードを基準にしているものの，肉眼的方法により行なわれている．また，脂肪交雑の粒子の大きさおよび形状なども，肉質の判定において重要な要因となっている．本研究では，それらの形質をコンピュータ画像解析により数値化する方法を検討した．また，1975年から1988年までの14年間に実施された，黒毛和種および日本短角種産肉能力間接検定時に撮影されたロース芯断面の写真に対して，開発した方法を適用し，得られた画像解析値に関する遺伝的パラメータを算出し，従来の格付による評価値と画像解析値との比較を行なった．遺伝的パラメータの推定には Harvey の LSMLMW (1986) を使用し，要因として年次-検定場，年次-検定場内種雄牛および検定開始時日齢への1次および2次の回帰をとりあげた．黒毛和種および日本短角種のロース芯断面内脂肪割合はそれぞれ7.88%，5.18%であり品種間の有意性が認められた．また，脂肪交雑粒子の大きさを示す面積値および形を表す形状値は両品種で有意差が認められなかった．画像解析で算出したロース芯断面内脂肪割合の遺伝率は黒毛和種が1.09，日本短角種が0.45であった．画像解析で算出した脂肪割合と格付による脂肪交雑評点との間の表型相関は，黒毛和種が0.63と比較的高かったものの，日本短角種では0.14と非常に低い値を示した．このことは，脂肪交雑程度が低い品種に対する肉眼による格付の難しさを示唆しているものと考えた．

日畜会報，*63 (2) : 121-128, 1992*