資料 6－4

USDA PHYSIOLOGICAL MATURITY VALIDATION STUDY: Validating the Relationship between Chronological Age and Physiological Maturity in the U.S. Fed-Beef Population

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PREFACE: Beginning in November 2004, the United States Government (USG) conducted a study to determine the relationship between the chronological age of cattle and the physiological maturity of their resulting carcasses. Following data analysis by both the Government of Japan (GOJ) and the USG, it was found that the physiological maturity threshold of A^{40} was the appropriate end point to ensure all beef products exported to Japan were from cattle 20 months of age (MOA) and younger. After completion of the original study and submission of the final report to the GOJ in January of 2005, the USG agreed to conduct a study to validate the appropriate end point threshold of A^{40}. The study began in January of 2006, but due to insufficient supply of cattle with known birthdates available in the winter of 2006, data collection did not begin until late April.

INTRODUCTION

After release of the joint press statement (October 23, 2004) between the two countries that addressed criteria for restoring trade in beef and beef products, the Agricultural Marketing (AMS) Service, Livestock and Seed (LS) Program conducted a study (November to December 2004) in which steers and heifers of known ages were identified and evaluated after they were harvested and chilled. The United States Standards for Grades of Carcass Beef (effective January 31, 1997) were used as the criteria for assessing physiological maturity. The purpose of the original study was to establish an overall physiological maturity score (e.g., A^{20}, A^{30}, A^{40},

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A^{50}, et cetera) that would effectively classify carcasses of steers and heifers from cattle that were 20 MOA and younger for the purpose of qualifying products for export to Japan via the mutually agreeable Export Verification Program. Following data analysis by both the GOJ and the USG, it was found that the physiological maturity threshold of A^{40} was the appropriate end point to ensure all beef products exported to Japan were from cattle 20 MOA and younger.

The current study, with the results reported herein, was conducted to validate the findings of the original study.

BACKGROUND

Each year, approximately 160 USDA/AMS graders evaluate the physiological maturity and other grade factors of approximately 27 million beef carcasses. Of the steers and heifers graded, it is estimated that approximately 90% are 20 MOA and younger, and only outliers of the U.S. feeding system are older than 24 MOA. The official standards for grades of steer and heifer beef were revised in 1965 to place added emphasis on physiological skeletal maturity (ossification) in grading carcasses. As cattle advance in chronological age, physiological maturity causes the amount of collagen cross-linkage in muscle to increase, resulting in tough meat; therefore, carcasses with advanced physiological skeletal maturity also have advanced physiological muscle maturity, and thus should be excluded from the premium grades of USDA Prime, Choice, Select, and Standard. Since physiological maturity was added to the grade standards, it has been used to classify maturity and to assist graders in the determination of the quality (i.e., expected palatability of the cooked lean product) of beef carcasses. At the time of grading, 36 - 48 hours after slaughter, USDA/AMS graders evaluate each carcass in order to determine the quality grade. USDA/AMS graders evaluate both physiological maturity and other factors to assist them in determining the final USDA Quality Grade. This system allows graders to identify and segregate beef carcasses according to quality differences within the U.S. beef population for purposes of establishing value, which ultimately is used in the marketing system to send economic signals upstream and downstream in the marketing chain; resulting in higher quality beef in a value-driven marketing system. Pictures depicting critical evaluation decision points are used by USDA/AMS graders to standardize and assure accuracy and precision of carcass evaluation and quality grade assignment (Image 1 and 2).

Since 1985, USDA/AMS has routinely conducted grading audit reviews to maintain accuracy of grade placement across the industry. In the Meat Grading and Certification (MGC) Branch, extensive training is conducted during the first two years of employment and stringent qualification requirements are established to insure accuracy of grade placement by graders-in-training, journeyman graders (graders with at least two years of experience), and expert graders (supervisors). In the current grading system, there is one supervisor for every nine graders, which demonstrates the level of hands-on commitment of the AMS/LS/MGC Branch to assure an accurate evaluation and application of the official USDA Quality and Yield Grades.

Reviews (internal and by an independent third party) are conducted to characterize the current carcass population and to evaluate performance of on-line graders. These reviews are conducted randomly at each major processing facility where graders are stationed. Since these intensive reviews began, the accuracy of all factors affecting accurate placement (assignment) of carcass grades on more than 30,000 carcasses has been specifically evaluated for both USDA Quality and Yield Grades. Data from these reviews provide assurance of the accuracy of the grading process that has been applied to approximately 500 million cattle slaughtered since 1985.

One of the primary factors in determining USDA Quality Grade is physiological maturity. The physiological maturity classification system segregates cattle into 5 different maturity groups; A (youngest), B, C, D, and E (oldest). Carcass maturity is determined by evaluating the size, shape, and ossification of the bones and cartilages along the split vertebral column of the carcass along with the color and texture of the lean at the 12th rib interface. Special attention is paid to the split chine bones, as the greatest difference in A maturity carcasses begin to occur along the split chine surface. In split chine bones, visually-evident changes in ossification (i.e., the degree to which cartilage has converted to bone) occur at an earlier stage of maturity in the posterior portion of the vertebral column (sacral vertebrae) and at progressively later stages of maturity in the lumbar, thoracic, and other anterior vertebrae. Changes in ossification occur in the cartilaginous tips of *spinous processes* (chine bones) located on the apex (dorsal extremity) of split thoracic vertebrae; these changes are especially useful in evaluating physiological maturity and are referred to frequently in the grade standards. The size and shape of the rib bones also are important considerations in evaluating differences in maturity.

In the very youngest A maturity carcasses (A^{00}) of beef, cartilage on the ends of the chine bones show no ossification, cartilage is evident on all of the vertebrae of the spinal column, and the sacral vertebrae show distinct separation. In addition, split vertebrae usually are soft and porous and very red in color. In such carcasses, rib bones are relatively round and have only a slight tendency toward flatness. However, the specifications for skeletal ossification in the oldest of A maturity carcasses consists of carcasses that have slightly red and slightly soft chine bones plus evidence of ossification in cartilage on the ends of the thoracic vertebrae. In addition, sacral vertebrae will be completely fused (i.e., no differentiation among individual vertebra), cartilage on the ends of lumbar vertebrae will be nearly completely ossified, and rib bones will become slightly wide and slightly flat.

For carcasses to be considered by an evaluator as A^{40}, they must have: (1) some evidence of cartilage in all vertebrae, (2) distinct separation of the sacral vertebrae and caps that show considerable evidence of cartilage, (3) caps on the lumbar vertebrae that tend to be partially ossified, (4) no ossification of the thoracic vertebrae, (5) split vertebrae surfaces that tend to be soft, porous, and red, (6) ribs that have some tendency toward flatness, and (7) lean texture that is very fine, and lean that is light red in color.

On the other hand, for carcasses to be evaluated as A^{50}, they must have: (1) some evidence of cartilage in all vertebrae, (2) separation of the sacral vertebrae caps show evidence of cartilage, (3) caps on the lumbar vertebrae that tend to be nearly moderately ossified, (4) no ossification of the thoracic vertebrae, (5) split vertebrae surfaces that tend to be moderately soft, porous, and moderately red, (6) ribs that have some tendency toward flatness and narrow, and (7) lean texture that is very fine and lean that is moderately light red in color (Images 1 and 2; Table 1).

MATERIALS AND METHODS

Identification of cattle with known birth dates: There were many challenges in the 2004 study, but principally, the largest challenge was identifying cattle with exact known birth dates or cattle that were born in a relatively small birth interval (known age within 62 days of birth). In this validation study, the scientists only targeted data collected from cattle with exact known birth dates or cattle born within a 30 day interval. Relatively few cattle that are 21 MOA and older have exact known birth dates or a birth interval of 30 days or less, as this is not typical of the U.S. beef production system. In this study, all cattle and resulting carcasses had exact known birth dates except one lot, and the birth interval for that lot was 54 days. All of the cattle with birth intervals were older than 21 MOA. This inclusion of cattle without exact birth dates resulted in a more conservative estimate of their age, as the young animals in this group were assigned a birth date of the oldest animal in the lot.

Data collection: During data collection, information was stored in a database and analysis began after the final carcass information was collected. Information collected included: skeletal, lean and overall physiological maturity scores; birth date and slaughter date (exact date to calculate days of age or birth interval); breed groups (British, Continental); gender; and background information (direct-fed, backgrounded in drylot, etc). Cattle age, in months, was calculated by subtracting the date of slaughter from the date of birth, and then dividing the days of age by 30. Physiological maturity data, complete chronological age and other production information was collected and processed for the statistical analysis (n=991). Additionally, data was collected on carcasses without chronological age information. These additional carcasses were used to "blind" the graders during data collection. Ten different MGC experts were used throughout the study due to grader availability and proximity to slaughter facilities.

RESULTS AND DISCUSSION

Of the 991 carcasses analyzed, eighty-seven percent (n=866) had exact birthdates and 125 were born in a window of 54 days (Table 2). In the calculation of age for the 125 cattle without exact birthdates, the age of the oldest animal was used as the age of the entire group. Also, there were 657 (66.3%) steers and 334 (33.7%) heifers included in the study (Table 3).

There were fewer breeds of cattle represented in this study compared to the original study, primarily due to the restrictions on the exact known birthdates (Table 4). For example, producers that raise cattle with high levels of *Bos indicus* influence (50% or greater) are often not present at the time of birth, therefore these cattle are usually age verified through a birth interval of 90 days or more, with the oldest animal in the group representing the entire age for the group.

In addition, no purebred continental cattle were included in the study, as purebred continental cattle are not as common in the feedlots; however the cross between continental and British cattle is predominant and well represented in this study (n=776). Purebred British cattle continue to serve as a primary source of high quality U.S. beef and they are represented (n=215) in this study. Finally, Holstein cattle are the youngest steers slaughtered in the U.S. and were not included in this study as they are often age verified under a birth date interval rather than exact age.

Although there are several production options to develop young cattle and beef in the United States, the most common methods for preparing cattle for the feedlot after weaning are: (1) Drylot (often called "growing yards" and "backgrounding" using a mild ration to train them to eat out of a feed trough) before entering the feedlot and (2) Grazing on grass and or wheat pasture before entering the feedlot. Drylot and Grazing were each represented in this study, with 76.0% and 16.0%, respectively (Table 5). In addition, to ensure there were adequate cattle 21 MOA and older, 8.0% of the sample population was from production systems that included both Grazing and Drylot before the feedlot (Table 5).

Eighty-three percent (n=823) of the cattle in the study were 20 months of age and younger, and 17% (n=168) were older than 20 months of age (Table 6). The physiological maturity score of each carcass was converted to numeric value (A^{40}=140, A^{70}=170, B^{20}=220, etc.) for statistical analysis. The mean physiological maturity of the 20 MOA and younger group was 158.5 (graded as A^{50}); whereas the mean physiological maturity of the 21 MOA and older group was 179.3(graded as A^{70}) (Table 7).

Table 8 demonstrates the distribution of the physiological maturity observations among cattle 20 MOA and younger and those 21 MOA and older. This table also shows that as the physiological maturity increases, the percentage of carcasses from cattle 20 MOA or younger decreases, and inversely, the percentage of carcasses from cattle 21 MOA and older increases. Of all samples (n=991), no carcasses from cattle 21 MOA and older had physiological maturity scores lower than A^{50} (Table 9).

CONCLUSION

Data from this study validate the findings of the original study. The physiological maturity threshold of A^{40} is an appropriate end point to ensure all beef products exported to Japan are from cattle 20 MOA and younger.

Additionally, an estimate of the probability of observing a carcass evaluated as A^{40} or less given that the carcass was 21 months of age is provided in Appendix A.

Image 1. Photographic demonstration of the lumbar vertebrae of a carcass with A^{40} Overall Maturity.

Image 2. Photographic demonstration of the lumbar vertebrae of a carcass with A^{50} Overall Maturity.

Table 1. The description of maturity characteristics within A maturity.

	A^{00}	A^{40}	A^{50}	A^{100}
All Vertebrae	Some evidence of cartilage in all vertebrae	Some evidence of cartilage in all vertebrae	Some evidence of cartilage in all vertebrae	
Sacral Vertebrae	Show distinct separation	Show distinct separation, caps show considerable evidence of cartilage	Show separation, caps show evidence of cartilage	Completely fused
Lumbar Vertebrae	No ossification	Caps tend to be partially ossified	Caps tend to be nearly moderately ossified	Nearly completely ossified
Thoracic Vertebrae	No ossification	No ossification	No ossification	Some evidence of ossification
Split Vertebrae Surfaces	Soft, porous and very red	Tend to be soft, porous and red	Tend to be moderately soft, porous and moderately red	Slightly red and slightly soft
Ribs	Only slight tendency toward flatness	Tendency toward flatness	Some tendency toward flatness and narrow	Slightly wide and slightly flat
Lean Texture and Color	Very fine, light grayish red	Very fine, light red	Very fine, moderately light red	Fine, moderately light red

Table 2. Stratification of sample population (n=991) by birth interval.

Birth Interval (days)	Frequency	%
Exact	866	87.4
1-54	125	12.6

Table 3. Stratification of sample population (n=991) by gender.

Gender	Frequency	%
Steer	657	66.3
Heifer	334	33.7

Table 4. Stratification of sample population (n=991) by breed.

Breed	Frequency	%
British	215	21.7
British X Continental	776	78.3

Table 5. Stratification of sample population (n=991) by production system.

Production System	Frequency	%
Grass, Drylot, Feedlot	79	8.0
Drylot, Feedlot	753	76.0
Grass/Wheat Pasture, Feedlot	159	16.0

Table 6. Stratification of the sample population (n=991) by months of age (MOA).

Age	Frequency	%
≤ 20 Months of Age	823	83.0
> 20 Months of Age	168	17.0

Table 7. Stratification of the physiological maturity scores of the sample population (n=991) among cattle that are ≤ 20 Months of Age (MOA) and ≥ 21 MOA.

		Physiological Maturity Score		
	n	Mean	Max	Min
≤ 20 MOA	823	158.5	300	130
≥ 21 MOA	168	179.3	360	150

Table 8. Distribution of cattle 21 MOA and older and cattle 20 MOA and younger in age by overall maturity classification (n=991).

Maturity Score	20 MOA and younger (n)	Frequency %	21 MOA and older (n)	Frequency %
A^{20}	0	0.0	0	0.0
A^{30}	3	100.0	0	0.0
A^{40}	88	100.0	0	0.0
A^{50}	226	97.4	6	2.5
A^{60}	294	89.1	36	10.9
A^{70}	173	73.0	64	27.0
A^{80}	27	47.4	30	52.6
A^{90}	5	35.7	9	64.3
B^{00} or older	7	23.3	23	76.7

Table 9. Contingency table characterizing the distribution of age among overall maturity scores in the validation study (n=991).

Age in Months

Overall Maturity Score	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
A^{20}																					0
A^{30}								3													3
A^{40}		3	18	38	11	5	2	11													88
A^{50}		6	49	98	51	16	6						6								232
A^{60}		4	50	161	49	23	7						36								330
A^{70}		2	17	93	36	18	7						64								237
A^{80}		1	1	13	3	3	5			1	2	10	16	2							57
A^{90}				1		2	2					1	3	4				1			14
B^{00}						2	1				1	4	2	3							13
B^{10}												1		1							2
B^{20}						1					1		1								3
B^{30}						1	1				1	1		1							5
B^{40}																					0
B^{50}													1								1
B^{60}																					0
$\geq C^{00}$						1							5								6
Total	0	16	135	404	150	72	31	14	0	1	5	17	134	11	0	0	0	1	0	0	991

Appendix A

ESTIMATING THE PROBABILITY OF OBSERVING A CARCASS EVALUATED AS A^{40} OR LESS GIVEN THAT THE CARCASS WAS 21 MONTHS OF AGE

The possibility of detecting a carcass that is 21 months of age or older in age and evaluated as A^{40} is not zero in any sampling environment. The purpose of the following is to compute hypothetical probabilities for such events.

Vertical Analysis

Considering that older chronological age essentially presents a higher maturity score, and that sample selections were made based on age but not on maturity grade, statistical analysis is performed by taking age as the regressor ("vertical analysis"). Therefore, the result of the estimation will be the probability of observing at least one carcass from a bovine carcass evaluated as A^{40} (or less) physiological maturity in the cattle of 21 months of age (It is appropriate that cattle at 22 months of age and older should be excluded, since the sampling target was focused on those at 21 months of age threshold and younger).

Sub-samples

The probability of observing at least one carcass from a bovine animal evaluated as A^{40} that is also 21 months of age was estimated using two different sub-samples of the total experimental population. The total experimental population consists of both samples collected in the original study and ones collected in the current validation study (n=4,329). The first sub-sample included n = 242 (sub-sample 1) carcasses that were evaluated as A^{50} physiological maturity or higher exactly 21 months of chronological age. The second sub-sample included n = 1,454 (sub-sample 2) carcasses having a chronological age of 19 to 21 months and also evaluated as A^{50} physiological maturity or higher (i.e., it included the first sub-sample of n = 242 carcasses). These sub-sample populations were selected to exclude carcasses of cattle that actually were 22 months of chronological age or older and the latter sub-sample reflected an observation that there were not any carcasses evaluated as A^{40} or lower in the total experimental population that were older than 18 months of chronological age.

Analysis

The intent is to illustrate the probability of detecting a carcass classified as equal to or less than A^{40} physiological maturity and over 20 months of chronological age using a sub-sample of the total experimental population that reflected (a) those that were exactly 21 months of age, and (b) those that were exactly 21 months of age plus those that were between 19 and 20 months of age (inclusively).

A level of Type I statistical error of $\alpha = 0.01$ in these "vertical" non-parametric analyses for standard significance testing of hypotheses was selected. Probabilities were computed as follows:

$$P \leq 1 - \alpha^{1/n} \qquad [(1 - P)^n \geq \alpha \leftrightarrow P \leq 1 - \alpha^{1/n}].$$

At α = 0.01, the probability for sub-sample 1 (n = 242) that an animal would be A^{40} or less in physiological maturity was *P* = 0.01885, while the increased number of observations and the greater statistical power provided by sub-sample 2 (n = 1,454) yielded a probability that an animal would be A^{40} or less in physiological maturity of *P* = 0.003162. In the original study, the probabilities calculated from sub-samples of same criteria were P= 0.01924 for sub-sample 1 and P= 0.003175 for sub-sample 2, respectively.

Conclusion

These results suggest that the probabilities of detecting carcasses 21 months or older and evaluated as A^{40} or less are hypothetically low.

Tables

Appendix Table 1. Contingency table characterizing the distribution of age among overall maturity scores in the total experimental study (the original study and the validation study).

Appendix Table 2. Contingency table characterizing the distribution of age among overall maturity scores in the original study.

Appendix Table 1. Contingency table characterizing the distribution of age among overall maturity scores in the total experimental study (the original study and the validation study n=4,329).

Age in Months

Overall Maturity Score

	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
A^{20}			1	1	1																3
A^{30}			3	1	47	6		3													60
A^{40}		5	37	50	103	74	4	11													284
A^{50}	1	13	80	126	93	151	106	10	18	10	19		6								633
A^{60}		5	108	335	204	102	171	105	297	39	69		36								1471
A^{70}		3	47	149	141	24	90	125	441	47	89		64								1220
A^{80}		1	1	15	11	3	16	56	218	55	39	11	17	2				2	1	1	449
A^{90}			1	4	12	2	5	1	36	14	17	1	3	4			1	2			103
B^{00}				3	1	3	1	2	13	4	5	4	2	3		2		1	1		45
B^{10}				4	3			1	9			1		1							19
B^{20}				4		1			7		3		1								16
B^{30}				2	1	1	1		1		1	1		1				1			10
B^{40}				1																	1
B^{50}				1	1								1								3
B^{60}									1												1
$\geq C^{00}$				2	1	1			2				5								11
Total	1	27	278	698	619	368	394	314	1043	169	242	18	135	11	0	2	1	6	2	1	4329

Appendix Table 2. Contingency table characterizing the distribution of age among overall maturity scores in the original study (n=3,338).

Age in Months

Overall Maturity Score

Overall Maturity Score

	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
A^{20}			1	1	1																3
A^{30}			3	1	47	6															57
A^{40}		2	19	12	92	69	2														196
A^{50}	1	7	31	28	42	135	100	10	18	10	19										401
A^{60}		1	58	174	155	79	164	105	297	39	69										1141
A^{70}		1	30	56	105	6	83	125	441	47	89										983
A^{80}				2	8		11	56	218	54	37	1	1					2	1	1	392
A^{90}			1	3	12		3	1	36	14	17						1	1			89
B^{00}				3	1	1		2	13	4	4					2		1	1		32
B^{10}				4	3			1	9												17
B^{20}				4					7		2										13
B^{30}				2	1				1									1			5
B^{40}				1																	1
B^{50}				1	1																2
B^{60}									1												1
C^{00}				2	1				2												5
Total	1	11	143	294	469	296	363	300	1043	168	237	1	1	0	0	2	1	5	2	1	3338