

Phenotypic and genetic parameters compared during repeated measures of longissimus muscle area and subcutaneous fat thickness in Nelore cattle

T.R. Pinheiro¹, M.E.Z. Mercadante¹, L.G. Albuquerque²,
J.N.S.G. Cyrillo¹ and R.H. Branco¹

¹Instituto de Zootecnia, Centro APTA de Bovinos de Corte,
Sertãozinho, SP, Brasil

²Faculdade de Ciências Agrárias e Veterinárias,
Universidade Estadual Paulista “Julio de Mesquita Filho”,
Jaboticabal, SP, Brasil

Corresponding author: M.E.Z. Mercadante
E-mail: mercadante@iz.sp.gov.br

Genet. Mol. Res. 10 (4): 2944-2952 (2011)

Received January 31, 2011

Accepted June 14, 2011

Published November 29, 2011

DOI <http://dx.doi.org/10.4238/2011.November.29.5>

ABSTRACT. Real-time ultrasound is currently used for *in vivo* carcass evaluation of beef cattle. We estimated heritability and repeatability coefficients for ultrasound-measured carcass traits in Nelore cattle. We measured longissimus muscle area, backfat thickness, and rump fat thickness in male and female animals ranging in age from 10 to 26 months. The variance components were estimated by single-trait analysis using the derivative-free restricted maximum likelihood method, under an animal model. The complete data file included 3077 records of 1172 animals born between 2003 and 2008. Two analyses were performed using a repeatability model: a) all records of longissimus muscle area, backfat thickness, and rump fat thickness of animals aged 10 to 26 months, and b) considering two age periods (11 to 17 and 18

to 24 months). The heritability estimates ranged from 0.33 to 0.46 for longissimus muscle area, from 0.20 to 0.26 for backfat, and from 0.26 to 0.29 for rump fat, demonstrating that direct selection for these traits can provide genetic gain. The repeatability estimates were moderate, ranging from 0.42 to 0.73. The highest repeatability estimates were obtained for longissimus muscle area in both the first (0.70) and second (0.73) analyses. The repeatability estimates suggest that ultrasound measures are precise; higher precision was obtained for longissimus muscle area than for subcutaneous fat thickness. The latter could be obtained during periods of greater feed availability to increase precision.

Key words: Carcass traits; Heritability; Repeatability; Ultrasound

INTRODUCTION

One of the most important tools for animal breeding is genetic evaluation, in which the identification and selection of genetically superior individuals will increase the economic efficiency of the herds. To achieve this economic efficiency these genetically superior animals need to be used as reproducers to increase the frequency of and to accumulate desirable genes.

One of the key points of breeding programs is the definition of the objectives and criteria of selection, which requires knowledge about the genetic variability of the traits in question. If the objective is to produce animals with higher edible meat yield and better subcutaneous fat deposition, adding value to the animals and increasing profitability to producers, the selection criterion should include some carcass traits (Wilson, 1992; Reverter et al., 2000).

Ultrasound is currently used to collect *in vivo* data of carcass traits in cattle, which are subsequently applied to the prediction of breeding values. Before the introduction of this technique in cattle farming, the identification of genetically superior bulls in terms of carcass merit was only possible by progeny testing, an expensive and time-consuming method (Wilson, 1992). Since ultrasound is now a well-established technique and genetic evaluation methods are available, it is possible to select superior animals and to obtain genetic gains in carcass traits since the heritability of these traits ranges from moderate to high (Reverter et al., 2000; Hassen et al., 2004; Meyer et al., 2004; Yokoo et al., 2009).

Many livestock traits are measured in the same animal over time in order to increase the precision of these measures in the case of experimental results, or to increase the accuracy of prediction of breeding values in animal breeding programs. According to Cruz et al. (2004), the repeatability coefficient is a parameter that can be defined in statistical terms as the correlation between records of the same individual obtained over time or space. This coefficient corresponds to the proportion of total phenotypic variance of a trait that is explained by permanent differences between individuals. These differences are due to variations in genotypes and to permanent environmental changes. According to Falconer and Mackay (1996), not only permanent differences between individuals, but also differences caused by the temporary environment contribute to total phenotypic variance. This variance can only be analyzed in terms of within- and between-individual variance when repeated measures of the same trait are obtained from each individual.

According to Hassen et al. (2004), carcass traits measured by ultrasound can be ob-

tained from the same animal over time, like other traits in beef cattle, a fact that permits to estimate the covariance between traits and to determine whether the measures present sufficient repeatability. Repeatability is used to evaluate technician skills in training courses and the certification for imaging of ultrasound carcass traits (BIF, 2002; Wilson, 2006).

The objective of the present study was to estimate heritability and repeatability coefficients for ultrasound-measured carcass traits in Nelore cattle to evaluate the precision of these measures and their possible use in selection programs.

MATERIAL AND METHODS

The data were obtained from Nelore animals born between 2003 and 2008 that belong to three lines selected for growth from the Zebu Breeding Program of Centro APTA de Bovinos de Corte, Instituto de Zootecnia, Sertãozinho, São Paulo, Brazil. The animals were kept on pasture until 7 months of age, when they were weaned. After this period, males were submitted to a performance test on feedlot. Females remained on pasture, except for those born in 2004, 2005 and 2008 that were also submitted to performance test on feedlot after weaning. After one year of age, males and females were kept on pasture, except for a small sample of males (about 30 animals per year born between 2006 and 2008) that received a high-energy feedlot finishing diet until reaching 8 mm of backfat thickness for slaughter. These differences in feed management (pasture and feedlot) were taken into account in the formation of the contemporary groups.

The following traits were measured by ultrasound in males and females between 2005 and 2010: longissimus muscle area (LMA), backfat thickness (BF), and rump fat thickness (RF). Evaluations were performed at a mean interval of 3 months. Ultrasound images of LMA and BF were obtained between the 12th and 13th rib by placing the transducer on the left side of the animal perpendicular to the spine using a standoff pad. RF images were obtained by placing the transducer at the insertion of the gluteus medius and biceps femoris muscles located between the hip and pin bones. The images were acquired and stored with a Pie Medical 401347-Aquila ultrasound device (Esaote Europe B.V.) equipped with a 3.5-MHz linear probe (18 cm) and the measurements were obtained using the Echo Image Viewer 1.0 program (Pie Medical Equipment B.V., 1996). LMA is reported in cm² and BF and RF in mm.

The variance components were estimated by single-trait analysis using the derivative-free maximum likelihood (REML) method under an animal model. The analyses were performed with the ASREML program (Gilmour et al., 1999). The complete data file consisted of 3077 records of 1172 animals born between 2003 and 2008, from 78 sires and 551 cows. The relationship matrix contained 7873 animals. The data were examined for consistency and, since the number of records for carcass traits was relatively small, some outliers were identified and corrected, if possible.

After the consistency of data, two distinct analyses were performed. Analysis 1 included 3014 records of 1150 animals, 389 males and 761 females corresponding to 34 and 66%, respectively, ranging in age from 10 to 26 months (mean: 17.45 ± 4.24 months). Over this age range, 29% of the animals were measured only once, 20% had two measurements, 17% had three, 29% had four, and only 5% had five. Two distinct periods were considered in analysis 2. Period 1 consisted of 1406 records of 685 animals with a mean age of 14.14 ± 1.72 months. Data were collected from October to February from 341 males and 374 females born in 2006, 2007 and 2008, with 87% of the animals possessing two measurements. Period

2 consisted of 1132 records of 835 animals with a mean age of 20.24 ± 1.42 months. Records were obtained from May to September from 217 males and 618 females born between 2004 and 2008. Only 34% of the animals with repeated measures had two records and the remaining ones had only one record.

The models included direct additive genetic effects and permanent environmental effect of the animal as random effects. The models used in analysis 1 included contemporary group formed by the selection line (1, 2, 3), year of birth, sex, management (1, 2), month and year of recording, and age class of dam at calving (3, ..., ≥ 10 years) as fixed effects, and age of animal as linear and quadratic covariate. In analysis 2, the models included the fixed effects of contemporary group consisting of selection line (1, 2, 3), year of birth, sex, management (1, 2), month of recording, and age class of dam at calving (3, ..., ≥ 10 years), and age of animal as linear and quadratic covariate. In analysis 1, the animals were divided into 93 contemporary groups, and in analysis 2 into 43 and 37 groups for periods 1 and 2, respectively. Contemporary groups with fewer than four animals were excluded from the analysis.

RESULTS AND DISCUSSION

Table 1 shows the means for the carcass traits studied in the two analyses. Mean LMA was 47.49 cm² in the first analysis at 17 months of age, and 45.29 and 48.98 cm² in the second analysis at 14 (period 1) and 20 (period 2) months of age. Similar values have been reported by Yokoo et al. (2008) for Nelore animals also at 17 months of age. In a study analyzing 4653 records of Angus animals ranging in age from 6 to 15 months, mean LMA was 77.6 cm² for males and 63.9 cm² for females (Hassen et al., 2004). Lima Neto et al. (2009) found a mean LMA of 58.10 cm² for Guzerat animals at a mean age of 17.6 months, which was higher than in the present study, probably because the sample contained 90% males. Meirelles et al. (2010) observed a mean LMA of 46.6 cm² for Canchim animals with a mean age of 18 months in a sample of males and females.

Table 1. Number of records, mean, standard deviation, minimum and maximum values for carcass traits measured by ultrasound according to the analysis performed.

	Trait	No. of records	Mean	SD	Minimum	Maximum
Analysis 1						
Repeated measures	LMA (cm ²)	3006	47.49	10.19	16.5	85.3
	BF (mm)	3002	1.34	1.13	0	10.1
	RF (mm)	2997	3.79	2.27	0	15.4
Analysis 2						
Period 1	LMA (cm ²)	1405	45.29	10.96	16.5	77.9
	BF (mm)	1401	1.03	0.91	0	7.5
	RF (mm)	1404	3.22	1.87	0	13.9
Period 2	LMA (cm ²)	1126	48.98	9.45	21.2	85.3
	BF (mm)	1126	1.74	1.28	0	10.1
	RF (mm)	1120	4.85	2.50	0	15.4

SD = standard deviation; LMA = longissimus muscle area; BF = backfat thickness; RF = rump fat thickness.

Means of BF and RF were low, a finding that may be explained by the breed studied, age of the animals and, especially, the production system used. According to Yokoo et al. (2008), young Nelore animals raised on pasture present a thin backfat thickness. Reverter et al. (2000) found higher means for BF (3.01 and 3.10 mm) and RF (4.2 and 4.9 mm) in Angus

and Hereford males, respectively, with a mean age of 480 days. A similar mean of BF observed in the present study was reported by Meirelles et al. (2010) for Canchim animals with a mean age of 18 months (1.90 ± 0.77 mm).

Means of BF and RF were low during period 1 since these records were obtained immediately after the dry season (Table 1). This season is characterized by a low nutritional value of forages, including a low crude protein and high fiber content, reducing energy availability to the animal. Although males were kept in the feedlot, the weight gain diet contained 11% crude protein and 64% total digestible nutrients in dry matter and the nutrient availability corresponds to that found in medium-quality pastures. Period 2 comprised records obtained after the rainy season, a period characterized by abundant forage resources, which explains the higher BF and RF means obtained during this period when compared to period 1 (Table 1). Silva et al. (2009) studied carcass traits in about 6500 Nelore animals ranging in age from 546 to 911 days and observed an LMA mean of 56.3 cm² and BF and RF means of 2.64 and 4.61 mm, respectively.

The effect of age on the LMA is illustrated in Figure 1. As expected, males presented higher LMA measures than females at all ages and lower growth deceleration after 18-20 months of age. No stabilization of growth in LMA was observed in either sex until the age studied. The fact that animals selected for weight have a high growth potential may be one of the reasons that no stabilization of muscle development is observed until the age studied.

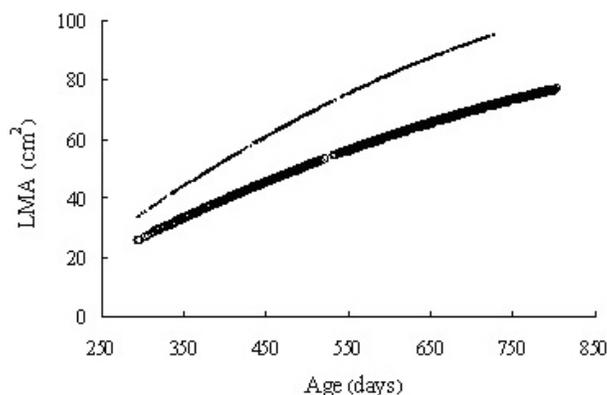


Figure 1. Predicted values of longissimus muscle area (LMA) of males (thin line) and females (thick line), by age. $R^2 = 0.70$.

The effect of age on BF and RF is illustrated in Figure 2. At younger ages, BF and RF were higher in females than in males, even though part of the females had suffered from the effects of the postweaning dry season. Close to 430 days of age, fat thickness was higher in males than in females and, at that time, fat deposition was higher in males. This period coincided with the rainy season (December, January and February). In addition, males did not suffer from the effect of the dry season since they were evaluated for weight gain in the feedlot, whereas most females were on pasture since weaning (7 months of age). A small part of the males were receiving a finishing diet and this may also explain the differences in subcutaneous fat at this age. In contrast, Reverter et al. (2000) reported a higher BF (4.7 and 3.0 mm) and RF (6.6 and 4.6 mm) for Angus and Hereford females when compared to males at a mean

age of 480 days. Yokoo et al. (2010) also observed higher mean BF and RF in Nelore females (2.8 and 5.2 mm) when compared to males (1.5 and 2.4 mm) at a mean age of 17 months. However, as can be seen in Figure 2, the fat deposition rate reached its maximum in males and started to decline, whereas the rate of rump fat deposition increased in females mainly after 550 days of age, probably due to the onset of puberty.

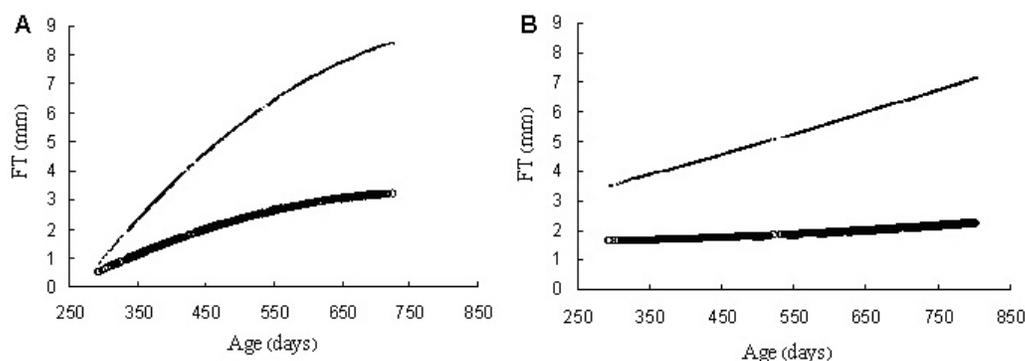


Figure 2. Predicted values of the subcutaneous fat thickness (FT) from back (thick line, $R^2 = 0.50$) and rump (thin line, $R^2 = 0.63$) of males (A), and females (B), by age.

According to Berg and Butterfield (1976), fat is first deposited in the hind and front quarters and then advances in the direction of the spine, a fact explaining the higher backfat depth when compared to rump fat.

The heritabilities (Table 2) obtained in analysis 1 for LMA (0.34 ± 0.06) and BF (0.20 ± 0.05) were similar to those estimated by Lima Neto et al. (2009) based on 1325 records of Guzerat males and females ranging in age from 10 to 32 months using a repeatability model (0.34 ± 0.09 and 0.32 ± 0.02 , respectively). However, the heritability for RF estimated in the present study (0.26 ± 0.05) was higher than that reported by Lima Neto et al. (2009) (0.10 ± 0.08). Heritability estimates differing from those observed in the present study have been reported by Silva et al. (2009) for LMA (0.27) and RF (0.42), but the heritability for BF was similar (0.21).

Table 2. Heritability and repeatability estimated for carcass traits by different analyses.

	Trait	$h^2 \pm SE$	$t \pm SE$
Analysis 1 Repeated measures	LMA (cm ²)	0.34 ± 0.06	0.70 ± 0.02
	BF (mm)	0.20 ± 0.05	0.52 ± 0.02
	RF (mm)	0.26 ± 0.05	0.48 ± 0.02
Analysis 2 Period 1	LMA (cm ²)	0.46 ± 0.10	0.73 ± 0.02
	BF (mm)	0.26 ± 0.08	0.43 ± 0.03
	RF (mm)	0.29 ± 0.08	0.42 ± 0.03
Period 2	LMA (cm ²)	0.33 ± 0.08	0.68 ± 0.03
	BF (mm)	0.24 ± 0.08	0.71 ± 0.03
	RF (mm)	0.29 ± 0.08	0.63 ± 0.03

h^2 = heritability; t = repeatability; SE = standard error of the mean; LMA = longissimus muscle area; BF = backfat thickness; RF = rump fat thickness.

In analysis 2 using repeated measures obtained for the two periods, the heritabilities were similar (Table 2), except for LMA, which was higher in period 1 (0.46 ± 0.10) than in period 2 (0.33 ± 0.08). These results might be explained by the higher percentage of females in period 2 compared to period 1. Reverter et al. (2000), studying Angus animals, and Meirelles et al. (2009), studying Canchim animals, observed that the heritability of this trait was higher in males than in females of the same age. In contrast, analyzing data of Hereford cattle, Reverter et al. (2000) and Meyer et al. (2004) found higher heritability estimates for LMA in females than in males.

In studies conducted in Brazil, heritabilities of 0.35, 0.52 and 0.40 were reported for ultrasound-measured carcass traits (LMA, BF and RF) of Nelore animals close to 17 months of age (Yokoo et al., 2008). Lower heritabilities were estimated by Urbinati et al. (2010) for LMA, BF and RF (0.26, 0.16 and 0.22, respectively) also in Nelore animals at a mean age of 15 months. Bonin et al. (2010), studying LMA and BF in 2190 Nelore animals at 18 months of age, estimated a heritability of low magnitude for BF (0.06) and of medium magnitude for LMA (0.37). In general, the heritability estimates obtained in the present study were higher than those reported by other investigators for Nelore animals, demonstrating that animals selected for weight present genetic variability in ultrasound-measured carcass traits.

One important parameter to determine the precision of the ultrasound technique is repeatability, which is defined as the correlation between repeated measures obtained from the same animal. In addition, this parameter expresses the maximum value of heritability since it corresponds to the proportion of phenotypic variance that is attributable to genetic differences and confused with permanent effects of the environment that act on the genotype (Falconer and Mackay, 1996).

The estimates of repeatability for the studied traits are shown in Table 2. Although the measures were obtained at a mean interval of 3 months, the repeatability estimate in analysis 1 was high for LMA (0.70 ± 0.02) and moderate for BF (0.52 ± 0.02) and RF (0.48 ± 0.02). Mercadante et al. (2010), analyzing the same data set (age range from 343 to 773 days) as used in the present study and employing a random regression model, reported slightly higher repeatability estimates (0.74 for LMA and 0.64 for subcutaneous fat thickness) than those obtained with the repeatability models.

In analysis 2, the repeatability estimates of the fat measures were lower when obtained after the dry season (period 1) than after the rainy season (period 2), suggesting a lower precision of the technique in the case of lower BF and RF means (Table 2). According to Mercadante et al. (2010), differences in acoustic impedance between tissues (fascia and adipose tissue) provoke an increase in fascia thickness (image artifact). This fact is mainly observed for fasciae and adipose tissue that measure less than 1 mm in thickness when a frequency of 3.5 MHz is used, impairing the definition of points to be used for the measurement of fat thickness.

The repeatability estimates for LMA obtained for the two periods were high (0.73 and 0.68) and are among the highest values reported in the literature for *Bos indicus* (Table 2). Araújo (2003), studying Nelore animals at 15 to 24 months of age, estimated a repeatability of 0.44 for LMA, whereas Lima Neto et al. (2009) reported an estimate of 0.39 for Guzarat animals ranging in age from 10 to 32 months. However, these estimates are lower than those reported by Hassen et al. (2004) for Angus animals (0.80 to 0.88). These differences can be explained by the fact that the mean interval between carcass measurements was 3 months in the present investigation and in the studies of Araújo (2003) and Lima Neto et al. (2009), whereas Hassen et al. (2004) obtained measurement at intervals of 4 to 6 weeks.

The repeatability estimates for BF and RF were of a lower magnitude than those ob-

tained for LMA, in agreement with the results reported by Lima Neto et al. (2009) who found estimates of 0.75 for BF and of 0.49 for RF. However, a much lower repeatability estimate for BF of 0.04 has been reported by Araújo (2003). Lower repeatability estimates for subcutaneous fat thickness might be associated with variations in feed management of the animals during the period studied, taking into consideration that a large part of these animals were managed on pasture, possibly in the absence of satisfactory environmental conditions for the expression of the trait.

The repeatability estimates obtained by analysis 1 indicate that a single measurement is sufficient for the evaluation of LMA and that this trait can be measured at 12 months of age. In contrast, the best period for the evaluation of BF and RF would be January and February, a period characterized by greater feed availability. On the basis of the repeatability and heritability estimates, it can be suggested that the measurements should be obtained during period 1 when the animals are younger, since the heritabilities are the same or higher for the three carcass traits studied compared to period 2, despite the lower repeatability estimates for subcutaneous fat measures.

CONCLUSIONS

The carcass traits measured by ultrasound present sufficient genetic variability to be explored for the direct selection of Nelore animals. These traits can be measured at 12 months of age. The repeatability estimates obtained for LMA indicate that this trait is more precise than subcutaneous fat measures. The latter should be obtained during periods of greater feed availability to increase their precision.

ACKNOWLEDGMENTS

Research supported by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). We thank the staff of the Centro APTA de Bovinos de Corte for operational support during the execution of this experiment.

REFERENCES

- Araújo FRC (2003). The Use of Real-Time Ultrasound to Estimate Variance Components for Growth and Carcass Traits in Nelore Cattle. Master's thesis, Department of Animal Science, University of California, Davis.
- Berg RT and Butterfield RM (1976). New Concepts of Cattle Growth. John Wiley & Sons, New York.
- BIF (2002). Guidelines for Uniform Beef Improvement Programs. 8th edn. Beef Improvement Federation, Athens.
- Bonin MN, Ferraz JBS, Silva SL, Gomes RC et al., (2010). Genetic Parameters for Body Measurements and Ultrasound Carcass Traits in Nelore Cattle. Proceedings of 9th World Congress on Genetics Applied to Livestock Production, Leipzig, CD-ROM.
- Cruz CD, Regazzi AJ and Carneiro PCS (2004). Modelos Biométricos Aplicados ao Melhoramento Genético. 3ª ed. Universidade Federal de Viçosa, Viçosa.
- Falconer DS and Mackey TFC (1996). Introduction to Quantitative Genetics. 4th edn. Longmans Green, Harlow.
- Gilmour A, Cullis BR, Welham SJ and Thompson R (1999). ASReml-R Reference Manual. New South Wales Agriculture, Department of Primary Industries, Orange.
- Hassen A, Wilson DE, Rouse GH and Tait RG Jr (2004). Partitioning variances of growth in ultrasound longissimus muscle area measures in Angus bulls and heifers. *J. Anim. Sci.* 82: 1272-1279.
- Lima Neto HR, Bergman JAG, Gonçalves TM, Araújo FRC, et al. (2009). Parâmetros genéticos para características de carcaça avaliadas por ultrassonografia em bovinos da raça Guzerá. *Arq. Bras. Med. Vet. Zootec.* 61: 251-258.
- Meirelles SL, Alencar MM, Oliveira HN and Regitano LCA (2009). Estimativas de Parâmetros Genéticos em Função do

- Sexo para Características de Carcaça de Animais da Raça Canchim. In: Anais da 46^o Reunião Anual da Sociedade Brasileira de Zootecnia, Maringá.
- Meirelles SL, Alencar MM, Oliveira HN and Regitano LCA (2010). Efeitos de ambiente e estimativas de parâmetros genéticos para características de carcaça em bovinos da raça canchim criados em pastagem. *Rev. Bras. Zootec.* 39: 1437-1442.
- Mercadante ME, Faro L, Pinheiro TR, Cyrillo JNSG, et al. (2010). Estimation of Heritability and Repeatability for Ultrasound Carcass Traits in Nelore Cattle Using Random Regression Models. Proceedings of 9th World Congress on Genetics Applied to Livestock Production, Leipzig, CD-ROM.
- Meyer K, Johnston DJ and Graser H-U (2004). Estimates of the complete genetic covariance matrix for traits in multi-trait genetic evaluation of Australian Hereford cattle. *Aust. J. Agric. Res.* 55: 195-210.
- Reverter A, Johnston DJ, Graser H-U, Wolcott ML, et al. (2000). Genetic analyses of live-animal ultrasound and abattoir carcass traits in Australian Angus and Hereford cattle. *J. Anim. Sci.* 78: 1786-1795.
- Silva SL, Ferraz JBS, Mourão GB, Tarouco JU, et al. (2009). Tendências Genéticas para Características de Carcaça Avaliadas por Ultrassom em um Rebanho Nelore. In: Anais da 46^o Reunião Anual da Sociedade Brasileira de Zootecnia, Maringá, CD-ROM.
- Urbinati I, Venturini GC, Chud TCS, Bezerra LAF, et al. (2010). Parâmetros Genéticos e Fenotípicos de Peso Corporal aos 450 Dias de Idade e Características de Carcaça de Animais da Raça Nelore. In: Anais da 47^o Reunião Anual da Sociedade Brasileira de Zootecnia, Salvador, CD-ROM.
- Wilson DE (1992). Application of ultrasound for genetic improvement. *J. Anim. Sci.* 70: 973-983.
- Wilson DE (2006). Ultrasound Certification Statistics. In: Anais 2^o Workshop de Ultra-Sonografia para Avaliação de Carcaça Bovina, Uberaba, CD-ROM.
- Yokoo MJI, Albuquerque LG, Lôbo RB, Bezerra LAF, et al. (2008). Genetic and environmental factors affecting ultrasound measures of longissimus muscle area and backfat thickness in Nelore cattle. *Livest. Sci.* 117: 147-154.
- Yokoo MJI, Rosa GJM, Magnobosco CU, Sainz RD, et al. (2009). Efeitos Genéticos que Afetam as Características de Carcaça Medidas por Ultrassom, em Duas Diferentes Idades, e suas Correlações com outras Características de Importância Econômica em Rebanhos da Raça Nelore. In: Anais da 46^o Reunião Anual da Sociedade Brasileira de Zootecnia, Maringá, CD-ROM.
- Yokoo MJ, Lôbo RB, Araújo FRC, Bezerra LAF, et al. (2010). Genetic associations between carcass traits measured by real-time ultrasound and scrotal circumference and growth traits in Nelore cattle. *J. Anim. Sci.* 88: 52-58.