Note

Genetic relationships and expected responses for genetic improvement of carcass traits of Berkshire pigs

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ABSTRACT: The Berkshire pig (*Sus domestica* L.) breed has thin muscle fibers and excellent water-holding capacity. The Berkshire meat makes it widely accepted in the Japanese premium pork market. This study evaluates the accuracy of improving carcass quality with the use of live animal records of Berkshire pigs. Traits analyzed in live animals were: body weight at 60 days of age (W60), age at finish (AGF), daily weight gain from birth to finish (DG), back fat thickness at finish (BFTF), and loin eye area at finish (LEAF), and in carcasses were: carcass weight, loin eye area (LEA), and subcutaneous fat thickness (SCF) at some points, using the records of 4,773 purebred Berkshire pigs. Variance components for the traits were estimated according to the animal model by the Restricted Maximum Likelihood (REML) procedure using the VCE6 program (Neumaier and Groeneveld, 1998). Correlated responses were also calculated. Genetic correlations of back fat thickness (BFT) in live animals with SCF in slaughtered animals were strong, whereas that of LEA between live and slaughtered animals was low. The expected gains by actual selection including W60 and BFTF as selection criterion were superior to other selections. Therefore, selection of live animals at an early stage of growth would be conducive to the production of high quality meat.
Keywords: correlated response, pig breeds, meat productivity trait, ultrasound equipment

Introduction

The Berkshire pig (*Sus domestica* L.) breed has thin muscle fibers and excellent water-holding capacity (National Pork Producers Council, 1995). The characteristic quality of the Berkshire meat makes it widely accepted in the Japanese premium pork market, where the retail price of purebred Berkshire is 50 % higher than that of commercial pigs produced by three-way crossbreeding (Suzuki et al., 2003).

Recently, measurement of meat productivity by ultrasound (US) imaging equipment is widely used, and phenotypic correlations between such measurements on slaughtered and live animals have been described (Szabo et al., 1999). Accurate measurements on live animals are crucial, especially because selection efficiency and precision are influenced thereby. Real time US is used to evaluate measurements on live animals. The accuracy of collecting and interpreting ultrasonic images, however, depends on operator and equipment as well as on probe type and reproducibility (Bahelka et al., 2007; Herring et al., 1994; Olsen et al., 2007). Here, a population of Berkshire was measured by US to evaluate meat productivity of live animals. Genetic parameters and the effectiveness of selection based on traits in live animals have been described (Tomiyama et al., 2009). Although precise measurement by US equipment is an important requisite, the accuracy of the measurements of live animal traits and their genetic relationship has not been evaluated because of the cost of analyzing carcass records.

The aim of this study was to estimate the genetic parameters of meat productivity traits in live and slaughtered Berkshire pigs for the improvement of carcass traits through traits in live animals, and to evaluate the accuracy of measurements by US.

Materials and Methods

"Data for this study comes from records of 4,773 purebred Berkshire (2,458 males and 2,315 females) pigs produced from 38 sires mated with 121 dams between April 1994 and March 2007 (Table 1) in Okayama, Japan (34.67 N, 133.92 E). The number of carcass records was smaller than that of live animal records because the measurements were taken after 2005. The records of 2006 and 2007 included only carcass measurements.

Animals from the same litter were reared together in the same pen from birth to 60 days of age. Breeding animals were then selected (around 20 %) based on their body weight at 60 d of age because of limited breeding facilities and management system. Traits at finish (when body weight reached 105 kg) were measured only in selected animals; unselected pigs were reared separately for fattening. All the pigs were provided with restricted feeding and allowed free access to water. The restricted feeding regime was determined by the age of piglets, as detailed by Tomiyama et al. (2008). The piglets were weaned on the nearest Thursday after reaching 25 d of age.

Analyzed traits of live animals were: body weight at 60 d of age (W60, kg), age at finish (AGF, day), daily gain from birth to finish (DG, kg per day), back fat thickness at finish (BFTF, cm), and loin eye area at finish (LEAF, cm^2), and for slaughtered animals were: carcass weight (CW, kg), loin eye area (LEAC, cm^2), subcutaneous fat thickness at midpoint (SCFB, cm), at the shoulder (SCFS, cm), at the loin (SCFL, cm), on half carcass length (SCFH, cm) and at the 10th rib (SCF10, cm). The measurement of carcass traits started in 2005 at the slaughterhouse. In live animals, BFTF and LEAF were measured by US (Super eye meat 500, Fujihira Industry Co., Ltd., Tokyo, Japan) at the mid-point of the body and three cm down from the top of the midline. LEAF was the average of measurements on both sides of the body. SCFS and SCFL were measured at the site of thickest fat, whereas SCFB was measured at the site of thinnest fat; all measurements were based on Japanese technical guidelines for performance evaluation.

The fixed effects and covariates in the model were determined according to a preliminary analysis with GLM in SPSS (SPSS Inc., Chicago, IL). The model selection was carried out in the following order of priority: by excluding insignificant interaction**,** main effect and covariates.

Variance components for the traits were estimated according to the animal model by the Restricted Maximum Likelihood (REML) procedure using the VCE6 program (Neumaier and Groeneveld, 1998). To minimize the effect of selection, three-trait models (including W60 as a common trait) were used. The statistical models, except for W60, were as follows:

$$y_i = Xb_i + Za_i + e_i,$$

where $\boldsymbol{y}_i$ is the vector of observations for the ith trait, $\boldsymbol{b}_i$ the vector of fixed effects including contemporary groups, sex effect and covariates including age at finish, body weight at finish or slaughter age for the ith trait; $\boldsymbol{a}_i$ the vector of random additive genetic effect for the ith trait; $\boldsymbol{e}_i$ the vector of random error for the ith trait; $\boldsymbol{X}$ and $\boldsymbol{Z}$ are incidence matrices relating records of the trait to the fixed effect and the random effects, respectively. The statistical model for W60 was as previously described by Tomiyama et al. (2009). A management group was defined as a contemporary group according to the year and season of birth (spring: March to May; summer: June to August; autumn: September to November; and winter: December to February), and a total of 48 management groups was included in the model.

Table 1 – Data structure of records.

Year	No. of records	No. of males	No. of females
1994	215	123	92
1995	313	167	146
1996	320	153	167
1997	294	152	142
1998	308	160	148
1999	310	162	148
2000	299	135	164
2001	347	179	168
2002	454	254	200
2003	542	282	260
2004	544	263	281
2005	602	314	288
2006	170	87	83
2007	55	27	28
Total	4,773	2,458	2,315

Correlated responses were calculated according to the equation based on the desired gain index (Yamada et al., 1975). The proportion of animals at truncation selection was assumed to be the top 20 % of pigs of both sexes. The breeding goal was assumed to be 10 % below the present average for SCFH and 10 % above the present average for LEAC.

Results and Discussion

The number of records for AGF, DG, BFTF, and LEAF was larger than that for the other traits because the former included records of candidate sires and dams. The CV for CW was the smallest among all the traits. For traits in live animals, heritability for DG was low (0.13), and heritabilities for AGF, BFTF, and LEAF were moderate to slightly high (0.50, 0.54, and 0.34, respectively). The heritability for W60 has been reported to be low (0.22) (Tomiyama et al., 2009). Heritabilities for SCFB, SCFL, SCF10, LEAC, and CW were moderate (0.35, 0.41, 0.41, 0.35, and 0.32, respectively), whereas those for SCFS and SCFH were low (0.22 and 0.23, respectively) (Table 2).

Table 2 – Number of records (n), Minima of records (Min), Maxima of records (Max), means, standard deviations (SD), coefficient of variation (CV) and heritabilities (h^2).

Traits†	n	Means	SD	CV	h^2 ± SE
W60	3779	20.1	3.80	0.19	0.25 ± 0.07
AGF	959	209.5	20.9	0.10	0.50 ± 0.07
DG	888	0.50	0.1	0.20	0.13 ± 0.06
BFTF	948	1.88	0.50	0.27	0.54 ± 0.10
LEAF	928	25.5	4.7	0.18	0.34 ± 0.08
SCFB	297	2.30	0.50	0.22	0.35 ± 0.11
SCFS	297	4.27	0.63	0.15	0.22 ± 0.08
SCFL	297	3.60	0.66	0.18	0.41 ± 0.14
SCFH	297	2.60	0.53	0.20	0.23 ± 0.10
SCF10	297	3.00	0.52	0.17	0.41 ± 0.14
LEAC	249	22.2	2.9	0.13	0.35 ± 0.15
CW	297	71.0	5.1	0.07	0.32 ± 0.15

†W60 = body weight at 60 days of age; AGF = age at finish; DG = daily gain from birth to finish; BFTF = back fat thickness at finish; LEAF = loin eye area at finish; SCFB = subcutaneous fat thickness on back; SCFS = subcutaneous fat thickness on shoulder; SCFL = subcutaneous fat thickness on loin; SCFH = subcutaneous fat thickness on half carcass length; SCF10 = subcutaneous fat thickness between 10th and 11th rib, LEAC = loin eye area on carcass; CW = carcass weight.

Table 3 – Estimates of genetic correlations (±standard error) between traits at finish (column) and carcass traits (row).

Traits[†]		SCFB	SCFS	SCFL	SCFH	SCF10	LEAC	CW
W60	r_g	-0.17 ± 0.32	-0.58 ± 0.24	-0.17 ± 0.31	-0.56 ± 0.30	-0.45 ± 0.29	0.72 ± 0.22	0.37 ± 0.33
	r_p	-0.29	-0.43	-0.20	-0.10	-0.13	0.31	-0.04
AGF	r_g	0.39 ± 0.23	0.93 ± 0.21	0.04 ± 0.20	0.26 ± 0.31	0.30 ± 0.15	-0.66 ± 0.26	0.03 ± 0.17
	r_p	0.07	0.21	-0.01	0.12	0.07	-0.08	0.03
DG	r_g	0.11 ± 0.42	-0.57 ± 0.45	-0.20 ± 0.45	-0.44 ± 0.56	-0.36 ± 0.23	0.95 ± 0.26	0.17 ± 0.22
	r_p	0.01	-0.11	-0.05	0.01	0.00	0.11	-0.05
BFTF	r_g	1.00 ± 0.02	0.90 ± 0.09	0.52 ± 0.18	0.92 ± 0.09	0.78 ± 0.14	-0.55 ± 0.30	0.42 ± 0.21
	r_p	0.40	0.36	0.30	0.44	0.50	-0.04	0.29
LEAF	r_g	-0.36 ± 0.25	-0.37 ± 0.34	0.05 ± 0.17	-0.56 ± 0.32	-0.14 ± 0.23	0.20 ± 0.27	-0.14 ± 0.24
	r_p	0.04	0.11	0.20	0.08	0.15	0.16	0.15

[†] W60 = body weight at 60 days of age; AGF = age at finish; DG = daily gain from birth to finish; BFTF = back fat thickness at finish; LEAF = loin eye area at finish; SCFB = subcutaneous fat thickness on back; SCFS = subcutaneous fat thickness on shoulder; SCFL = subcutaneous fat thickness on loin; SCFH = subcutaneous fat thickness half carcass length; SCF10 = subcutaneous fat thickness between 10th and 11th rib, LEAC = loin eye area on carcass; CW = carcass weight.

The genetic correlation of W60 was low with SCFB and SCFL (-0.17 and -0.17, respectively), moderately negative with SCFS, SCFH and SCF10 (-0.58, -0.56, and -0.45, respectively), and highly positive with LEAC (0.72); that of CW was low with W60, AGF and DG (0.37, 0.03, and 0.17, respectively) and that of AGF was positive with all sites of SCF, but low with only SCFL (0.04). In comparing live animal measurements with carcass traits, the genetic correlation of BFTF was strongly positive with SCFB, SCFS, SCFH, and SCF10 (1.00, 0.90, 0.92, and 0.78, respectively) but moderately positive with SCFL (0.52), whereas that between LEAF and LEAC was low (0.20). The genetic correlation of LEAF was low to moderately negative with SCFB, SCFS, SCFH, and SCF10 (-0.36, -0.37, -0.56, and -0.14, respectively), but approximately zero with SCFL (0.05); that of CW was 0.42 with BFTF and -0.14 with LEAF. The genetic correlations of SCF and LEA showed a tendency similar to that of phenotypic correlations: the relationships of SCF were stronger than those of LEA (Table 3).

The expected response (Table 4) was calculated by the selection index to compare indirect selection for SCFH and LEAC with direct selection for BFTF and LEAF. Traits on objective were SCFH and LEAC, and the selection responses attributed to direct selection on SCFH and LEAC were -0.01 and 0.11, respectively; those attributed to indirect selection on SCFH and LEAC were -0.06 and 0.55, respectively.

The heritabilities for SCFB, SCFS, SCFL, SCFH, and SCF10 under the restricted feeding regimen ranged between 0.22 and 0.41 (Table 2) and were consistent with the average estimate (0.31) in the review made by Clutter and Brascamp (1998). Also, the heritability for SCF10 was consistent with the average heritability (0.52) for SCF at the 10th rib (Stewart and Schinckle, 1989). Thus, it is suggested that the heritabilities of SCF do not depend upon the differences of breeds or breeding populations.

Table 4 – Direct and correlated responses of traits (BFTH and LEAC) by selection on criteria.

Selection criteria[1]	Trait on objective	
	SCFH (d)	LEAC (cm²)
W60 and BFTF (actual selection)	-0.10	0.86
BFTF and LEAF (direct selection)	-0.01	0.11
SCFH and LEAC (indirect selection)	-0.06	0.55

[†] W60 = body weight at 60 days of age; BFTF = back fat thickness at finish; LEAF = loin eye area at finish; SCFH = subcutaneous fat thickness half carcass length; LEAC = loin eye area on carcass.

The genetic correlation of W60 with BFTF and LEAF was -0.19 and 0.16, respectively (Tomiyama et al., 2009), whereas in the present study, those of W60 with SCFS, SCFH, SCF10 and LEAC (-0.58, -0.56, -0.45, and 0.72, respectively) were stronger (Table 3). The results of the present study were more favorable than previous ones for genetic improvement of SCF and loin eye area because the decrease of fat thickness and the increase of loin eye area were attained by the genetic improvement of W60.

Estimates of the genetic correlation between age (days) at 100 kg and back fat thickness was -0.13 (Lo et al., 1992), -0.16 for Large White, -0.06 for Landrace, -0.l7 for Duroc, and -0.10 for Hampshire (Li and Kennedy, 1994). In the present study, the genetic correlation of AGF with SCFB and SCF10 was weakly positive (0.39 and 0.30, respectively) (Table 3) and not consistent with reported values. It is suggested that these differences depend upon the characteristics of the breed. These favorable genetic relationships indicate that genetic improvement is attainable in SCFB and SCF10 by a decrease of AGF, whereas the genetic correlation between AGF and SCFL was weak (0.04). This contradictory result may be due to measurement errors on the carcass because measurements of SCFL tend to yield a large error component depending on the body type of the animals and the choice of the measuring site by technicians. Therefore, we considered SCFL not appropriate for the genetic evaluation of back fat thickness.

The estimated genetic correlation between age (days) at 100 kg and LEAC was 0.35 (Lo et al., 1992), whereas in this study, it was different **(**-0.66**)** and favorable for genetic improvement of carcass traits. The negative genetic correlation between BFTF and LEAC (-0.55) was also favorable for attaining greater loin eye area and reduced back fat thickness.

The strong genetic correlation of BFTF with SCFB, SCFS, SCFH, and SCF10 was markedly favorable for genetic improvement of carcass traits and consistent with 0.85 reported by Lo et al. (1992) and 0.81 by Nguyen and McPhee (2005), suggesting that back fat measured by US is prospectively conducive for the improvement of back fat thickness on carcasses in this Berkshire population. Nevertheless, because of the low genetic correlation between LEAF and LEAC (0.20), loin eye area measured by US was not effective in improving loin eye area in carcasses. The premise in this study that at least a moderately positive correlation must exist between LEAF and LEAC was not confirmed, which was not consistent with the strong correlation (0.87) reported by Lo et al. (1992). The difference seems to be due to the skill of operators as suggested by Szabo et al. (1999). Although some uncertainty during measurements cannot be explained, except as random errors attributed to operators, environment and equipment, precision can be maintained at an acceptable level (Olsen et al., 2007). Therefore, technical standards for operators need to be established for more accurate measurements by US (McLaren et al., 1991; Miller, 1996).

The expected response to actual, direct and indirect selection is evaluated and presented in Table 4. The actual selection was based on the selection criteria of W60 and BFTF whose genetic correlations with the SCF trait were strong. The ratio of expected direct response, including BFTF and LEAF, to the indirect response including SCFH and LEAC, showed that the ratio of the former was approximately 20 % of the latter, suggesting that direct selection based on measurements by US is less efficient for improvement than indirect selection based on carcass measurements. Therefore, the protocol of measuring traits by US in such populations needs to be modified. The expected gain by both direct and indirect selection was, however, inferior to that by actual selection. Besides the need for modifying the measurement protocol, selection criteria of W60 and BFTF would adequately improve SCF and LEA on carcasses. Therefore, the selection based on W60 has the potential for genetic improvement of carcass quality.

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