



Estimation of Genetic Associations between Production and Meat Quality Traits in Duroc Pigs

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ABSTRACT: Data collected from 690 purebred Duroc pigs from 2009 to 2012 were used to estimate the heritability, and genetic and phenotypic correlations between production and meat quality traits. Variance components were obtained through the restricted maximum likelihood procedure using Wombat and SAS version 9.0. Animals were raised under the same management in five different breeding farms. The average daily gain, loin muscle area (LMA), backfat thickness (BF), and lean percent (LP) were measured as production traits. Meat quality traits included pH, cooking loss, lightness (L*), redness (a*), yellowness (b*), marbling score (MS), moisture content (MC), water holding capacity (WHC), and shear force. The results showed that the heritability estimates for meat quality traits varied largely from 0.19 to 0.79. Production traits were moderate to highly heritable from 0.41 to 0.73. Genotypically, the BF was positively correlated ($p < 0.05$) with MC (0.786), WHC (0.904), and pH (0.328) but negatively correlated with shear force (-0.533). The results of genetic correlations indicated that selection for less BF could decrease pH, moisture content, and WHC and increase the shear force of meat. Additionally, a significant positive correlation was recorded between average daily gain and WHC, which indicates pork from faster-growing animals has higher WHC. Furthermore, selection for larger LMA and LP could increase MS and lightness color of meat. The meat quality and production traits could be improved simultaneously if desired. Hence, to avoid further deterioration of pork characteristics, appropriate selection of traits should be considered. (**Key Words:** Genetic Parameters, Production Traits, Meat Quality Traits, Duroc)

INTRODUCTION

The swine industry plays a very important role in the animal industry as it accounts for 42% of the total animal production (RDA report, 2011). Consumer demand is rapidly increasing, necessitating that genetic potential be maximized and overall farm management improved. Additionally, improvements in production have the potential to boost exports to neighboring countries. Improvements of animal performance to their highest

genetic potential have been made possible through modern technology and knowledge. Such improvements focus on growth and production efficiency, carcass yield and meat quality. Many of these traits are moderately to highly heritable, and the response to selection is highly dependent on variations in the population and selection intensity (Falconer, 1989; Dube et al., 2013). The response to selection is influenced by correlations among traits that could be desirable or undesirable (Miar et al., 2014). Therefore, heritability and correlation between production traits and meat quality traits should be considered during selection.

This study was conducted to determine the relationship between production traits and meat quality traits of purebred Duroc pigs. Specifically, heritability and the phenotypic and genetic correlations between traits were estimated. The results of this study will lead to improved selection of traits that are economically important.

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MATERIALS AND METHODS

Experimental animals

Data for this study were obtained from 690 finishing Duroc pigs over 4 years (2009 through 2012). The data were combined from five different breeding farms under national genetic improvement project. The animals were composed of 633 females and 57 males raised under the same management conditions. Piglets were delivered to different farms at approximately 10 to 20 days of age and raised under commercial finishing conditions. A standard health and vaccination protocol was implemented. All pigs were raised in a adjusted open-front finisher with a partially slotted floor and given 1.4 m² of pen space per pig.

Performance measurement

Performance data were collected when the animals reached 9 to 22 weeks of age. The average daily gain (ADG) was obtained from the difference between final weight and initial weight divided by the days fed. Lean meat percentage (LP) was acquired by determining the percentage weight of the whole carcass. The loin muscle area (LMA) was measured between the third and fourth ribs 3 inches away from the midline using an A-mode ultrasound device (PIGLOG 105), then calculated using the following equation:

$$\text{LMA} = \text{loin muscle measurement} + \frac{(90 - \text{test end weight}) \times \text{loin muscle measurements}}{(\text{test end weight} + 70.31)}$$

The backfat thickness (BF) was measured on all live animals ultrasonically at the tenth rib 4cm from the midline and adjusted to 90 kg using the formula below:

$$\text{BF} = \text{backfat measurement} + \frac{(90 - \text{test end weight}) \times \text{backfat measurements}}{(\text{test end weight} - 11.34)}$$

Meat quality measurements

The samples were collected from two different slaughterhouses, where different farms were instructed to bring the animals after they reached the target end weight of 120 kg for carcass evaluation, and then carried to the laboratory immediately for meat quality measurement. The pH value of meat was measured using an Orion 3 Star (Thermo Electron Corp., Waltham, MA, USA) pH meter in the loin muscle at 2 locations at 24 h postmortem. Shear value and cooking loss (CL) were determined on the same sample block after thawing overnight in a chiller. The samples were weighed and cooked at 72°C, after which the CL was determined by dividing the weight loss after

cooking by the weight of the sample before cooking. Shear values were measured in an Instron Universal Testing Machine (Model 3342, Instron Corporation, Norwood, MA, USA) on six core samples with a 0.5 inch diameter using a crosshead speed of 400 mm/min and a 40 kg/f load cell. The moisture content (MC) was obtained through a slightly modified method of the AOAC methods (AOAC, 1995). The water holding capacity (WHC) was determined after the ground meat was centrifuged at 1,000 rpm for 10 minutes at 4°C and measured using absorbent cotton placed inside of a Falcon tube. The meat colors, lightness (L*), redness (a*) and yellowness (b*) were measured after cutting and blooming for more than 15 min using a Konica Minolta Spectrophotometer CM-2500d with an 8 mm measuring port, D 65 illuminant and 10° observer. The tristimulus parameters L*, a*, and b* values, representing lightness (L* = 0 is completely black, and L* = 100 is completely white), redness (positive a* values mean red colors and negative a* values mean green colors) and yellowness (positive b* values mean yellow colors and negative b* values mean blue colors), respectively, were measured in duplicate on three fixed sites of each chop surface of the loin, in the dorsal ventral direction. Minolta instrument was directly connected to a computer, and a barcode scanner gave a fast and accurate measurement.

Statistical analyses

The general linear model (GLM) procedure of the Statistical Analysis Systems Institute (SAS, 2002) was used to test the significance of fixed effects, covariates and any possible interactions among factors. Pearson correlation coefficients between traits were calculated using the PROC CORR procedure. Variance-covariance components and standard error were obtained through the Restricted Maximum Likelihood procedures of WOMBAT and SAS program version 9.0. The model used accounted for random direct genetic, common environmental litter and maternal genetic effects. In matrix form, the model is:

$$\mathbf{y}_{ijk} = \boldsymbol{\mu} + \mathbf{f}_i + \mathbf{S}_j + (\text{Day})\boldsymbol{\beta}_{ijk} + \mathbf{e}_{ijk}$$

where \mathbf{Y}_{ijk} is the vector of observations of the traits, $\boldsymbol{\mu}$ is the overall mean, \mathbf{f}_i is the i th farm effect, \mathbf{S}_j is the j th sex effect, $\boldsymbol{\beta}$ is the regression coefficient of slaughter day (Day), \mathbf{e}_{ijk} is the random error. All fixed factors included in the model were significant ($p > 0.05$) based on the GLM analysis. Heritability was calculated as the ratio of animal genetic variance to the sum of additive genetic, common environment, and residual variances. Three generations of pedigree information comprising 5,869 animals from January 2007 to June 2012 were included in the analysis. Genetic and phenotypic correlations were estimated using a multi-trait model. All traits were analyzed together in one

model.

RESULTS AND DISCUSSION

Descriptive statistics for production and meat quality traits are presented in Table 1. The mean ADG, BF, LMA and LP were 640.41 g/d, 14.61 mm, 28.25 cm² and 55.89%, respectively. For meat quality traits, the average pH, CL, marbling score (MS), MC, shear force, and WHC were 5.74, 22.45%, 3.72, 72.72%, 4.40, and 54.93, respectively. In meat colors, the mean L*, a*, and b* were 54.67, 9.76, and 9.82, respectively.

Heritability

The heritability estimates with standard error for some production traits are presented in Table 2. Production traits such as ADG, BF, LMA, and LP were highly heritable. Heritability estimates with standard error for ADG, BF, LMA, and LP were 0.67±0.06, 0.65±0.06, 0.41±0.05, and 0.73±0.08, respectively. These estimates are higher, except LMA, in the review study conducted by Akanno et al. (2013), where heritability estimates for the same traits were ranging from 0.24 to 0.32, 0.36 to 0.52, 0.37 to 0.65, and 0.35 to 0.49, respectively. Stewart and Shinckel (1990) used a weighted average of results reported in studies from the United States and Europe and found a heritability of 0.47 for LMA, which is similar to the results of the present study (0.41). Other estimates of heritability of backfat in the literature ranged from 0.23 to 0.79 (Van Steenberg et al., 1990). Lo et al. (1992) reported that the heritability estimate for ADG data from a 2×2 parallel mating system of Landrace and Duroc pigs was 0.36, which is lower than the 0.67±0.06 observed in the present study.

Table 2 presents the heritability estimates and standard

Table 1. Summary of production and meat quality traits

Trait	N	Min	Max	Mean	SD
ADG (g/d)	616	488.00	828.80	640.41	57.64
BF (mm)	616	8.61	24.23	14.61	2.66
LMA (cm ²)	554	19.72	38.78	28.25	3.21
LP (%)	554	44.00	65.90	55.89	3.49
pH	598	5.44	6.49	5.74	0.15
MC (%)	593	63.20	79.33	72.72	2.25
WHC	597	10.44	88.72	54.93	21.93
CL (%)	597	6.65	42.60	22.45	6.68
MS	574	0.59	14.02	3.72	1.64
L*	608	41.23	66.95	54.67	4.14
a*	608	2.08	20.61	9.76	4.87
b*	608	3.65	17.67	9.82	2.71
Shear force	597	1.25	8.80	4.40	1.66

SD, standard deviation; ADG, average daily gain; BF, backfat thickness; LMA, longissimus muscle area; LP, lean percent; MC, moisture content; WHC, water holding capacity; CL, cooking loss; MS, marbling score; L*, lightness; a*, redness; b*, yellowness.

Table 2. Estimates of total genetic and environmental variances, heritability and standard error for production and meat quality traits in Duroc pigs

Trait	Total genetic variance	Environmental variance	Heritability	SE
ADG	508.7	254.82	0.67	0.06
BF	3.678	1.953	0.65	0.06
LMA	3.508	4.96	0.41	0.05
LP	6.06	2.24	0.73	0.08
pH	0.0129	0.008	0.61	0.08
MC	0.906	2.471	0.27	0.06
WHC	5.558	23.37	0.19	0.06
CL	9.981	6.211	0.62	0.07
MS	1.694	0.463	0.79	0.08
L*	4.945	6.264	0.44	0.08
a*	2.595	1.233	0.68	0.08
b*	2.532	1.420	0.64	0.05
Shear force	0.066	1.578	0.04	0.05

SE, standard error; ADG, average daily gain; BF, backfat thickness; LMA, longissimus muscle area; LP, lean percent; MC, moisture content; WHC, water holding capacity; CL, cooking loss; MS, marbling score; L*, lightness; a*, redness; b*, yellowness.

error for meat quality traits, which varied largely from 0.19 to 0.79. In a study conducted by Lo et al. (1992), heritability estimates for pH, MC, WHC, CL, MS, and shear force were 0.14, 0.14, 0.25, 0.06, 0.17, and 0.17, respectively. These values were comparatively lower than those reported in the present study, particularly for the pH (0.61±0.08), marbling score (0.79±0.08), and CL (0.62±0.07). A number of studies (e.g. Wilson and Johnson, 1981; Lowe et al., 2011) showed that Duroc breed had a high amount of marbling and more rapid growth than Hampshire and Yorkshire breeds. Ciobanu et al. (2011) reported an average heritability value of 0.16 for CL. In comparison, high common environmental effects were also shown in this study for CL (0.62). Cameron (1990b) reported a heritability of 0.20 for muscle pH at 24 hour postmortem. This study revealed that pH was highly heritable in purebred Duroc pigs, which are considered one of the most important traits in meat quality. Furthermore, this study also obtained a higher heritability estimate for lightness, which was 0.44 with standard error of 0.08. Suzuki et al. (2006) reported that the heritability estimates for meat color (L*) was 0.16 while Hermesh et al. (1993a) reported an estimate of 0.29.

Genetic correlations

The genetic correlations between production and meat quality traits are presented in Table 3. Generally, some of the correlations were significant ($p < 0.05$). Genetic correlations estimated in the current investigation support the general impression that selection for increased backfat

Table 3. Phenotypic and genetic correlations between production and meat quality traits

Traits	ADG		BF		LMA		LP	
	r _p	r _G	r _p	r _G	r _p	r _G	r _p	r _G
pH	-0.06	-0.004	-0.07	0.328	0.12	-0.226	0.07	-0.104
MC	-0.10	-0.010	0.02	0.786	0.00	0.038	-0.22	-0.342
WHC	0.14	0.875	0.06	0.904	-0.16	0.002	-0.02	-0.504
CL	0.00	0.185	-0.05	0.206	0.17	0.044	0.15	-0.072
MS	0.02	0.011	0.04	-0.414	-0.18	0.307	-0.22	0.307
L*	0.08	0.025	0.13	-0.173	-0.10	0.325	-0.32	0.248
a*	-0.02	-0.053	0.17	0.455	-0.13	0.236	-0.24	-0.027
b*	-0.06	-0.084	-0.17	-0.240	0.18	0.187	0.29	0.265
Shear force	0.01	0.478	-0.21	-0.533	0.05	0.516	0.18	0.503

ADG, average daily gain; BF, backfat thickness; LMA, longissimus muscle area; LP, lean percent; r_p, phenotypic correlation; r_G, genotypic correlation; MC, moisture content; WHC, water holding capacity; CL, cooking loss; MS, marbling score; L*, lightness; a*, redness; b*, Yellowness.

should lead to a correlated increase in MC and WHC. In this study, the BF was positively correlated with MC (0.786), WHC (0.904) and a* (0.455). According to Suzuki et al. (2005), as the intramuscular fat content increases, the WHC will also increase. Moreover, WHC was strong positively correlated with ADG (0.875). These findings showed that pork from faster-growing pigs has higher WHC. The MS was positively correlated with LP (0.307) and negatively correlated with BF (-0.414). These results showed that meat from leaned and less backfat animals had better MS. The shear force was positively correlated with ADG (0.478), LMA (0.516) and LP (0.503) but negatively correlated with BF (-0.533). These results showed that when selection favors production traits such as ADG, BF, LMA, and LP, it will favored the shear force of meat, which is a good indication of meat tenderness. These findings contrast the result reported by Suzuki et al. (2005), who found that tenderness was negatively correlated with ADG (-0.44).

Phenotypic correlations

Phenotypic correlations between production and meat quality traits varied greatly (Table 3). Hermes et al. (2000b) reported that production traits were genetically independent from meat quality traits, while selection for improved feed efficiency and increased leanness will increase the incidence of pale, soft, and exudative (PSE) meat and reduce intramuscular fat. These results are similar to those of the present study. The pH of meat, which served as a significant source of variations in meat quality (Price and Schweigert, 1987), showed a positive correlation with LMA (0.12), but showed no significant correlation with other production traits. Bidanel et al. (1994) reported that selection for reduced backfat could reduce pH, and thus increased the incidence of PSE meat.

The WHC showed a negative correlation with LMA (-0.16) and positive correlation with ADG (0.14). This correlation between WHC and ADG showed that pork from

fast-growing pigs has phenotypically higher WHC. Berg et al. (2003) investigated several breeds and found higher values of WHC, intramuscular fat, content and ultimate pH, as well as lower lightness in the *longissimus dorsi* muscle for Duroc pig compared to Landrace. The marbling score, lightness, and redness were negatively correlated with LP and LMA. This moderate negative correlation (-0.22) between MS and LP showed that leaned pigs do not show high marbling score phenotypically. The lightness and redness traits were positively correlated with BF, which was in contrast to the yellowness trait.

Moreover, shear force was positively correlated with LP (0.18), but negatively correlated with BF (-0.21). This could be explained by the amount of intramuscular fat content. It is well known that shear force is an important index for evaluation of the tenderness of pork. The shear force decreases with increasing intramuscular fat content when the pH increases above 4.5 (Jelenikova et al., 2008). Correlations were found between shear force (tenderness) and intramuscular fat content. Similarly, a positive relationship was observed between shear force and pH value at 4.5 minutes (pH 4.5) post mortem.

IMPLICATIONS

The present study revealed that there were desirable and undesirable correlations between production and meat quality traits of Duroc pigs. The pH was associated with high heritability estimates, although it had unfavorable genetic correlations with LMA and LP, and an insignificant relationship with ADG. In addition, the observed genetic correlations broadly indicate that selection for less BF could lower pH, MC, and WHC. Moreover, selection for larger LMA and LP could increase marbling score and lightness color of meat, genotypically, but LP was phenotypically negatively correlated with MS. This results showed that LP and MS has desirable genetic correlation but does not appear physically. Therefore, it was suggest for more deep

study in this correlation. A significant positive genetic correlation of WHC with ADG and BF, and negative genetic correlation with LP were also recorded in this study. These findings imply that meat quality and production traits could be improved simultaneously if desired. Therefore, appropriate traits should be selected to avoid further deterioration of pork characteristics.

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