Relative Genetic Effects of Duroc and Taoyuan Breeds on the Economic Traits of Their Hybrids

N. T. Yen[1], C. Tai[2], Y. S. Cheng[3] and M. C. Huang*
Dept. of Animal Science, National Chung Hsing University, 250 Kao-Kung Road, Taichung, Taiwan, ROC

ABSTRACT : For determining the relative genetic effects of Duroc (D) and Taoyuan (T) breeds on the economic traits of their hybrids, 72 litters of pigs, from four mating types, namely TT (T♂×T♀), DD (D♂×D♀) and D-T hybrids (TD, T♂×D♀ and DT, D♂×T♀) were used in this study. The various crossbreeding parameters were estimated by comparisons among mating types using linear contrasts of least-square analysis. The results of reproductive traits analysis showed that T breed had contributed superior genetic effects on the total number of piglets at birth (TBN) ($p<0.10$) and number of live piglets at 21 days (LP21) ($p<0.05$) to the D-T hybrids. Estimates of maternal genetic effects showed that the T females were superior in TBN ($p<0.05$), but inferior in average birth weight (ABW) and average litter birth weight (LBW) ($p<0.01$) to the D females. Direct heterosis effects were significant for LBW, LP21 and LWT21 ($p<0.01$). Least-squares analysis of other economic traits showed that T breed had relative negative effects on all growth traits, withers height (WH), body type index (BTI), average backfat thickness (ABF), carcass length (LENG), loin eye area (longissimus) (LEARA), and lean percentage (LEAN) of D-T hybrids ($p<0.05$). Estimates of direct genetic effects showed that the D breed was superior to the T breed in all growth and carcass traits except the average backfat (BF). Estimates of maternal genetic effects showed that average body weight at 180 days (WT180) of progenies from T sows were lighter than from D sows. Progenies from D females had larger and leaner carcass than those from T females. Direct heterosis effects were significant for average daily weight gains from 150 to 180 days ($ADG_{150\text{-}180}$) ($p<0.05$) and for average body weights at 150 (WT150), and 180 days (WT180), average daily weight gains from birth to 150 and 180 days (ADG_{150} and ADG_{180}, respectively), WH, body length (BL), ABF, BTI, and LENG ($p<0.01$). The results showed that D-T hybrids tended to have superior TBN and LP21 than D breed, and to be superior in all growth and most conformation and carcass traits to the T breed. ***(Asian-Aust. J. Anim. Sci. 2001. Vol. 14, No. 4 : 447-454)***

Key Words : Relative Genetic Effects, Duroc, Taoyuan, Heterosis

INTRODUCTION

Determination of an efficient method of utilizing genetic diversity among breeds depends upon the reproductive rate and the relative magnitudes of heterosis, of recombination effects, and of breed differences in individual, maternal, and paternal performances (Dickerson, 1973). The Taoyuan (T) pig is one of the native breeds in Taiwan, and is classified as a Southern Chinese type (Tai et al., 1988). Coat color of T is black or dark gray. The distinct visible characteristics in appearance of this breed are marked wrinkles over the entire face and body skin; broad and flat face; large and floppy ears; cloven hoof in contact with the ground; and concave back. T pig has a smaller body size, slower growth rate and less lean meat content than exotic pig breeds. Based on the study of gene frequencies of the blood group loci, Oishi and Tanaka (1992) found that the genetic distances among Chinese pigs, including the T pigs, were very small. The reputation of remarkable palatability for the meat of purebred or crossbred Chinese pigs is confirmed by not only Chinese consumers but also French researchers (Touraille et al., 1989; Gandemer et al., 1992). This superiority seems to be highly associated with the higher intra-muscular fat content (Gandemer et al., 1992). Hog farmers in Taiwan used to regard the T breed as a prolific breed. However, Makita (1965) reported that the average litter size of T breed was 9.11, ranging from 6 to 13. Today, the native T swine breed has become a rare breed. Due to the limited animal genetic resources available in Taiwan, it is important and necessary to start work on conserving and utilizing the local T pig which has some superior characteristics, such as prolificacy and to prevent the breed's disappearance. A random mating closed stock herd of T pigs (10 boars and 30 sows) was conserved in the Research Farm of Taiwan Livestock Research Institute (TLRI). Duroc (D) is one of the most popular exotic breed and is the best breed for growth and carcass performance in Taiwan. Their total number of piglets at birth (TBN) and number of live piglets at 21 days (LP21) are inferior compared to Landrace, Yorkshire and T (Chou, 1987; Tai et al., 1992). Consumers in Taiwan prefer the special taste and flavor of black pig's pork.

* Address reprint request to M. C. Huang. Tel: +886-4-2850223, Fax: +886-4-2860265, E-mail: mchuang@mail.nchu.edu.tw.
[1] Taiwan Livestock Research Institute, Hsinhua, Tainan, Taiwan, ROC.
[2] Institute of Biotechnology, National Cheng Kung University, Tainan, Taiwan, ROC.
[3] Taiwan Livestock Research Institute, Hsinhua, Tainan, Taiwan, ROC.

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Occasionally, T pig is used to produce black hogs through crossbreeding with D or other breeds by the hog farmers in Taiwan. TLRI started a series of projects to develop a synthetic line, Taiwan Black (TB) pig, by crossing T and D pigs in order to improve the reproductive efficiency of the D pig and to meet the special needs of the domestic Taiwanese consumer (Tai et al., 1992). The objectives of this study were to understand the relative genetic effects of D and T breeds on the economic traits of D-T hybrids.

MATERIAL AND METHODS

Animals and experimental design

Offspring from 72 litters of four mating types, namely TT (T♀×T♂), DD (D♀×D♂) and D-T hybrids (T♀×D♂ and D♀×T♂) were used in this study. The data structure for investigating the economic traits in pigs is listed in table 1. As the conserved T population was small, sample size of T was limited. The numbers of purebred T dams used in the mating types of TT and DT were both 14, and the numbers of purebred D dams used in the mating types of DD and TD were 11 and 14 respectively. Females were treated with Regumate (Hoechst, Ltd., UK) according to the manufacturers instruction for estrus synchronization. About three to five days after withdrawal of Regumate, females were bred twice at 12h intervals by artifical insemination. Semen from four to ten boars of the same breed were collected and pooled for insemination.

Pellet feeds of different nutrient levels provided for various growing stages as follows: nursing stage, CP 20%, ME 3,135 kcal/kg; growing stage, CP 18.5%, ME 3,100 kcal/kg; and for sows and boars, CP 15%, ME 2,970 kcal/kg. Pregnant sows were kept in individual pens with solid floor. Feeds were restricted to 2 kg per day each and water was supplied *ad libitum*. Sows with piglets were kept in farrowing pens supplied with heating lamps. Piglets were given creep feed from 10 days of age, and were weaned at 5 weeks of age. Postweaning piglets were kept in slotted-floor pens with feed and water *ad libitum*, and were removed into growing pens with solid floor (L435×W145×H90 cm) at 11 weeks of age. At that time, they were separated by sex, and two to three pigs were kept in each pen with growing stage feed and water supplied *ad libitum*. Pigs were weighed at 150 and 180 days of age. Body conformation was evaluated at the 180 days of age. Carcass traits of the progenies from TT, DD, DT, and TD mating types were measured at 254, 223, 225, and 235 days of average age, respectively. The progeny of TT mating type were measured later than the others because they grew the slowest. Carcass data were obtained on the chilled carcass after approximately 24 h of cold storage. The cutting was done according to procedures outlined by Chen et al. (1991). Only the left side of the carcass was measured.

Traits assessed

The reproductive performances of all four mating types were assessed according to the evaluation of the total number of piglets at birth (TBN), number of piglets born alive (NBA), average birth weight (ABW), average litter birth weight (LBW), number of live piglets at 21 days (LP21), average litter body weight at 21 days (LWT21), and survival rate from birth to 21 days old (SR21). Growth performances were then evaluated by average body weights at 150 (WT150), and 180 days (WT180), average daily weight gains from birth to 150 and 180 days (ADG_{150} and ADG_{180}, respectively), and average daily weight gains from 150 to 180 days ($ADG_{150-180}$) for TT, DD, DT and TD.

The conformation characteristics assessed were: Withers height (WH): height at the shoulder; Body length (BL): distance from the middle point between the two ears at the forehead to the tail root; Chest girth (CG): circumference at the chest; Chest depth (CD): the height over the chest; Body type index (BTI): (CG+CD)/(BL+WH) (Taricenko, 1962); Average

Table 1. Data structure for investigation of performance in pig reproduction, growth and conformation of different mating types

Mating type[1]	TT	DD	DT	TD
No. of dams	14	11	14	14
Litters (parity 1-3)	18	14	21	19
No. of progeny subjected to growthperformance evaluation	40M, 29F	21M, 28F	58M, 48F	43M, 56F
No. of progeny subjected to conformation measurement	10B, 11G	7B, 10G	10B, 11G	10B, 10G
No. of progeny subjected to carcass measurement	10B, 10G	10B,10G	10B, 11G	10B, 10G

[1] The first letter represents the breed of sire, and the second letter represents the breed of dam in each mating type; T= Taoyuan, D=Duroc. M: male, F: female, B: barrow, G: gilt.

backfat thickness (ABF) estimated at three measuring points (fourth rib, the last rib and the last lumbar vertebra). The higher the BTI values were, the broader and shorter were the bodies expected to be.

The carcass data obtained were: Carcass weight (CW): the weight of slaughtered pig after the removal of the lungs, heart, liver, intestines and ancillary organs or mesentaries, bladder, reproductive organs and blood; Dressing percentage (DRESS): carcass weight/ live weight × 100; Carcass length (LENG): measured from the anterior edge of the first rib at its junction with the vertebra to the anterior edge of the aitch bone; Average backfat (BF): based on three measurements taken at the first rib, last rib and last lumbar vertebra; Loin eye area (longissimus) (LEARA): measured by a plastic grid between the 4th and 5th ribs; Lean percentage (LEAN): total lean weight/carcass weight × 100.

Statistical analysis

The genetic parameters estimated in this study were g^o=average direct genetic effects (additive effects of an individual's genes on its performance) of the offspring, g^M=maternal genetic effects (effects of genes in the dam of the individual that influence the performance of the individual through the environment provided by the dam), h^o=direct heterosis effects (the deviation between the mean of the reciprocal F1 crosses and the mean of the two parent breeds) in the crossbred progenies. Equations for the expected contributions of genetic effects on purebred T and D and their crosses were listed in table 2 (Malik, 1984). Estimations of genetic effects by mating type comparisons in which the mean of a crossbred type represents the value of the reciprocal crosses in that type are listed in table 3 (Malik, 1984). Data analysis was performed using the mixed model procedures (SAS, 1989). Genetic parameters were estimated from mating type comparisons using linear contrasts of least-square means.

The reproductive performances (TBN, NBA, LP21, SR21, ABW, LBW, and LWT21) of all dams were analyzed according to the following model:

$$Y_{ijkl}=\mu+m_i+p_j+r_k+e_{ijkl} \quad (1)$$

Where: Y_{ijkl}=the reproductive performance of the l^{th} litter in the k^{th} farrowing season at the j^{th} parity of the i^{th} mating type; μ=overall mean; m_i=fixed effect common to the i^{th} mating type; p_j=fixed effect common to the j^{th} parity, j=1, 2, and 3; r_k=fixed effect common to the k^{th} farrowing season, k=1,2,3,4. Seasons here were defined, from March through May, from June through August, from September through November, and from December through February as numbers 1, 2, 3 and 4, respectively. In the formula, e_{ijkl}=random residual error, with a mean of zero and a variance of σ_e^2.

Growth traits were analyzed by the following model:

$$Y_{ijklm}=\mu+m_i+p_j+r_k+s_l+e_{ijklm} \quad (2)$$

Where: Y_{ijklm}=the growth performance of m^{th} individual of the l^{th} sex in the k^{th} farrowing season at the j^{th} parity of the i^{th} mating type; s_l =fixed effect common to the i^{th} sex, i=1 for male, and i=2 for female; e_{ijklm}=random residual error, with a mean of zero and a variance of σ_e^2. The definition of m_i, p_j, and r_k were the same as those in model (1). In order to adjust for variation in age at weighing, a covariate for age was fitted to the model for the growth traits of TT, DD, DT and TD.

Individual conformation and carcass characteristics were analyzed according to the following model:

$$Y_{ilm}=\mu+m_i+s_l+e_{ilm} \quad (3)$$

Where: Y_{ilm}=the conformation or carcass performance of m^{th} individual of the i^{th} sex in the i^{th}

Table 2. Equations for expected contributions of genetic effects on purebred Taoyuan and Duroc and their crosses

Breed group	Genetic contribution[2]
Purebred[1]	$TT=g_T^O+g_T^M$
	$DD=g_D^O+g_D^M$
Crosses	$DT=\frac{1}{2}g_T^O+\frac{1}{2}g_D^O+g_T^M+h_{TD}^O$
	$TD=\frac{1}{2}g_T^O+\frac{1}{2}g_D^O+g_D^M+h_{TD}^O$

[1] See footnote of table 1.

[2] g_T^O = Average direct effects of the T breed.

g_D^O = Average direct effects of the D breed.

g_T^M = maternal genetic effects of T dam.

g_D^M = maternal genetic effects of D dam.

h_{TD}^O = heterosis for the crossbred progeny of T and D breed.

Table 3. Estimation of genetic effects on purebred Taoyuan and Duroc and their crosses

Mating type comparison[1]	Genetic effects[2]
$\overline{TT}-\overline{DD}+\overline{DT}-\overline{TD}$	$g_T^O-g_D^O$
$\overline{TD}-\overline{DT}$	$g_T^M-g_D^M$
$\overline{F1}-\overline{P}$[3]	h_{TD}^O

[1,2] See footnote of table 2.

[3] $\overline{P}$=(TT+DD)/2; $\overline{F1}$=(DT+TD)/2.

mating type; e_{ilm}=random residual error, with a mean of zero and a variance of σ_e^2. The definition of m_i, and s_l were the same as those in model (2). A covariate for the linear regression of Y on the body weight at measurement for the conformation performance or carcass weight at measurement of the carcass performance was added to this model.

RESULTS AND DISCUSSION

Reproductive performance

The least-square means and estimates of genetic effects on reproductive traits are shown in table 4 and 5, respectively. TT and DT mating types led to larger TBN than DD and TD ($p<0.05$), and the TBN of TD was slightly larger than that of DD ($p<0.10$), but ABW and LBW of TT and DT were lighter than DD and TD. Purebred T dams (TT+DT) farrowed larger (+3.17 pigs) but lighter (-4.67 kg) litters than purebred D dams (DD+TD) ($p<0.05$). Purebred T dams also farrowed lighter ABW piglets than D dams ($p<0.05$). ABW of piglets from T dams were about 0.80 kg, ranging from 0.54 to 1.0 kg. Some piglets of T were also lighter for survival at birth, therefore purebred T dams farrowed more stillborn piglets than D dams (2.83 vs 0.67), but the survival rates from birth to 21 days of age (SR21) of all mating types were not significantly different. LP21s from mating type of DT and TD were 1.76 head more than that of DD mating type ($p<0.05$), but were similar to that of TT mating type. These results showed that the T breed had contributed superior survival implies relative genetic effects on TBN and LP21 to the D-T hybrids and indicates it could be incorporated as a component of maternal lines in TB breeding programs in order to improve the numerical productivity of D pig. In ABW and LBW, DT was slightly lighter than DD and TD mating types ($p<0.05$). However, there was no

Table 4. Least-square means, standard errors and estimates of genetic effects on litter size traits by mating types

Mating type[1]	Litter size traits			
	TBN	NBA	LP21	SR21
TT	12.32±0.72[a]	9.05±0.66[ab]	8.42±0.63[ab]	90.03±4.25
DD	8.32±0.81[b]	8.25±0.74[a]	7.07±0.70[a]	82.48±4.30
DT	12.31±0.69[a]	9.91±0.63[ab]	9.09±0.60[b]	86.94±3.94
TD	9.97±0.73[b]	9.60±0.67[ab]	8.83±0.64[b]	90.06±4.08
Genetic Effects				
$g_T^O - g_D^O$	1.65±1.35	0.49±1.23	1.09±1.17	10.67±5.50
$g_T^M - g_D^M$	2.34±0.88**	0.31±0.80	0.26±0.76	-3.12±3.59
h_{TD}^O	0.82±0.66	1.10±0.60	1.21±0.58*	2.25±2.71

[1,2] See footnote of table 3.

TBN=total number of piglets at birth; NBA=number of piglets born alive; LP21=number of live piglets at 21 days; SR21=survival rate from birth to 21 days old. Means that do not share superscripts for a particular trait within the same column differ significantly at the 5% level. *$p<0.05$, **$p<0.01$.

Table 5. Least-square means, standard errors and estimates of genetic effects on litter weight traits by mating types

Mating type[1]	Litter weight traits		
	ABW (kg)	LBW (kg)	LWT21 (kg)
TT	0.77±0.04[a]	7.16±0.75[a]	28.70±2.66[a]
DD	1.40±0.05[b]	11.54±0.83[b]	29.12±2.97[a]
DT	0.85±0.04[a]	8.67±0.71[a]	33.92±2.54[ab]
TD	1.47±0.04[b]	13.63±0.76[c]	38.99±2.70[b]
Genetic effects[2]			
$g_T^O - g_D^O$	-0.01±0.08	0.58±1.39	4.65±4.96
$g_T^M - g_D^M$	-0.62±0.05**	-4.97±0.91**	-5.07±3.24
h_{TD}^O	0.07±0.04	1.81±0.69**	7.55±2.44**

[1,2] See footnote of table 3.

ABW=average birth weight; LBW=average litter birth weight; LWT21=average litter body weight at 21 days.

Means that do not share superscripts for a particular trait within the same column differ significantly at the 5% level. * $p<0.05$, ** $p<0.01$.

difference in case of the comparison of LWT21 performances. ABW of TD was similar to that of DD, but the LBW and LWT21 of TD was significantly larger than those of DD ($p<0.05$).

From the estimates of the maternal genetic effects, it was shown that the T females were superior in TBN ($p<0.05$), but inferior in ABW and LBW ($p<0.01$) when compared to the D females. These results suggested that T pigs were more prolific than D pigs, and their prolificacy might result from maternal effects. Chen and Wu (1991) reported that the ovulation rate of T breed was greater than that of D breed (17.1 vs 12.0). Tzeng and Lin (1992) compared fetal survival rates between T and Landrace gilts during pregnancy and found that there was no difference in the number of corpora lutea but the difference in fetal survival rate was significant ($p<0.01$) between the two breeds. They suggested that the lower rate of fetal loss in the T gilts might be associated with their prolificacy. Bidanel et al. (1990) found that the ovulation rate of Meishan pigs was with an advantage of 1.2 ova greater as compared to Large White, embryonic survival of Meishan was significantly larger than that of Large White and there were significant heterosis effects on the number of embryos and embryonic survival. They suggested that the significant heterosis effects on reproductive traits were mainly due to maternal genes. Haley et al. (1995) also found that Meishan gilts and sows had a significantly higher ovulation rate than Large White females on similar chronological ages, maternal heterosis effects were highly significant and, even at a constant ovulation rate, Meishan purebred and crossbred females would have an appreciable advantage in their litter sizes. They also confirmed that the prolificacy of Meishan pigs was largely influenced by the maternal genotype but not by the genotype of the litter itself. The direct heterosis estimates were significant for LBW (1.81 ± 0.69 kg) ($p<0.01$), LP21 (1.21 ± 0.58) ($p<0.05$) and LWT21 (7.55 ± 2.44 kg) ($p<0.01$). There were significant direct heterosis effect on ABW, LBW and LWT21 traits between the Meishan and the Large White (Bidanel et al., 1991). They also found significant maternal genetic effects on NBA, ABW, and LWT21 traits between Meishan and Large White.

Growth performance

The least-square means and estimates of genetic effects on growth traits are shown in table 6. Purebred T pigs were 29 and 43 kg lighter than the D breed at 150 and 180 days of age, respectively ($p<0.05$). D-T hybrids pigs were about 11 kg lighter than the D breed at 180 days of age and TD pigs had heavier WT180 than DT pigs. In general, the descending order of all growth traits by mating type were DD>D-T hybrids>TT ($p<0.05$). These results showed that T breed had relative negative effects on all growth traits of D-T hybrids. The direct genetic effect of mating type was significant for all growth traits ($p<0.01$). The maternal effect estimate of WT180 was significant ($p<0.01$). This result showed that the WT180 of progeny from T sows were lighter than those from D sows. Estimates of direct heterosis for WT150 (9.5 ± 1.2 kg) ($p<0.01$), WT180 (11.3 ± 1.4 kg) ($p<0.01$), ADG_{150} (0.06 ± 0.01 kg/day) ($p<0.01$), ADG_{180} (0.06 ± 0.01 kg/day) ($p<0.01$), and $ADG_{150-180}$ (0.05 ± 0.02 kg/day) ($p<0.05$) were all significant. The results showed that the D breed was superior to the T breed in all growth traits examined. Significant direct heterosis and genetic effect were also found in weights at 73 and 154 days of age and average daily weight gains from 73 to 151 days between Meishan and Large White (Bidanel et al., 1991). In these studies

Table 6. Least-square means, standard errors and estimates of genetic effects on growth traits by mating types

Mating type[1]	Growth traits				
	WT150 (kg)	WT180 (kg)	ADG_{150} (kg/day)	$ADG_{150-180}$ (kg/day)	ADG_{180} (kg/day)
TT	38.7 ± 1.3^a	48.1 ± 1.5^a	0.256 ± 0.007^a	0.311 ± 0.025^a	0.263 ± 0.008^a
DD	68.4 ± 1.8^b	91.5 ± 2.1^b	0.453 ± 0.011^b	0.756 ± 0.035^b	0.500 ± 0.011^b
DT	62.2 ± 1.5^c	79.6 ± 1.8^c	0.411 ± 0.010^c	0.059 ± 0.030^c	0.437 ± 0.010^c
TD	64.0 ± 1.7^c	82.6 ± 1.8^d	0.422 ± 0.010^c	0.598 ± 0.030^c	0.450 ± 0.010^c
Genetic effects[2]					
$g_T^O-g_D^O$	-27.9 ± 2.3**	-40.5 ± 2.7**	-0.19 ± 0.02**	-0.42 ± 0.05**	-0.22 ± 0.02**
$g_T^M-g_D^M$	-1.9 ± 1.2	-3.0 ± 1.4*	-0.009 ± 0.008	-0.028 ± 0.024	-0.013 ± 0.007
h_{TD}^O	9.5 ± 1.2**	11.3 ± 1.4**	0.06 ± 0.01**	0.05 ± 0.02*	0.06 ± 0.01**

[1,2] See footnote of table 3.

WT150=average body weight at 150 days; WT180=average body weight; ADG_{150}=average daily weight gains from birth to 150 days; ADG180=average daily weight gains from birth to 180 days; $ADG_{150-180}$=average daily weight gains from 150 to 180 days.

Means that do not share superscripts for a particular trait within the same column differ significantly at the 5% level.

* $p<0.05$, ** $p<0.01$.

using genetic polymorphisms of blood groups, serum proteins and mitochondrial DNA, a remarkable genetic difference was revealed between East Asian and the European-American pig populations (Huang, 1986; Tanaka et al., 1983; Watanabe et al., 1985, 1986). T and other Chinese pigs are of the East Asian population, while Hampshire, Landrace, D, and Large White belong to the European-American pig population (Tanaka et al., 1983; Watanabe et al., 1986). Expansion of superior breeds and a corresponding reduction of inferior breeds had been the usual method of breed utilization. Grading up or backcrossing to the superior breed is quite efficient because it utilizes the reproductive capacity of the breeds which are being displaced (Dickerson, 1973). D-T crosses could obtain further improvement on their growth performance by grading up with D boar.

Conformation and carcass performances

The least-square means of conformation traits are shown in table 7. Generally the conformation performance of the T pigs was inferior to that of the D pigs. The BTI for TT, DD, DT, and TD were 0.877, 0.741, 0.790 and 0.774, respectively. TT were shorter, lower, and fatter than the other mating types ($p<0.05$). DD had a better BTI than that of the other mating types ($p<0.05$). DD pigs also had better WH and ABF than those of the two D-T hybrids ($p<0.05$). The BL of DD type was significantly longer than that of the TT type ($p<0.05$), but this was not the case when compared to that of the D-T hybrids. The results showed that the T breed had relative negative effects on WH, BTI and ABF of D-T hybrids. The coat color of all D-T hybrids was black or dark gray and marked wrinkles did not appear on their bodies. The cloven hooves of the D-T hybrids did not touch to the ground and their backs were solid. When compared to the ideal meat type, the conformation of D-T hybrids was beyond the request of the market.

The least-square means and estimates of genetic effects on carcass traits are shown in table 8. Generally, the carcass performance of the T pigs was also inferior to that of the D pigs except the dressing percentage (DRESS) and average backfat (BF). The DRESS for TT, DD, DT and TD were 84.2, 84.9, 84.5 and 82.7, respectively; TD had a lower percentage ($p<0.05$) than DD and DT mating types. DD had a better loin eye area (longissimus) (LEARA) and lean percentage (LEAN) than the other mating types ($p<0.05$). The carcass length (LENG) of DD type was significantly longer than that of the TT type ($p<0.05$), but this was not the case when compared to that of the D-T hybrids. These results showed that the T breed had relative negative effects on LENG, LEARA and LEAN of D-T hybrids.

The direct genetic effect of mating type was significant for LENG ($p<0.01$), LEARA ($p<0.01$), LEAN ($p<0.01$), and DRESS ($p<0.05$) carcass traits. These results indicated that the D breed was superior to the T breed in LENG, LEARA, LEAN, and DRESS carcass traits. Estimates of maternal effects of DRESS, BF ($p<0.01$) and LEAN ($p<0.05$) were significant. These results showed that the progeny of D sows had larger and leaner carcasses than those from T sows. The direct heterosis estimate of LENG (4.05 ± 0.79 cm) was significant ($p<0.01$) indicating that the hybrid progeny of the T and D breeds might obtain improvement on LENG. That the heterosis effects for carcass traits are small and not significant had been reported by most researchers (Johnson, 1981). The heterosis effects for backfat were significant in Hampshire×Landrace swine (Baas et al., 1992).

The growth, body conformation performance and carcass traits of D-T hybrids were beyond the requirement of the market in Taiwan. Bidanel et al. (1991) suggested that for most markets, using the Chinese breed as grand-maternal lines will greatly improve their growth and carcass performances without impairing their reproductive merit. Estimates of direct genetic effects showed that the D breed was superior to the T breed in the growth performance, most conformation traits (WH, BL, BTI and ABF) and all carcass traits except the BF. Direct heterosis effects

Table 7. Least-square means and standard errors of conformation traits by mating types

Mating type[1]	Conformation traits					
	WH (cm)	BL (cm)	CG (cm)	CD (cm)	BTI	ABF (cm)
TT	54.1 ± 1.2^{a}	103.8 ± 1.7^{a}	101.4 ± 1.3^{ab}	35.8 ± 0.5	0.877 ± 0.014^{a}	3.44 ± 0.15^{a}
DD	69.1 ± 0.9^{b}	11.4 ± 1.4^{b}	98.7 ± 1.0^{a}	35.1 ± 0.4	0.741 ± 0.011^{b}	1.71 ± 0.12^{b}
DT	62.5 ± 0.8^{c}	110.0 ± 1.2^{b}	100.9 ± 0.9^{b}	35.5 ± 0.4	0.790 ± 0.009^{c}	2.29 ± 0.10^{c}
TD	63.9 ± 0.9^{c}	110.8 ± 1.3^{b}	99.8 ± 0.9^{ab}	35.6 ± 0.4	0.774 ± 0.011^{c}	2.49 ± 0.11^{c}

[1] See footnote of table 3.

WH=withers height; BL=body length; CG=chest girth; CD=chest depth; BTI=body type index; ABF=average backfat thickness.

Means that do not share superscripts for a particular trait within the same column differ significantly at the 5% level.

* $p<0.05$, ** $p<0.01$.

Table 8. Least-square means, standard errors and estimates of genetic effects on carcass traits by mating types

Mating type[1]	Carcass traits					
	CW (kg)	LENG (cm)	BF (cm)	DRESS (%)	LEARA (cm^2)	LEAN (%)
TT	52.8±1.5	86.3 ±1.1a	3.52 ±0.14ab	84.2±0.8ab	10.23 ±0.96a	38.3 ±1.1a
DD	87.7±1.3	96.2 ±0.7b	3.28 ±0.08a	84.9±0.5a	17.65 ±0.57b	54.3 ±0.6b
DT	84.1±1.7	94.8 ±0.6b	3.53 ±0.07b	84.5±0.4a	13.84 ±0.50c	48.3 ±0.6c
TD	85.0±1.5	95.8 ±0.6b	3.16 ±0.08a	82.7±0.4b	14.96 ±0.52c	46.6 ±0.6d
Genetic effects[2]						
g_T^O g_D^O		-9.00±1.76**	-2.40 ±1.15**	-2.40±1.15*	-6.31 ±1.47**	17.54±1.65**
$g_T^M - g_D^M$		-0.95±0.75	1.77 ±0.49**	1.77±0.49**	-1.12 ±0.63	1.62±0.71*
h_{TD}^O		4.05 ±0.79**	-0.96 ±0.52	-0.96±0.52	0.47 ±0.66	1.15±0.75

[1,2] See footnote of table 3.

CW=carcass weight; DRESS=dressing percentage; LENG=carcass length; BF=average backfat; LEARA=loin eye area (longissimus); LEAN= lean percentage.

Means that do not share superscripts for a particular trait within the same column differ significantly at the 5 % level.

* $p<0.05$, ** $p<0.01$.

were also significant for all growth traits, WH, BL, ABF, BTI, LENG ($p<0.01$). Therefore grading up of D-T hybrid gilt using prolific D boar semen or introducing a third breed should be considered for developing a new synthetic line.

CONCLUSION

Comparisons of the performance of TT, TD, DT, and DD suggested that the T breed had contributed superior genetic effects on TBN and LP21 but had negative effects on WT150, WT180, WH, BTI, ABF, LEARA and LEAN of the hybrid offspring ($p<0.05$). Estimates of maternal genetic effects showed that the T females were superior in TBN to the D females. This result suggested that the T breed was more prolific than the D breed and this prolificacy might have resulted from maternal effect. Thus, it seems worthwhile to introduce the maternal genetic effects of the T breed into the breeding program. The significant direct heterosis of growth traits, some conformation traits (WH, BL, BTI, and ABF) and LENG carcass traits suggested the potential for utilizing the genetic diversity between the T and D breeds to develop a new crossbreeding system for the production of commercial black pigs in Taiwan.

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REFERENCES

Baas, T. J., L. L. Christian and M. F. Rothschild. 1992. Heterosis and recombination effects on Hampshire and Landrace swine: II. Performance and carcass traits. J. Anim. Sci. 70:99-105.

Bidanel, J. P., J. C. Carittez and C. Legault. 1990. Ovulation rate and embryonic survival in gilts and sows with variable proportions of Meishan and Large White genes. Mean performance and crossbreeding parameters between Meishan and Large White breeds. In: Chinese Pig Symposium (Ed. M. Molenat and C. Legault). Toulouse, France. pp. 109-110.

Bidanel, J. P., J. C. Carittez and C. Legault. 1991. Ten years of experiments with Chinese pigs in France. 2. Utilisation in crossbreeding. Pig News Info. 12 : 239-243.

Chen, L. R. and M. C. Wu. 1991. Procedure for surgical collection of porcine embryos and uniformity of embryos. J. Chin. Soc. Anim. Sci. 20:175-187.

Chen, Y. S., Y. C. Wu, C. C. Ju, L. T. Yeh and Y. S. Cheng. 1991. The comparison of carcass characteristics on various pig breeds in Taiwan. J. Chin. Soc. Anim. Sci. 20:341-347.

Chou, T. C. 1987. Studies on reproductive performance of major purebred female pigs in Taiwan. Jap. J. Swine Sci. 24:13-19.

Dickerson, G. E. 1973. Inbreeding and heterosis in animals. In: Proc. Animal Breeding and Genetics Symp. In Honor of J. L. Lush., ADSA and ASAS, Champaign, IL, pp. 54-77.

Gandemer, G., V. Michele, J. C. Caritez and C. Legault. 1992. Lipid composition of adipose tissue and muscle in pigs with an increasing proportion of Meishan genes. Meat Sci. 32:105-121.

Haley, C. S., G. J. Lee and M. Ritchie. 1995. Comparative reproductive performance in Meishan and Large White pigs and their crosses. Anim. Sci. 60:259-267.

Huang, T. M. 1986. Genetic analysis of serum protein and erythrocyte enzyme polymorphism on Small-ear miniature pigs in Taiwan. Master Thesis, National Taiwan University,Taipei. pp. 84-95.

Johnson, R. K. 1981. Crossbreeding in swine: Experimental results. J. Anim. Sci. 52:908-923.

Makita, T. 1965. Report on a study of crossbreeding between Taoyuan and Berkshire breeds of swine. Dept. of Anim. Sci. College of Agri., Sizuoka Univ. Japan. p. 7.

Malik, R. C. 1984. Two breeding schemes for estimation of heterosis and recombination effects. Livest. Prod. Sci. 11:227-233.

Oishi, T. and K. Tanaka. 1992. Genetic variations of blood group and biochemical polymorphisms in seven Chinese pig breeds. Proceedings of the International Symposium on Chinese Pig Breeds. Harbin, China, pp. 192-200.

SAS Institute Inc. 1989. SAS/STAT Guide for personal computers. Release 6.11th Edition. SAS Institute Inc. Cary, NC, USA.

Tai, C., Y. C. Huang and K. S. Hsu. 1988. The prolificacy of Chinese breeds and reproduction improvement in pigs. Proceedings of the 1st Symposium on Animal Genetics and Breeding in Taiwan. pp. 87-108.

Tai, C., Y. S. Cheng, N. T. Yen, G. S. Tsai, H. L. Chang, S. C. Chyr and T. Y. Chow. 1992. The breeding of Taiwan black pigs and prolific Duroc by crossing between Taoyuan and Duroc breeds. Proceedings of the International Symposium on Chinese Pig Breeds. Harbin, China. pp. 639-644.

Tanaka, K., T. Oishi, Y. Kurosawa and S. Suzuki. 1983. Genetic relationship among several pig populations in East Asia analyzed by blood groups and serum protein polymorphisms. Anim.Blood Grps. Biochem. Genet. 14: 191-200.

Taricenko, I. I. 1962. Characteristics of conformation and the production of pigs. Anim. Breed Abstr. 32:2197 (Abstr.).

Touraille, C., G. Monin and C. Legault. 1989. Eating quality of meat from European × Chinese crossbred pigs. Meat Sci. 25:177-186.

Tzeng, C. M. and J. H. Lin. 1992. Reproductive traits in chinese Taoyuan and Landrace gilts during early pregnancy. II. Development and survival of early fetus. J. Chin. Soc. Anim. Sci. 21:357-368.

Watanabe, T., Y. Hayashi, N. Ogasawara and T. Tomita. 1985. Polymorphism of mitochondrial DNA in pigs based on restriction endonuclease cleavage patterns. Biochem. Genet. 23:105-13.

Watanabe, T., Y. Hayashi, J. Kimura, Y. Yasuda, N. Saitou, T. Tomita and N. Ogasawara. 1986. Pig mitochondrial DNA: polymorphism, restriction map orientation, and sequence data. Biochem. Genet. 24:385-96.