# Average Direct and Maternal Genetic Effects and Heterosis Effects on Body Weight in Two Subspecies of Mice

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**ABSTRACT** : Data on body weights were analyzed in the four genetic groups from all possible crosses of two subspecies of mice to estimate average direct genetic effects (ADGE), average maternal genetic effects (AMGE) and heterotic effect (HE). The genetic groups used were $CF_{\#1}$ laboratory mouse (*Mus musculus domesticus*), Yonakuni wild mouse (Yk, *Mus musculus molossinus yonakuni*) and two reciprocal $F_1$ crosses of them, CY and YC. First symbol in the reciprocal $F_1$ represent subspecies of dam. Body weight at 1 (Wk1), 3 (Wk3), 6 (Wk6) and 10 weeks of age (Wk10) were analyzed from 258 mice of the four genetic groups. The model used to evaluate body weights included main effects of genetic group and sex, and interaction effect between genetic group and sex. The ADGE and the AMGE were estimated as deviations of Yk from $CF_{\#1}$. The HE was estimated from the differences between the reciprocal $F_1$ and the midparent mean. Results of this study showed that all effects, except sex and interaction between genetic group and sex at Wk1 and Wk3, were highly significant source variation ($p < 0.01$). The ADGE were positive and highly significant ($p < 0.01$) at all ages studied for both sexes, while the AMGE were highly significant at Wk3, Wk6 and Wk10. The ADGE were larger in contributing effect on body weight differences than the AMGE. The positive value of the HE were observed at all ages for males, while for females the positive effects occured from birth through weaning.

(**Key Words:** Direct and Maternal Effects, Heterosis Effects, Body Weight, Subspecies of Mice)

## INTRODUCTION

Effective crossbreeding design is depend on information about maternal performance and heterosis effects exhibited in crossing among the breeds to enhance productivity. Information on maternal influences is obtained from the performance of offspring which partitioned into direct genetic effects and maternal effects (Robinson, 1996). Pattie et al. (1990) stated that the difference among animals can occur because they have different genes which have a direct effect on the growth of the animal (direct genetic effects). A difference in growth can also be caused by genetic difference among their mothers in characteristics which are important for growth such as milk yield (maternal genetic effects).

Crossbreeding to use heterosis in addition to combining desirable characteristics from the parent types can offer the higher level of productivity. Heterosis is defined as the difference between the reciprocal crosses of two or more breeds and the average performance of their parents breeds (Lasley, 1978; Seridan, 1981; Pattie et al., 1990). The amount of heterosis depends on the degree of genetic difference between the breed used.

There have been numerous crossbreeding experiments with mice to estimate genetic effects on weight, in which population of mice used were commonly laboratory mouse (Bakker et al., 1976; Deodato et al., 1982). No estimates of genetic effects are available for body weight in subspecies of mice. Therefore, the present study was designed to use two subspecies of mice to estimate the average direct and maternal genetic effects, and heterosis effects on body weight.

## MATERIALS AND METHODS

### Mice

The two subspecies of outbred mice used were $CF_{\#1}$ laboratory mouse (*Mus musculus domesticus*) and Yonakuni wild mouse (Yk, *Mus musculus molossinus yonakuni*). The breeding history of these two subspecies, mating system and handling animals in detail have been

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described by Kurnianto et al. (1997; 1998).

All possible crosses of two subspecies were made by matings one male and two to three females. These crosses resulted in four genetic groups, two parental types designated $CF_{\#1}$ and Yk, and two reciprocals $F_1$ crosses designated CY and YC. The first symbol in the reciprocal $F_1$ crosses represent the subspecies of dam, and the second symbol was the subspecies of sire.

At birth, litters were standardized to six mice, three males and three females as nearly as possible. Litters with four youngs were augmented to six by taking another youngs of the same genetic group, sex and age; while litters having less than three youngs were excluded in observation. Only the first litter used. Litters were weaned at three weeks of age. At weaning the mice were separated and caged based on sex with three mice per cage.

Measurements taken on the individual offspring were body weights from birth (0) to ten weeks of age with Sartorius portable (model PT-1200). Both of food pellets (CE-2, Clea Japan Inc.) and tap water were provided at all times. Room temperature was maintained at approximately 24℃ and 76% relative humidity.

### Statistical analysis

Data on body weights analyzed to estimate genetic effects were restricted at 1 (Wk1), 3 (Wk3), 6 (Wk6) and 10 (Wk10) weeks of age. All data were analyzed by use of the following model:

$$Y_{ijk} = \mu + g_i + s_j + (gs)_{ij} + e_{ijk}$$

were $Y_{ijk}$ = an observation on the $k^{th}$ mouse of the $j^{th}$ sex in the $i^{th}$ genetic group; $\mu$ = overall mean; $g_i$ = fixed effect due to $i^{th}$ genetic group (i = 1,..., 4); $s_j$ = fixed effect due to the $j^{th}$ sex (j = 1, 2); $(gs)_{ij}$ = fixed effect due to the interaction between genetic group and sex; and $e_{ijk}$ = random residual error which assumed to be normally and independently distributed (NID) with zero mean and variance $\sigma^2_e$.

Data of the four genetic groups were analyzed by General Linear Model of SAS (1990). Contrasts involving mean from the four genetic groups were used to estimate genetic effects for body weight (table 1). The estimation of genetic effects are made with a mating-type comparison. The difference in mean body weight between $CF_{\#1}$ and Yk is assumed to be caused by parental type effects (PTE) which consist of an average direct genetic effects (ADGE) and average maternal genetic effects (AMGE). A crossing effect on $F_1$ performance is generally refered to as heterosis effects (HE). The first contrast represents differences between $CF_{\#1}$ and Yk which is assumed to be differences in ADGE plus AMGE. The second contrast represents differences in ADGE. The third contrast represent differences in AMGE, and the fourth contrast represent HE.

**Table 1.** Estimation of genetic effects and linear contrasts

| Genetic effects[1] | Mating-type comparison[2] | Contrast | | | |
|---|---|---|---|---|---|
| | | Parental types | | Reciprocal $F_1$[3] | |
| | | $CF_{\#1}$ | Yk | CY | YC |
| 1. PTE | $(\overline{CF}_{\#1} - \overline{Yk})$ | 1 | −1 | 0 | 0 |
| 2. ADGE | $(\overline{CF}_{\#1} - \overline{Yk}) - (\overline{CY} - \overline{YC})$ | 1 | −1 | −1 | 1 |
| 3. AMGE | $(\overline{CY} - \overline{YC})$ | 0 | 0 | 1 | −1 |
| 4. HE | $(\overline{F}_1 - \overline{P})$ | −1 | −1 | 1 | 1 |

[1] All genetic effects were estimated between $CF_{\#1}$ and Yk; PTE; parental type effects = ADGE + AMGE; ADGE: average direct genetic effects, AMGE: average maternal genetic effects, HE: heterosis effects.

[2] Bar over designation represents its mean, $F_1$: reciprocal $F_1$, P: parental types.

[3] The first symbol in reciprocal $F_1$ represent subspecies of dam, and the second symbol represent subspecies of sire, C is abbreviation $CF_{\#1}$, and Y is abbreviation of Yk.

## RESULTS AND DISCUSSION

Table 2 presents the analysis of variance for body weight at Wk1, Wk3, Wk6 and Wk10. All effects in the model, except for sex and interaction between genetic group and sex at Wk1 and Wk3, were highly significant source of variation.

Means and standard deviations for body weight calculated for each sex within genetic group are presented in table 3. Differences in mean body weights were significant ($p < 0.05$) between all possible pairs of the four genetic groups for both sexes. Among the four genetic group, $CF_{\#1}$ was the heaviest for both male and female at all ages, whereas Yk was the lighest. The reciprocal $F_1$ were intermediate between the parental types $CF_{\#1}$ and Yk. Clearly, genetic group ranking for body weight at all ages examined was $CF_{\#1}$ > CY > YC > Yk for both sexes. Among the possible reasons for differences in body weight performance among the genetic groups are additive direct and maternal genetic effects, and direct heterosis effects contribute to the

**Table 2.** Analysis of variance for body weight from the parental types and reciprocal $F_1$ of mice

| Source of Variation | DF[2] | Mean Squares[1] | | | |
|---|---|---|---|---|---|
| | | Wk1 | Wk3 | Wk6 | Wk10 |
| Genetic group | 3 | 104.17** | 531.28** | 3,822.74** | 5,290.98** |
| Sex | 1 | $0.02^{NS}$ | $7.68^{NS}$ | 1,383.70** | 2,243.64** |
| Genetic group × Sex | 3 | $3.21^{NS}$ | $6.94^{NS}$ | 97.55** | 127.32** |
| Error | 250 | 1.05 | 4.51 | 5.41 | 8.36 |

[1] Wk1, Wk3, Wk6 and Wk10 represent 1, 3, 6 and 10 weeks of age, respectively.
[2] Degree of Freedom.
[NS] Non significant ($p > 0.05$).
** Significant at $p < 0.01$.

**Table 3.** Means and standard deviations for body weight in the parental types and reciprocal $F_1$ of mice

| Items | Sex[1] | N[2] | Body weight (g) | | | |
|---|---|---|---|---|---|---|
| | | | Wk1 | Wk3 | Wk6 | Wk10 |
| Parental types | | | | | | |
| $CF_{\#1}$ | M | 45 | $6.12 \pm 0.80^{a,p}$ | $14.34 \pm 2.53^{a,p}$ | $34.80 \pm 2.95^{a,p}$ | $41.17 \pm 3.29^{a,p}$ |
| | F | 45 | $5.92 \pm 0.83^{h,p}$ | $13.23 \pm 2.23^{h,p}$ | $27.11 \pm 2.06^{h,q}$ | $31.57 \pm 3.18^{h,q}$ |
| Yk | M | 18 | $2.89 \pm 0.72^{d,p}$ | $6.18 \pm 0.78^{d,p}$ | $11.51 \pm 2.42^{d,p}$ | $14.16 \pm 3.41^{d,p}$ |
| | F | 18 | $2.84 \pm 0.76^{k,p}$ | $6.05 \pm 0.99^{k,p}$ | $10.53 \pm 1.51^{k,q}$ | $12.25 \pm 1.87^{k,q}$ |
| Reciprocal $F_1$ | | | | | | |
| CY | M | 42 | $5.02 \pm 1.46^{b,p}$ | $12.14 \pm 2.29^{b,p}$ | $24.73 \pm 2.66^{b,p}$ | $28.61 \pm 3.18^{b,p}$ |
| | F | 42 | $5.01 \pm 1.23^{i,p}$ | $11.82 \pm 1.98^{i,p}$ | $19.38 \pm 1.97^{i,q}$ | $21.30 \pm 2.43^{i,q}$ |
| YC | M | 23 | $4.21 \pm 1.02^{c,p}$ | $10.58 \pm 2.49^{c,p}$ | $22.60 \pm 1.97^{c,p}$ | $26.80 \pm 2.45^{c,p}$ |
| | F | 25 | $3.81 \pm 0.80^{j,p}$ | $9.76 \pm 1.89^{j,p}$ | $16.76 \pm 2.18^{j,q}$ | $19.62 \pm 2.29^{j,q}$ |

[1] M = male, F = female.
[2] The number of mice used.
[a,b,c,d] Means among genetic groups of male at the same age with different superscript are significantly differ at $p < 0.05$.
[h,i,j,k] Means among genetic groups of female at the same age with different superscript are significantly differ at $p < 0.05$.
[p,q] Means between sexes within genetic group at the same age with different superscript are significantly differ at $p < 0.01$, except for Yk which are significantly differ at $p < 0.05$.

performance. As shown in table 3, the within genetic group comparison revealed that males were significantly ($p < 0.05$ - $p < 0.01$) heavier than females at Wk6 and Wk10, and nonsignificant ($p > 0.05$) at Wk0 and Wk3. Sex differences in this study were in agreement with those reported by Shinjo (1974). In beef cattle, Dillard et al. (1980) reported that males were heavier than females at birth weight, daily gain and weaning weight.

By use of data from table 3, paternal type effects (PTE), avarage direct genetic effects (ADGE), average maternal genetic effects (AMGE) and heterosis effects (HE) for body weight between $CF_{\#1}$ and Yk were evaluated. The result of linear contrasts of these effects are presented in table 4. For this procedure, comparison in body weights between these two subspecies were computed as deviations from $CF_{\#1}$. Contrast 1 showed that PTE values were positive at all ages studied for both sexes ($p < 0.01$). This means that the $CF_{\#1}$ body weights were heavier than the Yk. These differences were partitioned into differences due to ADGE (contrast 2) and AMGE (contrast 3).

Contrast 2 showed that the ADGE were positive and highly significant at all age examined for both sexes, whereas contrast 3 showed that the AMGE was highly significant at all ages with exception to Wk1. Moreover, these contrasts revealed that the ADGE were larger in contributing effects on body weight difference between $CF_{\#1}$ and Yk than the AMGE, 74.92 vs 25.08% and 61.04

**Table 4.** Linear contrasts for PTE, ADGE, AMGE and HE on body weight between two subspecies of $CF_{\#1}$ and Yk mice

| Week(s) | Sex | PTE | ADGE | AMGE | HE[1)] | |
|---|---|---|---|---|---|---|
| | | | | | Unit | % |
| Wk 1 | M | 3.23** | 2.42** | 0.81$^{NS}$ | 0.11$^{NS}$ | 2.44 |
| | F | 3.08** | 1.88** | 1.20$^{NS}$ | 0.03$^{NS}$ | 0.68 |
| Wk 3 | M | 8.16** | 6.60** | 1.56** | 1.10$^{NS}$ | 10.72 |
| | F | 7.18** | 5.12** | 2.06** | 1.15$^{NS}$ | 11.93 |
| Wk 6 | M | 23.29** | 21.16** | 2.13** | 0.51$^{NS}$ | 2.20 |
| | F | 16.58** | 13.96** | 2.62** | −0.75$^{NS}$ | −3.99 |
| Wk10 | M | 27.01** | 25.20** | 1.81** | 0.04$^{NS}$ | 0.15 |
| | F | 19.32** | 17.64** | 1.68** | −1.45$^{NS}$ | −6.62 |

$^{NS}$ Non significant ($p > 0.05$).

** Significant at $p < 0.01$.

[1)] Unit of heterosis effects are estimated as $(\bar{F}_1 - \bar{P})$, and percentage of heterosis effects are estimated as $[(\bar{F}_1 - \bar{P}) / \bar{P}] \times 100\%$ in which P: parental types and $F_1$: reciprocal $F_1$.

vs 38.96% at Wk1, 80.88 vs 19.12% and 71.31 vs 28.69% at Wk3, 90.85 vs 9.15% and 84.20 vs 15.80% at Wk6, 93.30 vs 6.70 and 91.30 vs 8.70% at Wk10 for males and females, respectively. These results agree with those reported by Bakker et al. (1976) who used two selected lines ($H_6$ and M16) and two respective control lines ($C_2$ and ICR). The $H_6$ and M16 populations were selected for increased 6-week body weight and 3- to 6-week postweaning gain, respectively. Bakker et al. (1976) observed that the ADGE were by far the major factors responsible for the selection response difference between the selected line on body weight at three and six weeks of age, and gain from three to six weeks of age. Nagai et al. (1976) conducted and experiment to examine the portion of the direct or correlated response to long-term selection for increased growth rate in two populations of mice. It has been reported by Nagai et al. (1976) that selection response was primarily due to ADGE while the contribution of AMGE was secondary importance.

The positive AMGE values observed in this study therefore suggested that $CF_{\#1}$ dam possible provided more milk and other maternal ability to growth into offspring than that of Yk dam. Maternal effects have shown an important role in the farm animals, e.g. sheep (Bradford, 1972), beef cattle (Koch, 1972), swine (Robison, 1972), and dairy cattle (Robison et al., 1981).

Heterosis is the name given to the increased vigor of the offspring over that of the parents when unrelated individuals are mated. Contrast 4 accommodated a test of heterosis effects. The estimate of heterosis for crossing between these two subspecies were expressed as unit and as percentage obtained from deviations of average reciprocal $F_1$ crosses from the average of parental types. Heterosis effects for males were positive observed at all age examined. For females, the negative heterosis effects were observed after weaning. These results indicated that the heterosis effects on body weights occured at all age studied for males, but only evidenced through weaning for females. Negative heterosis effects observed in females for postweaning were due to the smaller weight attained by the reciprocal $F_1$ crosses than by their parental types (table 3).

It seems probably that there is no single explanation of heterosis but that dominance, whether partial or complete, and all type of genetic interaction combined in different situation result in heterosis (Bowman, 1959). Experimental evidence of McGloughlin (1980) on mouse was supportive of the dominance model. By crossing and repeated backcrossing in both direction using two unrelated strains of mice, females were produced which were 25, 50, 75 and 100% heterozygous. The crossbred females, as well as purebreds of both strains were mated to a sire line of a genetically distinct strain in order to standardize offspring heterosis. A significant positive relationshiop was found between performance and heterozygosity for several traits.

The patterns of ADGE, AMGE and HE from birth to ten weeks of age are shown in figure 1 for male and figure 2 for female. As shown in the two figures, the ADGE tended to increase with age, but the AMGE showed small value and relatively stable at all ages after birth. These large ADGE values observed were due to different genes between these two subspecies which have a direct effects on growth. HE showed the small values and decreased after weaning.

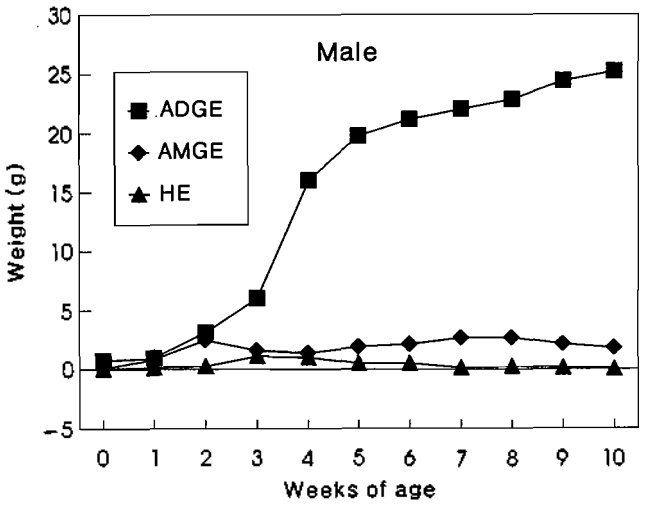


**Figure 1.** The patterns of ADGE, AMGE and HE from birth to ten weeks of age in male.

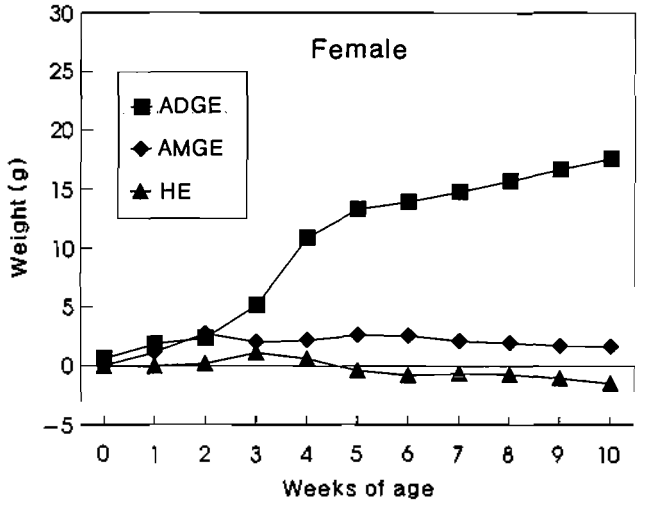


**Figure 2.** The patterns of ADGE, AMGE and HE from birth to ten weeks of age in female.

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