International Journal of Research in Agricultural Sciences
Volume 1, Issue 1

Estimation of Heterosis, Direct and Maternal Additive Effects from Crossbreeding Experiment Involving Two White Plymouth Rock Lines of Chickens

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***Abstract* — Eight hundred one-day-old female chickens from two White Plymouth Rock lines (line L and line K) and their reciprocal crosses obtained from 40 male and 480 females were used to form four genetic groups (LxL, KxK, LxK and KxL). The aim of this study was to investigate the differences among obtained genotypes, the direct and maternal additive effects and the heterosis with regard to the following traits: body weight from 2 to 10 weeks of age and at 18, 26 and 30 weeks of age, age at sexual maturity, egg production per hen-day until 46 weeks of age, average egg weight (between 32 and 46 weeks of age), liveability during the production period, egg fertility, hatchability of set and fertile eggs. The additive genetic model of Dickerson using crossbreeding program was used to determine the crossbreeding effects. The results demonstrated a statistically significant effect of the genotype on body weight during the different age periods ($p<0.001$), age at sexual maturity ($p<0.001$), egg production ($p<0.01$) and livability ($p<0.05$). On the basis of analysis of direct additive effects, it could be concluded that line L was superior for obtaining combinations with more intensive growth rate. Although the lack of direct additive effect with respect to the other traits studied, there was a positive tendency favouring line K. Maternal additive effects had a substantial effect on body weight in most studied periods and livability, favouring line L. The heterosis was important for body weights at different periods of life (3.76-22.33 %), age at sexual maturity (-8.32 %) and egg production (8.25 %) with positive effects on these traits. The results pointed at a mutual complementary effect between both lines as a result of crossbreeding.**

***Keywords* – Crossbreeding Hens, Direct Additive Effect, Heterosis, Maternal Additive Effect**.

I. Introduction

Crossbreeding results in alteration of genetic variance and allows combining the valuable traits of parent lines in their progeny. An objective evaluation of the value of a given strain and its exact place in combinations is performed on the basis of diallel cross experiments. The analysis of results contributes to establish the combinations with one or more heterotic traits (Saadey *et al., 2008*). From a theoretical point of view, the hybrid vigor is inversely proportional to the extent of genetic similarities between parental populations (Wilham and Pollak, 1985) and it is expected to be proportional to the extent of heterozygocity of crosses (Sheridan, 1981). Thus, heterosis results from non-additive genetic effects and is usually higher for reproduction rather than growth traits. It is influenced by maternal effects (Lui *et al.*, 1995), which are higher in cases with small heterosis (Fairfull *et al.*, 1983). According to some researchers (Fairfull and Gowe, 1990; Abou El-Ghar *et al.*, 2003; Abou El-Ghar and Abdou, 2004) the anticipated dominant effect is high for egg production traits, while others affirm that the additive effect is markedly higher than the dominant effect (Szydlowski and Szwaczkowski, 2001; Abou El-Ghar, 2009). It is shown that the main mechanism of heterosis in poultry is epistasis; this is supported by evidence provided by Sheridan (1980) and Fairfull *et al.* (1985, 1987). Iraqi *et al.* (2005) believes that in most cases, hybrid vigor due to the epistatic effect of genes was hard to be predicted, as the number of type of interactions are usually unknown and could be affected by dominance. Testing various combinations of available lines is the essence of breeding programmes in poultry farming. In the view of Wolf and Knizetova (1994) the determination of crossbreeding effects is of great significance. The characterization of genetic and maternal effects related to each strain or combination contributes to improvement of production. That is why, the present study aimed at determination of the direct additive effect, maternal additive effect and heterosis of most important economic traits – body weight, age at sexual maturity, egg production, egg weight, livability, egg fertility and egg hatchability after crossing two White Plymouth Rock lines, which would be used as maternal form for production of three-way crosses for broiler production.

II. Materials and Methods

A. Breeding plan and management

The tests on line combinations were carried out in the Selection Base of the Poultry Breeding Unit at the Agricultural Institute of Agriculture – Stara Zagora in 2010-2011. A total of 480 chickens from the K and L lines (240 from each line) were distributed in 40 pens with sex ratio of 1:12 and wood shavings litter. At 48 weeks of age, hens from each line were divided in two equal groups (120 birds each). The first group was mated with roosters from the same line whereas the second, with roosters of the alternative line to obtain reciprocal crosses. Eggs from the four genetic groups – L♂xL♀, K♂xK♀, L♂xK♀ and K♂xL♀ were collected on a daily basis and incubated in the same incubator. After determination of the sex of one-day-old chickens using a sexascope, 200 female chickens were wing banded depending on their genetic group. The different genotypes were reared in equal conditions, in the same premise on deep permanent litter according to technological requirements for housing and feeding up to 18 weeks of age, used in the Selection Base. After 18 weeks of age, the birds were housed 12 in a breeding pen on deep permanent litter, with equal main technological parameters – density, feeding and drinking width. Until 2 weeks of age, chickens were fed ad libitum, and thereafter - according a restriction schedule with weekly daily ration according to the age. During the different age periods, the content of rations was as followed: prestarter – 19 % CP, 2900 kcal/kg ME, starter – 17 % CP, 2800 kcal/kg ME, grower – 15 % CP, 2700 kcal/kg ME and egg production period – 16 % CP, 2750 kcal/kg ME.

B. Data and statistical analysis

The following parameters were monitored during the experimental period; egg fertility, egg hatchability from eggs set and fertile eggs in %, body weight – per fortnight basis between 2 and 10 weeks of age, and at 18, 26 and 30 weeks of age, age at sexual maturity – when reaching 50% egg production for each group, egg production per hen-day until 46 weeks of age, average egg weight (by weighing eggs laid every day at 2-week intervals between 32 and 46 weeks of age), liveability during the production period. The analysis of data was performed with Statistica software (Stat Soft), using one-way analysis of variance and the following statistical model:

$$Y_{ij} = \mu + g_i + e_{ij} \quad (1)$$

where *Yij* – j^{th} observation of the respective trait, μ - general mean of the trait, g_i – fixed effect of the i^{th} genotype (i=1-4), e_{ij} – random effect of non-observed factors. The LSD-test was used for estimation of mean values with statistically significant differences at p<0.05.

C. Genetic analysis

Crossbreeding parameters – direct additive effect (G^I), maternal additive effect (G^M) and heterosis (H^I) were analysed by means of Software Package CBE (*Wolf, 1996*) following the model of Dickerson (1969):

$$y_{ij} = \mu + \frac{1}{2}g_i + \frac{1}{2}g_j + m_j + \delta . h_{ij} + e_{ij} \quad (2)$$

where μ - general mean, g_i – direct genetic effect of the i^{th} purebred population, m_j – maternal effect of the j^{th} purebred population, δ=0 for purebreds and 1 for crossbreds, h_{ij} – heterosis of the combination i x j, e_{ij} – residual effect

III. RESULTS AND DISCUSSION

Means of genetic groups

The comparison of body weights of initial lines L and K (Table I) showed statistically significant differences until 10 weeks of age with higher values for the former line. The changes of this trait with age changes the level of significance and between-strain difference at 30 weeks of age were already insignificant – both lines had an almost equal body weight. The monitoring of this trait in crossbreds showed that by 2 and 4 weeks of age, the body weight of LxK chickens was higher that of the reciprocal combination and purebreds, but at 26 and 30 weeks of age, the highest body weight was established in KxL crosses (p<0.05). Straightbred and reciprocal crosses attained sexual maturity at an earlier age and began laying eggs at 203–206 days of age (p<0.05). The differences between breeder lines were however insignificant. The comparison of egg production showed that it was the highest in the KxL combinations (77.36 eggs), with statistically significant difference vs both parental lines (p<0.05), but not vs the reciprocal LxK. Maternal and paternal lines did not differ considerably with respect to this trait. Eggs of hens from the K line were heavier than those laid by line L (p<0.05) and KxL crosses. Both combinations had similar weights of their eggs, comparable to those of line K. The livability during the production cycle was the highest for pure lines and KxL crossbreds, and the lowest – in LxK (p<0.05) – 88.42 %. Data about eggs incubation traits presented in Table 1 demonstrates that the fertility percentages of pure lines and crossbreds did not differ substantially. The fertility was slightly although insignificantly higher in LxK chickens. Hatchability from eggs set and fertile eggs was higher in line K compared to line L (p<0.05), but no statistically significant difference could be found either between combinations or vs. pure lines.

Direct additive effects (G^I)

The estimates of direct additive effects (Table II) for body weight up to 10 weeks of age were positive and highly significant (p<0.01) for line L. Presented as percentage of pure line means, they varied from 4.89 to 15.23%. Iraqi *et al.* (2011) reported that additive genes had a positive effect on growth with estimates on body weight between 2.22 and 10.4% from 1 to 10 weeks of age. At 26 weeks of age, the values were negative, statistically significant (p<0.01) and superior in line K. The direct additive effect on body weight was probably due to the fact that this trait is characterised with high inheritance and has further an additive pattern. The age at sexual maturity, egg production, egg weight, livability, fertility and hatchability were not influence by additive effects. In their study, Razuki and Al-Shaheen (2011) did not report considerable additive effects on the age at sexual maturity and egg production, whereas substantial effects were observed for egg weight.

Maternal additive effects (G^M)

Maternal additive effects presented in Table III had negative values and were significantly (p<0.01) different for body weights at 2 and 4 weeks of age (- 6.11 % and - 2.94 %, respectively) meaning that the combination with line K as maternal line had a higher body weight. A highly significant positive maternal effect was observed at 8, 26 and 30 weeks of age varying between 2.15 and 5.24 % (p<0.01) in favour of line L. According to Barbato and Vasilatos-Younken (1991) combinations have a different body weight with respect to used maternal and paternal strains in breeding schedules. The same researchers established that the maternal effect in chickens changed with time and its considerable influence at a later age could be due to endoplasmatic inheritance which plays a role for the manifestation of the specific maternal effect between the strains. With respect to the other studied traits, maternal additive effects were not statistically significant except for livability (p<0.01). The estimates were negative and low for age at sexual maturity, egg weight, fertility of eggs, hatchability and ranged between - 0.56 and -2.11 % and were positive for egg production (1.89 %) and livability (3.36 %). The lack of maternal effects on egg production and egg weight agrees with the data of Iraqi (2008) and Razuki and Al-Shaheen (2011), while others emphasized on a substantial maternal effect on age at sexual maturity and egg production (Khalil *et al.*, 2004; Iraqi *et al.* 2007*)*. Maternal additive effects have contributed to higher livability of crossbred chickens with L strain as maternal line over the production cycle. In general, the analysis of maternal additive effects on age of sexual maturity and egg production revealed again a trend towards superiority of the L strain, whereas the progeny of the K strain as maternal line tended to have higher egg weight, and higher egg fertility and hatchability percentages.

Direct heterosis (H^I)

The data about the effect of heterosis shown in Table IV showed statistically significant values for body weights during the different studied ages. The heterosis effect on body weight was positive and varied from 3.76 to 22.33 %, and was the most obvious at the age of 6 weeks. Lamont and Deeb (2001) reported that the hybrid vigor with respect to body weight depended on age, while according to Williams *et al.* (2002) its power is variable and estimates could be positive or negative. Most studies provided evidence about positive hybrid vigor during the different life periods *(*Sabri and Hataba, 1994; Khalil *et al.*, 1999; Sabri *et al.*, 2000, Razuki and Al-Shaheen, 2011). The possible cause are non-additive genetic effects – dominance, overdominance and epistasis, which, together with maternal effect contributed to improved growth potential of crosses (Fairfull, 1990). The hybrid vigor with respect to age of sexual maturity was also proved, but was negative and beneficial as the time for attaining sexual maturity of crosses decreased by about 19 days or 8.32% (p<0.01). Some authors (Bordas *et al*, 1996; Mohammed, 1997; Williams *et al.,* 2002) outlined that heterosis estimates for the age of sexual maturity varied between -25 and 11.5 %. The calculated heterosis for egg production and egg fertility were positive, but a statistically significant heterosis effect was established only for egg production – 8.25 % (p<0.01). Negative and insignificant heterosis estimates were observed for egg weight, livability, hatchability from eggs set and fertile eggs. The data of Iraqi *et al.* (2007) reported hybrid vigor values between -22.2 and 20.1 %. Saadey *et al.* (2008) reported that breeding White Leghorn (WL) roosters and Rhode Island (RIR) hens with Fayoumi chickens did not result in higher egg weight and egg production, and pointed at negative values of heterosis for these traits – 3.82 and –3.15 % for the combination WLxF, -2.18 and -15.6 % for RIRxF. The estimated heterosis for egg weight in our study was comparable to the value obtained by Bais *et al.* (2008), i.e. -1.83 %. According to Abou El- Ghar *et al.* (2010) the negative heterosis could be to the epistasis effect of genes of original strains. After crossbreeding of 24 Leghorn strains Fairfull (1990) found out that the hybrid vigor for livability varied from -6.1 % to 9.1 %. The lack of heterosis effect on fertility and hatchability of eggs was also established by El-Gendy (2000), although Hossari and Dorgham (2000) reported heterosis for egg fertility of 2.73 % in two-line and 3.04 % in three-line crosses and outlined the presence of heterosis effect on hatchability in two-line crosses only.

IV. Conclusion

The results demonstrated a statistically significant effect of the genotype on body weight during the different periods of life (p<0.001), age at sexual maturity (p<0.001), egg production (p<0.01) and livability (p<0.05). On the basis of analysis of direct additive effects, it could be concluded that line L was superior for obtaining combinations with more intensive growth rate. Although the lack of evidence for a direct additive effect with respect to the other traits studied, there was a positive tendency favouring line K.

Maternal additive effects had a substantial effect on body weight in most studied periods and livability, favouring line L. The heterosis was important for body weights at different periods of life (3.76-22.33 %), age at sexual maturity (-8.32 %) and egg production (8.25 %) with positive effects on these traits.

The results pointed at a mutual complementary effect between both lines as a result of crossbreeding.

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Table I: Means and standard error (SE) for body weight, productive and hatchability traits in purebred and crossbred chickens

Traits	Genetic groups^				Significance
	L x L	K x K	L x K	K x L	
Body weight (g):					
- at 2 wk	251.16±1.67 b	209.18±1.71d	266.66±3.52 a	238.54±3.36 c	***
- at 4 wk	563.16±3.07 b	476.42±2.89 c	591.95±6.49 a	561.34±6.86 b	***
- at 6 wk	894.99±5.27 b	719.06±5.35 c	985.94±8.41 a	988.61±8.59 a	***
- at 8 wk	1138.34±5.51 a	959.59±6.06 c	1077.82±9.61 b	1153.95±11.61 a	***
- at 10 wk	1358.56±6.82 a	1053.35±6.44 c	1322.36±11.92 b	1298.75±13.58 b	***
- at 18 wk	1912.03±11.59 b	1903.35±11.88 b	1994.21±19.72 a	1964.81±20.02 a	***
- at 26 wk	2456.60±16.93 c	2583.19±23.28 b	2643.82±27.57 b	2908.13±35.10 a	***
- at 30 wk	3083.71±22.50 bc	3010.45±25.09 c	3152.66±27.41 b	3283.78±32.97 a	***
Age at sexual maturity (day)	222.30±1.56 a	223.82±2.86 a	206.00±0.89 b	203.00±1.35 b	***
Eggs per hen-day	70.38±1.49 b	69.07±2.26 b	73.59±1.60 ab	77.36±1.65 a	**
Av. egg weight (g)	63.28±0.72 b	65.23±0.67 a	63.55±0.49 ab	62.82±0.58 b	ns
Livability (%)	95.05±1.19 a	91.18±2.08 ab	88.42±1.71 b	95.14±1.27 a	*
Fertility (%)	84.52±3.92	88.60±1.96	91.00±1.46	88.83±2.36	ns
Hatchability (%):					
- fertile eggs	74.95±3.76 b	83.39±2.31 ac	80.33±1.86 bc	77.00±2.44 bc	ns
- set eggs	87.68±2.58 b	93.87±0.97 ac	88.28±2.85 bc	86.68±1.53 b	ns

^ - for each genetic group, the sire line is the first presented; Means with different letters on the same row differ significantly ($p<0.05$); * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$; ns=non-significant

Table II: Estimates of direct additive effects (G^I) and their percentages for body weight, productive and hatchability traits

Traits	G^I_L±S.D.	G^I_L%	Significance
Body weight (g):			
- at 2 wk	35.05±2.71	15.23	**
- at 4 wk	58.67±5.17	11.29	**
- at 6 wk	86.63±7.09	10.73	**
- at 8 wk	51.31±8.58	4.89	**
- at 10 wk	164.41±10.18	13.63	**
- at 18 wk	19.04±16.32	1.00	ns
- at 26 wk	-195.45±26.56	-7.76	**
- at 30 wk	-28.93±27.27	-0.95	ns
Age at sexual maturity (day)	0.74±1.82	0.33	ns
Eggs per hen-day	-1.23±1.78	-1.76	ns
Av. egg weight (g)	-0.61±0.62	-0.95	ns
Livability (%)	-1.43±1.60	-1.54	ns
Fertility (%)	-0.96±2.59	-1.11	ns
Hatchability (%):			
- fertile eggs	-2.55±2.69	-3.22	ns
- set eggs	-2.30±2.12	-2.31	ns

$G^I_{K} = -G^I_L$; ns=non-significant; ** = $p<0.01$

Table III: Estimates of maternal effects (G^M) and their percentages for body weight, productive and hatchability traits

Traits	G^M_L±S.D.	G^M_L%	Significance
Body weight (g)			
- at 2 wk	-14.06±2.43	-6.11	**
- at 4 wk	-15.30±4.72	-2.94	**
- at 6 wk	1.34±6.01	0.17	ns
- at 8 wk	38.07±7.54	3.63	**
- at 10 wk	-11.81±9.03	-0.98	ns
- at 18 wk	-14.70±14.05	-0.77	ns
- at 26 wk	132.16±22.32	5.24	**
- at 30 wk	65.56±21.44	2.15	**
Age at sexual maturity (day)	-1.50±0.81	-0.67	ns
Eggs per hen-day	1.89±1.15	2.71	ns
Av. egg weight (g)	-0.36±0.38	-0.56	ns
Livability (%)	3.36±1.07	3.61	**
Fertility (%)	-1.09±1.39	-1.26	ns
Hatchability (%):			
- fertile eggs	-1.67±1.53	-2.11	ns
- set eggs	-0.80±1.62	-0.88	ns

$G^M_{K} = -G^M_L$; ns=non-significant; ** = $p<0.01$

Table IV: Estimates of heterosis effects (H^I) and their percentages for body weight, productive and hatchability traits

Traits	H^I±S.D.	H^I%	Significance
Body weight (g):			
- at 2 wk	22.43±2.71	9.74	**
- at 4 wk	56.85±5.17	10.94	**
- at 6 wk	180.25±7.09	22.33	**
- at 8 wk	66.92±8.58	6.38	**
- at 10 wk	104.60±10.18	8.67	**
- at 18 wk	71.82±16.32	3.76	**
- at 26 wk	256.08±26.56	10.16	**
- at 30 wk	171.14±27.27	5.62	**
Age at sexual maturity (day)	-18.56±1.82	-8.32	**
Eggs per hen day	5.75±1.78	8.25	**
Av. egg weight (g)	-1.07±0.62	-1.67	ns
Livability (%)	-1.34±1.60	-1.44	ns
Fertility (%)	3.36±2.59	3.88	ns
Hatchability (%):			
- fertile eggs	-0.51±2.69	-0.64	ns
- set eggs	-3.29±2.12	-3.62	ns

** = $p<0.01$; ns=non-significant;