Heterotic and genetic components in 4x4 diallel mating experiment for egg production traits in chickens

By

Iraqi[*], M.M., Afifi[*], E.A., El-Labban[**], A.M. and Afram[**], M.

[*]*Faculty of Agriculture, Moshtohor, Benha University, Egypt*
[**]*Animal Production Research Institute, Ministry of Agriculture, Dokki, Cairo, Egypt*
iraqi@yalla.com

Abstract

Two local breeds, namely Fayoumi (F) and Dandarawi (D) and two exotic ones named Rhode Island Red (R) and White Leghorn (L) were used in 4x4 diallel cross mating system. Thirty-two breeding pens were used. Two sires were mated to 16 dams in each breeding pen. Progeny of F_1 of all breed groups (16 groups) were produced in two hatches within one year. Records of 587 hens were used to estimate general combining ability (GCA), heterosis, specific combining ability (SCA), maternal ability (MA) and reciprocal or sex-linked (SL) effects on productive traits [age at sexual maturity (ASM), body weight at sexual maturity (BWSM), egg production during the first 90-days (EP90D) and total egg production (TEP)]. A simple additive genetic model using crossbreeding program was used to determine the crossbreeding effects responsible for the differences among breeding groups.

Results showed that F hens had the earliest ASM (190.8 d) over all purebreds, followed by L (200.4 d). Purebred of R gave the highest BWSM, EP90D and TEP traits. Differences between means for productive traits of exotic and native breeds were significant (P<0.05). Average of crossbreds gave the earlier ASM than purebreds. Most of heterotic effects were highly significant (P<0.01) on ASM, BWSM traits, while it was significant (P<0.05) effect of D breed only on EP90D and non-significant for TEP. Crossbreds of LxF, FxL, DxR and LxR gave the highest heterosis for ASM, BWSM, EP90D and TEP, respectively. The percentages of heterotic effects came from these crosses were 6.1, 6.9, 18.4 and 20.1%, respectively. Significant (P<0.05 or 0.01) differences between purebreds for the effects of GCA, MA, SCA and SL were obtained on most the studied traits. The F breed gave the lowest (P<0.01) and negative effect of GCA on ASM, while D had superior MA for the same trait. The R had superior estimates (P<0.05 or 0.01) for GCA and MA in BWSM and TEP traits. Clearly, the RxF and LxD crosses gave the lowest (P<0.01) negative estimates of SCA for ASM trait compared to the other crossbreds. The RxD gave the highest (P<0.01) positive estimates of SCA for traits of BWSM and TEP. The RxF and RxD crosses had superior (P<0.05 or 0.01) SL effects for BWSM and EP90D traits, respectively.

From the previous results, it could be concluded that R sires (as an exotic breed) and F and/or D dams (as a native breed) would be selected to produce birds with earlier ASM and higher egg production in Egypt through crossbreeding programs.

Key words: Direct genetic effect**,** heterosis, specific combining ability, maternal effect, purebreds, sex-linked effect and egg production traits.

INTRODUCTION

Diallel cross is the most appropriate breeding scheme for drowing inferences with respect to gene actions involved in the inheritance of a trait. The knowledge of nature and magnitude of genetic variation helps in improvement through identifying superior nicking genetic group/groups. Importance of various combining ability effects in poultry have been shown by various workers (Fairful et al., 1983; Singh et al., 1983 and Gupta et al., 2000). In Egypt, some workers (Hanafi et al., 1991; Mohammed, 1997; Nawar and Abdou, 1999; Sabri et al., 2000; Afifi et al., 2002; Iraqi et al., 2005) crossed native breeds or strains of chickens with exotic adapted ones under Egyptian conditions to improve growth traits in broilers. Most of these reports evidenced that crossing local breeds with either local or exotic ones was associated with the existence of heterotic effects, because native chicken breeds had high non-additive genetic variance (Shebl et al., 1990; Hanafi et al., 1991; Sabri et al., 2000). This would encourage the Egyptian breeders to improve local breeds through crossbreeding. Few reports are applied in Egypt to improve egg production traits by diallel crossing.

Nowadays, we need more workers for crossing Egyptian native breeds with exotic ones to determine the superior breeds, gains in performance from complementary breed effects and heterosis and to develop the superior new breeds through selecting the best combinations of several breeds. On the other hand, ignoring any source of variation (genetic or non-genetic effects) in the model would increase the sampling errors in genetic parameters (Dickerson, 1992). Some previous studies (e.g. Hanafi et al., 1991; Mohammed, 1997) ignored heterotic and purebred effects in the genetic model. This might increase biased in estimates of genetic parameters. Therefore, all sources of variation should be considered in the genetic model (Eisen et al., 1983).

The objectives of this work were to: (1) evaluate genetically traits of egg production in 4x4 diallel mating system among two local (Fayoumi and Dandarawi) and two exotic (Rhode Island Red and White Leghorn) breeds, (2) identify superior genetic groups based on single crosses, (3) evaluate heterotic effect and heterosis from each purebred if used and (4) estimate of genetic components (general and specific combining abilities, maternal ability and reciprocals or sex-linked effects) for egg production traits.

MATERIALS AND METHODS

Breeding plan and management

This study was carried out at El-Qanater Poultry Research Station, Animal Production Research Institute, Ministry of Agriculture, Egypt. Two local breeds namely Fayoumi (F) and Dandarawi (D) and two exotic ones named Rhode Island Red (R) and White Leghorn (L) were used in 4x4 diallel mating system.

All possible purebreds (4 groups) and crossbreds (12 groups) were made among the four breeds. Thirty-two breeding pens were used. In each breeding pen, two sires were mated to 16 dams to constitute a particular cross that was repeated twice. All eggs produced from each breeding pen were individually recorded according to breed group and collected daily for a ten days period. Progeny of F_1 of all breed groups (16 groups) were produced in two hatches within one year. On day of hatch, all chicks were wings banded to keep their breed groups. The chicks were brooded and reared from hatch up to 12 weeks of age at the floor and fed *ad libitum* using ration contained 22.4 % crude protein, 4.8 % fat and 6.8 % fibers. Numbers of 587 pullets were chosen randomly at 18-weeks form all genetic groups to record the egg production performance. All birds were managed under the same conditions.

Data and statistical analysis

When the first egg is laid, age at sexual maturity (ASM) was determined in days for the period from hatching day to date of laying the first egg for each pullet. Body weight at sexual maturity (BWSM) was recorded in grams at the day of laying first egg for each pullet. Egg number laid per hen during the first 90 days of laying (EP90D) was recorded as well as total egg production (TEP) during 210 days was recorded for each pullet. Data of 587 hens were analyzed using Procedure GLM in SAS program under windows (SAS, 1996) according to the following linear models:

$$y_{ijk} = \mu + G_i + H_j + (GH)_{ij} + e_{ijk} \qquad \text{(Model 1)}$$

where y_{ijk}= the kth observation on hens produced from ith genetic group in the jth hatch, μ= the overall mean, G_i= the fixed effect of the ith genetic group, H_j= the fixed of the jth hatch, $(GH)_{ij}$= the fixed effect of interaction between ith genetic group and jth hatch, and e_{ijk}= the random error of the kth hen assumed to be independently randomly distributed (0, σ_e^2).

Genetic analysis

Data adjusted for the fixed effects were reanalyzed using **CBE** program (A universal program for estimating crossbreeding effects) Wolf (1996) under the following model suggested by Eisen et al. (1983):

$$y_{ij} = \mu + \frac{1}{2}v_i + \frac{1}{2}v_j + m_j + \delta(\bar{h} + h_i + h_j + s_{ij} + r_{ij}) + e_{ij} \qquad \text{(Model 2)}$$

where μ= the general mean

v_i = direct genetic effect of the ith purebred population

v_j = direct genetic effect of the jth purebred population

m_j = maternal effect of the jth purebred population

δ = 0 for purebreds and 1 for crosses

$\bar{h}$ = average of heterosis

h_i = line heterosis of the ith purebred population

h_j = line heterosis of the jth purebred population

s_{ij} = specific heterosis for the combination i x j, $(i \neq j)$ [this as specific combining ability (SCA)]

r_{ij} = residual reciprocal effect for the combination i x j, $(i \neq j)$ [this as sex-linked or reciprocal effect (SL)]

and e_{ij}= residual effect.

RESULTS AND DISCUSSION

Means of genetic groups

Results presented in Table 1 showed that F breed had the earliest ASM (190.8 d) and the lightest BWSM (1111.4 g), followed by L breed compared to the two other purebreds. Conversely, R breed had the latest ($P< 0.05$) ASM (277.7 d) and the heaviest BWSM (1802.1 g) compared to purebred parents. The differences in attaining sexual maturity might be due to the genetic makeup. Nawar and Abdou (1999) found that Egyptian indigenous chickens had the earlier sexual maturity (155 d) than the imported Rhode Island Red breed. For egg production at 90-day (EP90D) and total egg production (TEP), R breed had superior in both EP90D and TEP traits, followed by L breed. The differences between least-squares means for most productive traits were significant ($P<0.05$). Non-significant between means of EP90D was observed by Singh et al. (1983) in inbred lines of White Leghorn chickens.

For crossbreds, FxD crossbred had the earliest ASM (174 d) and the lightest BWSM (1024.6 g), but LxR crossbred had the latest ASM (237.6 d) and the heaviest BWSM (1550.3 g). Singh et al. (1983) found significant (P<0.01) differences between means of EP90D for all crosses. For egg production traits, the highest EP90D (50.08 egg) recorded for LxR cross, while the lowest was recorded for RxF cross. On the other hand, DxR crossbred had superior TEP (142.2 egg) compared to the other crossbreds. In general, crossbred genetic groups were recorded the earliest ASM and the lightest BWSM compared to purebreds. Conversely, purebreds were somewhat higher than crosses for egg production traits. Nawar and Abdou (1999) showed that crossbreds had the highest EP90D compared to the purebreds. Gupta et al. (2000) found differences means of 2.29 egg in favor of hybrid pullets. It is concluded that DxR and FxR crosses could be selected to produce hens had superior in egg production as well as FxD and DxF crosses could be selected to produce hens had the earliest ASM.

Heterosis

Estimates of heterosis and its percentages in Table 2 showed that RxD cross gave the highest negative heterotic effect (-27.1%) for ASM. While, the highest positive heterotic effect (12.6%) was attained when crossed F sires and L dams as well as its reciprocal. Therefore, the RxD cross is preferred to reduce the ASM. Some workers (Singh et al., 1983; Faifull et al., 1987; Bordas et al., 1996; Gavora et al., 1996; Mohammed 1997; Williams et al., 2002) found that heterotic percentages for ASM ranged from –25 to 11.5%. Heterotic effects for BWSM in the present study ranged from –25.8 to 6.9% across all crossbreds. Crossbred of FxL gave the highest positive heterotic effect (6.9%) for BWSM. Mohammed (1997) showed that Hi-sex x Dandarawi cross had the highest percent of heterosis (16.07%) for BWSM, while the lowest heterosis percent (-12.05%) was found when crossed sires of Mandarah with Hi-sex dams.

For egg production, LxR cross gave the highest positive heterotic effect (18.4%) for EP90D, but RxL cross gave the highest negative heterosis percent (-35.3%) for the same trait. Heterosis percentages were ranged from –22.2 to 20.1% for TEP. Crossbred of DxR gave the highest (20.1%) heterotic effect on TEP, followed by DxL crossbred (15.8%). Generally, most of crosses for TEP gave positive heterotic effects (Table2). Sheridan (1979&1980), Gavora et al. (1996) and Mohammed (1997) found positive heterosis percentages (ranged from 9.2 to 32.83 %) for egg production trait, while Horn (1985) and Wang and Pirchner (1992) observed negative and positive heterotic effect for the same trait.

Another point of view, heterosis estimates presented in Table 3 cleared that D and R breeds were significantly (P<0.01) contributed with negative heterotic effects on ASM, but L breed significantly (P<0.01) contributed with positive effect on the same trait. F breed significantly (P<0.01) contributed with 184 g as heterotic effect on BWSM, while R breed reduced (P<0.01) the BWSM with –179.7 g. Contributions of L and D breeds as heterotic effects on BWSM were non-significant. Singh et al. (1983) found significant (P<0.05 or 0.01) heterotic effect on ASM and BWSM traits. For egg production traits, the only D breed was significantly (P<0.05) contributed as heterotic effect (4.02 egg) on EP90D, while the other breeds had non-significant contributions on this trait. All purebreds had non-significant contribution as heterotic effects on TEP.

Direct genetic effect or general combining ability (GCA)

Estimates of GCA given in Table 3 showed that F and L breeds gave the earliest (P<0.01) ASM by –36.95 and –35.51 d, respectively, while R and D breeds gave the latest (P<0.01) ASM by 37.32 and 35.15 d, respectively. Breed of R gave the highest significantly (P<0.01) effect of GCA (455.3 g) on BWSM. Conversely, F breed gave the lowest significantly (P<0.01) effect of GCA (-411.2 g) on the same trait. Fairfull et al. (1983) and Singh et al. (1983) cited that GCA was significant for ASM and BWSM.

For egg production, results in Table 4 cleared that L breed had superiority (P<0.01) in GCA for EP90D, but D breed un-favored in GCA, because it is reduced (P<0.01) the general mean by 11.36 egg. Only R breed had superiority (P<0.05) in GCA for TEP (increased the general mean by 25.17 egg). The effects of GCA for the other purebreds were non-significant. Fairfull et al. (1983) and Gupta et al. (2000) found significant (P<0.01) effect of GCA for egg production traits. While, Singh et al. (1983) found that GCA was non-significant for EP90D and BWSM. From the previous results, it is concluded that L breed could be favored in GCA for ASM and EP90D, but R breed could be favored for BWSM and TEP traits.

Maternal ability (MA)

Maternal effects of R, L and D dams were highly significant (P<0.01) on ASM and BWSM, except only dam of D for BWSM trait (Table 3). Breed of D had superior in MA because the general mean of ASM reduced by –19.3 d when used as dam. The general mean of BWSM was increased by 113.2 g when used L breed as dam. Singh et al. (1983) found significant (P<0.01) maternal ability on BWSM, but non-significant on ASM.

For egg production traits, MA of R dam was positive and highly significant (P<0.01) on EP90D and TEP (Table 4). It is increased the general mean of EP90D and TEP by 7.97, and 23.33 egg, respectively. Conversely, MA of L and F dams were negative and highly significant (P<0.01) on EP90D and TEP. Singh et al. (1983) found non-significant effect of maternal ability on EP90D trait.

Specific combining ability (SCA)

Estimates of SCA in Table 3 indicate the RxD, RxF, LxD and LxF crosses gave highly significant (P<0.05 or 0.01) effect of SCA on ASM and BWSM. Effect of SCA was significant (P<0.01) effect for ASM and BWSM as reported by Fairfull et al. (1983) and Singh et al. (1983). Crosses of RxF and LxD are favored in SCA for ASM because it is reduced the general mean by 6.38 d. RxD and LxF crosses gave the highest effect of SCA on BWSM because it is increased the general mean by 53.6 g. The lowest effect (P<0.05) of SCA was due to RxF and LxD crosses.

Effect of SCA produced from all crosses (Table 4) was non-significant for EP90D and TEP traits, except RxL cross for TEP (P<0.05). RxD and LxF crosses gave the highest effect (but non-significant) of SCA on TEP because increased the general mean by 5.97 eggs. Crosses of RxL and DxF gave the lowest effect of SCA on TEP (it is decreased the general mean by 6.6 eggs). It is concluded that RxD and LxF crosses are favored in SCA for BWSM and TEP. Fairfull et al. (1983) and Gupta et al. (2000) found significant effect of SCA for egg production traits. While, Singh et al. (1983) found non-significant effect of SCA on EP90D trait.

Reciprocals or sex-linked effect (SL)

Effects of SL for RxL, RxF and LxD crosses were significant (P<0.05 or 0.01) on ASM, but effects of all crosses were highly significant (P< 0.01) on BWSM, except for RxD. Fairfull et al. (1983), Singh et al. (1983) and Bordas et al. (1996) reported that reciprocal effects were significant for ASM and BWSM. The highest negative (-8.41 d) effect of SL was due to RxL cross. However, RxF cross gave the latest (P<0.01) ASM by 5.86 d. Crosses of RxF and LxF gave the highest positive (P<0.01) SL effect on BWSM (Table 3). Conversely, crosses of RxL, LxD and DxF were un-favored for SL effect for that trait.

For egg production, effect of SL was significant (P<0.05 or 0.01) on EP90D for RxL, RxD and RxF crosses, but all crosses gave non-significant effect of SL on TEP. It concluded that crosses of RxD and DxF are favored in SL effect on EP90D. Gowe and Fairfull (1982), Fairfull et al. (1983), Singh et al. (1983) and Rahman et al. (2004) found significant effect of sex-linked on egg production. On the other hand, Gupta et al. (2000) found non-significant effect of sex-linked on egg production traits. In spit of all crosses gave non-significant effect of SL on TEP, but most of these crosses gave positive estimates (ranged from 1.5 to 4.24 eggs) of SL. It is concluded that RxL cross is preferred in SL effect by 4.24 eggs compared to the other crosses.

CONCLUSIONS

From the previous results, it could be concluded that:

- R sires (as an exotic breed) and F, and D dams (as a native breed) would be selected to produce birds with earlier ASM and higher egg production in Egypt through crossbreeding programs.
- Breed of D contributed with the highest heterotic effect on ASM and EP90D traits.
- DxR and FxR crosses could be selected to produce hens had superior egg production and FxD and DxF crosses could be selected to produce hens had the earliest ASM.
- L sires could be favored in GCA for ASM and EP90D, but R sires could be favored for BWSM and TEP traits. However, RxD and LxF crosses are favored in SCA for BWSM and TEP.
- RxL cross is preferred in sex-linked effect on TEP, while crosses of RxD and DxF are favored for EP90D.

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المكونات الوراثية والهجين لتجربة خلط تبادلى ٤x4 لانتاج البيض فى الدجاج

محمود مغربى عراقى[١] **عزت عطـــــا عفيفى**[١]
عبد الفتاح محمد اللبان[٢] **ميخائيـــــــل أفرام**[٢]

[١]قسم الانتاج الحيوانى – كلية الزراعة بمشتهر – جامعـــــــة بنـــها – مصر
[٢]معهد بحوث الانتاج الحيوانى – وزارة الزراعة – الدقى – القاهرة – مصر

الملخص العربى

استخدم فى هذه الدراسة نوعين من الدجاج المحلى هما الفيومى و الدندراوى ونوعين من الدجاج الأجنبى هما الرودأيلاند الأحمر واللجهورن الأبيض فى نظام خلط تبادلى ٤ x ٤ . وقد استخدم ٣٢ عش تزاوج حيث وضع ديكين مع ١٦ دجاجة فى كل عش ، وتم انتاج نسل الجيل الأول لكل المجاميع الوراثية (١٦ مجموعة) فى ثلاث تفريخات متتالية خلال عامين . وقد استخدم ٧٢٨٤ كتكوت فى تقدير قوة الهجين وتأثير كل من الأنواع النقية وقدرتى التوافق العامة والخاصة والمقدرة الأمية ، والارتباط بالجنس أو التزاوج العكسى على وزن الجسم . وكانت الصفات المدروسة هى وزن الجسم عند عمر الفقس ،٢ ، ٤ ، ٦ ، ٨ ، ١٢ أسبوع .

وقد أظهرت النتائج ما يلى :-

١ - أن دجاج الرودأيلاند الأحمر كان الأثقل وزنا عند كل الأعمار يليه دجاج اللجهورن الأبيض.

٢ - كانت الاختلافات بين متوسطات وزن الجسم للسلالات المحلية والأجنبية معنوية (عند مستوى ٥ %) ، كما كانت معظم الخلطان أعلى وزنا عن الأنواع النقية .

٣ - كانت قوة الهجين عالية المعنوية (عند مستوى ١ %) لكل الصفات المدروسة باستثناء صفة وزن الجسم عند عمر الفقس.

٤ - أعطى الخلط بين ذكور اللجهورن واناث الفيومى أعلى تقدير موجب لقوة الهجين لمعظم صفات وزن الجسم.

٥ - كانت الفروق بين السلالات النقية وتأثير كل من المقدرة الأمية ، قدرة التوافق العامة وقدرة التوافق الخاصة والارتباط بالجنس معنوية (عند مستوى ١ %) لكل الصفات المدروسة .

٦ - أعطت سلالة اللجهورن الأبيض أعلى تأثير موجب فى قدرة التوافق العامة لكل صفات وزن الجسم ، يليه دجاج الرودأيلاند الأحمر .

٧ - تفوقت سلالة الرودأيلاند الأحمر فى تقديرات المقدرة الأمية لمعظم صفات وزن الجسم.

٨ - أعطى خليط (الرودأيلاند الأحمر x الدندراوى) وخليط (اللجهورن الأبيض x الفيومى) أعلى تقديرات موجبة فى قدرة التوافق الخاصة لمعظم صفات وزن الجسم بالمقارنة بالخلطان الأخرى ، بينما تفوق خليط (اللجهورن الأبيض x الفيومى) فى الارتباط بالجنس لمعظم الصفات ، يليه خليط (الدندراوى x اللجهورن الأبيض).

٩ - من النتائج السابقة يمكن استنتاج أن ذكور اللجهورن (كسلالة أجنبية) واناث الفيومى (كسلالة محلية) قد تنتخب لانتاج دجاج لحم أثقل وزنا فى مصر من خلال برامج التربية بالخلط .

Table 1: Least-squares means and standard error (SE) for productive traits in purebreds and crossbreds of chickens.

Genetic groups^{+}	No.	ASM*			BWSM*			EP90D*			TEP*		
		LSM	±	**SE**	**LSM**	±	**SE**	**LSM**	±	**SE**	**LSM**	±	**SE**
Purebreds:													
R	١٧	٢٧٧.٣	±	٧.٦٤^{a}	١٨٠٢.١	±	٤٣.٣^{a}	٤٥.٤٧	±	٣.٨٣^{b}	١٥٢.٧٣	±	١٠.٩١^{a}
L	٢٢	٢٠٠.٤	±	٦.٨٠^{d}	١٢٤٣.٢	±	٣٨.٥	٣٩.١٦	±	٣.٤١^{bc}	٩١.٨٧	±	٩.٧٨^{cde}
D	٢٦	٢٤٤.٠	±	٥.٥١^{b}	١٢٧٣.٣	±	٣١.٢	٢٥.٥١	±	٢.٧٦^{ghi}	٨٤.٠٩	±	٧.٨٧^{cde}
F	٣٣	١٩٠.٨	±	١٣.٥٧^{cd}	١١١١.٤	±	٣٦.٩	٣١.٥٦	±	٦.٨١^{efgh}	٨٨.٢٣	±	١٩.٣٩^{de}
Average		**228.1**	±	**8.38**	**1357.5**	±	**37.5**	**35.43**	±	**4.20**	**104.23**	±	**11.99**
Crossbreds:													
RxL	٢٣	٢١٦.٧	±	٥.٧١^{d}	١٣٦٥.٤	±	٣٢.٣	٢٧.٤٠	±	٢.٨٦^{fghi}	١٠٢.٨٧	±	٨.١٦^{bcd}
RxD	٦٠	١٩٠.٠	±	٣.٦٢^{fgh}	١٢٩٤.٨	±	٢٠.٨	٣٤.٠٨	±	١.٨١^{bcd}	٩٢.١٠	±	٥.٢٥^{cde}
RxF	٥٦	١٩١.0	±	٣.٧٧^{ghi}	١٣٢٩.٦	±	٢١.٤	٢٤.٠١	±	١.٨٩^{hi}	٩٣.٩١	±	٥.٥٩^{cde}
LxR	٣٢	٢٣٧.٦	±	٤.٨١^{bc}	١٥٥٠.٣	±	٢٧.٢	٥٠.٠٨	±	٢.٤١^{a}	١١٦.٩٥	±	٧.٣١^{b}
LxD	١٧	١٨١.٨	±	٦.٧٨^{i}	١١١٢.٢	±	٣٨.٤	٣٤.٧٠	±	٣.٤0^{cdef}	٩٤.٦٣	±	٩.٨٦^{cde}
LxF	٢٧	٢٠٧.٦	±	٥.٤٦^{ef}	١٣٤١.١	±	٣١.٢	٢٨.١١	±	٢.٧٤^{ghi}	٩٥.٣٤	±	٨.٢٧^{cde}
DxR	٣٩	٢١٦.١	±	٨.٠٣^{de}	١٤٠٧.٢	±	٤٥.٥	٣٤.٦١	±	٤.٠٣^{i}	١٤٢.١٥	±	١١.٥١^{bcd}
DxL	٣٥	٢٢١.٣	±	٤.٥٢^{d}	١٣٧٢.٠	±	٢٥.٦	٣٠.٤٨	±	٢.٢٧^{defg}	١٠١.٨٨	±	٦.٤٦^{bcd}
DxF	٦٨	١٨٥.٦	±	٣.٦١^{fg}	١٠٨٥.٣	±	٢٠.٥	٢٦.٠١	±	١.٨٢^{defgh}	٧٧.٦٥	±	٥.٢٢^{e}
FxR	٣٧	١٩١.٦	±	٥.١٢^{hi}	١٣٧٦.٦	±	٢٩.٠	٣٢.٦٧	±	٢.٥٧^{ghi}	١٢٣.١٢	±	٧.٣١^{bc}
FxL	٣٧	٢٢٠.٢	±	٤.٤0^{d}	١٢٧٣.٧	±	٢٤.٩	٣٣.٢٥	±	٢.٢0^{cde}	١٠٥.٢٨	±	٦.٣٧^{bcd}
FxD	٥٨	١٧٤.٠	±	٣.٩٣^{hi}	١٠٢٤.٦	±	٢٢.٢	٢٨.١١	±	١.٩٧^{defg}	٨٧.١٤	±	٥.٧٤^{cde}
Average		**202.8**	±	**4.98**	**1294.4**	±	**28.3**	**31.96**	±	**2.50**	**102.8**	±	**7.25**

$^{+}$ R, L, D and F = Rhode Island Red, White Leghorn, Dandarawi and Fayoumi, respectively.

* ASM, BWSM, EP90D and TEP= age at sexual maturity, body weight at sexual maturity, egg production during 90 day and total egg production, respectively.

Table 2:Estimates of heterosis and its percentages for productive traits in 4x4 diallel mating of chickens.

Combination of mating group[+]	ASM[*]		BWSM[*]		EP90D[*]		TEP[*]	
	Unit	%	Unit	%	Unit	%	Unit	%
R x L	-22.1	-9.3	-310.8	-18.5	-14.9	-35.3	-19.4	-15.9
R x D	-70.6	-27.1	-292.3	-18.4	-1.4	-4.0	-26.3	-22.2
R x F	-43.0	-18.4	-83.8	-5.9	-14.5	-37.7	-26.6	-22.1
L x R	-1.3	-0.5	-433.0	-25.8	7.8	18.4	-5.4	-4.4
L x D	-40.4	-18.2	-349.0	-23.9	2.4	7.3	6.6	7.6
L x F	12.0	6.1	53.7	4.2	-7.2	-20.5	5.3	5.9
D x R	-44.5	-17.1	-313.8	-19.2	-0.9	-2.5	23.7	20.1
D x L	-0.9	-0.4	-54.0	-3.7	-1.9	-5.7	13.9	15.8
D x F	-31.8	-14.6	-113.0	-9.4	-2.5	-8.9	-8.5	-9.9
F x R	-42.5	-18.2	-302.0	-21.4	-5.8	-15.2	2.6	2.2
F x L	24.6	12.6	89.2	6.9	-2.1	-6.0	15.2	16.9
F x D	-43.3	-19.9	75.4	6.3	-0.4	-1.5	1.0	1.1

[+] R, L, D and F = Rhode Island Red, White Leghorn, Dandarawy and Fayoumi, respectively.
[*] ASM, BWSM, EP90D and TEP= age at sexual maturity, body weight at sexual maturity, egg production during 90 day and total egg production, respectively.

Table 3: Estimates of genetic and non-genetic parameters and their standard deviations (SD) and significance for age and body weight at sexual maturity of 4x4 diallel mating in chickens using EISEN et al. (1983) model.

Parameter[+]	Trait					
	Age at sexual maturity (ASM)			Body weight at sexual maturity (BWSM)		
	Estimate	SD	Significance[++]	Estimate	SD	Significance[++]
General mean (μ)	228.11	4.47	**	1437.3	15.3	**
GCA:						
R	37.32	7.75	**	455.3	39.1	**
L	-35.51	7.33	**	-0.1	33.1	ns
D	35.15	6.78	**	-44.0	30.6	ns
F	-36.95	10.93	**	-411.2	27.8	**
Maternal ability:						
R	11.88	3.30	**	-90.5	19.0	**
L	7.83	3.27	**	113.2	22.2	**
D	-19.30	3.28	**	-21.3	19.4	ns
F	-0.41	2.72	ns	-1.4	17.1	ns
Heterosis:						
R	-18.03	4.15	**	-179.7	22.0	**
L	30.95	3.97	**	3.2	18.5	ns
D	-19.90	3.71	**	-7.5	18.2	ns
F	6.98	5.74	ns	184.0	17.6	**
Average of heterosis	-25.32	4.71	**	-169.4	17.9	**
SCA:						
RxL	0.70	1.99	ns	-25.9	12.6	*
RxD	5.68	2.20	**	53.6	12.3	**
RxF	-6.38	2.11	**	-27.7	14.0	*
LxD	-6.38	2.11	**	-27.7	14.0	*
LxF	5.68	2.20	**	53.6	12.3	**
DxF	0.70	1.99	ns	-25.9	12.6	*
Reciprocal:						
RxL	-8.41	2.67	**	-40.7	17.1	**
RxD	2.55	2.80	ns	-23.8	15.1	ns
RxF	5.86	2.41	**	64.6	14.8	**
LxD	-6.21	2.73	*	-80.3	18.1	**
LxF	-2.20	2.46	ns	39.6	15.9	**
DxF	-3.67	2.33	ns	-104.1	14.1	**

[+] R, L, D and F = Rhode Island Red, White Leghorn, Dandarawi and Fayoumi, respectively.
[++] ns = non-significant; * = P≤0.05; ** = P≤0.01.

Table 4: Estimates of genetic and non-genetic parameters and their standard deviations (SD) and significance for egg production during the first 90-day and total egg production of 4x4 diallel mating in chickens using EISEN et al. (1983) model.

Parameter[+]	Trait					
	Egg production during the first 90-day (EP90D)			Total egg production (TEP)		
	Estimate	SD	Significance[++]	Estimate	SD	Significance[++]
General mean (µ)	35.43	2.24	**	104.23	6.39	**
GCA:						
R	2.08	3.88	ns	25.17	11.09	*
L	9.17	3.68	**	-13.14	10.56	ns
D	-11.36	3.40	**	-8.19	9.71	ns
F	0.11	5.48	ns	-3.84	15.64	ns
Maternal ability:						
R	7.97	1.65	**	23.33	4.77	**
L	-5.44	1.64	**	0.78	4.80	ns
D	1.45	1.65	ns	-11.95	4.74	**
F	-3.98	1.36	**	-12.16	3.98	**
Heterosis:						
R	-2.25	2.08	ns	-10.60	5.97	ns
L	1.20	1.99	ns	6.29	5.72	ns
D	4.02	1.86	*	4.83	5.33	ns
F	-2.97	2.88	ns	-0.52	8.23	ns
Average of heterosis	-3.47	2.36	ns	-1.48	6.74	ns
SCA:						
RxL	0.94	1.00	ns	-6.60	2.90	*
RxD	0.55	1.10	ns	5.97	3.21	ns
RxF	-1.49	1.06	ns	0.63	3.05	ns
LxD	-1.49	1.06	ns	0.63	3.05	ns
LxF	0.55	1.10	ns	5.97	3.21	ns
DxF	0.94	1.00	ns	-6.60	2.90	*
Reciprocal:						
RxL	-4.64	1.34	**	4.24	3.90	ns
RxD	2.99	1.40	*	-7.38	4.04	ns
RxF	1.64	1.21	ns	3.14	3.51	ns
LxD	-1.33	1.37	ns	2.74	3.96	ns
LxF	-3.30	1.23	**	1.50	3.62	ns
DxF	1.66	1.17	ns	-4.64	3.39	ns

[+] R, L, D and F = Rhode Island Red, White Leghorn, Dandarawi and Fayoumi, respectively.
[++] ns = non-significant; * = P≤0.05; ** = P≤0.01.