Minufiya J.Agric.Res.Vol.35 No. 4(1):1323-1239(2010)"http://agri.menofia.edu.eg/megla.html"

GENETIC GAINS AND HETEROSIS FOR SOME EGG PRODUCTION TRAITS IN TWO LINES OF NORFA CHICKENS

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(Received: May. 23 , 2010)

ABSTRACT: ***The ultimate goal of this study was to develop two lines of Norfa hens (i.e. line egg number at 42 weeks of age (EN) and line body weight (BW) at maturity (38WK)] by using a selection independent culling level method during three generations of selection and crossing two purelines to get hybrid vigor for some egg production traits. A control line was randomly formed from the base population before choosing the individuals of selected line.***

Generally the birds of (EN) line excelled those of (BW) line in both of ASM and EN while the birds of (BW) line were obviously heavier and laid the heaviest eggs comparing to birds of (EN) and control lines. The realized genetic gain for egg number traits during three generations of selection in (EN) line ranged from 10.2 to 26 eggs while expected genetic gain for the same trait in the same line ranged from 1.1 to 2.5 eggs. The realized genetic gains for (ASM) during three generations of selection in Norfa chickens in (EN) line ranged from -7.3 to -16.7 d while expected genetic gains for the same trait in the same line ranged from -0.66 to -1.8 d. All F_1 hyprids for studied traits exceeded the mid-parents in this study. All F_1 crosses for studied traits had positive heterosis values except F_1 crosses for age at sexual maturity (ASM) had negative heterosis value in this study. Heterosis percentages in crossline (BW×EN) for some egg production traits (i.e. ASM, BW_{SM}, BW_M, EW_{SM}, EW_M, EN_{90d}, EN_{42wk} and EN_{52wk}) were -5.1, 2.4, 6.5, 6.1, 3.1, 14.7, 13.4 and 9.2%, while these estimates in crossline (EN×BW) for the same traits were -2.5, 2.3, 3.9, 5.1, 2.9, 13.4, 6.4 and 3.9%, respectively.

From the previous results the parental lines EN and BW proved to exploited both additive and non additive variations and could be used to produce superior crosses for egg number and body weight.

Key words: ***Genetic gains and heterosis in norfa chickens***

INTRODUCTION

In Egypt, a lot of efforts have been done to improve indigenous chickens. The Egyptian indigenous breeds of chickens have many advantageous such as their high adaptability to local environment and genetic resistance to some serious diseases such as Marek beside the highly acceptable taste and favorable flavor for their meat and egg products.

El-Hadad (2003) found that means of age at sexual maturity (ASM) after four generation of selection for selected and control lines of Norfa chickens were 166.8 and 174.2 d, while these means for egg number till 42 weeks of age (EN_{42wk}) were 68.5 and 63.6 eggs, respectively. Abou El-Ghar and Abdou (2004) found that the egg numbers in the first ninety days of laying (EN_{90d}) were 55.4 and 48.1 eggs for two selected lines of Norfa layers (i.e. egg number and egg weight).

Enab *et al.* (2000) found that the actual and expected genetic gains for EN_{90d} after to generations in Norfa chickens were 8.8 and 2.4 eggs, while these means were 10.8 and 4.7 for EN_{42wk}, respectively. El-Hadad (2003) found that absolute genetic gains for EN_{42wk} in Norfa chickens were 5.8, 4.9, 8.4 and 4.9 eggs in G_1, G_2, G_3 and G_4, respectively.

Many investigators confirmed the superiority of crossbreds over the purebreds regarding egg production traits and some economic traits (Kosba *et al.* 1981; Farghaly and Saleh, 1988; Abdou, 1992; Nawar and Abdou, 1999, and Abou El-Ghar *et al.*, 2007). Crossing between native and foreign breeds had performed better than pure ones (Farhaly and Saleh, 1988, Nawar and Bahie El-Deen, 2000 and Amin, 2008). Abou El-Ghar (2003) showed that both dominance and epistasis were important in heterosis for egg production traits in Norfa strain crosses.

The main purpose of the present study is to improve Norfa strain by using a selection method of independent culling level during three generations of selection to develop two lines of Norfa strain (i.e. egg number "EN" and body weight "BW") to increase the genetic variations. In generation four, crossing the two lines of Norfa strain was done to exploit additive variations in the hybrid vigor in Norfa performance.

MATERIALS AND METHODS

I-Plan and management

The present experiment has been carried out at the Poultry Farm of the Faculty of Agriculture, Minufiya University, Shebin El-Kom, Egypt as a part of Norwegian-Egyptian project "NORFA" for improving hens during four generations through the hatching seasons 1997-2001. In the base population a total of 415 dams of Norfa chickens were divided into three lines based on egg number and body weight at maturity (165 EN, 150 BW and 100 control hens) to produce the next generation, whereas each three dams were mated artificially to a cook. The ultimate goal of this study was to develop two lines of Norfa hens (i.e. EN and BW) by using a selection independent culling level method during three generations of selection and crossing two purelines to get hybrid vigor for egg production traits.

Numbers of hens per generation, line, crosslines and control were shown in Table (1). Artificial insemination was done as a mating system during all generations, and the semen was collected from cocks and inseminated fresh and undiluted into dams. Each sire artificially inseminated three dams in

each generation. Mating of relatives was avoided. Insemination started one week before collecting hatching eggs, each dam was inseminated twice a week. Fertile eggs were collected daily for a couple of weeks and stored in a prepared refrigerator.

Cockerels were separated from pullets in brooding house at 8 weeks of age and at 14 weeks, cockerels moved to individual cages in cock's house while, pullets were moved to individual cages in laying house at 16 weeks of age.

Pullets were fed a starter ration contained 18% crude protein and 2833 kcal. ME/kg. ration until 18 weeks of age, from 19 weeks of age to the end of production period, a layer ration contained 16.5% crude protein and 2758 kcal. / kg. ration.

II. Studied traits.

The following traits were studied:

1. Body weight at sexual maturity (BWs_M), in grams.
2. Body weight at 38 weeks of age (BW_M), in grams.
3. Age at sexual maturity (ASM): number of days at the first egg laid.
4. Egg number (EN)
4.1. Number of eggs in the first ninety days of laying (EN_{90d}).
4.2. Number of eggs at 42 weeks of age (EN_{42WK}).
4.3. Number of eggs at 52 weeks of age (EN_{52WK}).
5. Egg weight (EW)
5.1. The average weight of 5 eggs at sexual maturity (EN_{SM}), in grams.
5.2. The average weight of 5 eggs during 35-38 weeks of age (EW_M), in grams.

III- Selection procedures:

During three generations of selection the independent culling levels procedure was applied in the base population to divide it into three lines (i.e. EN, BW and control). The egg number line (EN) was determined by using the overall mean for egg number at 42 weeks of age of the base population plus one standard deviation (μ+1 S.D.), while the body weight line (BW) was determined by using the overall mean of body weight at maturity (38 WK) of the base population plus one standard deviation (μ+1 S.D.). All individuals that failed to come down of these two levels were discarded. Moreover, those selected individual hens should attain at least the general averages of the base population concerning the other studied traits. The same selection method was applied in each of the following generations. Also, the cocks of the base population were divided into these three lines upon this procedure. The birds of the control line were chosen randomly before applying the independent culling levels in the base population to choose the individuals of the two selected lines (i.e. EN and BW).

In the fourth generation two crosslines (i.e. EN x BW and BW x EN) were obtained by crossing EN and BW lines.

Table 1

IV- Statistical analysis:

The statistical analysis was performed using linear models procedure of the statistical analysis system computer program (SAS, 1994). Duncan's new multiple range test was used to compare every two means of different traits studied (Steel and Torrie, 1960).

1. The statistical model:

The statistical model used for analyzing egg production traits between lines in different generation was as follows.

$$Y_{ijk} = \mu + L_i + G_j + LG_{ij} + e_{ijk}.$$

Where:

Y_{ijkl} = Observation on the ijkth chick.

μ = Overall mean,

Li = Effect of ith line. Gj = Effect of jth generation.

LGij = Interaction effect between ith line and jth generation.

eijk = Random error component, assumed to be normally distributed.

2. Genetic gains and heterosis:

Realized genetic gains (ΔGR) were calculated as a deviation of the mean of parental line from the control mean.

$$\Delta GR = \bar{x}\, s - \bar{x}\, c$$

Where:

$\bar{x}_S$ = Mean of parental line, $\bar{x}_C$ = Mean of control.

The expected genetic gains (ΔGE) were calculated according to the formula given by (Prichener's, 1979) as follow.

$$\Delta GE = i \,.\, h_j \,.\, \delta_A$$

Where:

i = Selection intensity.

h_j = Square root of heritability for the jth trait.

δ_A = Genetic standard deviation of the jth trait.

Average degree of heterosis (ADH %) based on the mid-parents (MP) was determined according to equation given by (Sinha and Khanna, 1975) as follows.

$$ADH\% = \bar{F}_1 - MP/MP \,.\, 100$$

Where:

$\bar{F}_1$ = Mean of crossbred, MP = mid-parents.

RESULTS AND DISCUSSION

1- Means

Means of lines and crosslines for egg production traits (ASM, BW_{SM}, BW_M, EW_{SM}, EW_M, EN_{90d}, EN_{42wk} and EN_{52wk}) are presented in Table (1). The averages of ASM during generation one were 147.8, 162.3 and 155.1d for EN, BW and control lines while the corresponding averages during generation two were 143.5, 169.2 and 157.1d, respectively. The results shown during the

first and second generations were in a good agreement with those reported by Enab (2001), Abou-Elewa (2004), Abou El-Ghar and Abdou (2004) and Ben Naser (2007). Whereas they recorded that averages of (ASM) for Norfa pullets ranged from 150.6 to 176.5 d. Means of BW_{SM} during generation one were 1118.8, 1369.4 and 1095.6g for EN, BW and control lines, while the corresponding averages during generation two were 1067.5, 1457.1 and 1110.3g, respectively. Many researchers reported that the average of Body weight at sexual maturity (BW_{SM}) in Norfa chickens ranged from 1005.0 to 1459.0 g (Enab *et al.,* 2000, El-Hadad, 2003, Abou El-Ghar, 2003, Abou-Elewa, 2004 and Ben Naser, 2007).

The data in Table (1) also show that means of EW_{SM} during generation one were 36.5, 39.6 and 35.4g for EN, BW and control lines, while the corresponding averages during generation two were 35.7, 42.4 and 36.5g, respectively. Similar results were reported by (El-Hadad, 2003; Abou El-Ghar and Abdou, 2004, Ben Naser, 2007 and Abou-Elewa, 2010) who showed that the average of EW_{SM} in Norfa chickens ranged from 35.6 to 39.1g. The averages of EN_{90d} during the generation one were 60.1, 52.2 and 49.9 eggs for EN, BW and control lines while the corresponding averages during the generation two were 65.3, 50.3 and 48.7 eggs, respectively. Similar results were reported by (El-Hadad, 2003; Abou-Elewa, 2004 and Abou El-Ghar and Abdou, 2004) who showed that the average of EN_{90d} in Norfa chickens ranged from 49.3 to 64.8 eggs.

There were highly significant differences between lines, generations and lines × generations interaction for all studied egg production traits (Table, 2).

2- Crossing

In generation three, means of age at sexual maturity (ASM) for two parental lines of Norfa strain (i.e. EN and BW) and control are given in Table (1). It was noticed that the (EN) parental lines had the lowest sexual maturity means (136.9d), while these means were 173.3 and 153.6 d for (BW) parental line and control, respectively.

In generation four, means of (ASM) for two crosslines for Norfa strain (i.e. EN and BW) and control are shown in Table (1). It was clear that the crossline (BW × EN) had the lowest sexual maturity mean (147.2), while these means were 151.2 and 156.9 for (EN × BW) cross line and control, respectively. The results in Table (1) show that (EN) parental line had the lowest sexual maturity means (136.9 d) than (BW) parental line and F_1 crosses. Generally, means of ASM in F_1 crosses were less than the parental means (149.2 vs. 155.1d). However, most crossbreds were earliest in reaching sexual maturity compared to pure breeds. Similar results were reported by Nawar (1995), El-Salamony (1996), Nawar and Abdou (1999) and El-Tahawy (2000).

In generation three, averages of body weight at maturity were 1081.8, 1724.5 and 1195.3g for EN, BW parental lines and control, respectively, (Table 1). In generation four, these means in the F_1 crosses were 1457.6, 1494.5 and

Table 2

1230.6g for (EN × BW), (BW × EN) crosslines and control, respectively. However, the (BW) parental line had significantly heavier body weight (1724.5g) than (EN) parental line and F_1 crosses. Generally, means of body weight at maturity in F_1 crosses were heavier than the parental means (1476.1 vs. 1403.2g) (Table, 1).

In generation three, the data listed in Table (1) show that the means of egg weight at maturity (EW_M) were 47.6, 56.2 and 46.1g for EN, BW parental lines and control, respectively. In generation four, the means of egg weight at maturity (EW_M) in the F_1 crosses were 53.4, 53.5 and 47.9g for (EN × BW), (BW × EN) crosslines and control, respectively. It was noticed that, (BW) of parental line had significantly heavier body weight (56.2g) than (EN) parental line and F_1 crosses. Generally, means of body weight at maturity in F_1 crosses were higher than the parental means (53.45 vs. 51.9) (Table, 1).

Generally, crosslines gave heavier body and egg weights at maturity than the native purelines. These results were in agreement with those reported by Nawar (1995), El-Salamony (1996), Nawar and Abdou (1999) and Abou El-Ghar (2003).

In generation three, Table (1) shows that the means of egg number at 42 weeks of age (EN_{42WK}) were 96.6, 70.1, 73.9 egg for EN, BW pure parental lines and control, respectively. In generation four, these means in F_1 crosses were 88.8, 94.6 and 72.5 eggs for (EN × BW), (BW × EN) crosslines and control, respectively. However, the (EN) parental line had significantly higher egg number at 42 weeks of age (96.6 eggs) than (BW) parental line and F_1 crosses. Generally, averages of (EN_{42wk}) in F_1 crosses were higher than the parental means (91.7 vs. 83.4 eggs) (Table, 1). In this respect Kosba *et al.* (1981), Wang and Prichner (1991), El-Hossari and Dorgham (1992) and Nawar and Abdou (1999) reported that, the strain crossing increased rate of laying.

3- Genetic gains

Table (3) presents the realized and expected genetic gains for egg production traits in EN and BW lines of Norfa strain during generations 1, 2 and 3. In EN line, the results in Table (3) show that the realized genetic gain for (ASM) in generations one, two and three were -7.3, -13.6 and -16.7d, while the expected genetic gains were -1.8, -1.2 and -0.66, respectively. In BW line, the results show that the realized genetic gains for (ASM) during the generations one, two and three were 7.2, 12.1 and 19.5d, while the expected genetic gain were 1.4, 0.99 and 0.47, respectively. These results showed that EN line reached sexual maturity earlier than the BW line. This is a result of indirect response for selecting to egg number in this line. These results agree with those obtained by Enab *et al*. (2001) who found that actual genetic gain for sexual maturity in different lines of W. Leghorn ranged from -2.88 to 2.95d, while expected genetic gain ranged from -3.99 to -2.30d. Abou El-Ghar (2003) reported that the realized genetic gains for age at sexual maturity in four lines (SM, EN, BW and EW) of Norfa strain were -26.0, -19.0, -15.0 and -11.0d, while the expected genetic gains for the same traits in the same lines were -0.10, -0.07, -0.06 and -0.05d, respectively.

Table 3

Table 3

In EN line, the results in Table (3) show that the realized genetic gain for (BW_{SM}) during the generations one, two and three were 23.2, -24.8 and -50.3g, while the expected were 13.6, -11.9 and -8.7g, respectively. In BW line, the realized genetic gain for (BW_{SM}) in the first, second and third generations were 273.8, 346.8 and 416.0g, while the expected were 17.4, 14.8 and 8.6g, respectively. These results agreed with those obtained by El-Sakka (1999), Enab *et al.* (2000) and Abou El-Ghar (2003) who reported that the realized genetic gains in (BW_{SM}) ranged from -80.8 to 367.0, while the expected genetic gains ranged from -0.6 to 0.23 in different lines of Norfa chickens.

In EN line, the results in Table (3) show the realized genetic gains for (EW_{SM}) in the generations one, two and three were 1.1, -0.8 and 0.2g, while the expected genetic gains were 0.91, -0.64 and 0.31g, respectively.

In BW line, the results in Table (3) show the realized genetic gains for (EW_{SM}) in the first, second and third generations were 4.2, 5.9 and 9.3g, respectively. Moreover, the expected genetic gains for (EW_{SM}) were 1.2, 0.74 and 0.35g in G_1, G_2 and G_3, respectively. These results agreed with those obtained by Abdou *et al.* (1997) and Abou El-Ghar (2003) who reported that the realized genetic gains in (EW_{SM}) ranged from -2.0 to 2.8g, while the expected genetic gains ranged from -0.32 to 1.12g in different lines of Norfa chickens.

In EN line, the results in Table (3) show the realized genetic gains for (EN_{90d}) in generations one, two and three were 10.2, 16.6 and 19.6 eggs, respectively, while the expected genetic gains for the same trait of the same line were 2.5, 2.4 and 1.2 eggs, in the same order.

In BW line, the results in Table (3) showed the realized genetic gains for (EN_{90d}) during the generations one, two and three were 2.3, 1.6 and -1.4 eggs, while the expected genetic gains for the same trait in the same line were 2.1, 2.0 and -1.1 eggs, respectively. The same results were obtained by Sherif (1991), El-Wardany *et al.* (1992), Enab *et al.* (2000) and Abou El-Ghar (2003) who reported that the realized genetic gains in (EN_{90d}) ranged from 3.2 to 11.0 eggs, while the expected genetic gains ranged from 0.02to 2.4 eggs in different lines of Norfa chickens.

4- Heterosis

Heterosis percentages of some egg production traits are presented in Table (4).

The expressions of averages degree of heterosis (ADH %) based on mid-parent for age at sexual maturity (ASM) in generation four are presented in Table (4). F_1 hybrids were earlier than the mid-parents in reaching sexual maturity. Therefore, negative heterosis values were obtained for these hybrids and the estimated (ADH %) were -2.5 and -5.1 % for (EN × BW) and (BW × EN) crosslines, respectively. The results of heterosis percentages for age at sexual maturity showed negative heterosis effects for all crosses (EN × BW) and (BW × EN). Similar results were obtained by Nawar (1995), Bordas *et al.* (1996), El-Salamony (1996) and Nawar and Bahie El-Deen (2000).

Table 4

In generation four, results of heterosis (ADH %) for body weight at sexual maturity are presented in Table (4). It showed that means of F_1 crosses had positive heterosis values. The estimates of heterosis for crosses EN × BW and BW × EN were 2.3 and 2.4 %, respectively. Similar results were obtained by Zatter (1994) and El-Salamony (1996).

In generation four, average degrees of heterosis (ADH %) for (EW_{SM}) are presented in Table (4). It noticed that egg weight at sexual maturity (EW_{SM}) showed positive heterosis effects in the crosses EN × BW (5.1 %) and BW × EN (6.1 %). These results are in agreement with those reported by El-Salamony (1996) and Nawar and Bahie El-Deen (2000).

In generation four, results of heterosis (ADH %) for egg number in the first 90d of laying (EN_{90d}) are presented in Table (4). It showed that means of F_1 crossed had positive heterosis values. Generally, means of (EN_{90d}) in F_1 crosses were higher than the parental means. The estimated of heterosis (ADH %) for crosses EN × BW and BW × EN were 13.4 and 14.7 %, respectively. These results are in agreement with those reported Zatter (1994), Nawar and Bahie El-Deen (2000), Abou El-Ghar *et al.* (2007) and Amin (2008).

In conclusion, the results of the present study indicate that crossbreeding between two lines of Norfa chickens (I.e. devolped for egg number; EN and body weight; BW) is considered an effective way to improve some of egg production traits.

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العائد الوراثي و قوة الهجين لبعض صفات إنتاج البيض في خطين من دجاج النورفا

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الملخص العربي

الهدف الأساسي من هذه التجربة هو تكوين خطين متخصصين في سلالة النورفا (خط لإنتاج البيض و آخر لوزن الجسم) باستخدام طريقة انتخاب مستويات الاستبعاد المستقلة خلال ثلاث أجيال من الانتخاب وخلط هذه الخطوط للحصول علي قوة الهجين لصفات إنتاج البيض.

كان من الواضح بصفة عامة أن البداري في الخط المنتخب لإنتاج البيض (EN) مبكرة في النضج الجنسي وتتفوق في إنتاج البيض عن تلك التي في الخط المنتخب لوزن الجسم (BW) في حين أن الدجاجات في الخط المنتخب لوزن الجسم (BW) كانت أعلي في وزن الجسم و انتجت بيض أثقل عن تلك التي في الخط المنتخب لإنتاج البيض (EN). العائد الوراثي الحقيقي لصفات عدد البيض خلال ثلاث أجيال من الانتخاب في الخط المنتخب لإنتاج البيض في دجاج النورفا يتراوح بين ١٠.٢ إلي ٢٦ بيضة بينما العائد الوراثي المتوقع لنفس الصفات في نفس الخط تراوحت بين ١.١ إلي ٢.٥ بيضة. العائد الوراثي الحقيقي لصفة العمر عند النضج الجنسي خلال ثلاث أجيال من الانتخاب في الخط المنتخب لإنتاج البيض في دجاج النورفا يتراوح بين – ٧.٣ إلي –١٦.٧ يوم بينما العائد الوراثي المتوقع لنفس الصفة في نفس الخط تراوحت بين – ٠.٦٦ إلي –١.٨ يوم. أوضحت النتائج في هذه الدراسة تفوق كل هجن الجيل الأول F1 لصفات إنتاج البيض علي متوسط الآباء. أوضحت الدراسة في أن كل هجن الجيل الأول F1 لصفات إنتاج البيض ظهرت به قوة هجين موجبة فيما عدا صفة العمر عند النضج الجنسي كل هجن الجيل الأول ظهرت به قوة هجين سالبة. في الهجين (EN × BW). كانت قوة الهجين لصفات إنتاج البيض (العمر عند النضج الجنسي ، وزن الجسم عند النضج الجنسي، وزن

الجسم عن تمام النضج ، وزن البيض عند النضج الجنسي ، وزن البيض عند تمام النضج ، عدد البيض عند ٩٠ يوم من الانتاج ، عدد البيض عند عمر ٤٢ أسبوع ، عدد البيض عند عمر ٥٢ أسبوع) -٥.١ ، ٢.٤ ، ٦.٥ ،٦.١ ،٣.١، ١٤.٧، ١٣.٤، ٩.٢ % في حين كانت قوة الهجين لنفس الصفات للهجين (BW × EN) -٢.٥ ، ٢.٣ ، ٣.٩ ، ٥.١ ، ٢.٩ ، ١٣.٤ ، ٦.٤ ، ٣.٩ % علي التوالي.

ويمكن أن نستخلص من نتائج هذا البحث أن خلط خطين من دجاج النورفا (أحدهما محسن لصفة عدد البيض والأخر لوزن الجسم) تعتبر وسيلة فعالة لتحسين بعض صفات إنتاج البيض لدجاج النورفا.

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Table (1): Mean ± S.d. for some egg production traits in three lines of Norfa chickens (EN, BW and control) in generations 1, 2, 3 and 4.

Generation	Traits / Lines	No.	ASM	BW_{SM}	BW_{M}	EW_{SM}	EW_{M}	EN_{90d}	EN_{42wk}	EN_{52wk}
Generation 1	(EN)	201	147.8 ± 6.9a	1118.8 ± 76.4 a	1195.1 ± 77.9 a	36.5 ± 2.2 a	48.8 ± 2.1 a	60.1 ± 4.7 a	82.9 ± 6.7 a	120.5 ± 7.6 a
	(BW)	195	162.3 ± 7.3 b	1369.4 ± 82.8 b	1518.2 ± 95.3 b	39.6 ± 2.4 b	51.9 ± 2.4 b	52.2 ± 4.6 b	73.9 ± 5.8 b	112.1 ± 6.7 b
	cont.	114	155.1 ± 8.1 c	1095.6 ± 119.2c	1221.5 ± 192.1a	35.4 ± 4.3 c	47.2 ± 4.5 c	49.9 ± 9.1 c	72.2 ± 9.6 c	107.6 ± 15.1 c
	Mean	510	155.1 ± 9.4	1194.6 ± 155.9	1311.6 ± 197.1	37.2 ± 3.6	49.3 ± 3.7	54.1 ± 7.8	76.3 ± 8.9	113.4 ± 11.8
Generation 2	(EN)	198	143.5 ± 3.8 a	1067.5 ± 51.5 a	1137.1 ± 58.5 a	35.7 ± 1.5 a	48.3 ± 1.2 a	65.3 ± 3.4 a	90.1 ± 3.2 a	128.9 ± 3.5 a
	(BW)	198	169.2 ± 4.5 b	1457.1 ± 59.2 b	1621.7 ± 73.7 b	42.4 ± 1.7 b	54.6 ± 1.7 b	50.3 ± 3.3 b	71.5 ± 4.1 b	109.4 ± 4.3 b
	cont.	105	157.1 ± 7.9 c	1110.3 ± 120.4 c	1230.1 ± 194.2 c	36.5 ± 5.1 a	48.1 ± 5.6 c	48.7 ± 9.5 b	71.6 ± 10.1 b	106.7 ± 16.2 b
	Mean	501	156.6 ± 11.9	1211.6 ± 195.7	1329.6 ± 244.9	38.2 ± 4.3	50.3 ± 2.4	54.8 ± 9.2	77.7 ± 10.6	115.1 ± 13.4
Generation 3 parental lines	(EN)	192	136.9 ± 1.8 a	1030.4 ± 28.9 a	1081.8 ± 34.8 a	35.1 ± 0.9 a	47.6 ± 0.7 a	70.4 ± 1.4 a	96.6 ± 1.7 a	135.1 ± 2.1 a
	(BW)	189	173.1 ± 1.6 b	1496.7 ± 27.8 b	1724.5 ± 29.4 b	44.2 ± 0.8 b	56.2 ± 0.9 b	49.4 ± 1.8 b	70.1 ± 1.9 b	107.2 ± 2.2 b
	cont.	102	153.6 ± 8.8 c	1080.7 ± 117.6 c	1195.3 ± 190.2 c	34.9 ± 4.9 a	46.1 ± 5.8 a	50.8 ± 10.2 b	73.9 ± 11.9 c	109.1 ± 15.8 b
	Mean	483	154.5 ± 15.5	1202.6 ± 218.7	1333.9 ± 298.8	38.1 ± 5.1	50.1 ± 4.9	56.9 ± 11.2	80.2 ± 13.4	117.1 ± 15.1
Generation 4 cross lines	(EN×BW)	183	151.2 ± 7.1 a	1292.3 ± 64.3 a	1457.6 ± 89.1 a	41.7 ± 1.4 a	53.4 ± 1.6 a	67.9 ± 6.3 a	88.8 ± 6.5 a	125.9 ± 7.3 a
	(BW×EN)	179	147.2 ± 4.3 b	1294.3 ± 52.5 a	1494.5 ± 80.5 b	42.1 ± 2.5 a	53.5 ± 3.1 a	68.7 ± 5.1 a	94.6 ± 4.1 b	132.3 ± 4.2 b
	cont.	93	156.9 ± 9.5 c	1100.7 ± 123.4 b	1230.6 ± 194.3 c	36.1 ± 4.8 b	47.9 ± 5.3 b	49.2 ± 10.6 b	72.5 ± 9.9 c	108.1 ± 15.9 c
	Mean	455	151.8 ± 7.4	1229.1 ± 125.3	1394.2 ± 178.1	39.9 ± 4.3	51.6 ± 4.4	61.9 ± 10.9	85.3 ± 11.9	122.1 ± 14.9

Mean with different letters in each trait are significantly differ at 5% level.
(EN) = egg number line **(BW) = body weight line**
ASM = age at sexual maturity **BW_{SM} = body weight at sexual maturity** **BW_{M} = body weight at maturity**
EW_{SM} = egg weight at sexual maturity **EW_{M} = egg weight at maturity**
EN_{90d} = egg number in the first 90 days after sexual maturity. **EN_{42wk} = egg number at 42 weeks of age**

EN_{52wk} = egg number at 52 weeks of age

Table (2): Analysis of variance for some egg production traits in three lines of Norfa chickens (EN, BW and control) in generations 1, 2, 3 and 4.

source of variation	d.f.	Mean of squares							
		ASM	BW_{SM}	BW_M	EW_{SM}	EW_M	EN_{90d}	EN_{42wk}	EN_{52wk}
Bet. lines	2	58966.59**	20775814.6**	32864532.3**	8588.43**	8595.34**	48029.12**	57185.93**	73655.17**
Bet. Gen.	3	2474.56**	99674.75**	643317.70**	640.35**	388.54**	6993.45**	8061.24**	7325.87**
inter Lin × Gen.	6	13930.91**	1897432.16**	3170936.22**	832.84**	725.07**	5745.74**	10786.84**	11671.24**
error	1937	38.57	7017.91	15672.99	8.24	9.02	36.75	45.04	93.33

** Significant at 1% level

(EN) = egg number line (BW) = body weight line

ASM = age at sexual maturity BW_{SM} = body weight at sexual maturity BW_M = body weight at maturity

EW_{SM} = egg weight at sexual maturity EW_M = egg weight at maturity

EN_{90d} = egg number in the first 90 days after sexual maturity. EN_{42wk} = egg number at 42 weeks of age

EN_{52wk} = egg number at 52 weeks of age

Table (3): Realized and expected genetic gains for some egg production traits during three generations of selection in two lines of Norfa chickens (EN and BW).

Traits / Gene.	Genetic changes	ASM			BW_{SM}			BW_M			EW_M		
		(EN)	(BW)	Control	(EN)	(BW)	Control	(EN)	(BW)	Control	(EN)	(BW)	Control
G1	$\bar{x}$	147.8	162.3	155.1	1118.8	1369.4	1095.6	1195.1	1518.2	1221.5	36.5	39.6	35.4
	Realized absolute	-7.3	7.2		23.2	273.8		-26.4	296.7		1.1	4.2	
	expected	-1.8	1.4		13.6	17.4		-4.6	12.4		0.91	1.2	
G2	$\bar{x}$	143.5	169.2	157.1	1067.5	1457.1	1110.3	1137.1	1621.7	1230.1	35.7	42.4	36.5
	Realized absolute	-13.6	12.1		-42.8	346.8		-93.0	391.6		-0.8	5.9	
	expected	-1.2	0.99		-11.9	14.8		-6.4	12.3		-0.64	0.74	
G3	x	136.9	173.1	153.6	1030.4	1496.7	1080.7	1081.8	1724.5	1195.3	35.1	44.2	34.9
	Realized absolute	-16.7	19.5		-50.3	416.0		-113.5	529.2		0.2	9.3	
	expected	-0.66	0.47		-8.7	8.6		-5.9	6.2		0.31	0.35	

(EN) = egg number line (BW) = body weight line
ASM = age at sexual maturity BW_{SM} = body weight at sexual maturity BW_M = body weight at maturity
EW_{SM} = egg weight at sexual maturity EW_M = egg weight at maturity

EN_{90d} = egg number in the first 90 days after sexual maturity. EN_{42wk} = egg number at 42 weeks of age
EN_{52wk} = egg number at 52 weeks of age

Table (3): Cont.

Traits / Gene.	Genetic changes	EW_M			EN_{90d}			EN_{42wk}			EN_{52wk}		
		(EN)	(BW)	Control	(EN)	(BW)	Control	(EN)	(BW)	Control	(EN)	(BW)	Control
G1	x	48.8	51.9	47.2	60.1	52.2	49.9	82.5	73.9	72.2	120.5	112.1	107.6
	Realized absolute	1.6	4.7		10.2	2.3		10.3	1.7		12.9	4.5	
	expected	0.81	1.9		2.5	2.1		2.0	1.2		1.9	1.3	
G2	x	48.3	54.6	48.1	65.3	50.3	48.7	90.1	71.5	71.6	128.9	109.4	106.7
	Realized absolute	0.2	6.5		16.6	1.6		18.5	-0.1		22.2	2.7	
	expected	0.41	0.69		2.4	2.0		2.0	-2.2		1.2	1.1	
G3	x	47.6	56.2	46.1	70.4	49.4	50.8	96.9	70.1	73.9	135.1	107.2	109.1
	Realized absolute	1.5	10.1		19.6	-1.4		23.0	-3.8		26.0	-1.9	
	expected	0.23	0.38		1.2	-1.1		1.1	-1.2		1.2	-1.2	

(EN) = egg number line (BW) = body weight line
ASM = age at sexual maturity BW_{SM} = body weight at sexual maturity BW_M = body weight at maturity
EW_{SM} = egg weight at sexual maturity EW_M = egg weight at maturity
EN_{90d} = egg number in the first 90 days after sexual maturity. EN_{42wk} = egg number at 42 weeks of age

EN_{52wk} = egg number at 52 weeks of age

Table (4): Mean performance of the parental and hybrids, heterosis from the mid-parents (MP) for egg production traits of Norfa chickens in generation four.

Cross / lines / Traits	(EN × BW)					(BW × EN)				
	P_1	P_2	MP	F_1	ADH %	P_1	P_2	MP	F_1	ADH %
ASM	136.9	173.3	155.1	151.2	-2.5	173.3	136.9	155.1	147.2	-5.1
BW_{SM}	1030.4	1496.7	1263.6	1292.3	2.3	1496.7	1030.4	1263.6	1294.3	2.4
BW_M	1081.8	1724.5	1403.2	1457.6	3.9	1724.5	1081.8	1403.2	1494.5	6.5
EW_{SM}	35.1	44.2	39.7	41.7	5.1	44.2	35.1	39.7	42.1	6.1
EW_M	47.6	56.2	51.9	53.4	2.9	56.2	47.6	51.9	53.5	3.1
EN_{90d}	70.4	49.4	59.9	67.9	13.4	49.4	70.4	59.9	68.7	14.7
EN_{42wk}	96.6	70.1	83.4	88.8	6.5	70.1	96.6	83.4	94.6	13.4
EN_{52wk}	135.1	107.2	121.2	125.9	3.9	107.2	135.1	121.2	132.3	9.2

(EN) = egg number line (BW) = body weight line
P_1 = the mean of the first parent P_2= the mean of second parent
ASM = age at sexual maturity BW_{SM} = body weight at sexual maturity BW_M = body weight at maturity

EW_{SM} = egg weight at sexual maturity **EW_{M} = egg weight at maturity**
EN_{90d} = egg number in the first 90 days after sexual maturity. **EN_{42wk} = egg number at 42 weeks of age**
EN_{52wk} = egg number at 52 weeks of age