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HETEROTIC EFFECTS ON GROWTH TRAITS IN CROSSBREEDING EXPERIMENT BETWEEN APRI AND MOSHTOHOR RABBIT LINES

Abdelwahab H. Khattab[1,2], Mahmoud M. Iraqi[1], Maher H. Khalil[1,*], Emad M. Amin[2], and Ayman G. EL Nagar[1]

[1]Dep. of Anim. Prod., Fac. of Agric. at Moshtohor, Benha Uni., 13736, Egypt.

[2]Dep. of Anim. and Poult. Breeding, Anim. and Poult. Prod. Divi., Desert Res. Center, Minis. of Agric., El-Matareya 11753, Cairo, Egypt.

[*]**Corresponding author:** Maher H. Khalil[1] E-mail**: maher.khalil@fagr.bu.edu.eg**

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ABSTRACT: Five years crossbreeding experiment was preformed involving two synthetic rabbit lines of APRI (A) and Moshtohor (M) where bucks of APRI line and does of Moshtohor line were used to produce F_1 crossbreds (½A½M), followed by *inter-se* mating to obtain F_2 crossbreds $(½A½M)^2$. A total number of 263 sires, 445 dams and 1998 kits were used to estimate heritabilities and predicted breeding values (PBV) for post-weaning body weights (BW) and daily weight gains (DG). The variance components estimated by Gibbs Sampling were used to solve the mixed model equations using the PEST software, getting the solutions for genetic groups' effects along with the solutions for other fixed effects. The crossbreeding effects in terms of direct additive genetic effects (G^I), maternal effects (G^M), direct heterosis (H^I) and maternal heterosis (H^M) were obtained according to Dickerson model using the procedure of Generalized Least Squares (GLS). Heritability estimates were low to moderate, ranging from 0.17 to 0.36 for BW and 0.09 to 0.23 for DG. The ratios of common litter effects were low to moderate and ranging from 0.04 to 0.16 for BW and 0.03 to 0.26 for DG. The interse cross $(½A½M)^2$ had the lowest ranges in PBVs for BW and DG relative to the other three genetic groups. The percentages of G^I were in favor of M line by 0.2 to 2.3 % for BW and by 0.5 to 3.2 % for DG. Also, the percentages of G^M were in favor of M line by 2.1 to 4.6 % for BW and by 1.6 to 9.4 % for DG. The estimates of H^I were mostly significantly positive and ranging from 15.1 to 20.9 % for BW and 5.0 to 32.3 % for DG. Also, the estimates of H^M were significantly positive by 6.8 to 11.0 % for BW and 0.7 to 18.1 % for DG. In practice, new synthetic rabbit lines could be established in Egypt using the APRI line as a sire-group and the Moshtohor line as a dam-group.

Keywords: Rabbits, crossbreeding, growth, heritability, direct and maternal effects, heterosis.

INTRODUCTION

In the last three decades, some genetic attempts were conducted to establish new rabbit lines in Egypt through crossing V-line does with Baladi Red bucks to produce APRI line (Youssef et al., 2009) and with Sinai Gabali bucks to produce Moshtohor line (Iraqi et al., 2008&2010a,b). In addition to another line developed through selection for traits related to growth, nominated as Alexandria line. This line was established by crossing Baladi Black (BB) bucks with V-line does, then three backcrossing generations with V-line bucks to obtain progeny of 87.5% V-line and 12.5% Baladi Black ($^{7}/_{8}V^{1}/_{8}BB$), then two generations of *inter-se* mating were performed along with selection for daily gain between 28-63 days to get Alexandria line (El-Raffa, 2007). The main purposes of any crossbreeding experiment in farm animals are to exploit the heterotic effects, benefit from breed complementarity, to improve fitness and fertility, breakdown of accumulated inbreeding, which could have increased throughout the selection process and consequently avoiding the negative consequences of inbreeding depression (Adenaike et al., 2013; Abdel-Hamid, 2015; Abdel-Kafy et al., 2021). Crossbreeding can increase the efficiency of meat production by utilizing the diversity of rabbit breeds and lines characterized by high genetic merit for certain economic traits (Piles et al., 2004). However, post-weaning body weights and gains from weaning to slaughtering age are the criteria commonly used in selection for synthesizing the paternal rabbit lines (Khalil and Al-Saef, 2008; Khalil, 2010). Most of the crossbreeding experiments in the Egyptian and non-Egyptian studies have shown significant direct additive genetic effects, maternal effects and heterotic effects on body weights and gains at different ages (e.g. Abou Khadiga et al., 2008; Iraqi et al., 2008; Khalil, 2010; Zaghloul et al., 2019). The main objectives of the present study were: (1) to evaluate on quantitative genetic bases some post-weaning growth traits in different genetic groups obtained from crossbreeding experiment between bucks of APRI rabbit line and does of Moshtohor line in terms of variance components, heritability estimates and predicted breeding values, and (2) to estimate some crossbreeding effects on post-weaning body weights and daily weight gains.

MATERIALS AND METHODS

Animals and mating system used, management and feeding regime

Five years crossbreeding experiment was performed between bucks of APRI rabbit line (A) and does of Moshtohor line (M) to produce F_1 crossbred rabbits (½A½M), followed by *inter-se* mating to obtain F_2 crossbreds $(½A½M)^2$. Therefore, four genetic groups were used to assess the crossbreeding effects on post-weaning growth traits in terms of direct additive genetic, maternal effects and direct and maternal heterosis. The total number of sires, dams and kits used in this experiment were presented in Table 1. The experimental work was started from September 2016 to June 2020 in the rabbitry belonging to the Department of Animal Production, Faculty of Agriculture, Benha University, Egypt. APRI line rabbits was synthetized in the rabbitry of Animal Production Research Institute through crossing Baladi Red bucks with V-line does, followed by two generations of *inter-se* mating with selection for litter weight at weaning (Youssef et al., 2009). Moshtohor line rabbits was developed in the rabbitry of Department of Animal Production, Faculty of Agriculture at Moshtohor, Benha University, Egypt through crossing Sinai Gabali bucks with V-line does, followed by four generations of *inter-se* mating along with selection for litter weight at weaning and individual weight at 56 days (Iraqi et al., 2008&2010a,b).

The breeding bucks and does were first mated at the age of 18 to 20 weeks old. Throughout the duration of the experiment, all the animals were housed in the farm under the same management system and conditions. The rabbitry is supplied by cooling system to maintain the temperature between 15 to 30°C, with a relative humidity from 35 to 75 %. The photoperiod was 16L:8D and the breeding cages were arranged in flat-deck batteries. Using natural mating, bucks were divided into different families, each family consisted of one buck and three does; avoiding the matings between animals with common parents to control the inbreeding. Each doe was checked for pregnancy using an abdominal palpation on day 12 after mating, and the non-pregnant does were remated with the same assigned buck. Litters were checked every morning during the suckling period to remove the dead kits. Kits were raised by their dams and weaned at 28 days after kindling. Then, each animal was given a unique identification number tattooed on the left ear before being moved to the fattening cages (5-6 rabbits per cage) until marketing at 84 days.

Pelletized commercial diets were provided *ad libitum* to both breeding animals and offspring. The pelleted diet containing 16% crude protein and 14% crude fiber was used during the growing period of offspring from weaning until the start of mating of does with bucks, and a diet containing 18 % crude protein and 12 % crude fiber with a digestible energy of 2500 kcal/kg was used during the breeding season.

Data and model of analysis

In the studied four genetic groups, body weights were recorded individually at 4 (BW4), 6 (BW6), 8 (BW8), 10 (BW10) and 12 (BW12) weeks of age, along with daily weight gains (DG) during the age intervals from 4 to 6 (DG4-6), 6 to 8 (DG6-8), 8 to 10 (DG8-10) and 10 to 12 (DG10-12) weeks, respectively. These sets of data were analyzed using the following single-trait animal model:

$$y = X\mathrm{b} + Z_a u_a + Z_c u_c + \mathrm{e} \quad (Model\ 1)$$

where y = vector of the observed growth trait for the weaned rabbit; b = vector of the fixed effects of genetic group of the weaned rabbit (4 levels: A, M, ½A½M and $(½A½M)^2$), kit sex (male and female), year-season of birth (16 levels), parity order (6 levels), and litter size in which the kit was born (10 levels); u_a = vector of random additive genetic effect of the weaned rabbit; u_c = vector of random effects of the non-additive common litter effects; X = incidence matrix of fixed effects; Z_a = incidence matrix of random additive genetic effects; Z_c= incidence matrix of common litter effects; e = vector of the random residual effects. The data were renumbered and recoded using the renumf90 software (Misztal et al., 2018). The pedigree file was checked for the relationship issues using the CFC v.1.0 software (Sargolzaei et al., 2006). The variance components for the random effects of the studied traits and heritabilities were estimated based on a Bayesian Inference of Gibbs Sampling Algorithm using the TM software (Legarra et al., 2008) where the Gibbs sampler algorithm comprised 200,000 iterations and discarding the first 20,000 iteration. Afterwards, one sample in each 200 iterations was saved. The estimated variance components were used to solve the mixed model equations using the PEST software (Groeneveld, 2006), getting the solutions for genetic groups effects along with the solutions for other fixed effects and their error variance-covariance matrix.

The BLUPF90 software (Misztal et al., 2018) was used to estimate the predicted breeding values (PBVs) for each growth trait of each animal adopting single-trait animal model (Model 1). The correlations between the true and predicted breeding values were used to define the accuracy (r_A) of PBVs. The accuracy of PBV was calculated for each animal as described by Meyer (2004): $r_A = \sqrt{1-(PEV/\sigma_a^2)}$ where, PEV is the prediction error variance estimated using the elements of the mixed model equations as PEV = $(SEP)^2$ and SEP is the standard error of prediction and σ_a^2 is the additive genetic variance of the trait.

Estimation of crossbreeding effects

The CBE software (Wolf, 1996) was used to estimate the crossbreeding effects. The solutions for the crossbreeding genetic group effects were obtained according to Dickerson model (Dickerson, 1992), using the procedure of Generalized Least Squares (GLS) and applying the following linear model:

$y = Xb + e, \quad Var(y) = V$ (Model 2)

where: y = vector of the estimated genetic groups solutions for growth trait; X = incidence matrix of genetic group effects; b = vector of estimable crossbreeding genetic effects; e = vector of random error; V = the error variance-covariance matrix of y. The crossbreeding parameters were estimated, representing the differences between the genetic groups in terms of direct additive effects ($G^I = G^I_A - G^I_M$), maternal effects ($G^M = G^M_A - G^M_M$), direct heterosis (H^I) and maternal heterosis (H^M). Thus, we have four parameters and these parameters were estimated according to Dickerson (1992) and Wolf (1996) as a vector called b-vector:

$b = [(G^I{}_A - G^I{}_M)\,(G^M{}_A - G^M{}_M)\;\; H^I\;\; H^M]$

where G^I_A and G^I_M = Direct additive genetic effects for APRI and Moshtohor lines, respectively; G^M_A and G^M_M = Maternal effects for APRI and Moshtohor lines, respectively. The solutions of b were calculated by the method of Generalized Least Squares using the following equation:

$$\hat{b} = (X'V^{-1}X)^{-}X'V^{-1}y$$

where X was the matrix of the coefficients relating the means of the genetic groups with the estimable crossbreeding effects (Table 2), V^{-} = the generalized error variance–covariance matrix, with the variance–covariance matrix of the estimate of b, being,

$$\text{Var}\,\hat{b} = (X'V^{-1}X)^{-}$$

RESULTS AND DISCUSSION

Descriptive statistics for growth traits

The main statistical parameters estimated by Gibbs Sampling Algorithm using the TM software for growth traits across the four genetic groups studied were shown in Table (3). The overall means for body weights were 530, 840, 1130, 1425 and 1745 g for BW4, BW6, BW8, BW10 and BW12 and 23.0, 21.3, 21.6 and 25.1 g for daily gains at intervals of DG4-6, DG6-8, DG8-10 and DG10-12, respectively. The present means were within the range of previously reported values given by several Egyptian investigators for various breeds/ lines (Abou Khadiga et al., 2008; Zaghloul et al., 2019; Iraqi et al. 2008; Youssef et al., 2009; Sanad et al., 2022).

The wide ranges between minimum and maximum values of body weights at various stages and daily weight gains (Table 3) indicate that improvement of growth traits through phenotypic selection may be easier to achieve. The coefficients of variation (CV%) for body weights were mostly moderate (11 to 16%) and decreased with the advance of age (Table 3). This pattern may be due to that young rabbits become progressively less sensitive to non-genetic maternal effects as reported earlier by Khalil et al. (1987). The coefficients of variation ranged from 29 to 41% for daily weight gains. These values were fitted within the ranges reported by some Egyptian investigators (Abdel-Ghany et al., 2000; Iraqi et al., 2002; El-Deghadi and Ibrahim, 2017; Abdel-Kafy et al., 2021).

Heritability estimates and common litter effects

Heritability estimates for body weights and daily weight gains in APRI and Moshtohor lines and their crosses were mostly moderate and ranging from 0.17 to 0.36 for body weights and 0.09 to 0.23 for daily weight gains (Table 4). In several studies involving synthetic lines of rabbits, the heritability estimates for body weights and daily weight gains were mostly moderate or high, ranging from 0.10 to 0.61 for BW4, 0.15 to 0.65 for BW6, 0.10 to 0.44 for BW8, 0.10 to 0.53 for BW10, 0.09 to 0.52 for BW12, 0.08 to 0.79 for DG4-6, 0.10 to 0.36 for DG6-8, 0.05 to 0.49 for DG8-10 and 0.07 to 0.48 for DG10-12 (Iraqi et al., 2002; Hekil et al., 2011; Sanad et al., 2022). The reviewed heritability estimates for body weights and gains in synthesized rabbit lines were lower than those estimates in the original breeds/or strains since the synthetic lines were subjected to intensive selection programmes in their foundation (Khalil and Al-Homidan, 2014).

The ratios of common litter effects (c^2) for post-weaning body weights and gains were moderate at weaning age and decreased thereafter, ranged from 0.04 to 0.16 for body weights and from 0.03 to 0.26 for daily weight gains (Table 4). The ratios of c^2 showed that common litter effects should be considered in genetic evaluation of breeding programs. Abdel-Kafy et al. (2021) stated that the common litter effects on body weights were large at weaning then declined gradually as the rabbit grew older at 20 weeks of age. However, common litter influences might be of considerable importance for post-weaning growth in rabbits due to the effect of the genetic variation on some characters of the dam, such as mothering or maternal ability (Khalil and Al-Homidan, 2014; El-Deghadi and Ibrahim, 2017).

Predicted breeding values (PBV)

The ranges in PBV and their accuracy of predictions (r_A) estimated by BLUPF90 software (Misztal et al., 2018) for post-weaning body weights and daily weight gains within each genetic group are presented in Table 5. In general, the interse cross group (½A½M)^2 recorded the lowest ranges in PBVs for body weights and gains, while the other three groups (APRI, Moshtohor and ½A½M) have inconsistent trend in estimates of PBV. The ranges in PBV's for body weights among the four genetic groups were high and ranging from 146 to 237 g for BW4, 140 to 222 g for BW6, 175 to 263 g for BW8, 165 to 419 g for BW10 and 278 to 435 g for BW12. Also, the ranges in PBV's for daily weight gains were high and ranging from 9.9 to 26.6 g for DG4-6, 7.8 to 18.3 g for DG6-8, 9.4 to 16.9 g for DG8-10 and 11.2 to 16.3 g for DG10-12. Similarly, the reviewed estimates of PBV for post-weaning body weights and daily weight gains cited in an Egyptian study showed that the ranges in PBV's were high and ranging from 175 to 221 g for BW4, 72 to 264 g for BW6, 69 to 299 g for BW8, 148 to 420 g for BW10 and 179 to 660 g for BW12 (El-Deghadi et al., 2023).

Crossbreeding effects

Direct additive genetic (G^I) and maternal (G^M) effects

The estimable generalized least square solutions for direct additive genetic effects (G^I) were in favour of Moshtohor line with percentages ranging from 0.2 to 2.3 % for body weights and 0.5 to 3.2 % for daily weight gains (Table 6). However, the direct additive effects for body weights and gains estimated in the Egyptian crossbreeding experiments were mostly in favour of the exotic breeds/lines such as V-line, New Zealand White, Californian, Bouscat, Flemish Giant and Rex (e.g. Abou Khadiga et al., 2008; Youssef et al., 2009; Hekil et al., 2011; Abdel-Hamid, 2015), while the reversible direct additivity were recorded by the local strains such as Sinai Gabali, Moshtohor, Baladi Black and Baladi Red (Abdel-Ghany et al., 2000; Iraqi et al., 2008; Zaghloul et al., 2019; Sanad et al., 2022). The estimates of direct additive effects for body weights reviewed from the Egyptian studies (Iraqi et al., 2008; Zaghloul et al., 2019; Abdel-Kafy et al., 2021; Sanad et al., 2022) were mostly significantly in favour of V-line, Giant Flander, New Zealand White, Sinai Gabali, Moshtohor and Baladi Black rabbits where the estimates ranged from 2.7 to 22.1 % for BW4, 4.1 to 31.2 % for BW6, 4.2 to 32.8 % for BW8, 2.6 to 31.1 % for BW10, 2.9 to 25.2 % for BW12. In addition, the estimates for daily weight gains were also in favour of V-line, New Zealand White, Sinai Gabali, Moshtohor and Baladi Black rabbits where the estimates ranged from 3.7 to 35.4 % for DG4-6, 6.1 to 38.1 % for DG6-8, 9.2 to 21.9 % for DG8-10 and 3.7 to 25.7 % for DG10-12.

The generalized least square solutions and their percentages for the maternal effects (G^M) for growth traits were mostly significantly in favour of Moshtohor line, with percentages ranging from 2.1 to 4.6 % for body weights and 1.6 to 9.4 % for daily weight gains (Table 6). These findings are consistent with the other Egyptian crossbreeding studies, which showed that maternal effects were of considerable importance for the majority of post-weaning growth traits (Abou Khadiga et al., 2008; Iraqi et al., 2008; Hekil et al., 2011; Zaghloul et al., 2019; Abdel-Kafy et al., 2021; Sanad et al., 2022). However, the estimates of maternal effects on body weights and daily weight gains in the Egyptian crossbreeding experiments were mostly in favour of the exotic breeds/lines such as V-line, New Zealand White, Giant Flander, Californian (Abou Khadiga et al., 2008; Youssef et al., 2009; Abdel-Hamid, 2015), while the reversible maternal effects were recorded by the local breeds/strains such as Sinai Gabali, Moshtohor, Baladi Red and Baladi Black (Khalil and Afifi, 2000; Iraqi et al., 2008; Zaghloul et al., 2019; Sanad et al., 2022). In general, most of the estimates of maternal effects reviewed from the Egyptian studies showed that maternal effects were in favour of Giant Flander (Abdel-Kafy et al., 2021), V-line, Moshtohor, Sinai Gabali, Baladi Red and New Zealand White rabbits where the estimates of maternal effects for body weights were mostly moderate and significantly favorable from 2.8 to 22.0 % for BW4, 4.1 to 33.0 % for BW6, 3.5 to 34.8 % for BW8, 3.5 to 33.3 % for BW10 and 3.1 to 27.2 % for BW12 (Abdel-Ghany et al., 2000; Abou Khadiga et al., 2008; Sanad et al., 2022). But, the estimates for post-weaning daily weight gains were relevantly in favour of New Zealand White and Moshtohor line rabbits where the estimates ranged from 5.2 to 29.5 % for DG4-6, 4.8 to 33.4 % for DG6-8, 5.2 to 30.0 % for DG8-10 and 2.9 to 24.7 % for DG10-12 (Hekil et al., 2011; Abdel-Hamid, 2015).

Direct (H^I) and maternal (H^M) heterosis

The generalized least square solutions and their percentages of direct heterotic effects (H^I) for growth traits were mostly positive and significant, with the percentages ranging from 15.1 to 20.9 % for body weights and 5.0 to 32.3 % for daily weight gains (Table 7). These estimates fall within the ranges cited in most of the Egyptian crossbreeding studies where the significant estimates revealed favorable direct heterotic impacts ranging from 3.1 to 16.9 % for BW4, 2.4 to 20.3 % for BW6, 3.4 to 20.3 % for BW8, 3.2 to 21.0 % for BW10 and 3.6 to 16.7 % for BW12, 4.4 to 29.5 % for DG4-6, 5.0 to 27.2 % for DG6-8, 4.7 to 30.4 % for DG8-10 and 3.5 to 36.8% for

DG10-12 (Abdel-Hamid, 2015; Zaghloul et al., 2019; Abdel-Kafy et al., 2021; Sanad et al., 2022). Khalil and Al-Homidan (2014) in a crossbreeding experiment involving Saudi Gabali and V-line rabbits, found that the estimates of direct heterosis were significantly positive and ranged from 4.5 to 5.4% for body weights and 6.6 to 9.6% for daily weight gains.

The generalized least square solutions and percentages of the maternal heterosis (H^M) were significantly favorable for most growth traits, with percentages ranging from 6.8 to 11.0 % for body weights and 0.7 to 18.1 % for daily weight gains (Table 7). According to our knowledge, most of the Egyptian crossbreeding experiments in rabbits spanned only one generation, while the estimation of maternal heterosis requires at least two crossbreeding generations, therefore, the reviewed maternal heterotic effects in rabbits are scarce in Egypt. However, the estimates of maternal heterotic effects for body weights obtained in the present study fall within the ranges cited in most of the Egyptian crossbreeding studies where the estimates revealed significant favorable maternal heterotic effects ranging from 4.5 to 7.9 % for BW4, 3.9 to 15.2 % for BW6, 4.8 to 13.2 % for BW8, 8.5 to 16.0 % for BW10 and 4.5 to 15.4 % for BW12 (Abou Khadiga et al., 2008;. Iraqi et al., 2008; Abdel-Kafy et al., 2021).

CONCLUSIONS

1) Desired heterotic consequences have been reported from crossing APRI line with Moshtohor line rabbits and this crossing could be beneficial to improve growth performance traits in rabbits.

2) In Egypt, new synthetic rabbit lines could be established using the APRI line as a sire-group and the Moshtohor line as a dam-group, based on the estimated direct and maternal effects.

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DECLARATION OF INTEREST

The authors declare no conflict of interest.

ETHICS STATEMENT

All experimental procedures involving animals handling and treatment were approved by the Research Ethics Committee of the Faculty of Agriculture, Benha University, Egypt (REC-FOABU).

SOFTWARE AND DATA REPOSITORY RESOURCES

Data used is available from the corresponding author upon reasonable request.

FINANCIAL SUPPORT

The experiment was financially supported by the Faculty of Agriculture, Benha University, Egypt.

Table (1): Genetic groups and numbers of sires, dams and kits categorized according to their genetic groups

Sire genetic group (N)	Dam genetic group (N)	Kit genetic group	No of kits weaned
APRI line (95)	APRI line (141)	APRI line	520
Moshtohor line (92)	Moshtohor line (164)	Moshtohor line	604
APRI line (64)	Moshtohor line (104)	½A½M	374
½A½M (12)	½A½M (36)	(½A½M)²	500
Total No. = 263	Total No. = 445		Total No. = 1998

N = Numbers given in brackets.

Table (2): Genetic groups of kits with their sires and dams and coefficients of the matrix relating the means of the genetic groups with crossbreeding effects

Genetic groups of			Mean	Coefficients of the matrix of the estimable crossbreeding effects					
Sire	Dam	Kit		G^I_A	G^I_M	G^M_A	G^M_M	H^I	H^M
A	A	A	1	1	0	1	0	0	0
M	M	M	1	0	1	0	1	0	0
A	M	½A½M	1	0.5	0.5	0	1	1	0
½A½M	½A½M	(½A½M)^2	1	0. 5	0. 5	0. 5	0. 5	0.5	1

A=APRI rabbit line; M=Moshtohor rabbit line, G^I_A and G^I_M = Direct additive genetic effects for APRI and Moshtohor lines, respectively; G^M_A and G^M_M = Maternal effects for the APRI and Moshtohor lines, respectively; H^I = Direct heterosis; H^M = Maternal heterosis.

Table (3): Descriptive statistics in terms of generalized least square means (GLM), standard deviations (SD), minimum and maximum values and coefficients of variation (CV%) for post-weaning growth traits across all genetic groups studied

Trait$^+$	N	GLM	SD	Minimum	Maximum	CV%
Body weight (g):						
BW4	1998	530	87	300	918	16
BW6	1862	840	104	520	1185	12
BW8	1745	1130	132	740	1570	12
BW10	1700	1425	174	1000	2310	12
BW12	1459	1745	199	1100	2390	11
Daily weight gain (g):						
DG4-6	1660	23.0	9.5	2.8	59.3	41
DG6-8	1549	21.3	7.18	7.5	57.9	33
DG8-10	1479	21.6	7.5	8.6	56.8	35
DG10-12	1355	25.1	7.2	8.6	52.1	29

$^+$BW4, BW6, BW8, BW10 and BW12= Body weight at 4, 6, 8, 10 and 12 weeks of age, respectively; DG4-6, DG6-8, DG8-10, and DG10-12= Daily weight gain during the intervals from 4 to 6, 6 to 8, 8 to 10 and 10 to 12 weeks of age, respectively.

Table (4): Estimates of heritability and their standard errors (h^2±SE), the proportion of phenotypic variance explained by common litter effects (c^2±SE) and random error (e^2±SE) estimated by Bayesian Inference of Gibbs Sampling using the TM software for post-weaning growth traits across all genetic groups

Traits	N	h^2±SE	c^2±SE	e^2±SE
Body weight:				
BW4	1998	0.36±0.06	0.16±0.03	0.48±0.05
BW6	1862	0.22±0.05	0.04±0.03	0.74±0.05
BW8	1745	0.17±0.07	0.07±0.03	0.76±0.06
BW10	1700	0.27±0.07	0.13±0.04	0.60±0.06
BW12	1459	0.21±0.11	0.10±0.05	0.69±0.08
Daily weight gain:				
DG4-6	1660	0.18±0.08	0.26±0.04	0.56±0.07
DG6-8	1549	0.09±0.06	0.08±0.03	0.83±0.05
DG8-10	1479	0.23±0.07	0.05±0.03	0.72±0.06
DG10-12	1355	0.20±0.07	0.03±0.02	0.77±0.07

[+] Traits as defined in Table (3).

Table (5): The ranges in predicted breeding values (PBV) estimated by BLUPF90 software for post-weaning body weights (BW) and daily weight gains (DG) in different genetic groups studied

Trait[+]	Genetic group							
	APRI line (A)		**Moshtohor line (M)**		**½A½M**		**(½A½M)^2**	
	N	**PBV range**	**N**	**PBV range**	**N**	**PBV range**	**N**	**PBV range**
Body weight (g):								
BW4	520	216	604	237	374	233	500	146
BW6	471	222	542	168	358	219	491	140
BW8	436	263	491	215	350	253	468	175
BW10	423	317	478	392	340	419	459	165
BW12	347	367	367	435	301	278	444	422
Daily weight gain (g):								
DG4-6	415	23.5	488	20.4	317	26.6	440	9.9
DG6-8	390	17.3	449	18.3	301	16.3	409	7.8
DG8-10	369	13.6	426	15.3	294	16.9	390	9.4
DG10-12	336	13.5	365	16.3	280	12.9	374	11.2

[+] Traits as defined in Table (3). The accuracies of predictions in PBV (r_A) were high and ranged from 0.92 to 0.99 for body weights and from 0.90 to 0.99 for daily body gains.

Table (6): Generalized least square solutions and percentages of direct additive genetic effects (G^I) and maternal effects (G^M) and their standard errors (SE) estimated by Dickerson model for post-weaning growth traits in crossing APRI bucks with Moshtohor does

Trait$^+$	Direct additive genetic effects (G^I)				Maternal effects (G^M)		
	N	$G^I = G^I_A - G^I_M$ (in units)	SE	G^I as %$^{++}$	$G^M = G^M_A - G^M_M$ (in units)	SE	G^M as %$^{++}$
Body weight (g):							
BW4	1998	-11.3**	0.05	2.3	-22.8**	0.05	4.6
BW6	1862	-10.1*	0.06	1.3	-34.1**	0.06	4.4
BW8	1745	3.2^{NS}	0.09	0.3	-33.3**	0.08	3.1
BW10	1700	-2.2^{NS}	0.12	0.2	-59.9**	0.10	4.5
BW12	1459	3.8^{NS}	0.16	0.2	-34.8**	0.15	2.1
Daily weight gain (g):							
DG4-6	1660	-0.7*	0.01	3.2	-0.8**	0.01	3.7
DG6-8	1549	0.1^{NS}	0.01	0.6	-0.4^{NS}	0.01	1.9
DG8-10	1479	-0.4^{NS}	0.01	2.1	-1.8**	0.01	9.4
DG10-12	1355	0.1^{NS}	0.01	0.5	-0.3^{NS}	0.01	1.6

$^+$ Traits as defined in Table (3), $^{++}$Percentage computed as [Estimate of G^I or G^M in units/(A+M)/2]x100; NS= Not Significant, *=P≤ 0.05 and **=P≤ 0.01.

Table (7): Generalized least square solutions and percentages of direct heterotic effects (H^I), maternal heterotic effects (H^M) and their standard errors (SE) estimated by Dickerson model for post-weaning growth traits in crossing APRI bucks with Moshtohor does

Trait$^+$		Direct heterotic effects (H^I)			Maternal heterotic effects (H^M)		
	N	H^I (in units)	SE	H^I as %$^{++}$	H^M (in units)	SE	H^M as %++
Body weight (g):							
BW4	1998	95**	0.10	19.1	52**	0.09	10.5
BW6	1862	146**	0.12	18.7	71**	0.10	9.1
BW8	1745	160**	0.15	15.1	102**	0.15	9.6
BW10	1700	257**	0.21	19.4	90**	0.19	6.8
BW12	1459	341**	0.35	20.9	180**	0.25	11.0
Daily weight gain (g):							
DG4-6	1660	1.1^{NS}	0.02	5.0	0.2^{NS}	0.01	0.7
DG6-8	1549	2.8**	0.01	14.5	2.7**	0.01	14.2
DG8-10	1479	6.2**	0.01	32.3	-0.6^{NS}	0.01	2.9
DG10-12	1355	5.4**	0.02	24.1	4.0**	0.01	18.1

$^+$Traits as defined in Table (3), $^{++}$Percentage computed as [Estimate of H^I or H^M in units/(A+M)/2]x100; NS= Not Significant and **=P≤ 0.01.

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Rabbits, crossbreeding, growth, heritability, direct and maternal effects, heterosis.

الملخص العربى

تأثيرات قوة الخلط على صفات النمو في تجربة لخلط أرانب خط أبري مع خط مشتهر

عبد الوهاب حسن خطاب[1،2] ، محمود مغربي عراقي[1]، ماهر حسب النبي خليل[1]، عماد محمد أمين[2]، أيمن النجار[1]
1- قسم الإنتاج الحيواني - كلية الزراعة بمشتهر - جامعة بنها - مصر
2- قسم تربية الحيوان والدواجن – شعبة الإنتاج الحيواني والدواجن – مركز بحوث الصحراء – وزارة الزراعة – مصر

أجريت تجربة خلط لمدة خمس سنوات بين خطين مستنبطين من الأرانب (خط أبري وخط مشتهر)، حيث تم الخلط بين ذكور أرانب أبري مع إناث أرانب مشتهر لإنتاج الجيل الأول الخليط (½أبري½مشتهر)، متبوعاً بالتزاوج البيني بين أفراد الجيل الأول لإنتاج الجيل الثاني الخليط (½أبري½مشتهر)^2. تم إستخدام بيانات عدد 263 أب، 445 أم، 1998 أرنب مفطوم لتقدير المكافئ الوراثي، القيمة التربوية المتوقعة. أستخدمت مكونات التباين المحسوبة بواسطة برنامج Gibbs sampling في حل معادلات النموذج المختلط MME مستخدما برنامج PEST وذلك للحصول على حلول للمربعات الدنيا المعممة Generalized Least Square solutions للمجموعات الوراثية تحت الدراسة مصحوبة بحلول للتأثيرات الثابتة Fixed effects. تم تقدير مكونات الخلط (الأثر الوراثي التجمعي المباشر، الأثر الأمي، قوة الخلط المباشرة وقوة الخلط الأمية) لصفات وزن الجسم والزيادة اليومية في الوزن بعد الفطام طبقا لنموذج ديكرسون وبإستخدام طريقة المربعات الدنيا المعممة Generalized Least Squares. أظهرت النتائج أن قيم المكافئ الوراثي منخفضة إلى متوسطة وتراوحت بين 0.17 إلى 0.36 لصفات وزن الجسم وبين 0.09 إلى 0.23 لصفات معدل الزيادة اليومية في الوزن. كانت نسب التأثيرات الشائعة للخلفة منخفضة إلى متوسطة وتراوحت بين 0.04 إلى 0.16 لصفات وزن الجسم، وبين 0.03 إلى 0.26 لصفات معدل الزيادة اليومية في الوزن. كانت القيم التربوية لصفات وزن الجسم ومعدل الزيادة اليومية في الوزن منخفضة في خلطان الجيل الثاني مقارنة بالمجاميع الوراثية الأخرى. كانت النسب المئوية للأثر الوراثي التجمعي معنوية لصالح خط مشتهر، وتراوحت بين 0.2 إلى 2.3% لصفات وزن الجسم، وبين 0.5 إلى 3.2% لصفات معدل الزيادة اليومية في الوزن. كما كانت النسب المئوية للأثر الأمي معنوية لصالح خط مشتهر، وتراوحت بين 2.1 إلى 4.6% لصفات وزن الجسم، وبين 1.6 إلى 9.4% لصفات معدل الزيادة اليومية في الوزن. كانت قيم قوة الخلط المباشرة غالباً معنوية وموجبة وتراوحت بين 15.1 إلى 20.9% لصفات وزن الجسم، وبين 5.0 إلى 32.3% لصفات معدل الزيادة اليومية في الوزن. كما كانت قيم قوة الخلط الأمية معنوية وموجبة وتراوحت بين 6.8 إلى 11.0% لصفات وزن الجسم، وبين 0.7 إلى 18.1% لصفات معدل الزيادة اليومية في الوزن. ومن الناحية التطبيقية أوضحت الدراسة إمكانية إستباط طرز جديدة في مصر من خلال الخلط بإستخدام الذكور من أرانب خط أبري وإستخدام الإناث من خط مشتهر.