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GENETIC EVALUATION OF A CROSSBREEDING EXPERIMENT INCLUDED TWO SELECTED LINES OF JAPANESE QUAIL AND THEIR CROSSES FOR SOME GROWTH AND MATURITY-RELATED TRAITS**G. Abou Khadiga^{1*}, Bothaina Y. F. Mahmoud² and Ensaf A. El-Full²**¹Fac. of Desert and Environmental Agric., Fuka, Alexandria Univ., Matrouh Branch, Egypt;²Fac. of Agric., Fayoum Univ., Egypt.

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ABSTRACT: Data of the present study were obtained on a total of 2502 birds of purebred (1300) and crossbred (1202) birds of two differently selected Japanese quail lines (paternal and maternal), as well as their reciprocal crosses. The studied traits were weekly body weight from hatch up to 6th week of age, body weight (BW_{SM}) and age at sexual maturity (ASM) of females, egg number for the first 50 days of production (EN_{50}) and degree of sexual dimorphism for body weight (DSD) weekly from hatch to 6th week of age. The crossbreeding effects (heterosis, direct additive, maternal additive) were estimated for all traits. Fixed effects (line, sex and hatch) and their possible interactions were included in the models to analyze the studied traits. Line differences were significant for all traits. Paternal line showed expected significant ($P<0.05$) superiority over the rest of the genetic groups for body weight traits. Both crossbreds showed significantly ($P<0.05$) better performance in ASM, EN_{50} and DSD than their purebred parents. Degree of sexual dimorphism (DSD) for body weight was significant ($P<0.05$) at later ages at 5th and 6th weeks but not apparent earlier in the whole experiment. Both sex and hatch significantly ($P<0.05$) affected body weight traits, except the effect of sex on hatch weight. Hatch effect was significant ($P<0.05$) on BW_{SM} , ASM and EN_{50} . Direct heterosis was almost significant ($P<0.05$) for all traits, except for W_H though generally negative for body weight traits, while it was positive and significant for EN_{50} and most of DSD traits. Direct additive and maternal additive effects were significant ($P<0.05$) for most traits, except for W_H , ASM and EN_{50} , where only direct additive effect estimates were significant. DSD traits showed inconsistent effects and trends for both direct and maternal additive effects. Impact of additive rather than maternal effects were clear in most traits. Generally, it could be concluded that crossbreeding between one paternal line with another maternal line had negative heterotic effects on body

Key Words: Japanese quail, crossbreeding, body weight, sexual maturity, egg production.

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weight but improved both ASM and EN₅₀ in Japanese quail. DSD traits showed positively significant heterotic effects during the whole experiment. The use of maternal line in a sire position and paternal line in a dam position in crossbreeding experiments when the goal is to improve sexual maturity and egg production traits in Japanese quail could be beneficial.

INTRODUCTION

Advantages of Japanese quail such as small body size, fast growth rate, short generation interval, high level of egg production and high quality of meat are revealed (Özsoy and Aktan, 2011 and Tavaniello, 2014). So, these advantages encourage genetic studies on growth and body composition traits (Saatci et al., 2003, and Ojedapo and Amao, 2014) and egg production (Minvielle et al., 2000; Vali et al., 2006 and Saatci et al., 2006). Poultry breeding programs are aimed to improve genetic potential of chicks through selection and crossbreeding plans (Narinc et al., 2014). Crossbreeding is a major tool to produce favorable individuals which are influenced by various genetic and non-genetic factors. It is also valuable for averaging of breed effects and achieving intermediate values that are superior to opposite extremes (Kinghorn, 2000 and Yongjun et al., 2006). Though, reliable crossbreeding parameter estimates including heterotic, direct and maternal effects are required to design a sound crossbreeding program. Performance comparisons among breeds and their crosses are justified because genetic differences among breeds or strains are large relative to genetic variation within breeds (Dickerson, 1992). These differences are important potential source of genetic improvement of the flocks through heterotic and complementary breed effects. It appears that there is not a single, simple explanation for heterosis. Instead, it is likely that heterosis arises in crosses between genetically distinct individuals as a result of a diversity of mechanisms (Ferdous, 2013). Heterosis generally results

from the action of multiple loci, and different loci affect heterosis for different traits and in different hybrids. Hence, multi-gene models are likely to prove most informative for understanding heterosis. Falconer and Mackay (1996) reported that the magnitude of heterosis depends, from many impetuses upon the directional dominance and the relative merit of the dominance variance. Moreover, they showed that heterosis in the F₁ depends on the difference in gene frequencies in the parental lines and on the degree of dominance. Practically, heterosis amount can vary dramatically due to the surrounded environment and the genetic makeup of the populations being crossed. Another reason for crossbreeding is to combine favorable qualities of two or more breeds of different type in a complementarity fashion. Breed complementarity refers to the production of a more desirable offspring by crossing breeds that are genetically different from each other, but that have complementarity attributes (Bourdon, 1997). Non-additive genetic effect is important in meat and laying stocks because of the opportunities to combine stocks that complement each other (Nofal, 2006). Characters with considerable non-additive genetic variation (dominance and epistasis) are most likely to show heterosis. In relation to complementarity, crossing exploits differences in average performance between populations (i.e. differences in additive effects between populations). Maternal effects may be caused by the genes that a mother is carrying and by the environment she provided for her offspring. However, the maternal effect herein could be confounded with the reciprocal effect

(i. e. sex linkage) due to additive effects of the genes concerned and carried on the sex chromosomes. Nevertheless, few studies have been published on crossbreeding experiments comparing different lines of Japanese quail for growth and maturity-related traits providing estimates of additive crossbreeding genetic parameters in Japanese quail. So, the objective of the current study was to study the fixed effects of line, sex and hatch on body weight and egg production traits in Japanese quail of two lines (paternal and maternal) and the two reciprocal crosses, as well as to assess heterotic, direct and maternal line additive genetic effects for the studied traits.

MATERIALS AND METHODS

Population Structure and Bird Management:

The study was conducted at the Poultry Research Center, Faculty of Agriculture, Fayoum University, Egypt. Data were obtained on a total number of 2502 birds of paternal line (P, 775), maternal line (M, 725), PxM cross (660) and MxP cross (642) of Japanese quail. Paternal line (P) was selected to increase body weight at 4 weeks for 5 generations and maternal line (M) was selected to increase egg production for 50 days of production for five generations. Chicks were wing banded at hatch (3 hatches) and were housed in groups of six per cage. From hatch up to five weeks of age, all quail fed ad libitum on a starter diet containing 24% CP and 2900 K cal/ME and water. From six weeks to the end of the study, a breeder diet containing 20% CP, 2900 K cal/ME, 2.25% calcium and 0.43% available phosphorous were supplied according to NRC (1994). Birds were in continuous light for the first two weeks of age and then reduced to 16 hours of light day thereafter. All birds were kept under the same managerial hygienic and environmental conditions.

Studied traits and statistical analysis:

The studied traits were individual body weight at hatch (W_H), one (W_1), two (W_2), three (W_3), four (W_4), five (W_5) six (W_6) weeks of age, along with degree of sexual dimorphism at the same ages (DSD_H , DSD_1 , DSD_2 , DSD_3 , DSD_4 , DSD_5 , DSD_6). Maturity traits of females included body weight at sexual maturity for females (BW_{SM}), age at sexual maturity for females (ASM) and egg number at first 50 days of production (EN_{50}). The degree of differences between male and female, defined as degree of sexual dimorphism (DSD) in body weight at 6 weeks of age was calculated by the following formula (Sezer et al., 2006):

$$\text{Degree of sexual dimorphism (DSD\%)} = \left[\frac{FW_t - MW_t}{FW_t} \right] \times 100$$

where: FW_t is the mean female live weight at time t and MW_t is the mean male live weight at time t.

Traits were analyzed using three different models in the framework of the GLM procedure of SAS package, 2011 (version 9.3). The first model was for analyzing body weight traits included the main fixed effects of: line of the bird (4 levels), sex (2 levels) and hatch (3 levels), while the second model to analyze maturity and egg production traits excluded the fixed effect of sex. The third model included the main effects of line and hatch to analyze DSD% traits. All models included all possible second and three interactions among main factors. The estimated least-squares means were used as input data for the program package CBE, version 4.0 (Wolf, 1996) that was used to estimate the crossbreeding parameters (direct additive G^i ; maternal additive G^m ; direct heterotic H^i effects) for the studied traits according to Dickerson (1992). They were estimated from linear contrasts between the line types means according to the following coefficients:

Direct heterosis effect:

$$H^i: P \times M = [(P \times M + M \times P) - (P \times P + M \times M)]$$

Direct additive effect:

$$(G^iP - G^iM) = [(P \times P) + (P \times M)] - [(M \times M) + (M \times P)]$$

Maternal additive effect:

$$(G^mP - G^mM) = [(M \times P) - (P \times M)]$$

Where:

- G^i and G^m represent direct and maternal additive effect of the subscript genetic group respectively.
- Percentages of all the above mentioned effects were proportioned to the mean of purebred parents.

RESULTS AND DISCUSSION

Descriptive statistics of the studied traits were presented in Table 1. Observed means from the current study were in the range of the reviewed literature (Nofal, 2006; Sezer et al., 2006; Akinola et al., 2012 and Tavaniello, 2014). Moreover, Least-squares means of the body weight, maturity-related and DSD traits, along with significance of fixed effects of line, sex, hatch and the associated interactions were presented in Tables 2, 3 and 4.

Fixed effects

Line:

Implementation of a crossbreeding system provides the opportunity to exploit differences among genetic groups. This can give greater flexibility to adjust the breeding program to changes in farm practices and market conditions. In the current study, highly significant ($P < 0.01$) effects of line were observed for body weight, maturity-related traits (Table 2), while it showed significance ($P < 0.05$) for DSD traits in later ages (5th and 6th weeks) rather than earlier ages (Table 4). It was clear that the purebred lines were heavier in weight compared to their crosses. Definitely, P line showed superiority for

body weight traits from hatch to maturity age followed by M line in most cases. However, the cross P x M surpassed the M line for body weight at the early stage of life (W_H and W_1), then rate of growth was reversed between both genetic groups. M x P cross showed inferiority to all the other groups in body weight traits. The superiority of the P line for growth traits was expected as the line was already selected for increased body weight at 4 weeks of age for several generations. Similarly, Sabra (1990); Nofal (2006) and Devi et al. (2010) reported that differences among different genetic groups for growth traits were significant. Strain difference in growth of commercial Japanese quails and consequently growth weights, is often ascribed to stage of maturity (Moran et al., 1978 and Moran et al., 1984). However, Blair et al. (1989) also cited evidence for a Japanese quail strain difference in growth composition that may influence nutrient requirement. Moreover, Alkan et al. (2010) reported significant effects of selection for body weight on some egg traits, as well. Except for W_H , where the cross P x M surpassed M line, both reciprocal crossbreds were inferior to the purebred lines in body weight. However, the cross between P males and M females showed superiority over its reciprocal for growth traits. Contrarily to its performance in body weight traits, M x P cross was superior for ASM and EN₅₀.

Sex:

Sex differences were highly significant ($P < 0.01$) for body weight traits except for hatch weight favoring females than males (Table 2). The present results indicated the superiority of Japanese quail females over their counterparent males. Alike results were revealed by Selim et al. (2006); Seker et al., (2007) and Tarhyel et al. (2012). Weight differences could be attributed to higher metabolic rate in males (Marks, 1990) and/or as a result of performance of male sexual activities due

to the hormonal change (Selim et al., 2006). In this regard, Ojedapo and Amao (2014) suggested that at similar ages, Japanese quail did not have the same proportional growth traits. This could be controlled by genetics that could significantly influence sexual dimorphism. In this study, there were no differences in hatch weight between males and females but this changed in later ages. Meanwhile, interaction (Line x Sex) effects were significant ($P < 0.05$) for all traits. It was clear that the purebred lines were heavier in weight compared to their crosses for most traits (Table 3). The pure line P showed the heaviest body weight in both sexes followed, mostly, by M line. However, the cross PxM exceeded M line for W_H in both sexes, and W_1 in males.

The overall mean of degree of sexual dimorphism (DSD) was low between W_1 and W_4 (between 3.56% and 4.08%), but increased significantly ($P < 0.05$) to 8.23% and 11.60% at 5th and 6th weeks of age, respectively, for the whole experiment (Table 4). Pure lines showed higher DSD% than their crosses for DSD_H , DSD_1 and DSD_3 , while the trend was reserved in the rest of traits. The cross MxP showed the highest DSD% in DSD_2 , DSD_4 , DSD_5 and DSD_6 , whereas it did not differ significantly from its reciprocal PxM for DSD_2 and DSD_4 . The results of the current study were in agreement of Sezer et al. (2006) as they reported a small amount of DSD during the first four weeks of age, then a noticeable increase was found. This could be interpreted as members of the larger sex begin to produce gametes at an older age than members of the smaller sex in some species. This could be expected, because members of the larger sex require more time to grow to a larger size (Anderson, 1994 and Charlesworth, 1994), or they postpone the development of fully adult characteristics until they have acquired the experience necessary to breed successfully (Stearns, 1992). On the other hand, in many bird species showing sexual

dimorphism, both sexes begin to produce gametes at the same age, but members of the larger sex delay final reproductive development to an older age (Stamps and Krishnana, 1997). The current results were, however, higher than those found for DSD at slaughter age reported by Ojedapo and Amao (2014). Nevertheless, they determined effects of sexual dimorphism of Japanese quail on body weight at slaughter age and carcass traits. Contrarily, Saatci et al., (2003) and Sezer (2007) concluded that body weights of males were significantly heavier than those of females from hatch to the age of four weeks. Moreover, the interaction of line x sex showed significant ($P < 0.05$) effects on body weight traits except W_H . This result indicated the variability of superiority of assumed one sex among different genetic groups.

Hatch:

Significant ($P < 0.05$) effects of hatch on all the studied traits were found in this study with inconsistent trend through the whole period of study, in general (Table 2). This kind of effects could be attributed to the environmental conditions such as warming or lacking of optimum conditions. In addition, these hatch differences could be ascribed to the environmental changes during the growing period of the laying flock specially after the 2nd hatch or to the physiological status of the dams producing these eggs, which could change with advance of flock age (Nofal, 2006). Except for W_H , inferiority of the first hatch compared to the later hatches was observed in this study. The superiority of the later hatch could be attributed to better pre-ovipositional maternal effects in terms of oviductal factors that exert their effects on egg size, egg weight, shell quality, yolk composition and immune bodies transmitted (Aggrey and Cheng, 1994 and Khalil et al., 1999) to the hatched chicks relative to that in the earlier hatch. Significant effect of rearing group was reported as a common phenomenon in the

literature (Aggrey and Cheng, 1994; Saatci et al., 2003; Nofal, 2006; Vali et al., 2006 and Sezer 2007). Otherwise, hatch effect and the interaction (Line x Hatch) had insignificant effects on DSD traits during the whole period of study and inconsistent trend of hatch effect was observed (Table 4).

Crossbreeding parameters

Purebred differences:

Comparing both purebred lines (purebred differences) showed significant superiority of the P line over the M line for body weight and maturity-related traits except for EN₅₀, the selection criterion of the M line (Table 5). Percentages of differences between both lines ranged between 8.79% to 25.16% favoring the P line, except for EN₅₀ where the M line was significantly superior to the P line with 20.70%. Regarding DSD traits, purebred differences were significant ($P < 0.05$) or highly significant ($P < 0.01$) at earlier ages (DSD_H, DSD₁) and later ones (DSD₅ and DSD₆) but not for the intermediate ages (Table 6). The M line showed higher rates of sexual dimorphism over P line at all ages, except for DSD_H and DSD₆, which ranged between -1.93% to -15.00%. This result indicated the potentiality of P line against sexual dimorphism effects on growth of body weight over age advancing. This could be interpreted as P line is selected for increased body weight at 4 weeks of age which could lead to solid ability of this genotype to decrease the presumed margins of disarrayed body weight during the growing period related to sex.

Heterotic effect:

Several reports on heterosis, in Japanese quail, have been published (Piao et al., 2004; Nofal, 2006 and Ferdous, 2013). Estimates of direct heterosis (H^1), calculated in units (g) and percentage (%) for body weight, maturity-related and DSD traits are presented in Table 5 and 6.

Estimates of direct heterosis were negative for all body weight traits from hatch to maturation age within the range of -3.3% to -23.59% increasing gradually by age advancing. However, these traits showed significant ($P < 0.05$) estimates for all traits, except for weight at hatch (W_H). Evidence of heterotic effects on most of growth traits were reported by several investigations (Piao et al., 2004; Nofal, 2006; Vali et al., 2006 and Ferdous, 2013). Significant direct heterosis estimates could be an emphasis of the existence of non-additive genetic variations regarding growth traits. On the other hand, negative estimates of direct heterosis could lead to determine that involvement of a maternal line, selected for egg production, in crossbreeding experiment could not enhance the improvement of growth traits. However, negative direct heterosis, might be attributed to directional dominance of genes affecting these traits, as well as, the nature of the measurement of the trait itself. Meanwhile, maturity and egg production traits, significant ($P < 0.05$) estimates of direct heterosis for BW_{SM} , ASM and EN₅₀, along with the superiority of the cross MxP over M line in both ASM and EN₅₀ evidenced the role of crossbreeding in improvement of such traits through overdominance. Negative estimate of direct heterosis for ASM (-17.79%) was favorable as it means to shorten the time before reaching the sexual maturity which could lead to longer productivity life of a female. The appearance of heterosis in this experiment with a modest population size might be a direct consequence of increasing inbreeding levels within lines selected for different criteria. The present work has shown that heterosis for maturation and egg production traits resulted from genetic effects or interactions which were present in both selected lines from the start, but which were revealed or built up preferentially depending on the method of selection, and which consequently induced

a different pattern of heterosis in different traits.

Regarding DSD traits, it was observed that estimates of direct heterosis were significant ($P < 0.05$ or $P < 0.01$) for all DSD traits, except for DSD_1 . Estimates of direct heterosis were shrunk from -11.00% at hatch (DSD_H) to -4.90% at 1st week of age (DSD_1), then increased gradually, in apposite way, to reach its maximum value (19.99%) at 6th week of age. (DSD_6). The current results could emphasize the impact of heterotic effects on such traits (DSD) and how it be could improved or inhibited through this different types of matings in crossbreeding experiments. Further, it could imply indicators to genetic segregations that affect negatively on DSD traits when both purebred and crossbreds were compared (Table 6).

Direct additive effect:

In the current study, direct additive effects were found to be positive and significant for body weight and maturity-related traits, except for EN_{50} , favoring the P line in paternal position compared to the M line (Table 5). The later result confirmed that of Nofal (2006) indicating the superiority of genetic groups sired by meat-line males rather than egg-line males. Estimates of direct additive effects for body weight traits, as percentage, increased from 13.19% for W_H to 34.15% for W_1 and then decreased hereafter, still higher in magnitude than estimate for W_H within the range of 17.40% to 21.79% at 5th week of age. In this respect, Sabra, 1990 and Khalil et al., 1991 concluded the presence of significant effect of sire breed and high direct additive genetic variations on most of growth traits considered, while Nofal (2006) reported positive but insignificant estimates of direct additive effects for growth traits. Likewise, significant estimates of direct additive effects were found for BW_{SM} and ASM with estimates of 20.50% and 26.66%, respectively. Contrarily, EN_{50} trait showed negative

(-22.90%) estimate of direct additive effect. Similar (positive for ASM and negative for egg production) results were revealed by Nofal (2006). Moreover, the later author reported highly significant estimate of direct additive effect for ASM but the same parameter was insignificant for egg number for the first twenty days of production (EP_{20}). The apparent existence of direct effects in this study for these traits could indicate to its importance to be measured precisely in crossbreeding experiments to interpret the obtained results, particularly when the interpretation is genetic, i.e., when it addresses the question of whether heterosis exists. Further, it provides the needed information to setup mating plans in crossbreeding experiments indicating to the best genetic groups in sire position. However, through the whole experiment, direct additive effects showed inconsistent trend for DSD traits (Table 6). Estimates varied between 4.25% to -27.00% showed negative estimates, in most, except for DSD_H and DSD_3 .

Maternal additive effect:

Results of maternal additive effect on body weight and maturity-related traits were significant for most traits except for W_H (Table 5). Quantitative geneticists have historically defined maternal effects of a mother as the influence of the maternally provided environment on the phenotype of her offspring (Legates 1972 and Cheverud 1984). This view of maternal effects has led to the development of various quantitative genetic models of phenotypic evolution that explicitly include maternal effects (Willham 1972 and Cheverud 1984). However, Wolf et al. (2009) defined maternal effects as the causal influence of the maternal genotype or phenotype on the offspring phenotype. Under this definition, maternal effects may result directly as a consequence of maternal traits, or may result indirectly from maternal traits such as when mothers lay eggs in particular environments and these environments, in

turn, have effects on offspring traits (e.g. effects of oviposition site choice on offspring sex in species with environmental sex determination. Depending on this definition, maternal cytoplasmic inheritance and genomic imprinting are not maternal effects.

In this study, estimates of maternal additive effects for body weight and maturity-related traits were in the range of 4.40% to 15.76%, and the trend of estimates was inconsistent over time (Table 5). Further, these estimates were mostly less than a half of direct additive effects at the same age. The current study emphasized those of Sabra (1990) and Khalil et al. (1991) who showed that maternal effects had considerable importance on most studied growth traits. However, maternal effects for maturity and egg production traits were low and insignificant for both ASM and EN₅₀. Otherwise, BW_{SM} showed significant ($P < 0.05$) and higher maternal effect (12.96%) than ASM (1.5%) and EN₅₀ (-2.15%). The last result could be an extension to similar trend for earlier body weight results in the present study. Contrarily to the current results, Nofal (2006) found that maternal effects on

sexual maturity traits were not significant except for ASM.

Estimates of maternal additive effect were mostly significant ($P < 0.05$ or $P < 0.01$) except for DSD_H and DSD₂. Negative estimates were observed, favoring M line, except for DSD₂ and DSD₃ (Table 6). The current results could suggest imposing the maternal line M in the female position in a crossbreeding experiment led to higher DSD%, in most cases.

CONCLUSION

From the current results, it could be concluded that crossbreeding between two different lines of Japanese quail selected for different criteria (body weight and egg production) had negative heterotic effects on body weight but improved both ASM and EN₅₀ significantly. The use of maternal line sires and paternal line dams in crossbreeding experiments when the goal is to improve sexual maturity and egg production traits in Japanese quail could be beneficial. Moreover, the impact of direct additive effects on the studied traits were apparent for most traits than maternal additive effects. Degree of sexual dimorphism (DSD) for body weight was significant at later ages than earlier ones.

Table (1): Descriptive statistics of the experiment: number of observations (N), mean, standard deviation (SD), minimum, maximum for body weight and maturity-related traits¹

	W_H	W₁	W₂	W₃	W₄	W₅	W₆	BW_{SM}	ASM	EN₅₀
N	2502	2494	2494	2487	2477	2424	2237	1112	1112	1096
Mean	8.99	26.01	58.66	103.00	133.99	161.05	176.10	200.30	48.04	41.88
SD	1.00	4.99	10.49	16.46	20.41	25.60	30.74	44.69	8.00	24.83
Minimum	5.10	15.23	23.11	65.24	77.53	99.75	135.21	188.24	44.00	34.38
Maximum	10.9	30.7	71.2	144.8	161.5	191.4	240.3	235.67	58.00	45.20

¹W_H: weight at hatch; W₁ to W₆: weights at 1, 2, 3, 4, 5 and 6 weeks of age; BW_{SM}: body weight at sexual maturity; ASM: age at sexual maturity and EN₅₀: egg number for the first 50 days of production..

Table (2): Least-squares means (+standard error) along with significance of fixed effects for the body weight and maturity-related traits¹

	W _H	W ₁	W ₂	W ₃	W ₄	W ₅	W ₆	BW _{SM}	ASM	EN ₅₀
Line										
P	9.50±.02 ^a	29.05±.12 ^a	68.30±.27 ^a	120.80±.35 ^a	155.90±.44 ^a	186.00±.58 ^a	203.80±.71 ^a	225.00±1.82 ^a	58.00±.35 ^a	34.38±.85 ^c
M	8.70±.02 ^c	24.30±.12 ^c	60.20±.27 ^b	107.90±.35 ^b	140.60±.44 ^b	172.00±.58 ^b	190.50±.71 ^b	205.00±1.84 ^b	49.00±.35 ^b	42.33±.85 ^b
PxM	9.00±.04 ^b	27.00±.15 ^b	55.40±.30 ^c	95.00±.38 ^c	127.00±.49 ^c	155.00±.63 ^c	168.00±.85 ^c	200.00±2.10 ^c	46.00±.41 ^c	44.38±.96 ^b
MxP	8.60±.04 ^c	22.75±.15 ^d	50.00±.30 ^d	88.00±.39 ^d	110.00±.49 ^d	130.50±.63 ^d	140.00±.85 ^d	168.00±2.12 ^d	44.00±.41 ^d	45.20±.96 ^a
Sex										
Male	8.84±.03	25.31±.14 ^b	57.49±.24 ^b	101.19±.34 ^b	130.75±.45 ^b	154.31±.54 ^b	165.98±.78 ^b	×	×	×
Female	9.06±.03	26.24±.14 ^a	59.46±.23 ^a	104.66±.34 ^a	136.00±.45 ^a	167.45±.53 ^a	185.18±.78 ^a	199.50±1.34	49.25±.24	41.57±.75
Hatch										
1	9.25±.03 ^a	25.90±.13 ^b	55.50±.25 ^a	101.00±.35 ^b	130.58±.48 ^b	157.87±.58 ^b	171.16±.79 ^c	199.70±1.94 ^b	48.50±.33 ^b	42.09±.87 ^a
2	8.65±.04 ^c	23.50±.11 ^c	57.35±.24 ^b	106.80±.37 ^a	138.28±.44 ^a	158.79±.55 ^b	180.47±.74 ^a	198.22±1.88 ^b	49.15±.38 ^b	41.55±.92 ^b
3	8.95±.03 ^b	27.95±.13 ^a	62.58±.24 ^b	100.99±.34 ^b	131.28±.47 ^b	165.99±.59 ^a	175.12±.77 ^b	203.05±1.96 ^a	50.10±.38 ^b	41.07±.93 ^b
Overall	8.95±.02	25.78±.10	58.48±.21	102.93±.33	133.38±.41	160.88±.52	175.58±.65	199.50±1.34	49.25±.24	41.57±.75
Significance										
Line	**	**	**	**	**	**	**	**	**	**
Sex	NS	*	**	**	**	**	**	×	×	×
Hatch	*	*	*	*	*	*	*	*	*	*
Line x Sex	NS	*	**	**	**	**	**	×	×	×
Line x Hatch	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Line x Sex x Hatch	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

¹W_H: weight at hatch; W₁ to W₆: weights at 1, 2, 3, 4, 5 and 6 weeks of age; BW_{SM}: body weight at sexual maturity; ASM: age at sexual maturity and EN₅₀: egg number for the first 50 days of production;

P: paternal line; M: maternal line; PxM: paternal x maternal cross and MxP: maternal x paternal cross;

NS: not significant, *: significant at P<0.05, **: significant at P<0.01; Means in the column with different letters (a, b, c and d) are varied significantly;

×: not measured

Table (3): Least-squares means (+standard error) along with significance of Line x Sex interaction for body weight and maturity-related traits¹

	W _H	W ₁	W ₂	W ₃	W ₄	W ₅	W ₆
Males							
P	9.31±.02 ^a	28.45±.14 ^a	67.11±.24 ^a	118.71±.35 ^a	152.91±.46 ^a	178.93±.56 ^a	192.80±.82 ^a
M	8.54±.02 ^b	23.81±.14 ^c	59.08±.24 ^b	105.93±.35 ^b	137.85±.46 ^b	165.00±.56 ^b	180.08±.82 ^b
PxM	8.85±.03 ^b	26.55±.16 ^b	54.32±.26 ^c	92.94±.36 ^c	124.50±.47 ^c	148.25±.58 ^c	158.05±.84 ^c
MxP	8.45±.03 ^c	22.32±.16 ^c	49.05±.26 ^d	86.58±.36 ^d	107.25±.48 ^d	124.04±.58 ^d	128.97±.84 ^d
Female							
P	9.69±.02 ^a	29.45±.14 ^a	69.49±.23 ^a	122.89±.34 ^a	158.89±.45 ^a	193.07±.54 ^a	214.80±.80 ^a
M	8.86±.02 ^c	24.79±.14 ^c	61.32±.23 ^b	109.87±.34 ^b	143.35±.45 ^b	179.00±.55 ^b	200.92±.80 ^b
PxM	9.15±.03 ^a	27.45±.16 ^b	56.48±.25 ^c	97.06±.36 ^c	129.50±.47 ^c	161.75±.57 ^c	177.95±.83 ^c
MxP	8.75±.03 ^b	23.18±.16 ^c	50.95±.26 ^d	89.42±.37 ^d	112.75±.47 ^d	136.96±.57 ^d	151.03±.83 ^d

¹W_H: weight at hatch; W₁ to W₆: weights at 1, 2, 3, 4, 5 and 6 weeks of age; BWSM: body weight at sexual maturity; ASM: age at sexual maturity and EN₅₀: egg number for the first 50 days of production;

P: paternal line; M: maternal line; PxM: paternal x maternal cross and MxP: maternal x paternal cross;

Means with different letters (a, b, c and d) in the same column are varied significantly (P<0.05)

Table (4): Least-squares means (+standard error) along with significance of fixed effects for DSD% traits¹

	DSD_H	DSD₁	DSD₂	DSD₃	DSD₄	DSD₅	DSD₆
Line							
P	3.92±.10 ^a	3.40±.12 ^b	3.42±.14 ^b	3.40±.21 ^a	3.76±.34 ^b	7.32±.55 ^d	10.24±.73 ^d
M	3.61±.10 ^b	3.95±.12 ^a	3.65±.15 ^b	3.59±.21 ^a	3.84±.35 ^b	7.82±.55 ^c	10.37±.73 ^c
PxM	3.28±.12 ^c	3.28±.14 ^d	3.82±.18 ^a	4.24±.27 ^b	3.86±.39 ^a	8.35±.61 ^b	11.18±.79 ^b
MxP	3.43±.12 ^c	3.71±.15 ^c	3.73±.18 ^a	3.18±.27 ^c	4.88±.39 ^a	9.43±.61 ^a	14.61±.79 ^a
Hatch							
1	3.55±.10	3.60±.12	3.65±.14	3.61±.23	4.07±.37	8.22±.56	11.58±.75
2	3.55±.10	3.57±.13	3.67±.14	3.59±.25	4.07±.38	8.23±.59	11.61±.78
3	3.57±.11	3.58±.13	3.65±.15	3.60±.25	4.11±.38	8.25±.59	11.62±.78
Overall	3.56±.08	3.58±.10	3.66±.12	3.60±.20	4.08±.33	8.23±.52	11.60±.71
Significance							
Line	*	*	*	*	*	*	*
Hatch	NS	NS	NS	NS	NS	NS	NS
Line x Hatch	NS	NS	NS	NS	NS	NS	NS

¹ DSD_H: DSD% at hatch; DSD₁ to DSD₆: DSD% at 1, 2, 3, 4, 5 and 6 weeks of age;

P: paternal line; M: maternal line; PxM: paternal x maternal cross and MxP: maternal x paternal cross;

NS: not significant, *: significant at P<0.05; Means with different letters (a, b, c and d) in the same cloumn are varied significantly (P<0.05)

Table (5): Crossbreeding parameters (Linear function \pm SE) effects for the studied traits¹

	W_H	W₁	W₂	W₃	W₄	W₅	W₆	BWSM	ASM	EN₅₀
Purebred difference P vs. M										
Units	0.80 \pm .03*	4.90 \pm .04*	8.10 \pm .04*	12.90 \pm .04*	15.30 \pm .06*	14.00 \pm .07*	13.30 \pm .09*	17.12 \pm 1.67*	13.08 \pm 3.65*	-7.95 \pm 1.50*
%	8.79	18.39	12.61	11.28	10.32	7.82	6.75	7.54	25.16	-20.70
Direct heterosis										
Units	-0.30 \pm .02	-1.75 \pm .04*	-11.55 \pm .04*	-22.85 \pm .04*	-29.75 \pm .05*	-36.50 \pm .07*	-43.15 \pm .08*	-53.58 \pm 1.57*	-9.25 \pm 3.24*	6.44 \pm 1.00*
%	-3.30	-6.57	-17.98	-19.98	-20.07	-20.39	-21.89	-23.59	-17.79	16.79
Direct additive effect										
Units	1.20 \pm .04*	9.10 \pm .08*	13.50 \pm .08	19.90 \pm .08*	32.30 \pm .08*	39.00 \pm .10*	41.30 \pm .16*	46.55 \pm 2.18*	13.86 \pm 3.88*	-8.78 \pm 1.41*
%	13.19	34.15	21.01	17.40	21.79	21.79	20.94	20.50	26.66	-22.90
Maternal additive effect										
Units	0.40 \pm .03	4.2 \pm .07*	5.40 \pm .07*	7.00 \pm .07*	17.00 \pm .08*	25.00 \pm .11*	28.00 \pm .12*	29.43 \pm .114*	0.78 \pm 1.13	-0.82 \pm 1.21
%	4.40	15.76	8.40	6.12	11.46	13.97	14.20	12.96	1.50	-2.15

¹W_H: weight at hatch; W₁ to W₆: weights at 1, 2, 3, 4, 5 and 6 weeks of age; BWSM: body weight at sexual maturity; ASM: age at sexual maturity and EN₅₀: egg number for the first 50 days of production;

P: paternal line; M: maternal line;

*: significant at P<0.05

Table (6): Crossbreeding parameters (Linear function \pm SE) effects for for DSD% traits¹

	DSD_H	DSD₁	DSD₂	DSD₃	DSD₄	DSD₅	DSD₆
Purebred difference							
P vs. M							
Units	0.31 \pm .03*	-0.60 \pm .05**	-0.23 \pm .05	-0.18 \pm .06	-0.07 \pm .06	-0.50 \pm .08**	0.75 \pm .07**
%	8.23	-15.00	-6.44	-5.28	-1.93	-6.57	6.97
Direct heterosis							
Units	-0.41 \pm .03*	-0.20 \pm .06	0.24 \pm .05**	0.22 \pm .06*	0.57 \pm .06**	1.32 \pm .08**	2.19 \pm .07**
%	-11.00	-4.90	6.72	6.20	14.98	17.40	19.99
Direct additive effect							
Units	0.16 \pm .04	-1.00 \pm .04*	-0.13 \pm .04	0.88 \pm .06**	-1.09 \pm .07	-1.58 \pm .07**	-2.67 \pm .08**
%	4.25	-27.00	-3.75	25.31	-28.69	-20.9	-24.90
Maternal additive effect							
Units	-0.15 \pm .04	-0.40 \pm .04*	0.10 \pm .04	1.07 \pm .06**	-1.02 \pm .07**	-1.09 \pm .07**	-3.42 \pm .08**
%	-3.98	-12.00	2.69	30.59	-26.76	-14.4	-31.9

¹ DSD_H: DSD% at hatch; DSD₁ to DSD₆: DSD% at 1, 2, 3, 4, 5 and 6 weeks of age;

P: paternal line; M: maternal line;

*: significant at P<0.05; **: significant at P<0.01

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الملخص العربي

تقييم وراثي لتجربة خلط اشتملت على خطين منتخبين وخطانها من السمان الياباني لبعض صفات النمو والصفات المرتبطة بالنضج الجنسي

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تم الحصول على بيانات الدراسة الحالية من عدد ٢٥٠٢ (١٣٠٠ نقي و١٢٠٢ خليط) طائر من خطين مختلفين منتخبين (خط أبوي وخط أمي) من السمان الياباني وخطانها. كانت الصفات المدروسة وزن الجسم أسبوعيا من عمر الفقس وحتى عمر ٦ أسابيع، وزن الجسم عند النضج الجنسي للإناث، العمر عند النضج الجنسي للإناث، عدد البيض المنتج خلال أول ٥٠ يوم من الإنتاج ودرجة الاختلاف المظهري بين الجنسين في وزن الجسم من عمر الفقس وحتى عمر ٦ أسابيع. التأثيرات الوراثية (قوة الخليط المباشر، التأثير المضيف المباشر، التأثير المضيف الأمي) تم تقديرها لكل الصفات. اشتملت النماذج الإحصائية لتحليل الصفات المدروسة التأثيرات الثابتة (الخط، الجنس ودفعة الفقس) وكل التداخلات الممكنة بينها. الفروق بين الخطوط كانت معنوية لكل الصفات المدروسة وأظهر الخط الأبوي تفوقا معنويا متوقعا على كل المجموع الوراثية الأخرى في صفات وزن الجسم. بينما أظهرت الخطان تفوقا معنويا في صفات العمر عند النضج الجنسي، عدد البيض المنتج خلال أول ٥٠ يوم من الإنتاج ودرجة الاختلاف المظهري بين الجنسين في وزن الجسم عن الأباء النقية. درجة الاختلاف المظهري بين الجنسين في وزن الجسم كانت معنوية في المراحل المتأخرة من النمو بينما لم تكن معنوية في الأعمار المبكرة خلال فترة التجربة. تأثيرات الجنس ودفعة الفقس كانت معنوية على صفات وزن الجسم عدا تأثير الجنس على وزن الفقس. تأثير دفعة الفقس كان معنويا على وزن الجسم عند النضج الجنسي، العمر عند النضج الجنسي وعدد البيض المنتج خلال أول ٥٠ يوم من الإنتاج. قيم قوة الخليط المباشر كانت معنوية لأغلب الصفات عدا صفات وزن الجسم عند الفقس حيث كانت القيم سالبة في الأغلب، بينما كانت معنوية وموجبة لصفات عدد البيض المنتج خلال أول ٥٠ يوم من الإنتاج ومعظم صفات درجة الاختلاف المظهري بين الجنسين في وزن الجسم. قيم التأثير المضيف المباشر والتأثير المضيف الأمي كانت معنوية لأغلب الصفات عدا وزن الجسم عند الفقس، العمر عند النضج الجنسي وعدد البيض المنتج خلال أول ٥٠ يوم من الإنتاج حيث كانت قيم التأثير المضيف المباشر وحدها معنوية. أظهرت صفات الاختلاف المظهري بين الجنسين في وزن الجسم نمطا متذبذبا لكل من التأثير المضيف المباشر والتأثير المضيف الأمي. التأثير المضيف المباشر كان أثره أوضح من التأثير المضيف الأمي لأغلب الصفات المدروسة. بشكل عام يمكن القول بأن الخلط بين خطين أحدهما أبوي والآخر أمي قد أظهر قيمة سالبة لقوة الخليط المباشر في صفات وزن الجسم ولكنه حسن في صفات العمر عند النضج الجنسي وعدد البيض المنتج خلال أول ٥٠ يوم من الإنتاج في السمان الياباني. صفات الاختلاف المظهري بين الجنسين في وزن الجسم أظهرت قيمة موجبة ومعنوية لقوة الخليط المباشر خلال التجربة. يمكن تحقيق استفادة باستخدام آباء من الخط الأمي مع أمهات من الخط الأبوي في تجربة خلط لتحسين الصفات المرتبطة بالنضج الجنسي وإنتاج البيض في السمان الياباني.