International Journal of Research in Agricultural Sciences
Volume 5, Issue 6, ISSN (Online): 2348 – 3997

Estimation of Heterosis, Combining Ability and Reciprocal Effects for Growth Traits in Chickens from a Full Diallel Cross

Mohamed H. Khalil[1], Ahmed A. Debes[2] and Mostafa K. Shebl[1*]
[1]Department of Poultry Production, Faculty of Agriculture, Alexandria University, Egypt.
[2]Animal Production Research Institute, Agriculture Research Center, Ministry of Agriculture, Egypt.
*Corresponding author email id: mkshebl@yahoo.com

Date of publication (dd/mm/yyyy): 25/11/2018

Abstract **– A 4x4 complete diallel cross was carried out involving four Egyptian local breeds of chickens: Alexandria (AA), Fayoumi (FF), Matrouh (MM) and Golden Montazah (GG). Data on body weight (BW) and body weight gain (BWG) at 4, 8, and 12 weeks of age were analyzed using complete diallel analysis. Heterosis estimates indicated that crossing between Fayoumi males and Matrouh females at earlier ages as well as between Matrouh males and Golden Montazah females at later age gave the highest heterotic effects for BW and BWG. General combining ability effects showed that additive genetic variance was important in determining BW and BWG and indicated superiority of AA breed in these traits. This breed therefore may be used as one of the parents if its improvement is sought through crossbreeding. The contribu--tion from specific combining ability was significant for BW and BWG during all ages. Reciprocal recurrent selection would be advantageous to exploit non-additive gene effects to produce commercial broilers (FM and MG). Reciprocal effects were significant for BW. This cleared that sex-linked effects were important for the genetic improvement of BW. This study suggested that use of crossbreeding tool to develop new synthetic breeds suitable to Egyptian conditions with acceptance performance.**

Keywords **– Diallel Cross, Heterosis, Combining Ability, Sex-Linked, Crossbred Chickens.**

I. Introduction

The rapid growth of the human population in Egypt has led to the relatively high demand for protein sources. Poultry meat is the cheapest source of protein compared to animal protein forms and probably the most consumed. The relevance of poultry meat for humans also has been recognized by the UN Food and Agricultural Organization (FAO), who considers this widely available, relatively inexpensive food to be particularly useful in developing countries, where it can help to meet shortfalls in essential nutrients. Moreover, poultry meat consumption also contributes to the overall quality of the diet in specific ages and conditions (Franca Marangoni et al., 2015). The local gene pool (native and indigenous chickens) in Egypt still provides the basis for the poultry sector. The genetic resource base of the indigenous chickens could form the basis for genetic improvement and diversification to produce breeds adapted to local conditions. Crossbreeding is one of the tools for exploiting genetic variation and is a better option than selection to obtain birds with a faster growth rate that is adapted to native environmental condition (Segura-Correa et al., 2004). The performance of a breed or strain or line in cross combination can be evaluated in terms of general and specific combining abilities. Data for growth traits (body weight and body weight gain) on four local Egyptian breeds of chickens were used. These breeds were one native (Fayoumi), and three indigenous (Alexandria, Matrouh and Golden Montazah). This study was undertaken to evaluate the percent heterosis, general and specific combining ability, and reciprocal effects in a full diallel cross involving the above four breeds.

II. Materials and Methods

This study was conducted at the Poultry Research Center, Poultry Department, Faculty of Agriculture, Alexandria University, Egypt during 2014/2015. The experimental pedigreed chickens (1776) were obtained by mating four local breeds of chickens in a full 4*4 diallel cross, which resulted in four pure-bred, six cross-bred and six reciprocal cross-bred progenies. These breeds were (Alexandria, Fayoumi, Matrouh and Golden Montazah). Sixteen pens representing 4 single sires of each breed were set up and each sire was concurrently mated to three females of its own breed and three females each of the other three breeds. Five hatches were used. Management conditions were similar throughout the experiment. The traits measured were individual body weights (BW) and body weight gain (BWG) in grams every 4 weeks from 4 to 12 weeks of age.

Statistical Analysis:

Data were analyzed for variation between the genotypes using the general linear model of SPSS software (IBM, SPSS, 2016). Differences were tested for significance using Duncan test (Duncan, 1955). Following linear model was tested to analyze the data:

$$Y_{ijkl} = U + G_i + H_j + S_k + GH_{ij} + GS_{ik} + HS_{jk} + GHS_{ijk} + e_{igkl}$$

Where: Y_{ijkl} = the observation on the genotype, U = the overall mean, G_i = the fixed effect of i^{th} genotype, H_j = the fixed effect of j^{th} hatch, S_k = the fixed effect of k^{th} sex, GH_{ij}, GS_{ik}, HS_{jk}, GHS_{ijk} = the interaction between the fixed effects, and e_{igkl} = random error

For the combining ability analysis and estimation of various gene effects, i.e., general combining ability (GCA), specific combining ability (SCA), and reciprocal effects (RE), the following fixed model of Griffing (1956) was used:

$$Y_{ij} = U + g_i + g_j + s_{ij} + r_{ij} + 1/c \sum_k e_{ijk}$$
$$i, j = 1 \text{ to } 4$$
$$k = 1 \text{ to } n_{ij}$$

Where, Y_{ij} = the mean of genotype, U = population mean, g_i (g_j) = general combining ability effect of the i^{th} and j^{th} parents, s_{ij} = specific combining ability effect for the cross between i^{th} and j^{th} parents, r_{ij} = reciprocal effect involving the reciprocal crosses between i^{th} and j^{th} parents, e_{ijk} = random environmental effect associated with ijk^{th} individual observation, c = average number of progeny per genetic group and calculated by the following formula:

$$c = \frac{1}{P^2 - 1}\left(n.. - \frac{\sum n_{ij}^2}{n..}\right)$$

Where, P = number of breeds, n.. = total number of progeny, n_{ij} = number of progeny per genotype

General Combining Ability (GCA) was calculated as the deviation of specific genotype means from overall mean for given trait estimated for sixteen diallel crosses [i.e, GCA_i = (y_i/n) - μ], where GCA_i = the GCA for breed i (the AA, FF and MM, GG Genotype), Y_i = trait for a progeny with either one of his or her parents or both parents from breed i and μ = overall mean for given trait estimated from all sixteen diallel crosses. Specific Combining Ability (SCA) was calculated as follows: SCA_{ij} = cross effect- (GCA_i + GCA_j), where the cross effect = certain trait mean of given cross- overall mean of certain trait, GCA_j = the GCA for breed j (the AA, FF and MM, GG Genotype) (Odeh et al., 2003). Reciprocal effect (r_{ij}) for the combination i x j was calculated as $r_{ij} = (y_{ij}-y_{ji})/2$. Heterosis was calculated on percentage of mid-parents: {F_1-[(P_1 + P_2)/2] / [(P_1 + P_2) / 2] x 100} using mean, where F_1 = the first filial and P_1 or P_2 is a parent in diallel and reciprocal crosses (Williams et al., 2002). Calculations of combining ability were done by CBE program package (Wolf, 1996).

III. Results and Discussion

Breed Effect

Body weight (BW) and body weight gain (BWG) of the sixteen genotypes from 4 x 4 full diallel are presented in tables 1 and 2, respectively. The breed effect was highly significant on BW and BWG at 4, 8, and 12 wks of age. For the purebreds, Alexandria breed (AA) recorded the heaviest weight at 12 wks of age (1058.10 g). The same trend was observed for BWG. For crosses, the AG cross and its reciprocal GA recorded the heaviest BW at 8 wks of age (568.04 and 550.44 g, respectively). In addition, the same cross and its reciprocal, beside the reciprocal FA recorded the heaviest BW at 12 wks of age (1045.69, 1003.88, and 1008.34 g, respectively). The cross AG and its reciprocal GA, besides the reciprocal FA and MA had the highest BWG at 4-12 wks of age.

Heterotic Effect

The crosses exhibited varying degrees of heterotic effects for BW and BWG at different ages (Table 3). Most heterotic effects were positive and ranged from -5.71 to 14.43 % for BW, and from -12.31 to 15.29 % for BWG. The cross (FM) was the best combination for BW at 4 and 8 wks of age (13.11 and 14.43 %, respectively), and for BWG at 4-8 wks of age (15.29 %). On the other hand, the (MG) cross recorded the best combination for BW at 12 wks of age (12.59 %), and for BWG at 8-12, and 4-12 wks of age (15.17 and 13.63 %, respectively). These results are considered for the poultry breeders in Egypt to cross these two breeds (M male and G female) to get hybrid vigor in growth traits. Most reviewed studies showed that body weight of crossbred chickens at different ages were associated with positive heterotic effects for growth traits (Shebl et al., 1990; Merat et al., 1994; Khalil et al., 1999; Iraqi et al., 2002; Singh and Singh 2005; Saadey et al., 2008; Mekky et al., 2008; Adebambo et al., 2011; Razuki and Shaheen, 2011; Siwendu et al., 2013). The variation in magnitude of heterotic effects may be attributed to the difference in the genotypes of breeds, strains, populations and their size (Verma et al., 1985). Lamont and Deeb (2001) showed the magnitude of heterosis for BW was age dependent. The magnitude of heterosis is inversely related to the degree of genetic resemblance between parental populations (William and Pollack, 1985) and is expected to be proportional to the degree of heterozygosity of the crosses (Sheridan, 1981), thus heterosis is a result of non-additive genetic effects. Heterosis for BW was observed in chickens when there were small differences in BW between the parental lines (Yalcin et al., 2000) and when there were large differences between the parental lines used in the cross (Liu et al., 1993).

General Combining Ability (GCA)

The combining ability analysis helps to identify the desirable combiners that may be utilized to exploit heterosis. Gardner and Eberhardt (1966) defined GCA as an average performance of a line in different hybrid combinations. The estimates of GCA reflect the importance of additive gene effects of breeds on body weight at different ages (Afifi et al., 2002). GCA effects were significant among the purebreds for BW and BWG at all ages studied (Table 4). This significance indicated the importance of additive genetic variance. This confirms the results of Jain and Chaudhary (1984); Razuki and Al-Soudi (2005); Mekki et al. (2008); Razuki and Al-Shaheen (2011). The differences in BW between these genotypes give good chance to select among them to improve their weight. The GCA effects of breeds (Table 5) indicated superiority of AA for BW and BWG at 4, 8, and 12 wks of age. While, FF had least GCA effect.

Specific Combining Ability (SCA)

Specific combining ability (SCA) defined as a numerical value that expresses the deviation of a specific cross compared to what would be expected from the average performance of the lines involved in that cross. The SCA also refers to the degree to which the average performance of a specific cross departs from additively (Griffing 1956) and it has been used to denote the degree of non-additive genetic effect in a population. As such, SCA is a result of either dominance or epistasis, or a combination of the two (Gardner and Eberhardt 1966).

The contribution from SCA was highly significant for BW and BWG during all studied ages (Table 4). The cross (FM) had the highest SCA for BW at 8 wks of age, and BWG at 4-8 and 8-12 wks of age. While, the cross (MG) was superior in SCA for BW at 12 wks of age, and BWG at 4-12 wks of age. In addition, the cross (FG) was superior in SCA for BW at 4 wks of age (Table 5). This indicated the importance of non-additive genetic effects for growth performance during this experiment. Reciprocal recurrent selection would be advantageous to exploit non-additive gene action in these crosses (Bowman 1959). Similar results were reported in the literature (Saadey et al., 2008; Adebambo et al., 2011; Siwendu et al., 2013). They reported positive SCA estimates for BW at different ages. The additive effects were generally more important than dominance in determining BW. This was corroborated by the higher values of GCA than SCA (Table 5). These results were supported by the work of Mekki et al. (2005) and Adebambo et al. (2011). This indicator that selection will be better tool to improve this trait.

Reciprocal Effect (RE)

Reciprocal effects (RE) were significant for BW during all studied ages, but not important for BWG (Table 5). The cross (MF) had the maximum RE, while the cross (FA) had the least RE for BW at different ages (Table 4). Fairbairn and Roff (2006) indicated that reciprocal effects could be attributed to sex linkage. These results suggested that MF cross was superior to FM cross in sex linked gene effect. The existence of reciprocal cross differences for BW in broilers is well documented (Shebl et al., 1990; Razuki and Al-Shaheen, 2011; Siwendu et al., 2013). They reported important reciprocal effects for BW in crosses between different breeds of chickens.

IV. Conclusion

Combining abilities show that the chicken breeds all have different breed advantages for the traits observed in this study. It is therefore recommended that an improvement program that involves exploiting the trait advantages of the breeds should be used. This study recommended the use of the (MM) breed to cross advantageously the breeds (FF and GG) for growth traits (BW and BWG) to produce commercial broilers (FM and MG). In addition, this study suggested the use of crossbreeding tool to develop new synthetic breeds suitable to Egyptian conditions with acceptance performance. The production animals will be hybrids in which all the desired traits are combined with a full exploitation of heterosis. The reciprocal recurrent selection or modifications of it will exploit the entire genetic variance, both additive (general combining ability) and non-additive (specific combining ability) due to heterosis, dominance, over-dominance and epistasis.

Table 1. Means and SEM of body weight (g) at different ages by genotype.

Genotype	Age (wks)					
	N	4	N	8	N	12
			Purebreds			
AA	180	213.73^{ab} ± 3.50	173	560.22^{ab} ± 11.96	130	1058.10^{a} ± 22.60
FF	80	187.42^{g} ± 4.25	68	459.03^{h} ± 14.44	32	871.56^{efg} ± 31.41
MM	63	194.79^{defg} ± 5.41	56	460.98^{h} ± 16.23	31	817.45^{g} ± 38.35
GG	107	192.98^{efg} ± 4.58	86	499.57^{efg} ± 15.22	40	908.10^{def} ± 46.51
			Crosses			
AF	124	195.48^{defg} ± 3.65	112	500.27^{efg} ± 12.78	71	909.73^{def} ± 29.92
AM	120	203.65^{bcde} ± 4.33	112	523.24^{cde} ± 12.45	74	951.81^{cde} ± 30.33
AG	218	218.96^{a} ± 3.38	204	568.04^{a} ± 9.72	151	1045.69^{ab} ± 21.54
FM	126	216.15^{ab} ± 3.92	112	526.40^{cde} ± 12.63	60	942.38^{cdef} ± 32.53
FG	160	210.50^{abc} ± 3.18	146	504.88d^{efg} ± 10.96	73	908.68^{def} ± 26.11
MG	105	211.74^{abc} ± 4.43	98	513.64^{de} ± 14.78	53	971.42^{bcd} ± 35.44
			Reciprocal			
FA	90	207.41^{abcd} ± 4.99	80	533.93^{bcd} ± 16.39	44	1008.34^{abc} ± 41.61
MA	94	202.15^{bcdef} ± 4.69	84	516.13^{de} ± 14.95	51	973.20^{bcd} ± 38.07
GA	98	208.99^{abcd} ± 4.77	93	550.44^{abc} ± 14.04	75	1003.88^{abc} ± 28.40
MF	63	188.75^{fg} ± 4.79	58	477.38^{gh} ± 14.93	34	863.74^{fg} ± 36.16
GF	81	204.59^{bcde} ± 4.66	75	482.67^{fgh} ± 15.91	37	865.73^{fg} ± 31.46
GM	67	198.43^{cdefg} ±5.77	58	510.95^{def} ± 20.11	27	935.15^{cdef} ± 50.47
All crosses	1776	203.48 ± 1.09	1615	511.74 ± 3.52	983	939.69 ± 8.25
Level of sig.		0.000		0.000		0.000

Means within a column with no common superscripts differ significantly ($P \leq 0.05$), Males are listed first in cross, AA: Alexandria, FF: Fayoumi, MM: Matrouh, GG: Golden Montazah

Table 2. Means and SEM of body weight gain (g) at different ages by genotype.

Genotype	Age (wks)		
	4-8	8-12	4-12
AA	343.66^{a} ± 9.95	469.42^{a} ± 13.39	838.25^{a} ± 20.61
FF	266.46^{g} ± 11.98	370.53^{cde} ± 18.38	670.78^{efg} ± 28.34
MM	260.71^{g} ± 13.19	323.42^{e} ± 24.00	613.23^{g} ± 34.48
GG	294.83^{def} ± 12.80	377.13^{cde} ± 30.30	701.18^{def} ± 41.93
AF	300.02^{cdef} ± 10.98	379.56^{cde} ± 16.77	703.35^{def} ± 27.53
AM	314.46^{bcd} ± 9.77	397.76^{bcd} ± 19.28	735.73^{cde} ± 27.08
AG	344.31^{a} ± 7.86	451.23^{ab} ± 14.76	815.52^{ab} ± 20.00
FM	303.83^{cde} ± 10.23	383.88^{cde} ± 23.20	712.22^{cdef} ± 30.07
FG	291.52^{def} ± 9.51	360.97^{de} ± 16.67	688.37^{defg} ± 24.97
MG	297.11^{cdef} ± 12.21	403.40^{bcd} ± 25.52	746.75^{bcde} ± 33.30
FA	321.78^{abc} ± 13.96	431.89^{abc} ± 29.36	785.20^{abc} ± 40.22

Genotype	Age (wks) 4-8	8-12	4-12
MA	$308.54^{cde} \pm 12.04$	$433.90^{abc} \pm 23.43$	$762.35^{abcd} \pm 34.95$
GA	$337.69^{ab} \pm 11.84$	$434.95^{abc} \pm 18.62$	$784.75^{abc} \pm 26.68$
MF	$282.59^{efg} \pm 12.94$	$355.71^{de} \pm 22.46$	$667.47^{efg} \pm 34.05$
GF	$275.76^{fg} \pm 12.96$	$327.81^{e} \pm 23.53$	$649.41^{fg} \pm 30.37$
GM	$302.02^{cde} \pm 16.77$	$364.70^{de} \pm 34.07$	$716.63^{cdef} \pm 46.26$
All crosses	302.83 ± 2.91	391.64 ± 5.36	724.45 ± 7.62
Level of sig.	0.000	0.000	0.000

Means within a column with no common superscripts differ significantly (P ≤ 0.05), Males are listed first in cross, AA: Alexandria, FF: Fayoumi, MM: Matrouh, GG: Golden Montazah

Table 3. Heterosis (%) for body weight and body weight gain at different ages (wks).

Genotype	Body weight at 4	8	12	Body weight gain at 4-8	8-12	4-12
Crosses						
AF	-2.54	-1.84	-5.71	-1.65	-9.62	-6.78
AM	-0.30	2.48	1.50	4.08	0.34	1.38
AG	7.67	7.20	6.37	7.85	6.61	5.95
FM	13.11	14.43	11.59	15.29	10.64	10.94
FG	10.67	5.34	2.12	3.88	-3.44	0.35
MG	9.21	6.95	12.59	6.98	15.17	13.63
Reciprocal crosses						
FA	3.41	4.77	4.51	5.48	2.84	4.07
MA	-1.03	1.08	3.78	2.12	9.45	5.04
GA	2.77	3.88	2.11	5.78	2.76	1.95
MF	-1.23	3.78	2.28	7.23	2.52	3.97
GF	7.57	0.70	-2.71	-1.74	-12.31	-5.33
GM	2.34	6.39	8.39	8.75	4.12	9.04
Average heterosis	4.30	4.60	3.90	5.34	2.42	3.68

Males are listed first in cross, AA: Alexandria, FF: Fayoumi, MM: Matrouh, GG: Golden Montazah

Table 4. Means squares from combining ability analysis.

Source	d.f	Body weight at different ages (wks) 4	8	12	Body weight gain at different ages (wks) 4-8	8-12	4-12
GCA	3	12151.1**	343260.4**	948591.2**	243501.2**	396874.2**	833465.4**
SCA	6	10269.7**	80607.6**	415366.7**	54696.7**	122117.2**	356981.6**
Rij	6	11055.7**	36579.6**	106686.5**	10615.8^{ns}	38616.5^{ns}	64102.6^{ns}
Residuals		1913.5	7805.7	33443.3	5746.5	20438.5	30869.2
d.f for residuals		1755	1593	961	1593	961	961

** P ≤ 0.01 ns = non significant

Table 5. Crossbreeding genetic statistics for body weight and body weight gain at different ages (wks).

Statistics		Body weight at 4	8	12	Body weight gain at 4-8	8-12	4-12
GCA	**AA**	4.53	27.33	61.42	23.94	41.88	58.48
	FF	-3.77	-18.79	-34.47	-14.28	-19.03	-31.00
	MM	-2.18	-13.02	-30.61	-11.59	-18.37	-28.50
	GG	1.42	4.48	3.66	1.93	-4.48	1.02
SCA for crosses	**AF**	-2.80	-3.17	-7.60	-1.59	-8.76	-7.65
	AM	-2.94	-6.35	-7.99	-3.68	0.68	-5.39
	AG	4.54	15.69	20.02	12.31	14.05	16.19
	FM	4.91	21.96	28.45	16.24	15.55	24.90
	FG	6.41	13.85	-21.67	-6.84	-23.74	-25.58
	MG	2.36	9.10	40.55	6.39	15.25	34.71
Reciprocal	**FA**	-5.97	-16.83	-49.31	-10.88	-26.17	-40.93
	MA	0.75	3.56	-10.70	2.96	-18.07	-13.31
	GA	4.99	8.80	20.91	3.31	8.14	15.39
	MF	13.70	24.51	39.32	10.62	14.09	22.38
	GF	2.96	11.11	21.48	7.88	16.58	19.48
	GM	6.66	1.35	18.14	-2.46	19.35	15.06

Males are listed first in cross, AA: Alexandria, FF: Fayoumi, MM: Matrouh, GG: Golden Montazah

REFERENCES

[1] A.K. Sheridan, "Crossbreeding and heterosis," Anim. Breeding Abstracts, vol. 49, 1981, pp. 131-144.

[2] A.O. Adebambo, C.O.N. Ikeobi, M.O. Ozoje, O.O. Oduguwa, and O.A. Adebambo, "Combining abilities of growth traits among pure and crossbred meat type chickens," Archiv. Zoot., vol. 60, 2011, pp. 953-963.

[3] B. Griffing, "Concept of general and specific combining ability in relation to diallel crossing system," Aust. J. Biol. Sci., vol. 9, 1956, pp. 463-493.

[4] C.O. Gardner, and S.A. Eberhart, "Analysis and interpretation of the variety cross diallel and related populations," Biometrics, vol. 22, 1966, pp. 439-452.

[5] D.B. Duncan, "Multiple range and Multiple F tests," Biometrics, vol. 11, 1955, pp. 1-42.

[6] D.J. Fairbairn, and D.A. Roff, "The quantitative genetics of sexual dimorphism: assessing the importance of sex-linkage," Heredity, vol. 97, 2006, pp. 319-328.

[7] D.M. Mekki, I.A. Yousif, R.M.K. Abdel, J.Y. Wang, and H. H. Musa, "Growth performance of indigenous × exotic crosses of chicken and evaluation of general and specific combining ability under Sudan condition," Poult. Sci., vol. 4, 2005, pp. 468-471.

[8] E.A. Afifi, M.M. Iraqi, A.M. El-Labban, and M. Afram, "Evaluation of heterosis and combining abilities for body weight traits in chickens," Ann. Agric. Sci. Mosh., vol. 40, 2002, pp. 857-870.

[9] F.M. Odeh, G.G. Cadd, and D.G. Satterlee, "Genetic characterization of stress responsiveness in Japanese quail. 1. Analyses of line effects and combining abilities by diallel crosses," Poult. Sci., vol. 82, 2003, pp. 25-30.

[10] G. Liu, E.A. Dunnington, and P.B. Siegel, "Maternal effects and heterosis for growth in reciprocal cross populations of chickens," J. Anim. Breed. Genet., vol. 110, 1993, pp. 423-428.

[11] I.C. Segura-Correa, S. Armando, J.G. Monforte, and R. Ricalde, "Productive performance of Creole chickens and their crosses raised under semi-intensive management conditions in Yucatan, Mexico," Br. Poult. Sci., vol. 45, 2004, pp. 342-5.

[12] IBM Corp. Released, "IBM SPSS Statistics for Windows," Version 24.0. Armonk, NY, IBM Corp, 2016.

[13] J.C. Bowman, "Selection for heterosis," Anim. Breed, vol. 27, 1959, pp. 261-273.

[14] J. Wolf, "User's Manual for the Software Package CBE," Version 4.0 (A universal program for estimating crossbreeding effects), Research Institute of Animal Production, Prague-Uhri neves, Czech-Republic, 1996.

[15] L.S. Jain, and A.L. Chaudhary, "Combining ability variance for some body-weight traits in a diallel cross involving White Leghorn, Rhode Island Red and desi chicken," Indian J. Anim. Sci., vol. 54, 1984, pp. 230-234.

[16] M. Franca, G. Corsello, C. Cricelli, N. Ferrara, A. Ghiselli, L. Lucchin, and A. Poli, "Role of poultry meat in a balanced diet aimed at maintaining health and wellbeing: an Italian consensus document," Food Nut. Res., vol. 59, 2015, p. 606.

[17] M.H. Khalil, I.H. Hermes, and A.H. Al-Homidan, "Estimation of heterotic components for growth and livability traits in a crossbreeding experiment of Saudi chickens with White Leghorn. Egyptian," Poult. Sci., vol. 19, 1999, pp. 491-507.

[18] M.K. Shebl, M.A. Ali, M.M. Balat, and T.H. El-Din, "Evaluation of combining ability for some body-size traits and feathering in a diallel cross of chickens," Egyptian Poult. Sci., vol. 10, 1990, pp. 159-177.

[19] M.M. Iraqi, M.S. Hanafi, M.H. Khalil, A.F.M. El-labban, and M. El-Sisy, "Genetic evaluation of growth traits in crossbreeding experiment involving two local strains of chickens using multi-trait animal model," Livest. Res. Rural Develop., 14, 2002, pp. 1-7.

[20] N.A. Siwendu, D. Norris, J. W. Ngambi, H.A. Shimelis, K. Benyi, "Heterosis and combining ability for body weight in a diallel cross of three chicken genotypes," Trop Anim. Health Prod., vol. 45, 2013, pp. 965-970.

[21] N. Singh, and R.P. Singh, "Heritability estimates of performance traits in purebred and crossbred egg type chicken," Indian J. Poult. Sci., vol. 40, 2005, pp. 52-55.

[22] P. Merat, F. Minvielle, A. Bordas, and G. Coquerelle, "Heterosis in normal versus dwarf laying hens," Poult. Sci., vol. 73, 1994, pp. 1-6.

[23] R.L. Willham, and E. Pollak, Heterosis and crossbreeding. Dairy Sci., vol. 68, 1985, pp. 2411-2417.

[24] S.J. Lamont, and N. Deeb, "Genetics of body composition in a novel broiler cross. In: Proceedings XV European Symposium on Quality of Poultry Meat," WPSA Turkish Branch, Ege Unvi., Izmir, Turkey, 2001, pp, 23-28.

[25] S.K. Verma, P.K. Pani, S.C. Mohapatra, and V. Ayyagari, "Evaluation of general combining ability, specific combining ability and reciprocal effects for some economic traits in layer type chickens," Indian J. Poult. Sci., vol. 20, 1985, pp. 165-172.

[26] S.M. Saadey, A. Galal, H. I. Zaky, and A. Zein el-dein, "Diallel crossing analysis for body weights and egg production traits of two native Egyptian and two exotic chicken breeds," Poult. Sci., vol. 7, 2008, pp. 64-71.

[27] S.M. Williams, S.E. Price, and P.B. Siegel, "Heterosis of growth and reproductive traits in fowl," Poult. Sci., vol. 81, 2002, pp. 1109-1112.

[28] S.S. Mekky, A. Galal, H.I. Zaky, and A. Zein-El-Dein, "Diallel crossing analysis for body weight and egg production traits of two native Egyptian and two exotic chicken breeds," Poult. Sci., vol. 7, 2008, pp. 64-71.

[29] S. Yalcin, X. Zhang, G.R. McDaniel, and D.L. Kuhlers, "Effects of divergent selection for incidence of tibial dyschondroplasia (TD) on purebred and crossbred perfor--mance," Br. Poult. Sci., vol. 41, 2000, pp. 566-569.

[30] W.M. Razuki, and K.A. Al-Soudi, "Combining ability and gene action to various strains of broiler parents. 1. Body weight," The Iraqi J. Agric. Sci., vol. 36, 2005, pp. 123-132 (In Arabic).

[31] W.M. Razuki, and S.A. Al-Shaheen, "Use of full diallel cross to estimate crossbreeding effects in laying chickens," Poult. Sci., vol. 10, 2011, pp. 197–204.

AUTHORS PROFILE'

Mohamed H. Khalil, Ph.D. is a lecturer at the University of Alexandria, Faculty of Agriculture, Poultry Production Department, Egypt. He finished his Doctor in poultry breeding from University of Alexandria in 2010. His Master in poultry breeding was taken from University of Alexandria in 2005. He is currently the director of Poultry Research Center of the University of Alexandria.

Ahmed A. Debes, Ph.D. is an assistant researcher at the Animal Production Research Institute, Agriculture Research Center, Ministry of Agriculture, Egypt. He finished his Doctor in quails breeding from University of Alexandria in 2004. His Master in poultry breeding was taken from University of Kafr El Sheikh, Egypt in 1999. He is currently an assistant researcher in Animal Produc--tion Research Institute of Borg El Arab, Egypt.

Mostafa K. Shebl, Ph.D. is an Emeritus Professor at the University of Alexandria, Faculty of Agriculture, Poultry Production Department, Egypt. He finished his Doctor in poultry breeding from University of Alexandria in 1986. His Master in poultry breeding was taken from University of Alexandria in 1980. He was the Head of Poultry Production Department of Alexandria University during 2010-2013. He is a Professor for the professional courses of Statistic and Genetics for the undergraduate and Graduate degree.