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Estimation of egg production and quality parameters through complete diallel crosses of pure and crossbred Japanese quails

Santosh Marandi and Raj Narayan

Abstract
An experiment was conducted to evaluate the egg production traits of offsprings produced by a complete 4 x 4 diallel cross of Japanese quails. The experiment involved 4 strains namely, Cari-uttam (CU), Cari-ujjwal (CJ), Cari-shweta (CS) and Cari-pearl (CP). A total of 16 genetic groups *viz*. four purebreds (CU, CJ, CS and CP), six crossbreds (CUxCJ, CUxCS, CUxCP, CJxCS, CJxCP, CSxCP) and six reciprocals (CJxCU, CSxCU, CPxCU, CSxCJ, CPxCJ and CPxCS) were obtained from this cross. Each genetic group was assigned 30 female birds. Breeding parameters like GCA, SCA, Reciprocal effect and heterosis were calculated for egg production characteristics *viz*, age of first egg, egg production at 8th, 10th, 12th, 15th, 20th, 25th and 30th weeks of age were recorded. Breeding parameters of egg quality characteristics *viz*, egg weight, shape index, specific gravity, shell thickness, haugh unit, albumen weight, albumen index, yolk weight, yolk index and yolk color were analyzed on 10th week of age. GCA values were high for egg production at 8th, 10th, 20th, and 30th week of age. SCA was highly significant for age of first egg, and all weekly interval egg production except 10th week. The heterosis value for age at first egg was highest in CUxCJ followed by CSxCP. Heterosis for egg production was higher in CUxCJ across all period except 25th week of age.

Keywords: Japanese quail, diallel cross, GCA, SCA, egg weight, Egg production

1. Introduction

Alternate or non-chicken poultry production system offers an opportunity to widen a resource base for the growing poultry sector and at same time provide alternative both, to the poultry producers as well as consumers. Production and consumption trends over recent years are indicative of an increase in the share of non-chicken poultry species to total poultry meat and egg production. Japanese quail, the smallest avian species used for egg and meat production (Baumgarterner, 1994) [1], is steadily gaining popularity among Indian consumers. These birds have also been utilized in various selection experiments because of their small body size, rapid replacement of generation and high reproductive performances. The low maintenance cost associated with its small body size (80-300 g) coupled with its short generation interval (3-4 generation per year), resistance to disease and high egg production rendered it excellent laboratory bird (Vali, 2008) [12]. It is thus been used extensively in many studies (Kayang *et al*., 2004) [6].

The genetic improvement is poultry is brought about by selection, crossbreeding or combination of both. The basic strategy is to exploit additive genetic effects at a large number of independent loci in selection methods, while it is to exploit favorable dominant effects in cross breeding system (Cunningham, 1987) [2].

Such a unique selection programme has contributed to the development of specialized sire and dam line which provide the net improvement in broiler and layer progeny performances. Utilization of these specialized sire and dam lines in commercial layer quail enterprise will result in heterosis of different economic traits which will ultimately minimize the production cost. Such specialized sire and dam lines are non-existent in commercial quail production system.

The second important feature in layer breeding is crossbreeding. In crossbreeding system, testing and identifying the superior cross combination is of utmost importance. The performance of lines in cross combination can be evaluated in terms of general and specific combining ability. In spite of various methods available for estimating the combining ability among the cross the diallel experiment has been found to be most useful (Nath, 1999 and Mohammed *et al*., 2005) [10, 9].

Literature on diallel experiments on chickens are available in plenty but only a few reports are available on Japanese quail, particularly with respect to the lines developed at CARI namely Cari Uttam, Cari Ujjwal, Cari Sweta and Cari Pearl.
Hence, the present study was conducted to estimate the egg production traits through complete diallel cross of four Japanese quail strains to find out suitable sire and dam quail line for commercial enterprise.

2. Materials and Methods

In the present study, a complete 4x4 diallel cross of four Japanese quail strains namely Cari Uttam (CU), Cari Ujjwal (CJ), Cari Shweta (CS) and Cari Peal (CP), was carried out at Japanese quail unit, Division of Avian Genetics and Breeding, Central Avian Research Institute, Izatnagar.

2.1 Mating plan

A total of 16 groups consisting of 480 sires (120 sires from each strain) and 480 dams (120 from each strain) were used in the study. 30 sires and 30 dams of each strain were randomly allotted for a particular group. The mating was carried out in individual pedigree laying cages, and all birds were provided uniform environment. From these, 16 groups, four purebreds (Cari Uttam, Cari Ujjwal, Cari Shweta and Cari Peal), six crosbreds (CU X CJ, CU X CS, CU X CP, CJ X CS, CJ X CP and CS X CP) and six reciprocals (CJ X CU, CS X CU, CS X CJ, CP X CU, CP X CJ and CP X CS) were obtained.
Eggs of these groups were collected twice a day, sorted, cleaned and marked as per genotype and stored for 10 days before setting them in automatic incubator. The eggs were transferred in pedigree boxes and then transferred to hatching trays on 14th day of incubation. The chicks were taken out from the hatchers on 17th day of incubation.

2.2 Brooding and managemental practices

Chicks of same genetic group were brooded and reared together in battery brooders upto 5th week of age. Standard managemental practices were followed throughout the experimental period which was uniform for all genetic groups. Sexing was done at 3rd week of age. Feeding and watering were provided *ad-libitum*.
40 laying birds from each group were transferred to individual laying cages at 5th week of age. The egg production traits recorded for the study included age of first egg and number of eggs
produced on 8th, 10th, 12th, 15th, 20th, 25th and 30th weeks of age. 20 eggs from each group were randomly taken at 10th week of age to study the quality parameters *viz*. Egg weight, Shape index, Specific gravity, Shell thickness, Haugh unit, Albumen weight, Albumen index, Yolk weight, Yolk index and Yolk color. The length and width of the shelled egg, albumen and yolk were measured in mm with the help of a vernier caliper. The height of albumen and yolk were measured at the top by spherometer on a table glass. The height of the albumen was measured at 3 locations and average was taken. Haugh Unit (H.U.) was calculated by using the formula HU= 100 log ($H+7.57-1.7W^{0.37}$), where, H is albumen height in mm and w is weight of egg in grams (Haugh, 1937) [5]. Albumen and yolk indices were estimated in percentage, as reported by previous workers (Kul and Sekar, 2004) [7]. Albumen weight was calculated as egg weight-yolk weight-shell weight.

2.3 Analysis of data

The analysis of data was performed using non-linear regression model procedure by statistical software SPSS (20). The differences considered to be significant were compared by Duncan's multiple range test. Heterosis was calculated by the following formula: Absolute heterosis = Average of two crossbreds – Average of two purebreds. Percent Heterosis = [(Average of two crossbreds – average of two purebreds)/Average of two purebreds] x 100. The diallel analysis for estimation of general combining ability, specific combining ability and reciprocal effect, was carried out as per the method of Griffing (1956) [4], method I, model I.
The mathematical model assumed was:

$$Y_{ijk} = \mu + g_i + g_j + s_{ij} + r_{ij} + (\tfrac{1}{n})\sum_k e_{ijk}$$

Where,
Y_{ijk} = the kth observation on the progeny of the mating of a dam from the jth line with a sire of ith line
μ = overall population mean.
g_i (g_j)= the general combining ability effect for the ith (jth) line.
s_{ij} = the specific combining ability effect for the cross between ith and jth parents such that $s_{ij} = s_{ji}$
rij = the reciprocal or sex-linkage effect involving the reciprocal crosses between ith and jth parents such that $r_{ij} = r_{ji}$
e_{ijk} = the random error associated with ijkth individual.
N = the number of progeny per genetic group.
To test significance of difference between different effects Critical Difference (C. D) test was applied. C. D. value was calculated as under:-
C. D. = t (table value, t at 5% = 1.96)

3. Result and Discussion

3.1 Egg Production traits: Least square estimates for egg production traits are given in table 1. Estimate of GCA, SCA and reciprocal effects are presented in table 2. Analysis of variance revealed that SCA for age at sexual maturity was highly significant under Griffing's model (Griffing, 1956) [4]. Least square estimates result showed that CJ had the highest (positive) significant value of GCA effect for age at sexual maturity (ASM) as compared to CU, CS and CP.

Table 1: Least square estimates of various crossbreeding parameters for ASM and egg production of CU, CJ, CS and CP

	ASM	8 wk	10 wk	12 wk	15 wk	20 wk	25 wk	30 wk
μ	**37.044**	**4.983**	**5.916**	**6.309**	**6.091**	**5.664**	**5.216**	**4.678**
General Combining Ability								
g_1	-0.200	0.192	-0.031	0.106	0.119	0.123	0.016	0.028
g_2	-0.069	0.220	0.122	0.025	0.109	0.142	0.213	0.319
g_3	0.294	0.214	0.097	0.025	-0.062	-0.005	0.134	0.181
g_4	-0.025	-0.627	-0.188	-0.156	-0.166	-0.261	-0.363	-0.528
Specific combining ability								
s_{12}	0.775	-0.008	-0.056	0.059	0.144	0.233	0.056	0.125

s_{13}	-1.587	0.223	0.056	0.009	-0.022	-0.083	-0.091	0.138
s_{14}	0.306	0.577	0.053	-0.022	0.156	0.086	-0.119	0.022
s_{23}	0.206	0.120	0.028	-0.022	-0.188	-0.114	-0.238	-0.228
s_{24}	-1.425	0.336	0.113	-0.103	-0.197	-0.420	-0.378	-0.331
s_{34}	0.762	-0.758	-0.325	-0.203	-0.150	-0.073	0.062	-0.194
Reciprocal effect								
r_{12}	-1.000	0.062	0.050	0.050	0.038	-0.087	-0.050	-0.025
r_{13}	-1.700	-0.212	-0.087	0.050	0.175	0.175	0.125	0.125
r_{14}	-3.325	0.500	0.275	0.188	0.100	0.213	0.450	0.775
r_{23}	-0.375	-0.063	-0.037	0.038	0.000	0.063	0.150	0.325
r_{24}	-0.525	0.663	0.188	0.175	0.163	0.500	0.713	0.863
r_{34}	-3.275	0.888	0.600	0.525	0.338	0.300	-0.075	0.187

µ - Least square mean; g- GCA effects; s- SCA effects; r - reciprocal effects; 1- CARI Uttam; 2- CARI Ujjwal; 3 - CARI Sweta; 4 - CARI Pearl.

Table 2: Analysis of variance showing the significance of cross breeding effects for ASM and egg production of CU, CJ, CS and CP using Griffing's model

Source of variation	D.F.	Mean sum of squares							
		ASM	8 wk	10 wk	12 wk	15 wk	20 wk	25 wk	30 wk
GCA	3	0.351	1.397**	0.161**	0.099**	0.153**	0.276**	0.520**	1.104**
SCA	6	2.117**	0.532**	0.058	0.046**	0.097**	0.152**	0.176**	0.179**
Reciprocals	6	8.696**	0.509**	0.161**	0.116**	0.061**	0.142**	0.252**	0.501**
Error	624	0.329	0.080	0.045	0.014	0.018	0.028	0.038	0.041

Source of variation; GCA – General combining ability; SCA – Specific combining ability; RE – Reciprocal effect; *$p \le 0.05$, **$p \le 0.01$.

3.1.1 Weekly egg production

In case of weekly egg production, CJ recorded highest (positive) value of GCA for 8th, 10th, 20th and 30th week of age, whereas CU exhibited highest (positive) GCA value at 12th and 15th week of age. CP recorded lowest (negative) value for GCA for all weekly egg production under study. Analysis of variance revealed that for egg production GCA was highly significant ($p<0.01$) in all interval of study, whereas SCA variance was highly significant ($p<0.01$) during all weekly interval except 10th week of age. Higher GCA was found during initial (8th week) and later phase (30th week) of egg production. On perusal of Griffing's model it was observed that SCA variance for age at sexual maturity was highly significant. Analysis of variance revealed that mean square of SCA variance was higher as compared to GCA indicating that non-additive genetic was more involved than additive genetic effects in inheritance of age at sexual maturity trait. However, in egg production the GCA variance was higher for 8th and 30th week indicating the enhanced role of additive genetic effect during these intervals. Analysis of variance for reciprocal effect of age at sexual maturity observed significant difference between different genotypes. Similar results were reported by Singh *et al* (2016) [11] in case of chicken breeds, but references regarding the concerned strains of Japanese quails were unavailable.

3.1.2 Heterosis

Heterosis estimates for egg production traits *viz*., age at sexual maturity and egg production are presented in Table 3. Heterosis of age at sexual maturity was negative in all combinations except CU×CJ and CS×CP. The highest (positive) heterosis was observed in Cross CU×CJ followed by CS×CP. Cross CU×CS had lowest (negative) heterosis than others for age at sexual maturity. It was observed that positive heterosis of very high amount was present in various crosses. The magnitude of heterosis for egg production was found higher in CU×CJ cross in all intervals under study except during 25th week of age. Other crosses mostly exhibited positive heterosis for 8th week egg production except for CS×CP. Negative heterosis was observed for most of the remaining weekly interval egg production. Higher magnitude of heterosis exhibited by CU×CJ cross indicated that use of CU as male line and CJ as female line would be more advantageous. However, no such study on the selected strains of Japanese quails was found in literature.

Table 3: Absolute and Percentage values of heterosis for egg production traits of Japanese quails

Parameters/Cross type*	Absolute value						Percentage value					
	CUxCJ	CUxCS	CUxCP	CJxCS	CJxCP	CSxCP	CUxCJ	CUxCS	CUxCP	CJxCS	CJxCP	CSxCP
Age at first egg												
	0.30	-2.15	-0.13	-0.32	-1.83	0.28	0.81	-5.70	-0.34	-0.86	-4.89	0.73
Egg production												
8 week	0.61	0.41	1.05	0.14	0.64	-0.89	12.83	7.93	25.77	2.55	14.91	-18.88
10 week	0.01	-0.04	0.00	-0.05	0.08	-0.53	0.21	-0.62	0.00	-0.80	1.27	-8.71
12 week	0.05	-0.08	-0.16	-0.16	-0.30	-0.48	0.78	-1.15	-2.54	-2.50	-4.71	-7.36
15 week	0.16	-0.06	0.20	-0.49	-0.41	-0.43	2.58	-1.01	3.33	-7.57	-6.60	-6.92
20 week	0.20	-0.10	0.00	-0.40	-0.78	-0.41	3.35	-1.72	0.00	-6.57	-13.14	-7.19
25 week	-0.30	-0.30	-0.41	-0.65	-0.88	-0.29	-5.17	-5.38	-7.99	-10.88	-15.73	-5.39
30 week	0.05	0.14	-0.09	-0.59	-0.80	-0.59	0.98	2.81	-2.04	-10.61	-16.20	-12.43

*Males are listed first in cross CU: CARI UTTAM, CJ: CARI UJJWAL, CS: CARI SWETA, CP: CARI PEARL

3.2 Egg quality traits
3.2.1 Combining ability effects for egg quality traits.
3.2.1.1 GCA
Least square estimates for egg quality traits at 10th week of age are presented in Table 4. Least square estimates of GCA effect revealed highest (positive) significant value for egg weight, shape index and albumen weight in CU; CJ for specific gravity and yolk weight; shell thickness and haugh unit in CS, whereas CP had the highest (positive) significant value for albumen index, yolk index and yolk colour. However, the lowest (negative) value of GCA effect for egg weight, shape index, specific gravity, shell thickness, albumen weight and yolk weight was found in CP. For haugh unit and yolk index lowest (negative) value was observed in CU, whereas lowest (negative) value for yolk colour trait was recorded in CJ.

3.2.1.2 SCA: Least square estimates for SCA effect for various egg quality traits at 10th week of age revealed that the line with best SCA effect for egg weight, specific gravity, albumen weight and albumen index was found in CU×CP. However, CU×CS cross had best SCA effect for haugh unit and yolk index, whereas CU×CP had best (positive) SCA effect for shell thickness. Yolk index and yolk colour exhibited best SCA effect in CJ×CS cross, while CS×CP recorded best SCA for shape index. On perusal of table it is evident that cross CU×CJ had highest positive value for egg weight and shell thickness. The cross CU×CS had highest positive value for yolk weight, whereas CU×CP had highest positive value for shape index, haugh unit and albumen index. Similarly, albumen weight, yolk index and yolk colour value were highest (positive) for cross CJ×CS, while CS×CP had highest (positive) value for specific gravity during this period.

Table 4: Least square estimates of various combining ability effects for egg quality traits at 10th week of age of CU, CJ, CS and CP

	Egg weight	Shape index	Specific gravity	Shell thickness	Haugh unit	Albumen weight	Albumen index	Yolk weight	Yolk index	Yolk color
μ	**12.799**	**76.683**	**1.075**	**0.213**	**90.008**	**6.010**	**0.121**	**4.147**	**0.470**	**5.488**
General Combining Ability										
g_1	0.465	0.822	0.00021	0.006	-0.866	0.087	-0.00060	0.095	-0.008	0.013
g_2	-0.028	-0.009	0.00035	-0.001	0.123	0.078	-0.00174	0.116	-0.007	-0.094
g_3	-0.013	-0.001	0.00002	0.007	0.708	0.065	0.00048	0.014	0.001	0.006
g_4	-0.423	-0.813	-0.00059	-0.013	0.035	-0.231	0.00186	-0.226	0.014	0.075
Specific combining ability										
s_{12}	0.024	-1.223	-0.00081	-0.006	-0.278	0.063	-0.00548	0.122	-0.006	-0.456
s_{13}	0.269	-1.663	0.00097	0.004	0.413	0.100	0.00318	0.226	-0.001	0.019
s_{14}	0.266	-0.637	-0.00149	0.009	-0.552	-0.075	-0.00363	0.130	-0.005	-0.100
s_{23}	-0.294	-0.128	-0.00187	-0.010	-0.652	0.006	-0.00010	-0.176	0.017	0.125
s_{24}	0.513	-0.360	0.00262	0.002	1.302	0.195	0.00347	-0.015	0.004	0.031
s_{34}	-0.062	1.733	0.00019	0.007	-1.004	-0.158	-0.00925	-0.025	-0.009	-0.294
Reciprocal effect										
r_{12}	0.236	-0.768	-0.00050	0.022	-2.486	0.087	0.00355	0.028	-0.009	-0.200
r_{13}	-0.098	-0.675	-0.00280	0.001	-0.177	0.002	-0.00253	0.106	-0.009	-0.525
r_{14}	-0.100	0.576	0.00137	-0.014	3.062	-0.064	0.01260	-0.408	-0.001	0.125
r_{23}	0.113	0.356	0.00125	-0.012	-0.065	0.287	0.00365	-0.171	0.019	0.275
r_{24}	0.153	-0.842	0.00113	0.013	-1.614	0.156	0.00010	-0.044	0.005	0.000
r_{34}	-0.273	-1.013	0.00238	0.014	1.029	-0.057	0.01035	-0.021	-0.001	-0.075

μ - Least square mean; g- GCA effects; s- SCA effects; r - reciprocal effects; 1- CARI Uttam; 2- CARI Ujjwal; 3 - CARI Sweta; 4 - CARI Pearl.

3.2.2 Cross breeding effects on egg quality traits
Estimates of GCA, SCA and reciprocal effects for egg quality traits at 10th week of age are presented in Table 5. Analysis of variance under Griffing's model for General combining ability for various egg quality traits i.e. egg weight, shape index, specific gravity, albumen weight, yolk weight, shell thickness, haugh unit and yolk index showed high significance at 10th week of age. However, GCA was found to be non-significant in yolk colour, specific gravity and albumen index. The variance due to GCA was found to be the chief source of genetic variance for all egg quality traits except yolk colour, specific gravity and albumen index. Analysis of variance for specific combining ability for various egg quality traits i.e. egg white, shape index, albumen weight, yolk weight, yolk colour, shell thickness, specific gravity, haugh unit, albumen index and yolk index at 10th week of age were highly significant. Singh *et al* (2016) [11] also reported similar result in his study on diallel cross of chicken breeds. However, literatures were not available on concern strains involved in this study.

Analysis of variance of reciprocal effect for various egg qualities at 10th week of age under Griffing's model revealed significant result in egg weight and yolk index, whereas highly significant result were observed in shape index, albumen weight, yolk weight, yolk colour, shell thickness, specific gravity, haugh unit and albumen index. Singh *et al.* (2016) [11] also reported significant reciprocal effect for egg weight, shape index, haugh unit and albumen weight, whereas, non-significant result was observed in shell, during his study on diallel cross on chicken breeds.

Table 5: Analysis of variance showing the significance of cross breeding effects on various egg quality traits at 10th weeks of age of CU, CJ, CS and CP using Griffing's model

Source of variation	D.F.	Mean sum of squares									
		Egg weight	Shape index	Albumen weight	Yolk weight	Yolk color	Shell thickness	Specific gravity	Haugh unit	Albumen index	Yolk index
G CA	3	1.057**	3.562**	0.190**	0.197**	0.039	0.00065**	0.0000014	3.378**	0.000019	0.00085**
SCA	6	0.315**	5.253**	0.041**	0.078**	0.196**	0.00019**	0.0000054**	1.548**	0.000078**	0.00024**
Reciprocal	6	0.062*	1.080**	0.040**	0.070**	0.138**	0.00039**	0.0000061**	6.418**	0.000099**	0.00018*
Error	624	0.025	0.175	0.013	0.006	0.021	0.00001	0.0000007	0.355	0.000021	0.00008

Source of variation; GCA – General combining ability; SCA – Specific combining ability; RE – Reciprocal effect; *$p \leq 0.05$, **$p \leq 0.01$.

3.2.3 Heterosis

Heterosis percentage for egg quality traits at 10th week of age is given in Table 6. CU×CJ recorded highest and positive value for heterosis for albumen weight, whereas, heterosis values for egg weight, specific gravity and haugh unit were highest in cross CJ×CP. Similarly, it was observed that highest (positive) values of heterosis for shell thickness, yolk weight and yolk index were recorded in cross CU×CP, CU×CS and CJ×CS, respectively. Yadav *et al.* (1983) [13] also reported positive heterosis in external egg qualities of chicken egg. Similarly, positive heterosis for egg weight was observed in various strain cross (Fairfull *et al.*, 1983 and Laxmi et.al., 2009) [3, 8]. Thus the cross with positive heterosis can be advised to employ for improvement of external and internal egg qualities.

The heterosis estimates indicated that CU male and CJ female produced the highest heterotic effects for egg production. Significant GCA (additive genetic effect) and SCA (non additive genetic effect) and reciprocal effects were observed for egg production from 8th week to 30th week of age. The genotype CU was observed to achieve sexual maturity earlier than other strains of Japanese quails under study.

Table 6: Absolute and Percentage values of heterosis for egg quality traits of Japanese quails

Parameters/ Cross type*	Absolute value						Percentage value					
	CUxCJ	CUxCS	CUxCP	CJxCS	CJxCP	CSxCP	CUxCJ	CUxCS	CUxCP	CJxCS	CJxCP	CSxCP
External Egg quality												
Egg weight	0.43	0.51	0.90	-0.22	0.99	0.25	3.32	3.88	7.42	-1.70	8.38	2.10
Shape index	-3.84	-3.45	-2.03	-1.01	-0.85	2.07	-4.79	-4.35	-2.60	-1.31	-1.11	2.74
Specific gravity	-0.005	-0.005	0.000	-0.005	0.005	0.000	-0.46	-0.46	0.00	-0.46	0.47	0.00
Internal egg quality												
Shell thickness	-0.01	0.01	0.02	-0.02	0.004	0.02	-4.50	3.67	10.81	-7.24	2.02	8.42
Haugh unit score	-0.30	-0.42	-0.88	-1.09	1.36	-1.75	-0.34	-0.46	-0.99	-1.19	1.51	-1.91
Albumen weight	0.24	0.12	-0.05	0.11	0.31	-0.20	3.98	1.90	-0.87	1.83	5.35	-3.45
Albumen index	-0.01	0.00	-0.01	0.00	0.00	-0.02	-7.72	-1.97	-8.46	-3.23	-1.57	-12.60
Yolk weight	0.33	0.48	0.41	-0.20	-0.01	0.03	7.85	11.94	11.07	-4.59	-0.13	0.83
Yolk index	-0.01	0.00	-0.02	0.03	0.01	-0.01	-1.10	-0.86	-3.48	6.08	1.37	-2.16
Yolk color	-0.87	-0.32	-0.55	-0.10	-0.30	-0.55	-15.02	-5.56	-9.13	-1.78	-5.17	-9.44

*Males are listed first in cross CU: CARI UTTAM, CJ: CARI UJJWAL, CS: CARI SWETA, CP: CARI PEARL.

4. Conclusion

The additive gene action was more significant as compared to non-additive genetic effect for inheritance of egg production traits. For egg quality traits, crosses involving CU as male line revealed significant difference, but for female line different strains revealed significant difference for separate egg quality trait. On the basis of these results it can be concluded that for egg production use of CU as male line and CJ as female line is the best strain combination due to its higher egg production performance and CU as male line can be selected for improved overall egg quality traits.

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